



Final Report

On Farm Series | Cotton Research & Development Corporation

*If you are participating in the presentations this year, please provide a written report and a copy of your final report presentation by 31 October.
If not, please provide a written report by 30 September.*

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number: USQ9

Project Title: Improved irrigation of cotton via real-time, adaptive control of large mobile irrigation machines

Project Commencement Date: March 2007 **Project Completion Date:** May 2010

CRDC Program: 4 Farming Systems

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Signature of Research Provider Representative:



Dr. Ren Yi - Director
Office of Research &
Higher Degrees

10/08/10



Part 3 – Final Report Guide (due 31 October 2010)

Background

Irrigation application and crop water use efficiencies can be improved by scheduling the irrigation of crops using physical and agronomic principles. The irrigation management strategy determined using these principles may be automatically implemented on lateral move and centre pivot irrigation machines. Irrigation control strategies can use historical or real-time quantitative measurements of the crop, weather and soil, either singly or in combination, to automatically adjust the irrigation application (i.e. volume and timing). Irrigation is traditionally applied uniformly over an entire field, although not all plants in the field may require the amount of water at any given time. In these cases, differential irrigation application to meet the plant requirements at different positions in the field would be required to improve operational performance; however, as the plant response and environmental conditions fluctuate throughout the season, control strategies which accommodate temporal and spatial variability in the field and which locally modify the control actions (irrigation amounts) need to be ‘adaptive’.

PhD research was conducted to investigate and develop adaptive control systems that improve the irrigation of cotton via real-time, adaptive control of large mobile irrigation machines. This research was funded by the Australian Research Council and Cotton Research and Development Corporation.

This research aimed to develop and implement a real-time control methodology which utilises both historical mapped data and real-time sensor input to improve the spatial and temporal precision of irrigation application through increased water use efficiency and/or crop yield. This was realised in the form of a decision-making framework which is an intelligent learning system including a set of databases that accumulates historical data. Consequently, decisions on varying the water applications may be based on both present sensed and historical recorded data. Predictive tools (e.g. meteorological forecast information) are also incorporated.

Objectives

The research objectives and a description of their achievement follow:

1. To develop and refine a software platform for simulating and evaluating irrigation control strategies. The software platform for evaluation of irrigation control strategies is operational. This objective has been achieved (and published as McCarthy et al., 2010a).
2. To validate and demonstrate calibration of the model in the software platform. The model in the developed software platform has been calibrated using field data and an automatic self-calibration procedure. This objective has been achieved.
3. To identify and implement appropriate irrigation control strategies for improving the performance of irrigation applications. A literature review and comparison of irrigation control requirements with various control strategies have been completed. This objective has been achieved.
4. To evaluate the benefits and limitations of the various control options with respect to data input requirements and the level of output control available. The evaluation of control



strategies is complete and appropriate control strategies for spatially varied irrigation and difference levels of data complexity have been identified. This objective has been achieved.

Methods

Development and refinement of a software platform for simulating and evaluating irrigation control strategies

Irrigation control strategies may require various levels of data input and have different levels of operational complexity and robustness. It was clear that the identification of the optimal control strategies for variable-rate irrigation would be more appropriate in a simulation environment rather than in field trials given the range and complexity of the control options available. A simulation model was used to evaluate the various irrigation control options under a range of environmental and crop management conditions; in contrast, field testing would have been limited to the evaluation of one control system under a limited set of field and seasonal characteristics.

The evaluation of the control strategies could only effectively be conducted using a simulation model and software platform that allowed for:

- the inclusion of field-scale variations in input parameters (e.g. crop response, crop age, target yield and management constraints);
- the input of data at a range of temporal scales; and
- the ability to apply the various levels of control strategies for variable-rate irrigation at different spatial scales.

A simulation framework 'VARIwise' was developed with these specifications. The cotton model OZCOT was integrated in VARIwise to simulate the response of the cotton to the irrigation prescribed by the irrigation control strategies and provide feedback to the strategies in the simulation environment.

Validation and calibration of a cotton production model in the software platform

The input parameters of OZCOT required adjustment to represent the spatial and temporal differences in each cell of the field. Hence, a procedure to adjust the model input parameters was developed and implemented. This involved adjusting the parameters until the simulated and desired responses were approximately the same. A sensitivity analysis was conducted to reduce the number of parameters to refine, and, hence, the computation time required. Fieldwork was conducted to collect weather, soil and plant response data and use this data to calibrate the cotton model and demonstrate the model calibration procedure.

Identification and implementation of appropriate irrigation control strategies for improving the performance of cotton irrigation

A literature review of control systems was conducted to identify strategies that were potentially applicable to irrigation. Many control strategies were inappropriate for irrigation because their assumptions were not practical in the irrigation environment. For example, many strategies required: (i) the system to be defined by state equations; (ii) the system response to be known in advance without feedback; or (iii) many iterations of the optimisation procedure to refine the control parameters.



Evaluation of the benefits and limitations of the various control options with respect to data input requirements and the level of output control available

The control strategies identified as applicable to irrigation were, firstly, implemented in VARIwise and, secondly, evaluated with a range of data input combinations. The simulated soil moisture content, leaf area index, square count and boll count were analysed to ensure the strategies had the desired performance, and indicated any errors in the strategy implementation (which were then corrected). The level of data input most suitable for each control strategy was determined from these simulations.

In a field implementation, it is unlikely that weather, soil and plant data will be available in every cell of the field or at a high temporal resolution. For example, an on-the-go plant sensor may only collect data for a particular cell of the field every few days. In addition, there is a risk of data limitations due to the sensor or other possible hardware failure. Hence, the robustness of the control strategies to data unavailability and irrigation machine constraints was evaluated in VARIwise. This was achieved by limiting the simulated data used by the control strategy, and, for evaluating the robustness of the strategy to data available only a number of data points in the field, spatially interpolating the available data and estimating the data at the unknown points.

Results

Development and refinement of a software platform for simulating and evaluating irrigation control strategies

A simulation framework 'VARIwise' has been created to aid the development, evaluation and management of spatially and temporally varied site-specific irrigation control strategies and the cotton model OZCOT has been integrated. VARIwise accommodates sub-field scale variations in all input parameters using a 1 m² cell size, and permits application of differing control strategies within the field, as well as differing irrigation amounts down to this scale. The transfer of data within the VARIwise framework is illustrated in Figure 1. VARIwise has the following major functional characteristics:

- the ability to input whole-of-field data;
- division of the field into variably sized cells;
- creation, accumulation and management of spatial databases;
- simulation of natural variability;
- incorporation of variable-rate application;
- incorporation of crop model/s (e.g. soil moisture response, plant response);
- calibration of crop model/s;
- implementation of control strategies; and
- display of control strategy output.

Two industry standard irrigation strategies were implemented in VARIwise to demonstrate the operation of the software. These were a fixed and soil moisture deficit-triggered irrigation strategies. The fixed irrigation strategy involves applying irrigation according to user-specified dates and amounts, whilst the soil moisture deficit-triggered irrigation strategy involves applying a user-specified irrigation amounts to the field when the soil moisture deficit at one point in the field reaches a set value. These strategies were evaluated with high and low irrigation machine uniformity distributions. Example VARIwise outputs of the fixed and soil moisture deficit-triggered irrigation strategies with the underlying soil variability in Figure 2 are shown in Figures 3 and 4, respectively. For the soil moisture deficit-triggered

mm soil moisture deficit was predicted (using the OZCOT model) in the three cells shown in Figure 2.

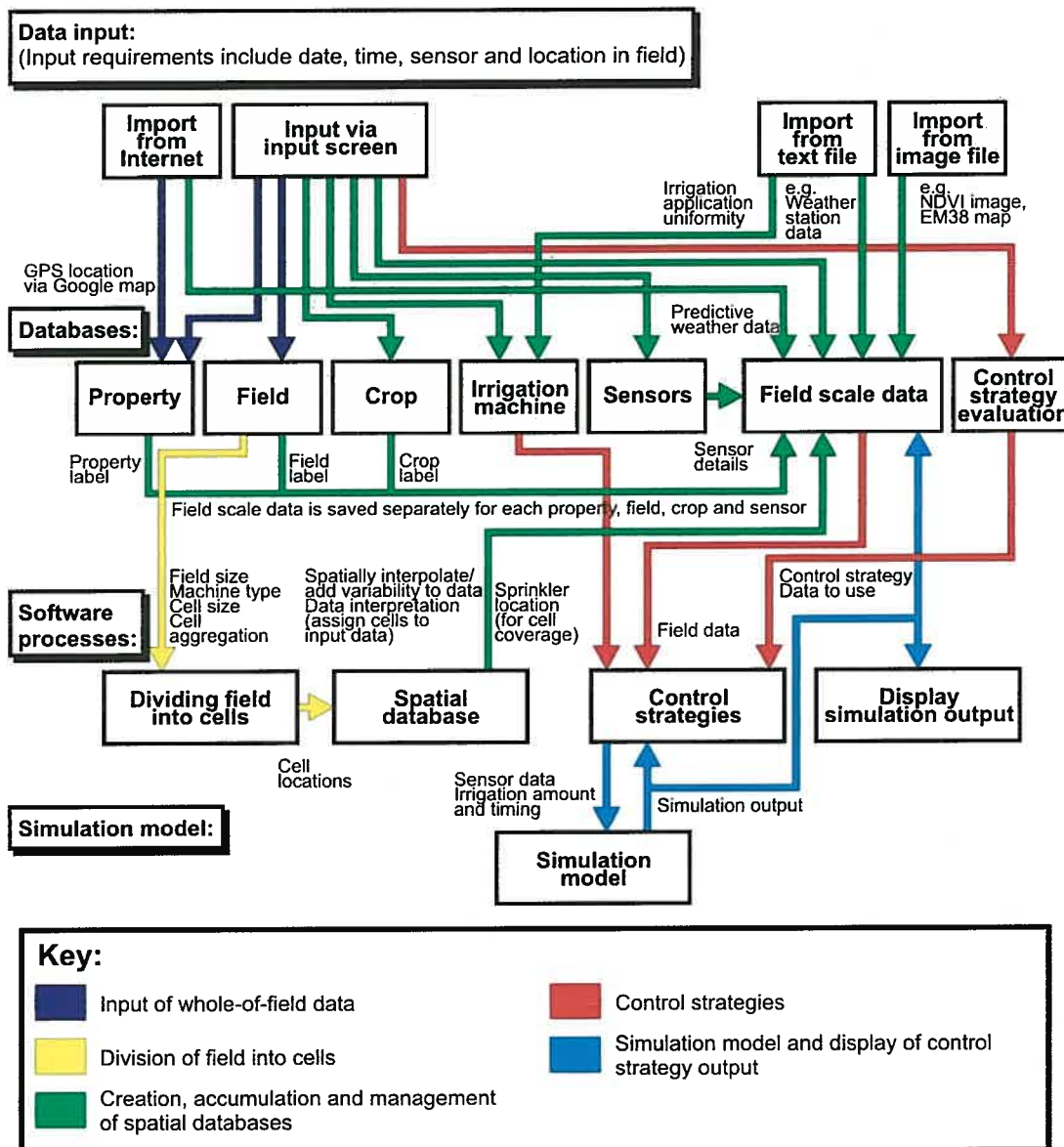


Figure 1: Block diagram for VARIwise software

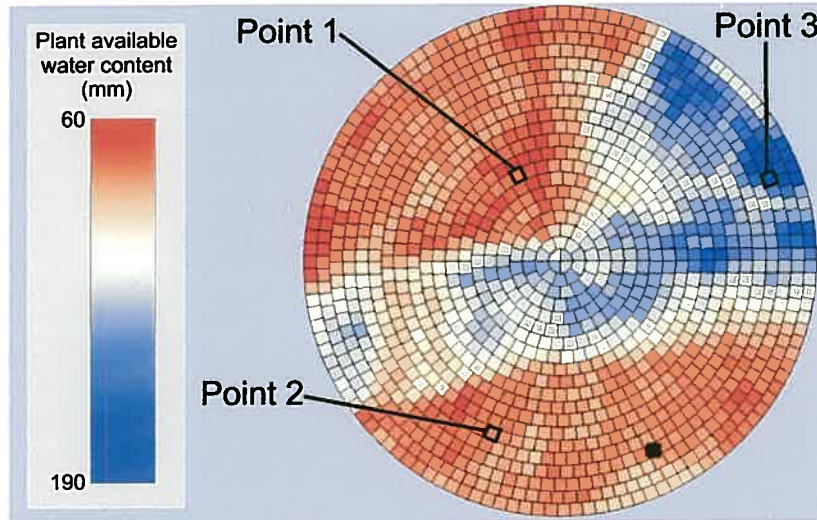
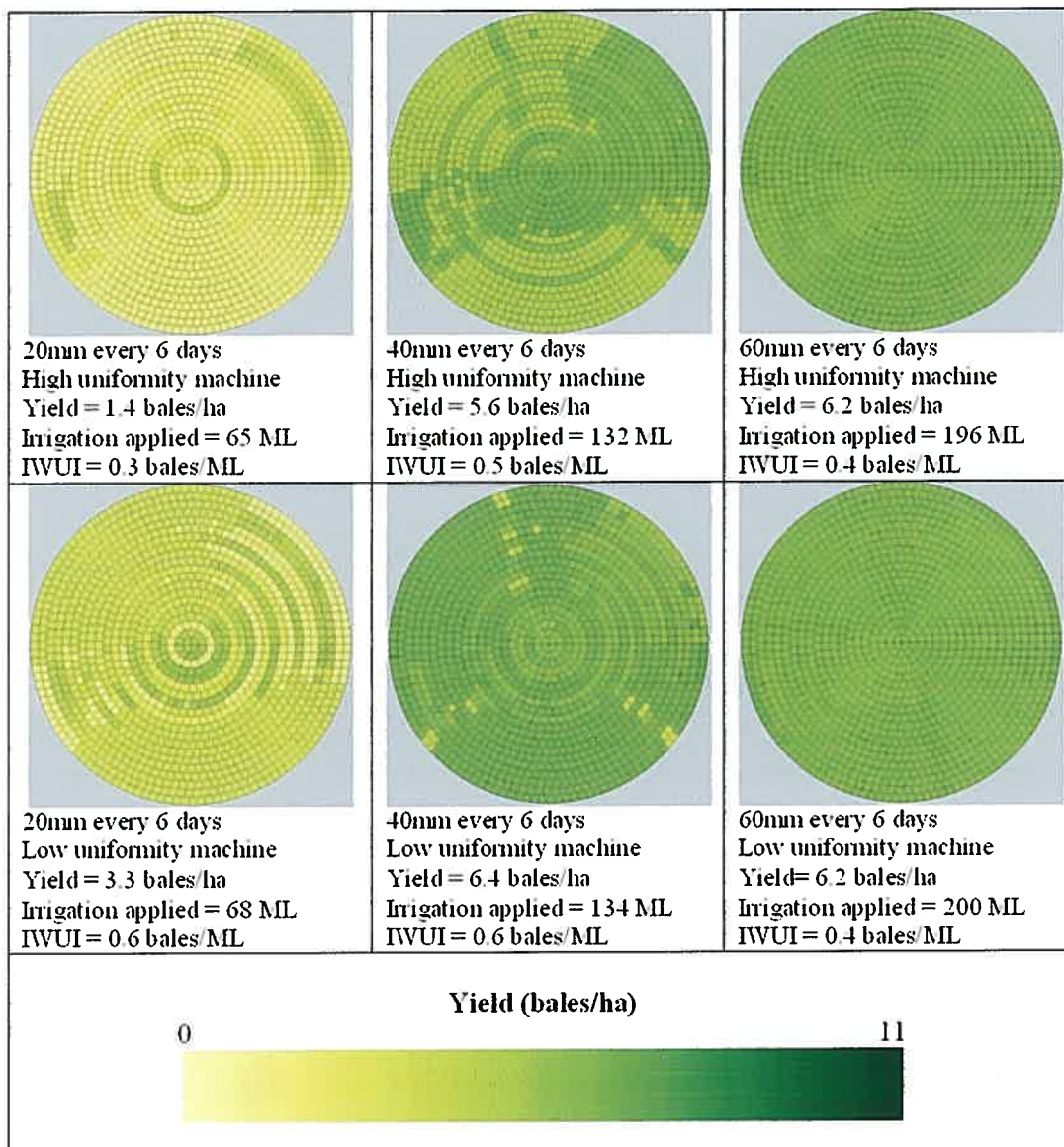


Figure 2: Electrical conductivity values assigned to each cell from imported EM38 map and trigger points used for soil moisture deficit-triggered irrigation strategy



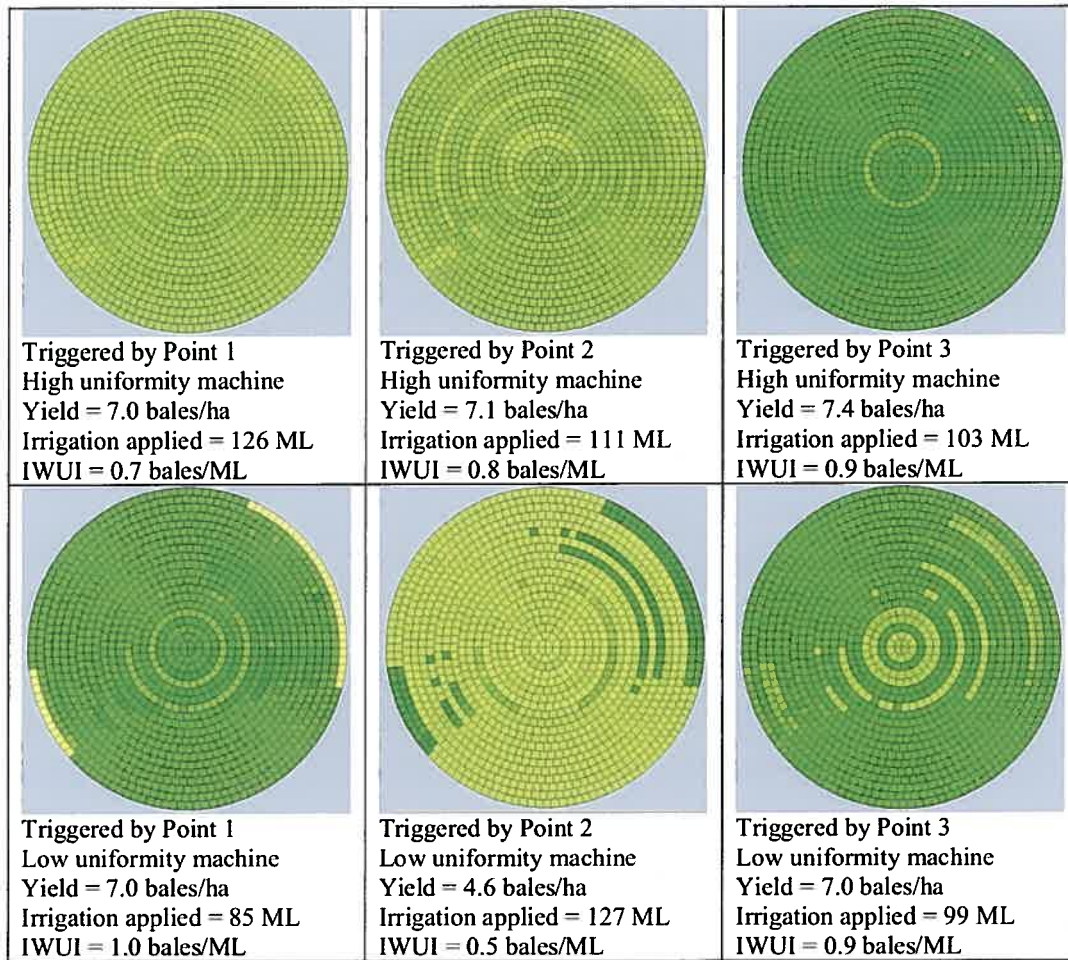


Figure 4: Yield output of the soil moisture deficit-triggered irrigation strategy

Validation and calibration of a cotton production in the software platform

A field experiment was conducted to demonstrate the automatic model calibration procedure in VARIwise and involved implementing three irrigation treatments with three replicates. Using measured soil and plant data from the fieldwork, the OZCOT model was accurately calibrated and the reliability of the modelled cotton growth variables improved under the same conditions as the fieldwork. There was no significant difference between the simulated and measured soil and plant response to the irrigations in the field trial.

The calibrated model was used to evaluate the effect of using different data inputs in an irrigation control system. Control strategies were developed for each seven possible input data combinations (i.e. weather, soil, plant individually and the four possible combinations of these). The data input combination indicated the data used as ‘real-time’ data input to the model and the irrigation volume applied, i.e. if soil input was in the combination the modelled soil moisture deficit was applied irrigation volume, whilst if no soil input was in the combination the estimated crop evapotranspiration was the applied irrigation volume. Three replicates of these strategy simulations were conducted using the initial measured plant and soil data from the three irrigation treatments. The results displayed in Figure 5 compare the simulated irrigation volumes and plant data each data input combination.

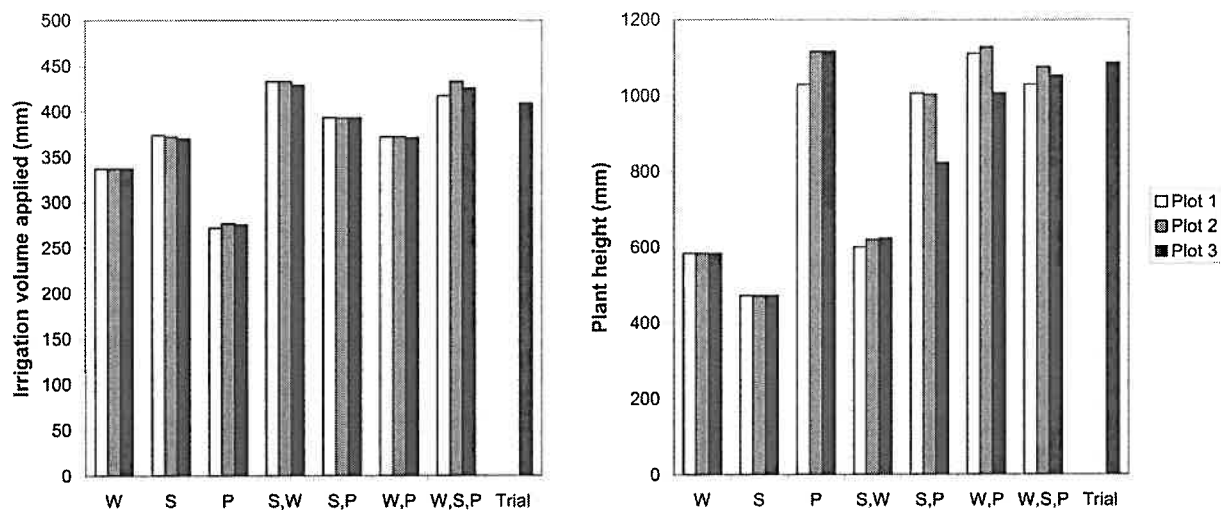


Figure 5: Irrigation volume applied and final cotton plant height for seven combinations of data input for low, medium and high irrigation treatment plots (W, S and P denote weather, soil and plant data input, respectively)

For the field conditions of the fieldwork, the model was most effectively calibrated using the full dataset (plant, soil and weather data). For a situation where only two data inputs were available, the simulations suggested that either weather-and-plant or soil-and-plant input were preferable.

Identification and implementation of appropriate irrigation control strategies for improving the performance of cotton irrigation

Three control strategies applicable to irrigation were identified from the literature review and developed. The control strategies were then implemented in VARIwise as follows:

Iterative learning control, as the name suggests, is a control strategy which continually amends (adapts) its control actions based on the success of previous action. This scheme was implemented by using the error between the desired and measured value of the soil moisture deficit to adjust the irrigation volume of the next irrigation event.

Iterative ‘hill climbing’ control does not imply irrigation on a hillside. Rather it is a control strategy which continually amends (adapts) its control actions in the direction of most likely improvement (‘uphill’), again based on acquired knowledge of the relationships between input variables. This scheme was implemented by: (i) dividing the field into groups of cells with homogeneous properties according to an input soil (e.g. EM38) variability map; (ii) selecting a small number of ‘test cells’ in each cell group to evaluate different irrigation amounts; (iii) applying different irrigation amounts to each test cell; and (iv) using the response of each test cell to the previous irrigation amount to decide the irrigation amount to apply to the non-test cells in each corresponding cell group.

Model Predictive Control (MPC) is a widely-used technique of modern (often called ‘advanced’) industrial process control which formulates and updates an internal model of the process, again based on acquired knowledge of the relationships between input variables. This model is then used to predict the evolution of the process and hence determine the optimal control actions. This scheme was implemented by using field data measurements of weather, soil and plant to calibrate a crop production model and an optimisation algorithm

that uses the calibrated model to predict the optimal irrigation application timing and site-specific volumes.

Evaluation of the benefits and limitations of the various control options with respect to data input requirements and the level of output control available

The performance of an irrigation control system will be limited by the attributes that are measured in the field, the spatial resolution of the sensor data for both static sensors (e.g. soil moisture probes) and on-the-go sensors (e.g. infrared thermometers) and the temporal resolution of the input data. The control system performance may also be affected by spatially variable rainfall or an irrigation machine with a capacity constraint such that it cannot deliver the optimal irrigation volumes in time. Adaptive irrigation control systems have differing robustness to these data availability and system constraints.

The three integrated control strategies each required different combinations of input data to perform optimally and these were identified in case studies as follows:

- the iterative learning control strategy targeted a fixed soil moisture deficit in each cell;
- the iterative hill climbing control strategy maximised the square count in each zone; and
- the model predictive control strategy maximised the predicted final yield using a complete dataset to calibrate the crop model.

The limitations and robustness of the three adaptive irrigation control strategies were explored in VARIwise. These simulations were conducted for a field divided into cells (i.e. management areas) with the underlying soil variability displayed in Figure 6.

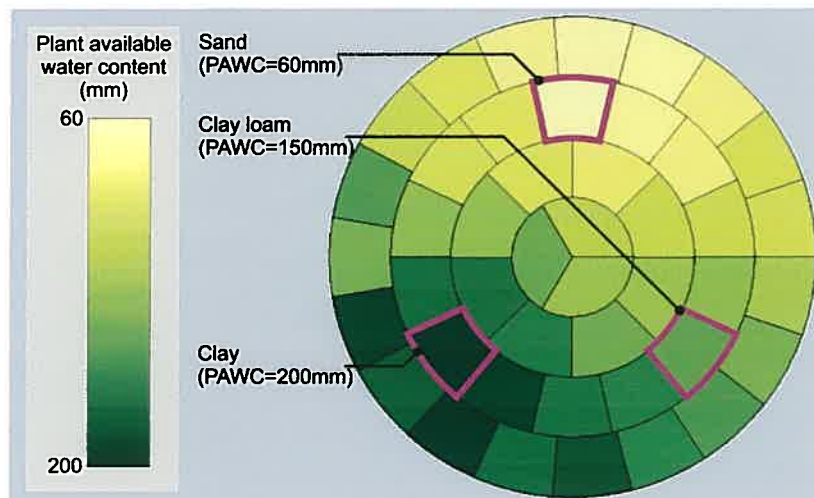


Figure 6: Underlying soil variability used to evaluate robustness of adaptive irrigation control strategies to sensor and irrigation machine constraints

The three adaptive control strategies were simulated with:

- data available at only a limited number of points in the field (where the points were selected randomly and ten replications were simulated, Figure 7);
- spatial variability of rainfall with imposed variability of $\pm 20\%$ and $\pm 50\%$ (with ten replications, Figure 8);
- data available at various temporal resolutions (Figure 9); and
- constraints on the irrigation machine capacity (Figure 10 for a centre pivot irrigation machine and Figure 11 for a lateral move irrigation machine).

In Figures 7 and 8, the average and standard error of the simulated outputs are shown for the averaged sets of replicates; and within each graph the use of matching superscripts (A, B, ... F) indicates no significant difference (at the 95% significance level) between the resulting performance measures and the simulations with data input at all points in the field (for Figure 7) and with constant rainfall (for Figure 8).

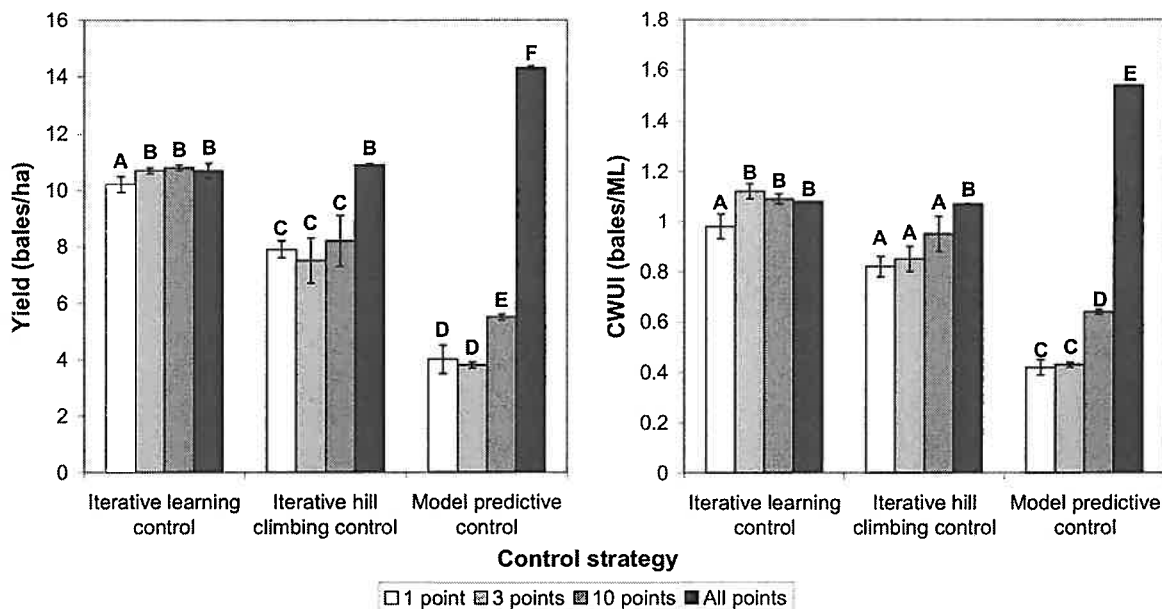


Figure 7: Yield and crop water use index simulated for three adaptive control strategies with various spatial resolutions of input data

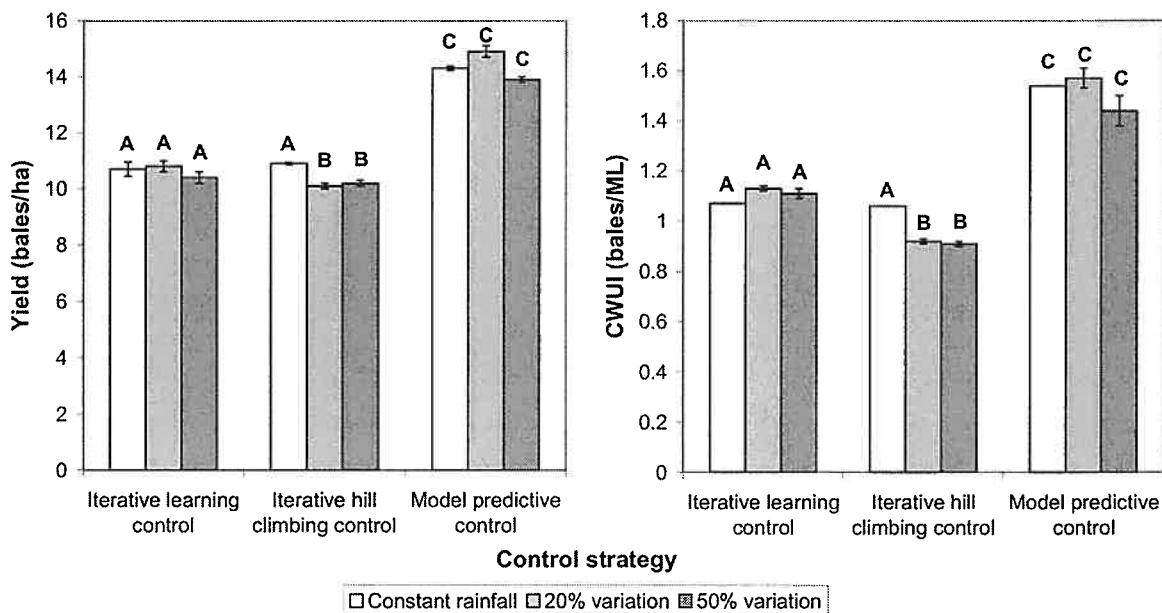


Figure 8: Yield and crop water use index simulated for three adaptive control strategies with spatial variability of rainfall

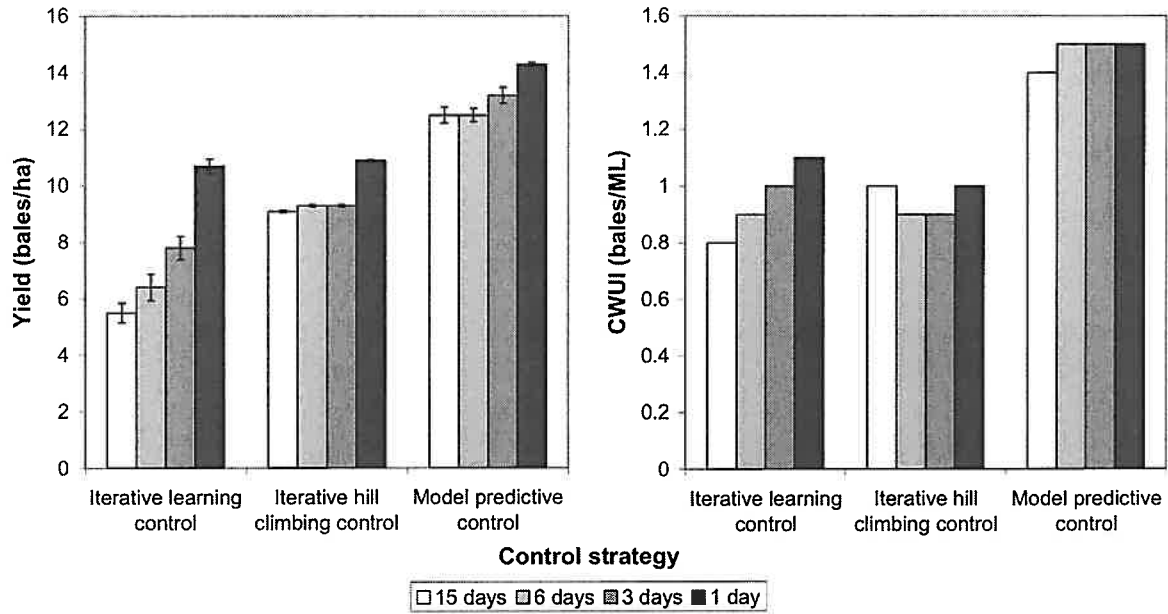


Figure 9: Yield and crop water use index simulated for three adaptive control strategies with various temporal resolutions of input data

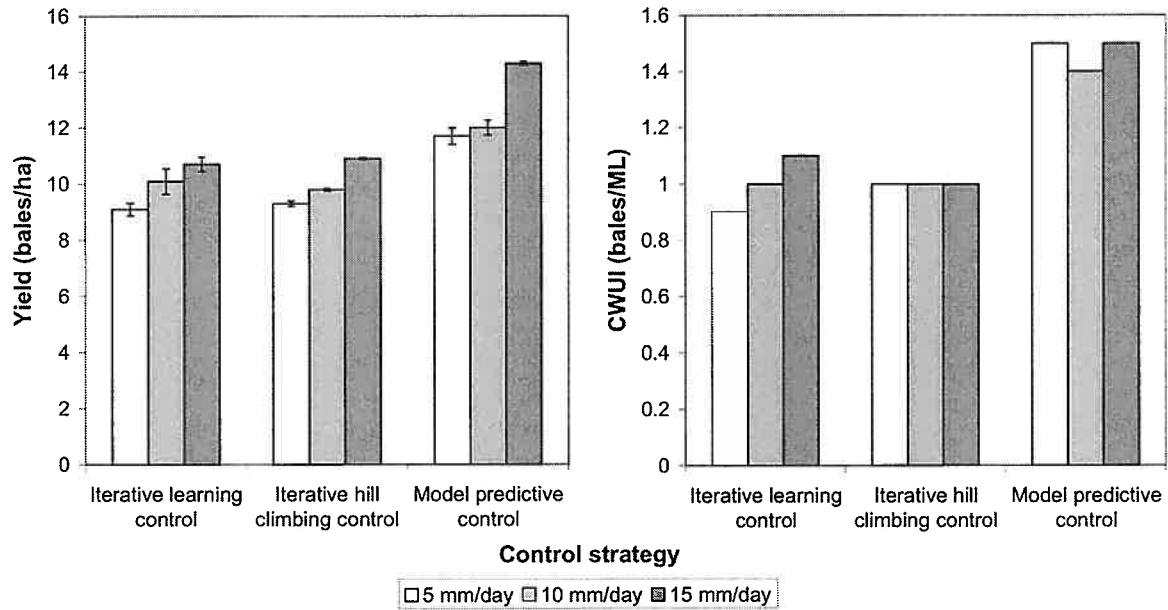


Figure 10: Yield and crop water use index simulated for three adaptive control strategies and centre pivot irrigation machine with various irrigation machine capacities

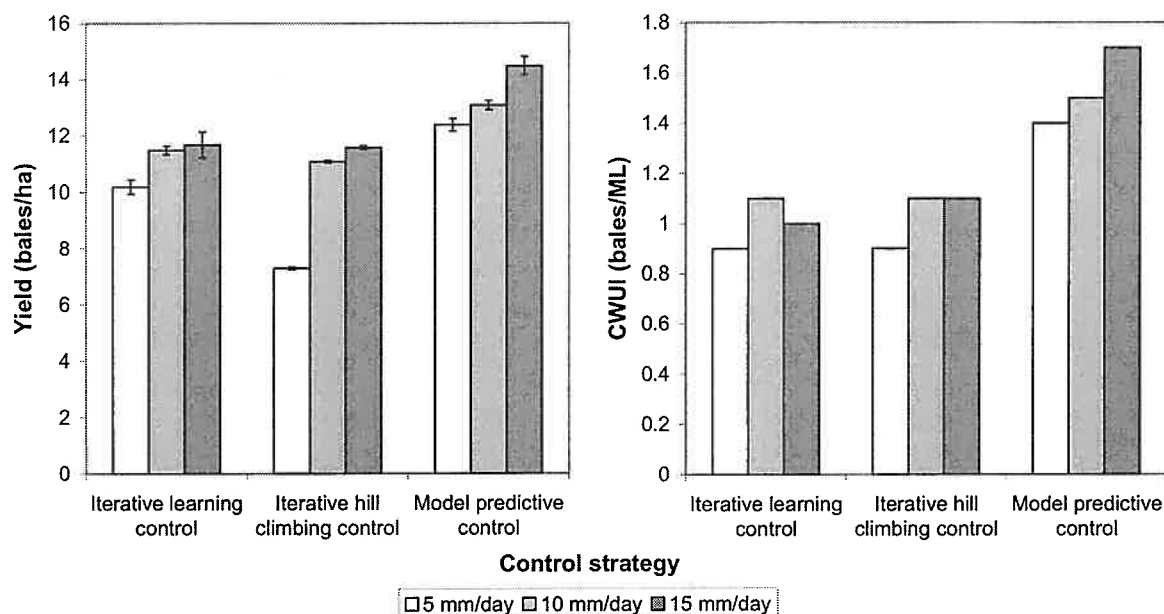


Figure 11: Yield and crop water use index simulated for three adaptive control strategies and lateral move irrigation machine with various irrigation machine capacities

From these comparisons, it was concluded that:

- the iterative learning control strategy is preferable in situations of sparse spatial data;
- the iterative hill climbing controller requires data input in specific cells (and not randomly selected cells) of the field to maintain control performance;
- iterative learning control and model predictive control are least sensitive to unquantified spatially variable rainfall and low irrigation machine capacities;
- all three adaptive control strategies can adapt to irrigation application via lateral move irrigation machines; and
- the model predictive control strategy outperforms the other strategies in situations of full data input, high spatial data availability and low temporal data availability.

Outcomes

This research delivered the outcomes as planned in the project application and these achievements are described in this section.

A software platform for simulating and evaluating irrigation control strategies for a general, spatially-varied field

The development of the software platform facilitated the evaluation of both uniform and variable-rate irrigation control strategies for centre pivot- and lateral move-irrigated cotton in simulation. Variability in underlying soil and crop properties and irrigation machine irrigation delivery (for a machine applying constant irrigation across the field) can also be simulated. This has enabled comparisons between uniform and variable-rate irrigation strategies and evaluation of options regarding the management of infield spatial variability.

The development of the software has led to improved understanding of how to use input real-time, historical mapped and predictive data to manage irrigations. In VARIwise mapped data (e.g. EM38 and NDVI surveys of the field) are used to describe the underlying variability in the field. These can also be used to identify the ‘management zones’ in the field to be treated homogeneously. Real-time sensor input is used as the soil and/or crop response to the



irrigation applied, whilst predictive (climate) data is used in the model predictive controller to determine which day and volume produces the desired crop response later in the crop season.

A validated and calibrated cotton model in the software platform

An automatic model calibration procedure was developed and validated using field data. This demonstrated that VARIwise could incorporate real-time weather, soil and plant measurements in irrigation control strategies and enable real-time control strategies to be implemented on an irrigation machine.

Appropriate automatic and self-adapting irrigation control strategies for improving the effectiveness of irrigation applications

To identify appropriate control strategies for improved irrigation of cotton, the requirements of an optimal irrigation control system and the applicability of classical control systems to irrigation were determined. This required strategies to be developed considering the embedded electronic and computing systems within complex operation systems. Real-time implementation of the software was explored and this indicated that VARIwise would enable real-time identification and implementation of irrigation control strategies on an irrigation machine.

An evaluation of the benefits and limitations of the various control options with respect to data input requirements and the level of output control available

Simulations were conducted to evaluate the robustness of the control strategies to sensor data availability and irrigation machine constraints. This identified the benefits and limitations of alternative irrigation control strategies for cotton with respect to data input requirements. These comparisons also helped to improve the targeting of sensing and monitoring tools, as some strategies could maintain control with limited data input, whilst others required sensor data at a high spatial resolution to maintain control. These simulations have helped to refine the strategies and sensor requirements for future field implementation. A number of these results were presented at the IAL Irrigation Conference 2010 and the World Congress on the International Commission of Agricultural Engineering Conference 2010 in relation to the control performance with spatially variable rainfall where only the average rainfall value was known, and with spatially variable soil where soil moisture and field capacity were only known at a limited number of points in the field.

4 a) Technical advances achieved:

A commercially significant development from this research is the creation of the software VARIwise. This has enabled comparison of uniform and variable-rate irrigation strategies and their respective robustness to in-field variability in simulation, and an evaluation of their performance in terms of cotton yield and irrigation water use efficiency.

4 b) Other information developed:

Adaptive control systems for irrigation have been developed which help circumvent the limitations of classical control systems applied to irrigation. Classical feedback control systems are typically implemented in processes which provide opportunity for actuation responses on timescales measured in seconds and often milliseconds (e.g. chemical processes, batch processing). This is in contrast to irrigations which occur days apart and plant response which may also not be measurable for days after the irrigation event. Direct application of many common place system identification strategies is not efficient due to the different time scales in irrigation. To circumvent this limitation, adaptive system



identification was incorporated into an irrigation control system to account for the slow speed of crop dynamics and the frequency of irrigation events. This involved evaluating a range of inputs to the system at each irrigation event (i.e. applying and evaluating a range of irrigation volumes on different sub-areas or 'cells' in the field).

Methods of overcoming data availability were implemented in adaptive control systems. For example, the spatial resolution of the sensed data could be effectively increased and used as input to the control strategies by spatially interpolating the known points to estimate the values at the unknown points. Alternatively, the control objectives used at the points with limited data available may be adjusted according to the data that is available in that area. This is effectively implementing different irrigation control strategies across the field depending on the data availability in each sub-area of the field.

4 c) (No changes to the Intellectual Property register are required.)

Conclusion

Likely impacts of the results and conclusions of the research project for the cotton industry (and take home messages) are:

- that cotton yield and water use efficiency may be significantly improved using adaptive control systems; and
- that adaptive control systems can reliably and appropriately adjust the irrigation application and improve cotton irrigation performance despite various data availability limitations and irrigation hardware constraints.

Extension Opportunities

Integration of VARIwise with commercial variable-rate irrigation systems will be investigated. By also incorporating an infield weather station, soil sensors and plant response measurements, field evaluation of a near-real-time adaptive irrigation control strategy on an irrigation machine will be enabled.

Three journal articles are planned for submission this year:

- Development of iterative learning and hill climbing irrigation control systems for irrigation
- Development of model predictive control system for irrigation
- Robustness of adaptive irrigation control strategies to data availability limitations and irrigation hardware constraints

Research results will also be presented during overseas university visits in March 2011.

Future research:

Postdoctoral research was commenced in July 2010 at the National Centre for Engineering in Agriculture (NCEA) to further develop VARIwise for cotton irrigation. This research will involve:

- Adapting VARIwise to optimise the seasonal management of surface irrigation
- Incorporating a self-learning capability into VARIwise
- Incorporating hydraulic and sprinkler simulation models for centre pivots and lateral moves
- Investigation of state space equation formulation for cotton growth dynamics

VARIwise is also being adapted to fodder irrigation as part of a South East Queensland Irrigation Futures program with the NCEA and Dairy & Fodder Water for Profit team.



VARIwise will be used to evaluate the performance of a fodder crop with variable-rate irrigation using collected field data and a simulation model. Field evaluation and validation of the strategies will also be undertaken.

List of Publications

A copy of all publications is provided on a CD.

Journal papers

MCCARTHY, A.C., Hancock, N.H. and Raine, S.R. (2010a) VARIwise: a general-purpose adaptive control simulation framework for spatially and temporally varied irrigation at sub-field scale, *Computers and Electronics in Agriculture*, **70**(1):117-128.

Smith, R.J., Raine, S.R., MCCARTHY, A.C. and Hancock, N.H. (2009) Managing spatial and temporal variability in irrigated agriculture through adaptive control, *Australian Journal of Multi-disciplinary Engineering*, **7**(1):79-90.

Refereed conference paper

MCCARTHY, A.C., Hancock, N.H. and Raine, S.R. (2010b) Holistic control system design for large mobile irrigation machines, *16th Annual Conference on Mechatronics and Machine Vision in Practice*, 22-24 June, Brunei.

Conference papers

MCCARTHY, A.C., Hancock, N.H. and Raine, S.R. (2010c) Simulation of site-specific irrigation control strategies with sparse input data, *XVIIth World Congress of the International Commission of Agricultural Engineering (CIGR)*, 13-17 June, Québec City, Canada.

MCCARTHY, A.C., Hancock, N.H. and Raine, S.R. (2010d) Simulation of adaptive site-specific irrigation control performance with spatially variable rainfall, *National Conference, Irrigation Association Limited*, 8-10 June, Sydney.

MCCARTHY, A.C., Hancock, N.H. and Raine, S.R. (2009) Exploration of data requirements for adaptive control of irrigation scheduling, *CIGR International Symposium of the Australian Society for Engineering in Agriculture*, 13-16 September, Brisbane, Australia. 8pp.

MCCARTHY, A.C., Hancock, N.H. and Raine, S.R. (2008a) Towards evaluation of adaptive control systems for improved site-specific irrigation of cotton, *National Conference, Irrigation Association Limited*, 20-22 May, Melbourne, Australia. 8pp.

Smith, R.J., Raine, S.R., MCCARTHY, A.C. and Hancock, N.H. (2007) Managing spatial and temporal variability in irrigated agriculture through adaptive control, *Society for Engineering in Agriculture 2007 National Conference: Agriculture and Engineering: Challenge Today, Technology Tomorrow*, 23-26 September, Adelaide, Australia. 12pp. [keynote]



Posters

MCCARTHY, A., Hancock, N. and Raine, S. (2008b) Development of simulation framework for variable-rate irrigation of cotton, *14th Australian Cotton Conference*, 12-14 August, Broadbeach, Australia. [poster]

MCCARTHY, A., Hancock, N. and Raine, S. (2010e) 'VARIwise' simulation of variable-rate irrigation of cotton via adaptive control: first results, *15th Australian Cotton Conference*, 10-12 August, Broadbeach, Australia. [poster]

Grower magazines

MCCARTHY, A., Hancock, N. and Raine, S. (2008c) Spatially varied irrigation – water where it's needed, *CRDC Spotlight Magazine*, Summer, p6.

Alcorn, G. (2008d) Prescription irrigation will be smarter and interactive, *Leading Edge, Australian Grain*, January-February 2008, pp 39-40.

Online resources:

No online resources have been developed at this time, but the domain www.variwise.com has been purchased and establishment of the website is underway.

Part 4 – Final Report Executive Summary

Principal researcher: Alison McCarthy
Supervisors: Nigel Hancock, Steven Raine

National Centre for Engineering in Agriculture
Faculty of Engineering and Surveying
University of Southern Queensland, Toowoomba QLD

Improving the efficiency of water use in agriculture is increasingly essential to maintain the profitability and sustainability of farms. This involves applying only the minimum necessary irrigation water to maintain or improve the yield of individual plants. Irrigation control strategies can be used to improve site-specific irrigation. These control strategies generally require weather, plant and/or soil data to determine irrigation volumes and/or timing that improve crop water use efficiency while maintaining or improving crop yield. As the plant response and environmental conditions fluctuate throughout the season, control strategies which accommodate temporal and spatial variability in the field and which locally modify the control actions (irrigation amounts) need to be 'adaptive'. Such irrigation control systems may then be implemented on large mobile irrigation machine, both 'lateral move' and 'centre pivot' configurations, to provide automatic machine operation.

A simulation framework 'VARIwise' has been created to aid the development, evaluation and management of spatially and temporally varied site-specific irrigation control strategies. The cotton model OZCOT has been integrated into VARIwise to provide feedback data in the control strategy simulations. VARIwise can accommodate sub-field scale variations in all input parameters using a one square metre cell size, and permits application of differing control strategies within the field, as well as differing irrigation amounts down to this scale. An automatic model calibration procedure was also developed for VARIwise to enable real-time input of field data into the framework. The model calibration procedure was accurately implemented with measured field data and the calibrated model was then used to evaluate the effect of using different data inputs in an irrigation control system.



A literature review of control systems identified three adaptive control strategies that are applicable to irrigation, namely: (i) Iterative Learning Control (ILC) which involves applying irrigation volumes to cells in the field calculated by comparing the desired and measured value of the input variable for control (e.g. soil moisture deficit); (ii) iterative hill climbing control which involves applying test irrigation volumes to test cells in the field to determine the application that produced the best crop response and applying that volume to the remainder of the field; and (iii) Model Predictive Control (MPC) which involves using a calibrated crop model to evaluate various irrigation applications and timings to determine which irrigation decision to implement.

The three control strategies were implemented and simulated in VARIwise to evaluate their respective robustness to limitations in data input and system constraints. These strategies effectively adapted to temporal changes in weather conditions and spatially variable soil properties. For the set of field conditions simulated in VARIwise, the ILC, iterative hill climbing and MPC controllers produced their highest yield and water use efficiency with soil data, weather-and-plant data, and the full dataset input, respectively. MPC was most sensitive to spatially sparse input data but performed well with spatially variable rainfall and limited machine capacity. ILC was least sensitive to spatially sparse input data and variable rainfall, whilst iterative hill climbing control was most sensitive to spatially sparse input data and variable rainfall. Hence, in situations of high data input MPC should be implemented, whilst in situations of low data input ILC should be implemented. Iterative hill climbing control was most sensitive to limited irrigation machine capacity.

It is further concluded that cotton yield and irrigation water use efficiency may be significantly improved using adaptive control systems; and that adaptive control systems can adjust the irrigation application and improve the irrigation performance despite various data availability limitations and irrigation hardware constraints.