ADAPTIVE LEARNING THROUGH FIVE STRANDS OF IRRIGATION DATA

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ABSTRACT

Irrigation R&D has proceeded around an engineering paradigm, where development and application of tools will deliver us a command and control solution. This view is contrary to the findings of census data and social research, which highlight the essential role of the irrigators' personal experience and adaptive learning. In this talk I will outline five strands of irrigation data and a sensor and logging platform that link irrigator experience with measured data, link atmospheric scheduling with soil based monitoring, and link water management with solute management, within an adaptive learning framework. The five strands of irrigation data are:
1) The knowledge of the irrigator based on their accumulated experience
2) Potential crop water use as the thermodynamic limit to irrigation
3) Soil water status monitoring
4) Depth of wetting front penetration, and
5) Electrical conductivity at the solute front

INTRODUCTION

The R&D community tends to view irrigation scheduling within an engineering paradigm, in which the irrigation 'problem' has a unique solution that can be implemented by the adoption of various monitoring or modeling tools. This is understandable. One hundred years of research into soil physics and plant physiology have revealed an enormous amount about how water and solutes move in and through soils, how plants extract water, and how water is turned into a profitable crop. The subsequent development of tools completes the picture. If we understand the cause and effect relationships in our system, and can measure the state of the system at a point in time, then we can manage the system in an optimal way.

It remains a conundrum, therefore, that 90% of commercial irrigators in the ABS surveys cite 'local knowledge', or their own experience, as a primary input into their irrigation management (ABS 2005, Stirzaker 2006). If we think of irrigation management as an engineering problem, then we will think in terms of command and control strategies. If we think of irrigation management as but one part of the complex business of running a profitable farm, then we should think in terms of adaptive learning (Roux et al. 2006). Adaptive learning means that managers have a conceptualisation of how their system works, and by drawing on several lines of enquiry they make decisions and learn from the outcome. This is not usually done in an explicit way, but if we could structure this learning we may be able to make faster progress.

In this talk I attempt to provide some structure to adaptive learning in irrigation by teasing out five strands of irrigation data and showing how they can be integrated. The five strands are:
1. *The knowledge of the irrigator based on their accumulated experience*
2. *Potential crop water use as the thermodynamic limit to irrigation*
3. *Soil water status monitoring*
4. *Depth of wetting front penetration*
5. *Electrical conductivity at the solute front.*

FIVE STRANDS OF INFORMATION

1. The knowledge of the irrigator based on their accumulated experience

Adoption of soil water monitoring tools increased from 13% to around 25% between 1996 and 2003, but this did not decrease the overwhelming percentage of irrigators who cite local knowledge as a major input into decision making. It appears that the objective methods of scheduling are not replacing the more subjective ones, but that these two ways of problem solving are being used together.

Extension programs working with growers on their own properties frequently elicit glowing testimonials about the benefits of soil water monitoring. Yet in many private conversations with farmers there is a balancing view, which partly helps to explain the disappointing adoption statistics. Some admit they have discontinued monitoring because 'they have found out what they needed to know'. Others say monitoring provides part of the solution and that they use the objective measures as a 'second opinion'.

Farm managers must divide their time among many tasks on the farm. Each task can be viewed as having an input – return relationship. At first the curve is steep and then it flattens out as there are lower marginal returns for each quantum of additional effort. Most irrigators know roughly where the 'flat part' of the curve is for water application, and thus where there are diminishing returns for their effort. Where the input - return curve is flat, information has low value, and it makes sense to put time and effort into some other aspect of farm management, other than soil water monitoring.

2. Potential crop water use as the thermodynamic limit to irrigation

Scheduling by evaporative demand has a long pedigree, from the Class A evaporation pan to automatic weather stations now aided by remote sensing (Doorenbos and Pruit 1984, Allen et al. 1998). The appeal is obvious. There is an upper limited to the amount of water a crop can use and it can be determined with considerable accuracy by thermodynamics (Monteith 19737?). We will often want to irrigate less than the limit, because of incomplete canopy cover or intentional deficit strategies, but we need a good reason to irrigate above this limit. The development of coefficients that link potential to actual evapotranspiration provide useful rules of thumb, and are particularly important in benchmarking performance of different farms in a particular area.

Given the above, it's unsettling to find out how often irrigators cannot tell you how much water a crop received. Irrigators can usually give the total water used on the farm, but few can give the amount used on a particular block and the final water productivity. This information would enable them to them to compare their performance against past years, against neighbours in the same year, and to connect with the experience recorded in scientific literature, or yield per unit water applied. If irrigators collected this information routinely, they could make use of publicly available climate data and find out what their own crop coefficients were.

3. Soil water status monitoring

Two decades ago, an irrigator had a choice between a tensiometer, neutron probe and perhaps a gypsum block. These days there are more than 20 different products on the market (Charlesworth 2005). Huge amounts of public money have been expended in Australia through training, incentives and subsidies to promote the adoption of these tools - with considerable success. For all their strong points, soil water monitoring tools are not a panacea. We have been too quick to label the tools as 'a solution' rather than one essential ingredient in the overall management strategy.

At times growers have told me that they simply 'do not believe the measurements', that the 'look of the crops or soil is telling a different story', and they may be right. The potential pitfalls of soil water monitoring are well known. Top of the list is interpretation of the data. Full and refill points are portrayed as constants when in fact they are dynamic. I have witnessed growers determine the full point in winter under rainfall and try to get back to this value under drip in summer. Measurements are to a greater or lesser extent affected by salinity and soil temperature. Many also misinterpret no change in water content at depth as no drainage, unaware that drainage takes place at unit gradient (no change in water content with depth) at a rate defined by the unsaturated hydraulic conductivity function. Installation is not straightforward either, particularly for the tools that measure a very small volume of soil. Placement relative to the drip emitter or wetting pattern of micro sprinklers, the impact of irrigation uniformity and variability in soil properties are all critical factors in data interpretation, but are frequently overlooked (Schmitz and Sourell 2000).

4. Depth of wetting front penetration

This is a relatively new way of looking at irrigation management, particularly for micro irrigation. When irrigation is applied frequently, then evapotranspiration, redistribution and drainage below the root zone can occur simultaneously. This makes it difficult to schedule irrigation by measuring the soil water deficit below a defined full point. An alternative is to monitor the depth the wetting front penetrates to, and to use this information to manage irrigation (Zur 1994, Stirzaker 2003).

Depth of wetting is not a precise measure of irrigation performance. First we have to specify the resolution (suction) at which we are detecting the wetting front, and fronts keep moving for hours or even days after irrigation is turned off. Second we need to know something about the width of wetting patterns under drip irrigation. Small changes in wetted diameter have large impacts on wetted depth because of the radial geometry of wetting patterns. However wetted depth is very useful as a check on whether a particular strategy is being carried out, and as a check on spatial variability. Growers develop rules of thumb, i.e. a certain percentage of wetting front detectors need to respond at a certain depth each week. If that is happening, then the strategy is on track.

5. Electrical conductivity at the solute front

Salt management has traditionally been seen as the requirement for a leaching fraction, usually calculated on an annual basis on top of the irrigation requirement (Ayers and Wescot 1989). The leaching fraction is the extra irrigation applied above that deemed to satisfy Et, to keep salt levels below some plant specific threshold. In practice the leaching fraction is rarely included in irrigation scheduling practices because the tendency toward over-irrigation makes intentional leaching management obsolete.

Solute and water monitoring are of course linked, and should help interpret each other, but are rarely viewed this way. If there is consistent under irrigation, with even slightly saline irrigation water, there will be a build up of salt within the rootzone. In this sense salt has a memory, and the signal – high salt at a certain depth – may be able to shed light on the general trend over an entire season. This is dealt with further in the next section. In contrast, nitrate monitoring can help identify periods of over-irrigation. It is difficult to interpret the magnitude of leaching events from soil water content data alone, but the drop in nitrate concentration can be dramatic, and provide a signal of more immediate interest to the irrigator.

INTEGRATION

In order to structure our learning from all five strands, we have to start somewhere – and this must be with strand 1 – the farmers' experience. Since the irrigator is still in business, there must be a considerable amount that is being done right. Most irrigators have done countless informal experiments on their farm, so we need to retain what is working and challenge what can be improved.

We can capture the manager's experience in two ways. First we must encourage the manager to be explicit about their conceptualisation of what they are doing. In other words we need to know why they changed from micro-sprinkler to drip, from weekly to daily to pulsed applications, or the other way round. Second we must capture what they are actually doing, and this means logging the irrigation on/off times.

Here I will describe a simple logging platform that integrates the five strands above, based on the Irrometer 900M 8-channel logger.   The Irrometer logger was designed principally for the Watermark sensor, which measures soil tension in the 5-200 kPa range. The sensor is comprised of an electrode buried in a porous matrix and contained within a stainless steel mesh. The porous matrix absorbs and desorbs water as it comes into equilibrium with the surrounding soil, and the resistance between the electrodes is measured. A gypsum pellet within the porous matrix maintains a saturated gypsum solution, which overcomes the variation in soil salinity from the resistance reading.

We built a simple conductivity probe with length and separation of the electrodes chosen to give an output in the range of the 0-30 kohm for the salinity range we are interested in (the resistance range used to measure a Watermark sensor). One conductivity probe is inserted into the irrigation line. When there is no irrigation the probe reads “dry” and when the crop is irrigated the probe reads the conductivity of the irrigation water for the duration of the irrigation event.

The on/off record gives us the farmers irrigation strategy, as well as the quality of the water source when there is switching between water sources (dam / bore) or an indication of the times that fertigation is occurring (strand 1). By knowing the irrigation application rate and accessing the potential ET from the Silo database, we can calculate the crop coefficient (strand 2).

Figure 1. The conductivity probe being lowered into the float housing of a WFD (left) the position of the electrode in the base piece of the WFD (centre) and the 8 channel Irrometer logger with in field display (right).

The conductivity probe was designed to retrofit the FullStop Wetting Front Detector (WFD) (Figure 1). Floats are removed from the detector and the probe dropped down the float housing. The probe positions the electrodes just above the filter in the base piece of the WFD. When a wetting front in the 0-3 kPa range moves past the WFD, water seeps through the filter and its conductivity is measured. The time the front arrives is recorded as an EC measurement of the soil solution. As the soil dries slightly after irrigation, water is withdrawn from the WFD by capillarity, and this time is marked by the logger as ’dry’, as in the case of the irrigation on/off probe.

WFDs are placed at two depths to give an indication of a light watering (no response) deep watering (both respond) or intermediate (shallow responses but not deep). Irrigators need to develop their own rules of thumb as to what response they are looking for (strand 4). WFDs do not provide information on soil drying, and this is provided by a Watermark sensor placed at a depth between the two detectors (Stand 3). In this sense the WFD and the Watermark are complementary. The Watermark is not accurate in the very wet range range, nor to rapid drying of surface soils. However, the Watermark placed near the centre of the root zone is a robust and reliable way to monitor average root zone drying and the WFD a robust way of measuring strong wetting fronts.

The EC measurements from the WFDs complete the picture (strand 5). Salt concentrates within the rootzone more quickly than we might expect, and provides an integral of drainage throughout the season. There are caveats on this, such as the assumption that water moves as piston flow and each mm of water draining carries its full complement of salt. The data shown in Figures 2 and 3 is from a modelled lucerne crop, where water is applied once the soil has reached a deficit of 50 mm in the top 600 mm soil. When the irrigation water is relatively fresh, 0.25 dS/m, the salinity in the top-soil will reach 2 dS/m within six months, well above the threshold tolerance for lucerne (Figure 2).

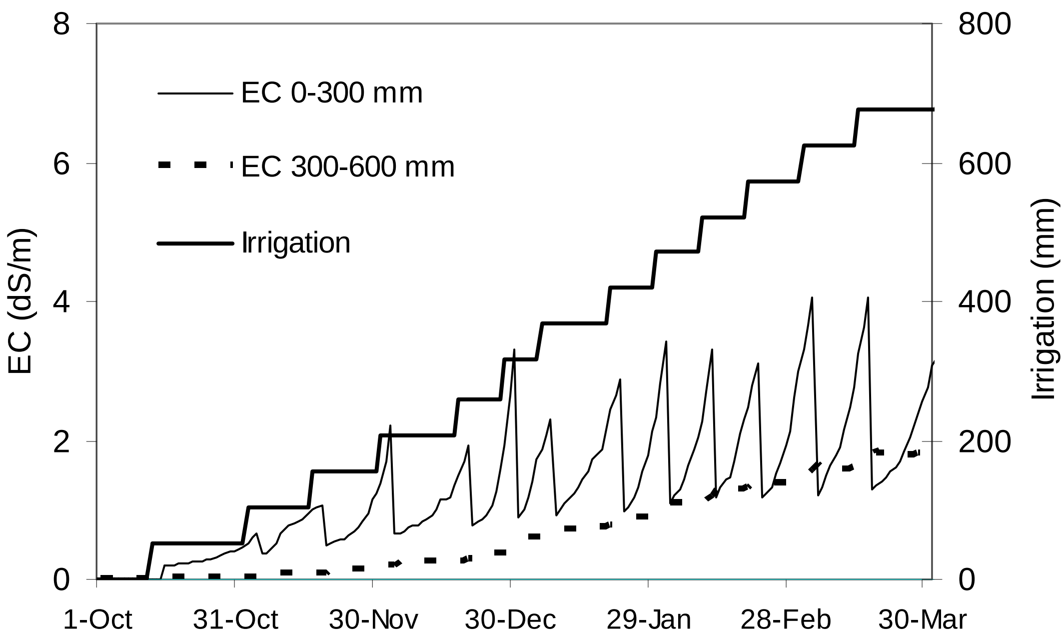

Figure 2. Modelled evolution of soil solution EC during 6 months irrigation of a lucerne crop over the 0-300 and 300 – 600 mm soil depths. Irrigation carried out when there is 50 mm deficit over the top 600 mm soil depth with water having conductivity 0.25 dS/m

The reason for the fluctuation in EC is the change in soil water content between irrigation events, i.e. the salt concentrates in the remaining water left behind after evapotranspiration. The effect is greater in the top-soil than the sub-soil. The WFD samples the EC at its lowest value, because a sample is only taken when a wetting front passes and the soil is at its wettest. When the irrigation water rises to 0.5 dS/m, the soil EC varies between 2 to 8 dS/m within six months, even though over 700 mm of water was applied (Figure 3). The magnification of the salt signal by crop evaporation makes salt a useful tracer. Each irrigation strategy should leave behind a solute signature which throws light on the seasonal irrigation performance in addition to the information cleaned from strands 2 and 3.

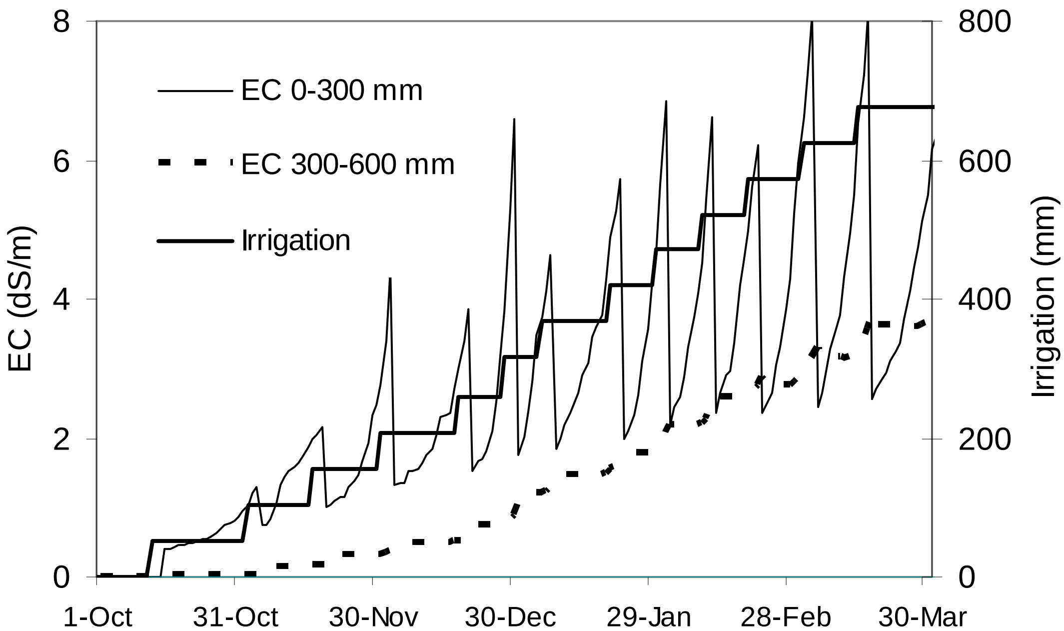

Figure 3. Modelled evolution of soil solution EC during 6 months irrigation of a lucerne crop over the 0-300 and 300 – 600 mm soil depths. Irrigation carried out when there is 50 mm deficit over the top 600 mm soil depth with water having conductivity 0.5 dS/m.

CONCLUSION

Each of the five strands has strengths and weaknesses. Personal experience is highly valued by managers, and is a robust way of getting the system roughly right, but can always be improved. Benchmarking performance against an agreed standard – potential ET calculated from a weather station – is an obvious next step. Sole reliance on atmospheric monitoring predisposes toward cumulative error, if parameters such as leaf growth and rooting depth do not reflect reality. This can be overcome by soil water monitoring. Yet to rely on point measurement alone exposes the irrigator to the problems of variability and calibration errors.

Wetting Front Detectors provide a means for linking irrigator knowledge with objective measurement, because most irrigators have an idea of how deeply they are trying to wet the soil. However the data from WFDs is made more useful by being able to relate irrigation depth to crop coefficients, and by the measurement of soil drying by Watermark sensor at a depth between two WFDs.

WFDs also provide the opportunity for linking water and solute monitoring and the development of custom electrodes for placement inside WFDs means the solute front can be logged to reveal the “solute signature”. Solute and water status monitoring should interpret each other i.e. if the EC is going up you are under-irrigating and if the nitrate is going down very fast it’s likely you are over irrigating.

The prototype logging platform that collects the five strands of irrigation data give us the opportunity to link

- irrigator experience with measured data
- atmospheric scheduling with soil based monitoring
- water management with solute management

within an adaptive learning framework.

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