Starting a dialogue between scientist and irrigator- lessons learnt from a simple wetting front detector

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ABSTRACT

A minority of irrigation farmers has adopted the proven tools and techniques for improving the productivity of irrigation water. We report on a strategy to draw more irrigators into a dialogue about how to improve irrigation practice. The dialogue is built around a Wetting Front Detector that shows farmers when water has penetrated to a certain depth into the soil after irrigation. We provide examples of how a simple tool has instigated on-farm change.

INTRODUCTION

There has been a major push to improve the on-farm efficiency of irrigation water in Australia. High profile government programs have developed education and advisory services combined with financial incentives to accelerate adoption of improved practices (Okello-Okanya 2004, Meldrum *et al* 2004). Though expensive, these programs have documented many successes; case studies show growers saving up to 30% of their irrigation water and/or yield increases of 30% or more (Charlesworth 2005).

It remains a conundrum therefore, that the latest agricultural census in Australia showed that four out of five irrigators still do not monitor soil water status (ABS 2005). Stevens *et al* (2005) reported similar statistics for South African irrigators.

At first sight the above statistics are perplexing, because irrigation scheduling does not seem that complicated. There is a full point and a refill point and a monitoring tool or model simply tells you where you sit between these limits. The scientific framework used by most scientists and advisors to try to convey this information to irrigators often follows the linear transfer of technology approach. This approach assumes that scientists know best, new technology is needed and new technology is better than old. The linear transfer of technology approach tends to have a reductionist approach to research, follows a positivist paradigm, relies on trickle down, focuses on one innovation and contains very little feedback (Chamala 1999).

Other extension models for agriculture have had much more farmer participation and much greater success. Such approaches recognise the many constraints to adoption that exist at farm level and recognise that farmers have often developed some remarkably robust rules of thumb to help them manage a complex and risk prone operation (Hayman 2001). Stevens *et al* (2005) maintain that there is a huge opportunity for combining this kind of farmer knowledge with existing scientific knowledge to improve the on-farm efficiency of irrigation.

THE TOOL

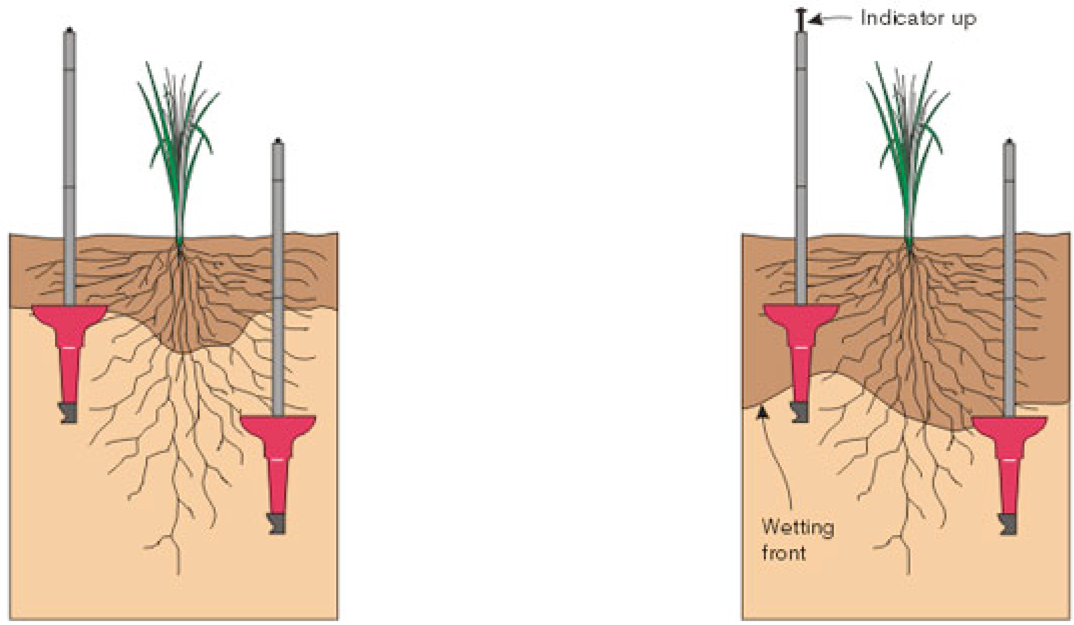
Our strategy is to build an advisor-farmer dialogue around a simple tool that most farmers can relate to, regardless of whether they operate on a large or small scale. The Wetting Front Detector (WFD) is a funnel-shaped instrument that is buried in the soil. The funnel concentrates the downward movement of water so that saturation occurs at the base of the funnel. The free (liquid) water produced from the unsaturated soil activates a mechanical float, alerting the farmer that water has penetrated to or past the desired depth. The detectors retain a sample of soil water that is used for nutrient and salt monitoring.

Knowing how deep a wetting front moves into the soil is critical for irrigation management. If a crop is given frequent but light sprinklings of water, the wetting front will not go deep and the WFD will not be activated. Much of the water will evaporate from the soil surface. If too much water is applied at one time, the wetting front will go deep into the soil, perhaps below the rooting depth of the crop, wasting water, nutrients and energy.

Dry soil can absorb a lot of water, so the wetting front may not go all that deep if the soil starts dry, even with a heavy irrigation. However, if the soil is already wet, a light irrigation can penetrate deeply into the soil. This is because wet soil cannot absorb much extra water, so any irrigation water just keeps moving downwards.

The Wetting Front Detector captures a small water sample from each passing front. By measuring the electrical conductivity of this water and its nitrate concentration, crop nutrient and salt management can be greatly improved. This is explained more fully at the WFD website: www.fullstop.com.au.

Wetting Front Detectors are usually used in pairs. The first is buried about one third of the way down the active root-zone. The second is buried about two-thirds the depth of the active root-zone (Figure 1). By active root-zone we mean the depth of soil that most of the roots are found in or the maximum depth of soil we aim to wet by irrigation. By watching how shallow and deep detectors respond through the season, the irrigator can get an idea if they are applying too much or too little water.



Too little water
If the indicator of the shallow detector rarely pops up, then water is not moving deep enough to fill most of the root zone. More water should be applied.

About right
The indicator of the shallow detector should p
regularly after irrigation. The deeper detector
respond during periods of high demand for w

Figure 1. The position of wetting front several hours after irrigation and the management response

THE DIALOGUE

Most irrigators identify water conservation as near the top of their concerns, but when it comes to taking concrete action, water conservation easily slips well down the priority list. Our hope is that the WFD, by virtue of its relative simplicity and low cost, can tempt irrigators who have not made use of existing technologies to take the first steps.

Kolb (1984) describes a learning cycle that starts with the individual taking an action step - in our case the installation of a WFD. A WFD will or will not pop up its float in response to irrigation - so there is something to *observe*. After several irrigation events the irrigator can then *reflect* on how a pair of WFDs respond to the way they irrigate. Reflection leads to *generalization* i.e. the shallow detector will only respond after less than one hour of irrigation if the soil is wet but after more than two hours if the soil is dry. From generalization the irrigator moves to *conceptualization* – improving the mental model of how water requirements change through the season. From here the irrigator can test their new understanding. Experimentation leads to more observation - reflection - etc. With each movement through the cycle, expertise is enhanced.

We aim to draw the farmer and advisor into a learning cycle or dialogue that unlocks the opportunities for improving productivity gains from irrigation. This dialogue has several stages, starting with the farmer **opportunities and constraints**. The second stage of the dialogue involves understanding the farmer's **goals and expertise**. During the third stage the farmer and advisor must come to a **shared understanding** of how to deploy the WFD and what to expect from it. Stage four involves **monitoring** during which time we strive to make the dialogue semi-quantitative. The final stage involves **learning**. What lessons can be put into practice to improve the productivity from irrigation?

The five stages are summarized below. Though laid out in a stepwise fashion we envisage a process more akin to Kolb's learning cycle than a linear information transfer process.

1. Opportunities and constraints

- Is water available on demand?
- Does the amount of water available limit productivity?
- Is the cost of water/energy a significant variable cost?
- What are your main constraints to improving water productivity?

2. Goals and expertise

- How do you irrigate and why?
- Do you think there is room for improvement and why?
- What steps have you taken thus far to improve irrigation management?
- What do you see as the next steps?

3. Shared understanding

- How deep should we put the detectors and why?
- What detector responses do we expect to see and why?
- What salt and nitrate responses do we expect to see and why?

4. Monitoring

- Check rate and uniformity of application
- Recorded duration of irrigation and the response of detectors
- Calculate water applied and estimate seasonal crop water use
- Measure EC and/or nitrate

5. Learning

- Does the WFD respond as expected – if not why?
- Do EC or nitrate measurements challenge expectations
- What are we learning?

THE WETTING FRONT DETECTOR GAME

Stages 3 and 4 are not simple, so we have tried to make a 'game' out of it. We ask the irrigator to record the duration of each irrigation event and record the response of the shallow and deep WFD. The table below gives a very basic interpretation.

Table 1. Response of Wetting Front Detectors to irrigation, what it means and the required action

Shallow WFD	Deep WFD	What it means	What you should do
		Not enough water for established crops.	Apply more water at one time or shorten the interval between two irrigations. May be the desired result for young crops or when trying to minimize leaching of nutrients.
		Wetting front has penetrated into the lower part of the root zone.	Much of the time this is the desired result. However during hot weather or when the crop is at a sensitive growth stage irrigation should be increased. The deep detector should respond from time to time, showing that the entire root zone is wet.
		The wetting front has moved to the bottom or below the root zone.	Both detectors should respond when irrigating to satisfy high demand for water. However if this happens on a regular basis over-watering is likely. Reduce irrigation amounts or increase the time interval between irrigations.
		Soil or irrigation is not uniform or the soil surface is uneven.	Ensure the soil is level over the detectors and water is not running towards or away from the installation site. Check uniformity of irrigation or location of drippers.

If the farmer expectation of the WFD response deviates from what they actually see in the field then they need to move onto the next stage of the game. This is an interactive visualization tool provided on a CD and website www.fullstop.com.au. The irrigator can type in their application rate and days since last irrigation and the game shows them how deep the wetting front should penetrate down into the soil.

The animation does require some additional information, such as the effective crop rooting depth and a guess at daily crop water use. It uses this information to choose the appropriate depths to place the WFDs, and to calculate the soil water deficit before irrigation. These inputs do not have to be absolutely correct, but are a way for encouraging irrigators to become semi-quantitative.

If the results of the animation game match the WFD response in the field, then the irrigator can start altering either the irrigation interval or duration. If the results of the WFD are very different from the animation, the CD/website provides a number of leads as to what might be happening. For example, water might be running off the surface of the beds and into furrows so the detector is not activated, or water might be infiltrating through preferential pathways and activating the detector much earlier than expected.

HARD SYSTEMS - SOFT SYSTEMS

Our mindset as researchers was that, if the tool was a good one, we will be able to say exactly how it should be used, and what the outcome will be. We developed a number of algorithms to convert the WFD response into a definitive management response. Different ways of responding to the WFD data were evaluated in a trial of irrigated lucerne (Stirzaker *et al* 2004).

1. Turn the water off as soon as a shallow WFD was activated
2. Same as above, but skip the next irrigation if the redistribution of water following irrigation was sufficient to activate a deep WFD
3. Increase or decrease the amount of water applied at the next irrigation by a set percentage depending on the number of deep WFDs that responded to the previous irrigation
4. Increase or decrease the crop factor by a set increment depending on the number of deep WFDs that responded to the previous irrigation

Method one worked well in summer and not so well in autumn. Method 2 gave very good results whereas method 3 tended to over-irrigate and method 4 tended to under irrigate. Our scientific mindset was to perfect the algorithms, but this proved to be misguided. We would probably have to develop different algorithms for every combination of soil, crop, climate and irrigation method.

The problem with algorithms is that they were too rigid - they did not learn from past events. For example our algorithms could not increase crop factors fast enough in summer to activate deep detectors. We could have developed smarter algorithms that took into account patterns of WFD response, but as Hayman (2001) showed, these kind of intuitive deductions are often made well by farmers.

For example, in the above experiments we repeatedly found soil water deficits occurred in summer even when shallow detectors were regularly activated. The remedy would be to carry out a long irrigation from time to time to activate all deep WFDs and ensure that the entire profile was full when crops were at their most yield sensitive stage in the middle of summer. Conversely we learnt that activating deep WFDs in a cool time of year generally wasted water.

This rather *ad hoc* approach, at first, seems less than adequate. Irrigation scheduling should be an exercise in accuracy and excellent tools already exist to show the exact tension or soil water content at a particular place and time. However, for many irrigators, scheduling is more about troubleshooting than accuracy. They want to quickly identify major problems or areas where they can easily improve. Time and money spent getting the last bit of value from soil water monitoring efforts are resources that could be used more profitably in some other part of the operation.

Although we now encourage an approach of 'learning-by-doing' we recognize that some of us had difficulty applying this method to ourselves. Our training was along the lines of hard systems research - information from the tool should lead to a certain unequivocal decision. A soft systems approach recognizes the central role of the farm manager. The farm manager takes into account information from a whole range of sources, and weights this information against their own experience and perception of risk.

LEARNING BY DOING

We have documented a number of cases where the minimalist data set derived from WFDs has stimulated irrigators to rethink their practices. In most cases soil water content or tension were measured by other more sophisticated methods, and confirmed that the WFDs were pushing the farmers in the right direction. Examples are given below:

- WFDs under drip were activated much more quickly than the grower expected. The grower responded by increasing the frequency of irrigation and decreasing the amount given at each irrigation (Stirzaker and Wilkie 2002).
- The grower over-estimated the amount of water needed at the start of the season and underestimated the amount needed at the critical flowering stage (Stirzaker and Wilkie 2002).
- Wine-grape growers were initially surprised that deep detectors were rarely activated. However when they were activated, there were high levels of dissolved salts in the water captured by the WFDs. The growers realized that their practices of deficit irrigation were causing unacceptable levels of salt build up in the root zone. (Stirzaker and Thomson 2004).
- Vegetable growers found out that they were leaching most of the nitrate from the profile in the first few weeks after planting (Stirzaker 2003, Stirzaker and Wilkie 2002).
- A grape grower used a strategy of 'insurance' irrigation during critical growth periods involving a very long irrigation once per week over and above the normal daily applications. The WFDs showed that this insurance policy was unnecessary and the practice was discontinued (Stirzaker *et al* 2004).
- One irrigator diagnosed poor distribution uniformity and another that pressure fluctuations meant they were not applying the amount of water they thought. In both cases the responses of the WFDs alerted the farmers to these problems (Stirzaker *et al* 2004).

In all the cases above the learning emerged from the dialogue, but the difficult part was sustaining the dialogue. Sometimes the initial dialogue was strained because growers expressed dissatisfaction with the performance of the WFD. A good example was the wine-grape growers mentioned above who felt that the deep detectors did not respond when they should have. This forced the researchers to consult simple evapotranspiration models and programs that show how wetting patterns move for a given amount of water applied, soil type and initial soil water content. These investigations tended to be in agreement with the WFD response (Stirzaker and Thomson 2004). Finally the salt accumulation data helped both parties to understand that the lack of response of detectors was substantially correct. Farms that recorded few WFD responses tended to measure very high salt concentrations in the water collected. Salt would not be accumulating above WFDs if water was moving past them.

LIMITATIONS AND OPPORTUNITIES

It is essential to recognize the limitations of a tool and to work within them. The WFD does not tell an irrigator when to start irrigating – it simply informs them how well the last irrigation filled the profile and helps them to make a decision about the timing and duration of the next irrigation. The WFD also has a sensitivity limitation. After irrigation has ceased and redistribution of water occurs down the profile, the wetting fronts become weaker and can fall below the detection limits of the WFD. In some situations we have observed significant amounts of water passing deep detectors without activating them. Work is continuing on more sensitive WFDs for specific applications.

It is worth noting that all scheduling methods have their advantages and disadvantages, and the best approach is to use more than one method. In South Africa we have used an irrigation decision support model to provide irrigation 'calendars' and the WFD as a check on the recommendation. Since the calendar is derived from thermodynamic principles it should be roughly correct. However, a weakness in relying solely on models is that the inevitable deviations between models and reality means that errors accumulate. It should be possible to use WFD to correct for this.

The WFD can also be deployed alongside real time monitoring of capacitance or granular matrix sensors used by the top echelon of growers. They can be spread out to capture some of the spatial variability while the more expensive methods can provide the detail in a few locations. The ability of the WFD to provide information on salt and nitrate accumulation and leaching makes them complementary to other methods.

However the biggest opportunity rests in getting irrigators who have not monitored soil water objectively before to start. In the success stories described above we were surprised how essential the scientist-advisor-farmer dialogue was in the process. Central to the dialogue is the notion that participants are all equal partners in the process of learning together. We were not simply transferring knowledge, but were committed to a learning/sharing paradigm (Ngomane 2004, Thompson 2004). The learning paradigm can be difficult for scientists, because it inevitably involves some failure 'in public'. However, if the technology we are promoting is robust, 'failure' is part of the learning journey.

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