# EXPLORATION OF DATA REQUIREMENTS FOR ADAPTIVE CONTROL OF IRRIGATION SCHEDULING

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## ABSTRACT

Irrigation scheduling using physical and agronomic principles can improve both application and crop water use efficiencies. However, irrigation traditionally involves applying the same volume of water across an entire field, although not all plants in the field have the same water requirements. An adaptive control strategy is needed to locally control water applications in response to infield temporal and spatial variability with the aim of maximising both crop development and water use efficiency.

A simulation framework ‘VARIwise’ has been created to aid the development, evaluation and management of spatially and temporally varied adaptive irrigation control strategies (McCarthy et al., 2008). VARIwise enables alternative control strategies to be simulated with different crop and environmental conditions and at a range of spatial resolutions.

This paper reports a 2008/09 field study which examined the utility of three sensed variables – weather (evaporative demand), soil moisture and plant height – for the determination of appropriate irrigation management strategies in a cotton crop. The relative significance of each sensed variable (either singly or in combination) as a control input was evaluated using VARIwise. The implications for sensed data requirements and the implementation of adaptive irrigation control strategies are discussed.

**Keywords**: irrigation scheduling, adaptive control, automation, water use efficiency, spatial variability

## 1. INTRODUCTION

Irrigation application and crop water use efficiencies can be improved by scheduling the irrigation of crops using physical and agronomic principles (Evans 2006). 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. However, 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. Hence, differential irrigation (and possibly fertiliser, via fertigation) application is required according to plant requirements at different positions in the field: control strategies which accommodate temporal and spatial variability in the field and which locally modify the control actions (irrigation amounts) need to be ‘adaptive’ (McCarthy et al., 2008; McCarthy et al., 2009; Smith et al., 2009).

Adaptive control systems automatically and continuously re-adjust the controller to retain the desired performance of the system and with the aim of maximising both crop development and water use efficiency (e.g. Warwick 1993). Similarly, adaptive control strategies may be used to accommodate the various levels of data complexity normally found in irrigation (i.e. for the various combinations of weather, soil and plant data depending on data availability). Optimal adaptive control strategies to determine irrigation volume and timing may be identified by simulating alternate adaptive control strategies in a simulation framework. A simulation framework ‘VARIwise’ has been created to develop, simulate and evaluate adaptive irrigation control strategies (McCarthy et al. 2009). VARIwise accommodates sub-field scale variations in all input parameters using a minimum 1 $m^2$ cell size, and permits application of differing control strategies within the field, as well as differing irrigation (and fertigation) amounts down to this scale.

Existing irrigation control strategies in the current literature use measured soil data (e.g. Capraro et al. 2008; Kim and Evans 2009; Kim et al. 2009; Park et al. 2009) and plant data (e.g. Peters and Evett 2008). These control systems respond (and adjust the irrigation control) only if the need to change control settings is manifest in the sensed variables. However, soil and weather sensors may not provide the most accurate indication of crop status; rather, the plant may be the best indicator of water availability (e.g. Kramer and Boyer 1995; Wanjura and Upchurch 2002; Jones 2004). This is because the plants essentially integrate the atmospheric and soil factors that affect plant water status. Hence, the incorporation of the multiple dimensions of sensed variables (i.e. weather, soil and plant data) will normally be required for an optimal irrigation control system. By integrating a range of control strategies and using different combinations of sensor variables, we may then explore the usefulness of additional sensors and the data requirements for adaptive irrigation control. In VARIwise, measured field data may be used to calibrate the incorporated simulation model/s (presently the cotton production model OZCOT). The relative significance of each sensor variable may then be explored by simulating and comparing irrigation control strategies using the calibrated model and different combinations of input data.

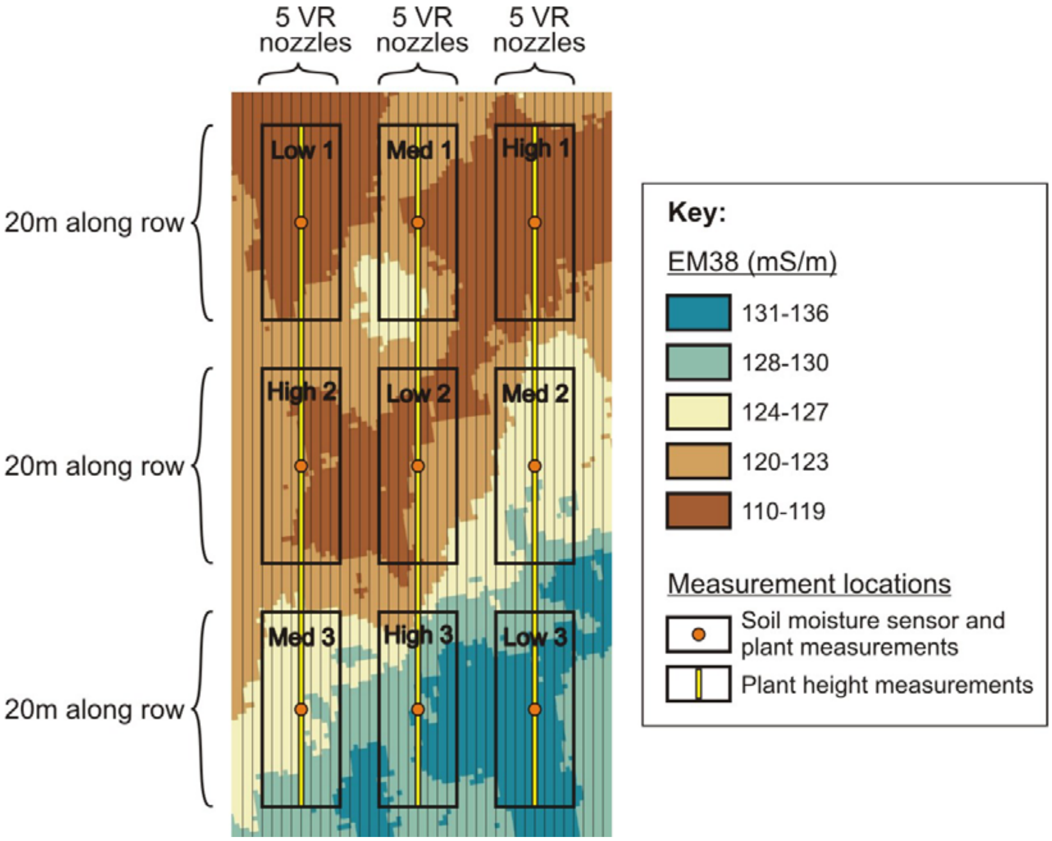
## 2. COLLECTION OF FIELD DATA FOR INCORPORATION INTO VARIwise

A field experiment was conducted to collect data for input into VARIwise and learn more about how to use each level of data complexity in adaptive control strategies. The experiment involved implementing three irrigation treatments with three replicates (i.e. a low, medium and high irrigation application compared to the commercial practice application determined from a soil moisture probe) (Figure 1). Sicot 70BRF variety cotton was planted under a lateral move irrigation machine in Dalby on 15 October 2008. The cotton was sprayed with urea on 14 October 2008. Three irrigations were applied prior to the field trial. Measurements were taken for three controlled irrigation events (on 9 January 2009, 28 January 2009 and 4 February 2009) and for one uncontrolled irrigation event (on 16 January 2009). There were two rainfall events during the trial (7.6 mm and 16.2 mm on 23 and 25 January 2009, respectively). A horizontal EM38 electrical conductivity survey was conducted on the field one week after cotton was sown to choose a trial area which was highly uniform (Figure 1).

The irrigation applications were varied by adjusting the ball valve on the droppers of the sprinklers used to irrigate the trial area and the three irrigation treatments were verified with catch can data. To achieve the high irrigation treatment, larger nozzles were installed on the sprinkler heads to be varied. The spray pattern of the sprinklers was maintained for the three irrigation treatments since the ball valve was only partly closed and the flow rate did not lower significantly.

Field data was collected between December 2008 and February 2009: soil data was collected for five depths (10 cm, 20 cm, 30 cm, 40 cm and 50 cm) from soil moisture sensors (Enviroscan probes); cotton square (‘squares’ are flowers on a cotton plant) and boll counts were collected manually; and vegetative growth was measured using a plant sensor. Leaf area index (LAI) is the vegetative growth variable used in the cotton production model currently integrated in VARIwise (OZCOT). However, measurement of LAI is typically destructive. Since experimental relationships between LAI and plant height have been developed for cotton (e.g. ASCE 1996; Richards et al. 2002), the plant height was measured and used to estimate LAI. A plant height sensor was developed for this fieldwork and consisted of an infrared distance sensor (Sharp Model GP2D12) mounted on a 1.7 m tall steel frame on two wheels. The frame was manually pushed down the cotton rows in the field trial and 44 data points were collected in every metre (at a travel speed of 1.5 m/s). There was an average standard deviation of 24 mm for ten replicate data sets measured using the plant height sensor along 75 metres of the field.

**Figure 1: Field trial layout with three replicates of low, medium and high application controlled via variable-rate nozzles on an EM38 electrical conductivity map of trial area (the dark areas at top and centre are lowest quintile; those at bottom are highest quintile).**



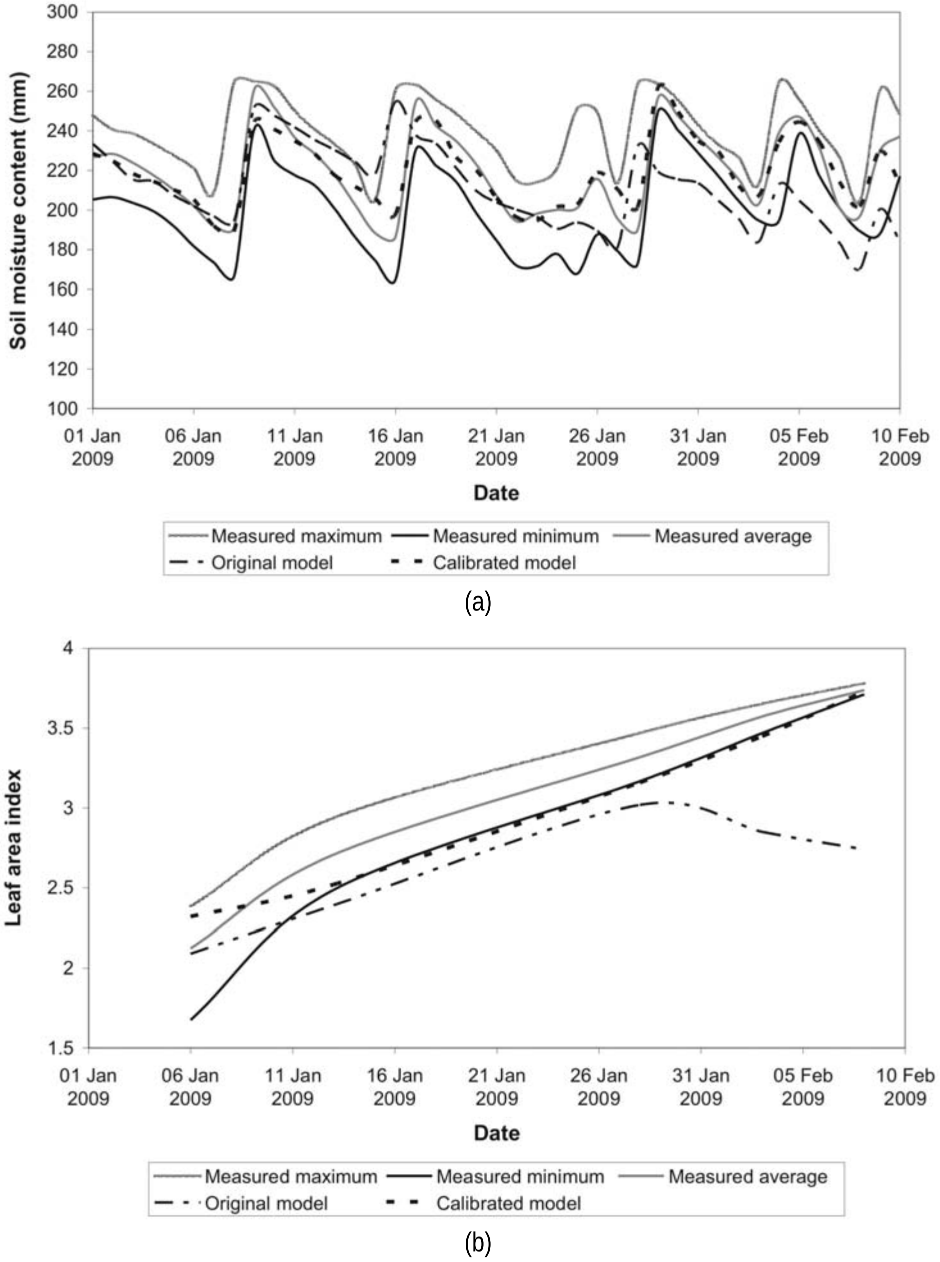
## 3. VALIDATION AND CALIBRATION OF MODEL USING FIELD DATA

SILO weather data for Dalby Airport was entered directly into the OZCOT model via a meteorological data file. The Enviroscan soil moisture sensor data required calibration before further data analysis as the raw sensor readings are estimations of the soil moisture levels and only the pattern of the soil water trends could be determined from the uncalibrated sensor. To estimate the magnitude of the crop water use, the soil moisture dataset was divided by the average amount of overestimation following the method of Pendergast and Hare (2007). The plant height data was converted to LAI for comparison with the modelled data using the experimental relationship developed by Richards et al. (2002) for cotton:

$$LAI = 0.00347 \times Height - 0.0352 \qquad R^2 = 0.914$$

The OZCOT model requires calibration to incorporate the measured soil moisture, square and boll count, and plant height (converted to LAI). The calibration of these parameters individually was straightforward and involved adjusting parameters in the soil properties or cotton variety OZCOT input file (depending on which parameter was being calibrated). However, the calibration of all four parameters must occur simultaneously as the parameters are interdependent: this calibration procedure involved iteratively adjusting the parameters in both the cotton variety and soil properties files based on the error between the modelled data and the measured data on the measurement days for the three irrigation treatments. The measured and calibrated model soil moisture and leaf area index data for the high irrigation treatment are illustrated in Figure 2.

**Figure 2: Comparison of model output with minimum, maximum and average measured: (a) soil moisture; and (b) leaf area index**



## 4. EVALUATION OF DATA OPTIONS

The relative significance of each sensor variable was explored by simulating an irrigation control strategy for each type of input data, singly and then in combination (Table 1). There were three individual sources of data input (i.e. weather, soil and plant) and four possible combinations of the data sources. For each option, this data was used as the 'real-time' data that was entered into OZCOT 'observation' files in which the measured soil moisture, LAI, square counts and boll counts were specified.

The real-time data was field trial data measured before the first irrigation in the trial period (on 9 January 2009) and averaged for the three low, medium and high irrigation treatment replicates. Measured data after the start of the trial period was not entered as the simulated irrigation applied would not be the same as the field trial. Hence, the starting conditions of the low, medium and high irrigation treatments are referred to as plots 1, 2 and 3, respectively. In plot 3 the soil moisture and plant height were initially the lowest of the plots, whilst in plots 1 and 2 the soil moisture and plant height were initially similar to each other.

The simulated irrigations were applied on the same days as the irrigation events in the field trial. When the soil data was used, the volume applied was the simulated soil water deficit; and when soil data was not used (and hence weather data was used), the volume applied was the cumulated crop evapotranspiration (ETc) since the previous irrigation. If no weather data was used then the volume applied was the cumulated ETc; however, the SILO weather data input used to calculate the ETc was averaged over the trial period (as input weather data is required for the OZCOT model).

The results displayed in Figure 3 compare the simulated irrigation volumes and plant data for the seven input data alternatives. The simulation results are also compared with the measured field data for the high irrigation treatment plots (displayed in the first row of Table 1) rather than the low and medium irrigation treatments which were deficit treatments.

A simulation using all the measured field data as real-time data input and irrigation events as per the field trial gave the same results are the measured field data. This is because the model was calibrated to fit the measured field data.

## 5. DISCUSSION

Data input from a single sensor gave a poor correlation to the measured data. However, of the single data input options, the soil-data-only option gave the best correlation to the irrigation volume applied but a poor prediction of the measured plant data, whilst the plant-data-only option alone gave the best correlation to the measured plant data but a poor prediction of the irrigation volume applied. If two sensors are available, either soil or weather combined with plant data gave the most accurate prediction of the trial data. The soil and plant combination gave the most accurate prediction of the irrigation volume applied in the trial (within 4%), whilst the weather and plant combination gave the most accurate prediction of the measured plant height (within 1%). However, the weather and soil data combination gave a poor correlation to both the irrigation volume applied and the plant data. The incorporation of all three sensors gave the best correlation to the measured data (within 4% of irrigation volume and 3% of plant height).

In plot 3 (with the lowest starting soil moisture and plant height), the irrigation volume applied and plant height were generally the lowest of the three treatment plots. This is because a smaller plant will generally have lower transpiration than a larger plant and therefore consume less water. Similarly, in plots 1 and 2, the irrigation volume and plant height (and hence the crop water use) were generally higher than in plot 3.

## 6. CONCLUSIONS

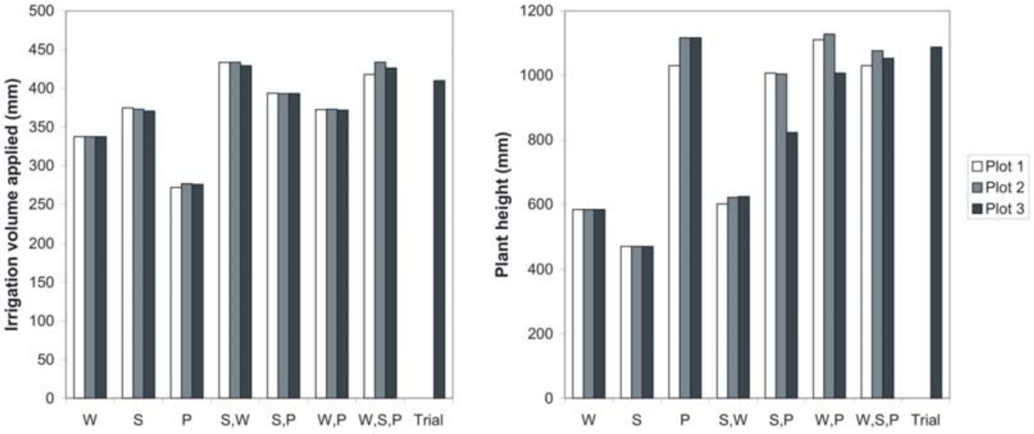
Using measured soil and plant data from the field trial conducted, the OZCOT model was accurately calibrated using ‘real-time’ field data as part of an adaptive irrigation control system. The results, both measured and simulated, illustrated the interactions between weather, soil moisture, irrigation and plant growth, and will inform future research on adaptive control strategies for optimal irrigation control.

Comparison of utility of different input data combinations – weather (evaporative demand), soil moisture and plant height, individually and in combination – to the irrigation control strategy indicated that either soil or weather in combination with plant data closely replicated the measured results. Single sensor data input produced inaccurate results as regards prediction of plant growth and irrigation volume applied. The measured results were most closely replicated using all data input sources. However, given the limited duration of this single set of field trials, these conclusions are regarded as illustrative rather than definitive.

**Table 1: VARIwise simulation output at end of trial period on 8 February 2009 for all combinations of input data and the three plot starting conditions**

| Input data combination | Observation file data input during trial | | | Irrigation volume calculation | Plot starting conditions | Irrigation volume applied (mm) | Final LAI | Final plant height (mm) | Final square count | Final boll count |
|---|---|---|---|---|---|---|---|---|---|---|
| | Plant data | Weather data | Soil data | | | | | | | |
| Measured weather, soil and plant | Nil | Nil | Nil | As for trial | 3 | 410 | 3.74 | 1088 | 7 | 8 |
| Weather (only) | Nil | Daily SILO | Nil | Cumulated ETc | 1 | 337 | 1.99 | 584 | 4 | 8 |
| | | | | | 2 | 337 | 1.99 | 584 | 4 | 8 |
| | | | | | 3 | 337 | 1.99 | 584 | 4 | 8 |
| Soil (only) | Nil | Averaged SILO | Measured daily | Modelled soil water deficit | 1 | 375 | 1.60 | 471 | 3 | 5 |
| | | | | | 2 | 373 | 1.60 | 471 | 3 | 5 |
| | | | | | 3 | 371 | 1.60 | 471 | 3 | 5 |
| Plant (only) | Measured daily | Averaged SILO | Nil | Cumulated ETc | 1 | 272 | 3.54 | 1030 | 3 | 6 |
| | | | | | 2 | 277 | 3.84 | 1117 | 3 | 7 |
| | | | | | 3 | 277 | 3.84 | 1117 | 4 | 8 |
| Soil and weather | Nil | Daily SILO | Measured daily | Modelled soil water deficit | 1 | 434 | 2.05 | 601 | 3 | 7 |
| | | | | | 2 | 434 | 2.12 | 621 | 3 | 7 |
| | | | | | 3 | 430 | 2.13 | 624 | 3 | 7 |
| Soil and plant | Measured daily | Averaged SILO | Measured daily | Modelled soil water deficit | 1 | 394 | 3.46 | 1007 | 6 | 4 |
| | | | | | 2 | 393 | 3.45 | 1004 | 5 | 4 |
| | | | | | 3 | 393 | 2.82 | 823 | 2 | 4 |
| Weather and plant | Measured daily | Daily SILO | Nil | Cumulated ETc | 1 | 373 | 3.82 | 1111 | 12 | 6 |
| | | | | | 2 | 373 | 3.88 | 1128 | 11 | 7 |
| | | | | | 3 | 372 | 3.46 | 1007 | 11 | 6 |
| Weather, soil and plant | Measured daily | Daily SILO | Measured daily | Modelled soil water deficit | 1 | 418 | 3.54 | 1030 | 6 | 8 |
| | | | | | 2 | 434 | 3.70 | 1076 | 6 | 8 |
| | | | | | 3 | 426 | 3.62 | 1053 | 5 | 8 |

**Figure 3: 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)**



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