

Simulation of adaptive site-specific irrigation control performance with spatially variable rainfall

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Introduction

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. A simulation framework 'VARIwise' has been created to develop, simulate and evaluate site-specific irrigation control strategies for centre pivot and lateral move irrigation machines (McCarthy *et al.*, 2010), and the cotton crop growth model OZCOT is currently integrated to evaluate strategies. In VARIwise, the field is divided into 1 m² cells to accommodate spatial variability and alternative irrigation control strategies have been implemented (McCarthy, 2010).

The spatial variability of natural rainfall in Queensland summer cropping areas is observed to be substantial on a scale of 10s to 100s of metres due to highly-localised cumulonimbus storms. Typically an automatic weather station or other data source will only provide rainfall data for a single point nearby, hence this variability is often unquantified and the effect on irrigation optimisation unknown. Using VARIwise, two adaptive control strategies were evaluated for performance and robustness to simulated spatial variability of rainfall. These strategies were:

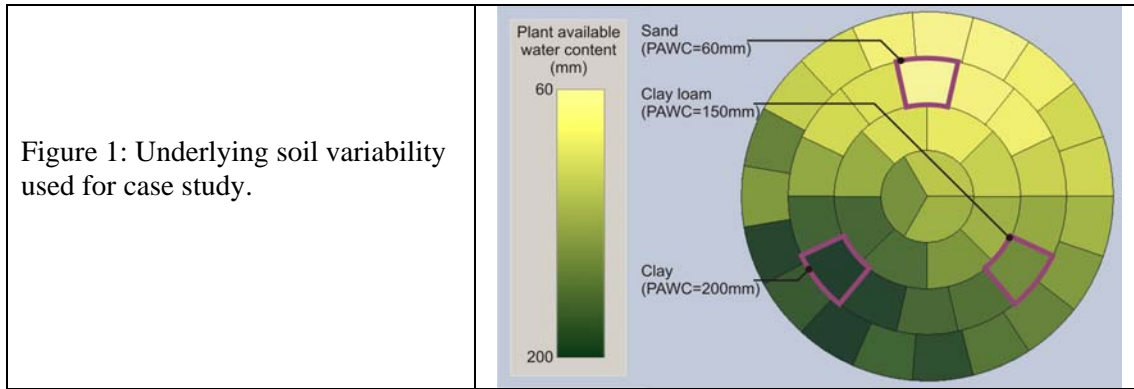
1. **Iterative Learning Control (ILC)** which uses the error between the desired and measured soil moisture deficit after the previous irrigation to adjust the irrigation volume of the next irrigation event; and
2. **Model Predictive Control (MPC)** which involves using a calibrated cotton model to simulate and evaluate various site-specific irrigation volumes and timings, and then implements the irrigation scheme (at that moment) that will maximise the cotton yield at the end of the crop season. The model calibration procedure (as required by MPC) must be emulated as there is no field data to calibrate the model in the simulation environment. This is achieved by utilising two crop models, each with different crop and soil properties where the output of one crop model (with the 'actual' field conditions) calibrates a second crop model (i.e. the 'base' model). The calibrated base model is used to optimise the irrigation management, whilst the actual model is used to determine the performance of the model predictive control strategy after the irrigation management options for the crop season have been determined.

Case study

In a simulation, cotton was sown on a 400 m diameter centre pivot-irrigated field on 4 October and was irrigated until 14 March of the following year. Nitrogen (250 kg/ha) was applied at the start of the season and the field was automatically divided into 44 cells for irrigation management. There was no stored soil moisture at the start of the season (i.e. 60, 150 and 200 mm deficit for the sand, clay loam and clay, respectively) and the irrigation machine capacity was 15 mm/day. The spatially varied soil properties (i.e. plant available water content) produced the underlying variability for the simulations presented in this case study (Figure 1).

Rainfall was spatially varied by applying a Gaussian distribution of variability to the rainfall measurement ascribed to each cell of the field. The average value of the rainfall was obtained from the weather profile for Dalby, Queensland during 2004/05 (QNRM 2009) and

Figure 1: Underlying soil variability used for case study.



two amounts of imposed variability, 20% and 50%, were evaluated. Ten replicates of each rainfall pattern were simulated for each control strategy.

The simulated yields and water use produced by the ILC and MPC controllers (Table 1) indicate that the performance of these control strategies will not be significantly affected by rainfall with 20% spatial variability; and with the 50% variability only marginally significant reductions in CWUI and IWUI are indicated. In each case both ILC and MPC strategies consider the rainfall in each cell via soil moisture measurements: for ILC the measured soil moisture is used to vary the irrigation volume; whilst for MPC the model is calibrated with the soil moisture data input and is then used to evaluate various irrigation timings and applications and determine which irrigation decision to implement.

Table 1: Performance (in simulation) of two adaptive irrigation control strategies with spatially variable rainfall. Average and standard error of the simulated outputs are shown for the averaged sets of replicates; and within columns the use of matching superscripts (A, B) indicates no significant difference (at the 95% significance level) between the resulting performance measures and the simulations with constant rainfall.

Control strategy	Rainfall variation (std. dev.)	Yield (bales/ha)	Total water applied (ML)	Irrigation applied (ML)	CWUI (bales/ML _{total})	IWUI (bales/ML _{irrigated})
Iterative Learning Control	± 50%	10.4 ± 0.2 ^A	117.7 ± 0.2	78.9 ± 0.1 ^A	1.11 ± 0.02 ^A	1.66 ± 0.03
	± 20%	10.8 ± 0.2 ^A	119.3 ± 0.6	79.6 ± 0.4 ^A	1.13 ± 0.01 ^A	1.71 ± 0.02
	0%	10.7 ± 0.5 ^A	125.3	82.4 ^A	1.07 ^A	1.63
Model Predictive Control	± 50%	13.9 ± 0.6 ^B	122.3 ± 0.6	81 ± 0.5 ^A	1.43 ± 0.06 ^B	2.16 ± 0.05
	± 20%	14.9 ± 0.2 ^B	119.4 ± 0.4	79.3 ± 0.3 ^A	1.57 ± 0.04 ^B	2.37 ± 0.05
	0%	14.3 ± 0.1 ^B	117.1	78.2 ^A	1.54 ^B	2.30

Conclusion

It has been demonstrated in simulation that two techniques of advanced process control, Iterative Learning Control (ILC) and Model Predictive Control (MPC), can not only be successfully applied to control of irrigation machines, but are also robust to the imposition of rainfall variability in the water management of a (simulated) cotton crop.

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References

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