Introducing a flow distortion Wetting Front Detector

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ABSTRACT

The move toward precision irrigation with frequent small applications of water has shifted the irrigation scheduling question from 'when to turn the water on' to 'when to turn the water off'. A Wetting Front Detector is a funnel-shaped object that is buried in the root zone. The infiltrating water converges inside the funnel and the soil at the base becomes so wet that water seeps out of it, passes through a filter and is collected in a reservoir. This water activates a float, which in turn operates an indicator flag above the soil surface. The detector also retains a sample of water which can be extracted via a tube using a syringe. This can be analyzed for its salt or nitrate concentration. This paper gives a brief outline of how the Wetting Front Detector works and how it is being used by irrigators. The Wetting Front Detector is a novel device that was awarded the WATSAVE Award for "Conservation of Water in Agriculture" by the International Commission for Irrigation and Drainage in 2003.

INTRODUCTION

Irrigation scheduling by soil water status requires the soil water content or tension to be directly measured. Knowledge of the drained upper limit of the soil and an acceptable level of soil water depletion and rooting depth completes the information needed to calculate the timing and duration of irrigation. Scheduling in this way can be compromised by the typically large site to site variability (Schmitz and Sourell, 2000) and uncertainty over the accuracy of the tools used (Evett et al 2002). Nevertheless, soil water monitoring overwhelmingly improves irrigation management when the water content at the monitored site is adequately correlated to other locations, and the relative change in soil water accurately reflected by the monitoring tool.

Accordingly, there has been a major effort to improve the adoption of soil water monitoring tools in Australia, with considerable success. Adoption rates among commercial irrigators increased from 13 to 22% between 1996 and 2003, but it appears a ceiling may have been reached, as less than 10% of irrigators surveyed intended to invest in soil water monitoring tools in the foreseeable future (Australian Bureau of Statistics 2005). Surveys conducted by Stevens *et al.* (2005) in South Africa showed that improving the accuracy of irrigation was still viewed as a low priority in the commercial sector, and a very low priority amongst the small-scale farmer sector.

In order to extend the benefits of irrigation scheduling to more irrigators, we seek the least and simplest information requirement that has the potential to improve irrigation practice. This paper reports of the development of a flow distortion Wetting Front Detector, and its deployment amongst irrigators in Australia and South Africa.

THE WETTING FRONT DETECTOR

The Wetting Front Detector (WFD) is a funnel-shaped instrument that is buried in the soil (Figure 1). 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 detector retains a sample of soil water that is used for nutrient and salt monitoring.

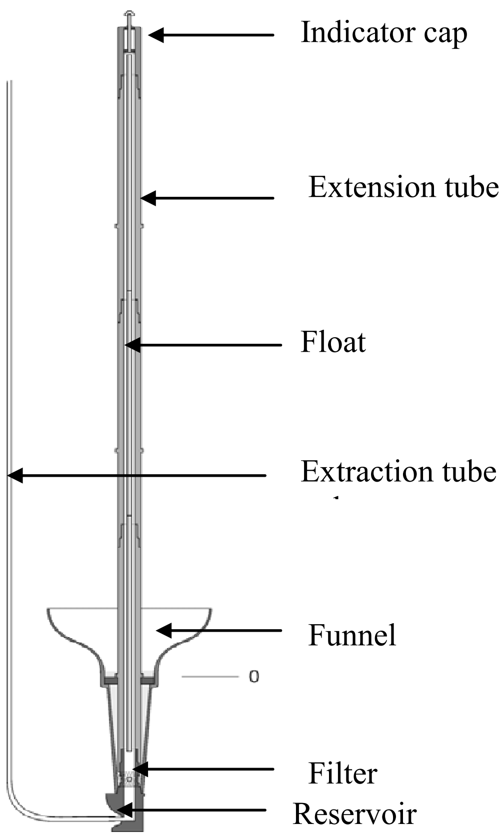


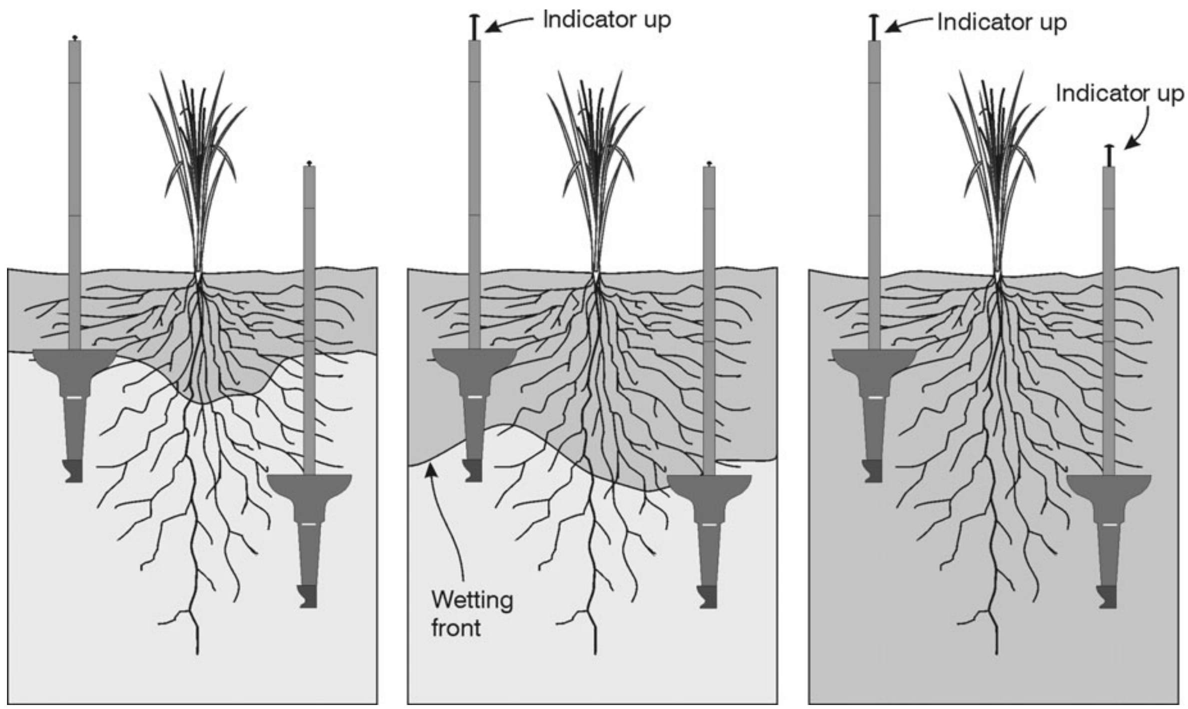
Figure 1. The funnel of the wetting front detector converges the downward flow of water, forming saturation at the base. Water moves through a filter into a reservoir and lifts a float, which in turn activates a magnetically latched indicator, visible above the soil surface. After irrigation, water is sucked out of the funnel by capillarity. A soil solution sample is retained in the device and can be removed using a syringe via the extraction tube.

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. 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, as described in the diagram below.



Shallow Indicator: DOWN Deep Indicator: DOWN	Shallow Indicator: UP Deep Indicator: DOWN	Shallow Indicator: UP Deep Indicator: UP
If neither indicator is triggered, then watering is generally too shallow	Water has moved past the shallow detector to the lower part of the root zone.	The deep indicator should be triggered only when it is necessary to fill the whole root zone.

Figure 2. The position of wetting front after irrigation and the management response

CONTROL and FEEDBACK

The original prototypes of the Wetting Front Detector contained two electrodes inside the filter in the neck of the funnel. The water passing through the filter completed the circuit between the two electrodes, thus providing the signal that the wetting front had reached the detector. This system proved to be very robust, but a cheaper solution was to replace the conductivity cell with an electronic float switch. The WFDs were used in automatic control mode. The conductivity cell or float switch was connected in series to a commercially available irrigation controller and a solenoid valve. The solenoid valve would open according to the start time set on the controller and the detector could override the run-time. For example, if the wetting front reached the desired depth before the end of the designated run time, the float switch would rise, thus breaking the circuit between the controller and the solenoid.

Trials showed that the above method worked well and resulted in accurate irrigation scheduling (Stirzaker 2003, Stirzaker and Hutchinson 2005). However, one of the most important factors determining farmer adoption of a new technology is their ability to try it out and “see if it works for them” (Pannell 1999). Most farmers do not have irrigation controllers and electronic valves that can be automatically shut down by a detector. For those who do, it is a considerable risk to hand over control to a buried device. Conventional soil monitoring equipment provides information to the manager but a WFD in control mode takes over the management. Something as simple as a broken wire could spell disaster.

The commercial version of the WFD was therefore designed to be completely mechanical – like the tensiometer, it requires no wires, batteries or loggers. It is used in feedback, rather than control mode. The operator simply adjusts the irrigation interval or duration according to the response of the WFD to the previous irrigation. In this sense the WFD is an interactive learning tool.

LEARNING BY DOING

Kolb (1984) describes a learning cycle that starts with the individual taking an action step - in our case the installation of a WFD. The indicator is either triggered or not 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 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. The response of the Wetting Front Detectors to irrigation, as shown by the position of the indicator float, what it means and the required action. The shallow WFD has a yellow indicator and the deep WFD a red indicator.

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.

Frequently the farmer expectation of the WFD response deviates from what they actually see in the field. To help them learn through this, an interactive visualization tool is provided on the website www.fullstop.com.au "The FullStop Game". The irrigator can type in their application rate and days since last irrigation and the visualization game shows them how deep the wetting front should penetrate down into the soil for drip and sprinkler irrigation.

If the results of the visualization tool 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 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.

One of the most difficult aspects to get right during the roll-out phase was the optimum depth of placement for a range of soil and crop types and irrigation methods. When the indicator float is in the “up” position, a wetting front has moved ***past*** the detector. The suggested depths in the table below are drawn from our experiences with many users. The depths may at first appear to be quite shallow, but when a WFD triggers the soil above is as wet as it can be (usually 12 to 2 kPa suction), and redistribution will occur to deeper soil layers. A third detector, 10 cm below the deep detector depth shown above, can be installed if necessary.

Type of irrigation	Notes	Shallow Detector	Deep Detector
Drip	Amount applied per dripper usually less than 6 litres at one time (e.g. row crops, pulsing)	30 cm	45 cm
Drip	Amount applied per dripper usually more than 6 litres at one time (perennial crops)	30 cm	50 cm
Sprinkler	Irrigation is usually less than 20 mm at one time (e.g. centre pivot, micro-jets)	15 cm	30 cm
Sprinkler	Irrigation is usually more than 20 mm at one time (e.g. sprinklers and draglines)	20 cm	30 cm
Flood	Deeper placements than shown needed for infrequent irrigations or very long furrow	20 cm	40 cm

FIELD EXPERIENCE

We have documented a number of cases where the simple data 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 moving the farmers in the right direction. Some 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 using slightly saline water 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).

- WFDs have helped irrigators diagnose poor distribution uniformity or find out that their systems application rates were very different from what they thought. (Stirzaker et al 2004).

The ability of the WFD to provide a soil solution sample is seeing them used increasingly for salt and nitrate monitoring. One grower of avocados, who has slightly saline irrigation water, uses the electrical conductivity for the WFD sample to adjust his crop factor. If the EC in the WFD sample is increasing, the crop factor is increased to lift the leaching requirement.

LIMITATIONS AND OPPORTUNITIES

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.

As with all soil water monitoring equipment, there is a concern over soil disturbance during installation. The WFD has a diameter of 20 cm and is generally installed by augering a hole from the surface. It is important to note that the velocity of the wetting front is strongly dependent on the initial water content but only weakly on the soil structure, as long as water is supplied at a rate below the saturated conductivity (Rubin and Steinhardt 1963, Stirzaker and Hutchinson 2005). Therefore the potential change to rooting patterns following installation is more important than changes to unsaturated hydraulic conductivity, which could be influenced by soil disturbance. For annual crops, the upper detector of a pair is usually in the ploughed layer, so disturbance is not such an issue. For perennial crops it is important to let the roots grow back into the disturbed area, so that the water content above the detector would be similar to an undisturbed area.

Over the past couple of years many thousands of WFDs have been installed by irrigators. The major limitation is the lack of experience with this type of device. It takes time to work out the depths and detector response rate that suit individual applications. We are heavily reliant on 'product champions' for the fine-tuning of their deployment in a multitude of different situations.

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REFERENCES

Australian Bureau of Statistics (2005). Water Use on Australian Farms 2002-03, Commonwealth of Australia.

Evett S, Laurent J-P, Cepuder P, Hignett C (2002).Neutron Scattering, Capacitance, and TDR Soil Water Content Measurements Compared on Four Continents.17th World Congress of Soil Science, August 14-21,2002, Bangkok, Thailand, Transactions, pp. 1021-1 - 1021-10.

Kolb DA (1984) Experiential learning: Experience as the source of learning and development. Prentice-Hall Inc., New Jersey.

Pannell DJ (1999). Social and economic challenges in the development of complex farming systems. Agroforestry Systems 45: 393-409.

Schmitz M, Sourell H (2000) Variability in soil moisture measurements. Irrig Sci 19:147–151.

Stevens, J.B., Duvel, G.H., Steyn, G.J. & Marobane, W. 2005. The range, distribution and implementation of irrigation scheduling models and methods in SA. Water Research Commission Report No. 1137/1/05, Pretoria, South Africa.

Stirzaker RJ (2003) When to turn the water off: scheduling micro-irrigation with a wetting front detector. Irrigation Science 22, 177-185.

Stirzaker, R.J. and Hutchinson, P.A. 2005. Irrigation controlled by a Wetting Front Detector: field evaluation under sprinkler irrigation. Aust. J. of Soil Res. 43: 935-943.

Stirzaker RJ and Wilkie J (2002). Four lessons from a wetting front detector. Irrigation Australia 2002 conference, 21-23 May, Sydney. Accessed from www.fullstop.com.au

Stirzaker R, Stevens J, Annandale J, Maeko T, Steyn J, Mpandeli S, Maurobane W, Nkgapele J & Jovanovic N (2004). Building Capacity in Irrigation Management with Wetting Front Detectors. Report to the Water Research Commission No. TT 230/04.

Stirzaker R and Thompson T (2004) FullStop at Angas Bremer: A report on the 2002-3 data to the Angas Bremer Water Management Committee. Accessed from www.fullstop.com.au

Stirzaker RJ, Sunassee S and Wilkie J (2004). Monitoring water, nitrate and salt on-farm: a comparison of methods. Irrigation Australia 2004 conference, 11-13 May, Adelaide. Accessed from www.fullstop.com.au