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Soil Solution Monitoring in Australia

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BETTER IRRIGATION BETTER ENVIRONMENT BETTER FUTURE



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Foreword

The sustainability of irrigated agriculture is dependant on how well solutes in water are managed. The last two decades have seen huge advances in our ability to monitor soil water on-farm. Solute monitoring has made nowhere near the same progress.

There are three reasons why solute monitoring has recently come back into prominence. First, either through lack of water, or by striving to use as little water as possible, leaching below the root zone has been reduced. In some areas salt in the root zone is building up to levels that will damage crops.

Second, fertiliser prices have significantly increased. We have evidence that water is being used more efficiently, but we cannot say the same for nutrients. We have developed sophisticated ways to apply nutrients (integrated advanced fertigation), but have not matched this with an ability to monitor and interpret nutrient levels in the root zone.

Third, there is increasing interest in using recycled water and groundwater of lower quality. Moreover we expect many surface waters to increase in their salt content. Poorer quality waters demand routine monitoring of root zone conditions.

This report was commissioned by the CRC for Irrigation Futures to look at the history of solute monitoring in Australia over the last two decades. Before we dive into new programs and develop new products, it is important to step back and look at some of the successes and failures of past attempts.

Steven Falivene has interviewed 18 ‘groups’ who have made a significant attempt to monitor soil solution on farm. Three lessons emerge

1. Most groups can point to genuine successes and enthusiasm from clients, but the momentum has not been sustained. Solute monitoring is still carried out by a small minority of growers.
2. Solute monitoring has proceeded in fits and starts and a number of groups have focussed on modifying existing equipment. It is not clear if lack of adoption is linked to deficiencies in the tools themselves, or simply a lack of awareness of the tools.
3. Even if we routinely take solution samples, there is no unambiguous way to interpret the results and make definitive recommendations

This report encourages us to fully evaluate the tools we already have, and to develop straightforward and robust methods to interpret and act upon the information they provide.

Richard Stirzaker
Project leader for Solute Signatures
CRC for Irrigation Futures

Summary

Analysing the soil solution using ceramic samplers has been in use since the early 1900's (Briggs and McCall, 1904). Narrow ceramic cylinder samplers were used in Australia since the late 1970's (Talsma et al 1979) and the use of plastic bodied soil solution extraction tubes (SSET) commenced in the early 1990's (Poss et al., 1995). Although the manufacture and use of soil solution extraction devices for salinity and nutrient management is not a new concept, its use in irrigated cropping has recently increased through the work of consultants and various research and extension projects. Numerous issues are faced by irrigators which include high soil salinity, maximising marketable production, reducing fertiliser costs and reducing environmental impact. Soil solution analysis is a tool that can assist in the managing these issues.

The extraction of water from the soil can be undertaken using two types of devices – active lysimeters and passive lysimeters. Active lysimeters, such as ceramic suction cups, draw water out of the soil through negative air pressure (suction) exerted within the ceramic cup. There are several manufacturers of ceramic cup samplers (Appendix A).

Passive lysimeters collect water by redirecting the downward flow of water during irrigation into a collection cup. Passive lysimeters can only collect a sample when a wetting front moves past the device. The FullStop Wetting Front Detector is an example of a passive lysimeter. When a sample is collected it triggers a signal. The signal can also be used to assist in irrigation management. There are some differences in the use and interpretation of results provided by active and a passive lysimeters. Both methods are viable options for sprinkler and drip irrigation systems.

Soil solution analysis is best used in conjunction with other monitoring tools (eg. leaf analysis, soil analysis, visual crop assessment). Adoption of soil solution analysis depends on the necessity. The greatest level of adoption has been from growers facing production losses from soil salinity issues, both annual and perennial horticultural crops. A moderate level of adoption has been by growers of intensive annual crops and a fair level of adoption by growers of perennial crops both of which use soil solution analysis as a nutrient management tool.

The case studies presented in this report demonstrate that soil solution analysis has helped many growers to identify problems before they have had a significant impact. These growers were able to modify their nutrition and/or irrigation practices within the growing season and avert possible crop decline. Soil solution analysis is also a useful environmental management tool to reduce nutrient leaching, however little government incentive or regulation is provided for grower to adopt soil solution analysis for this reason.

A significant barrier to adoption has been the lack of information and training as well as the perceived high cost of soil solution extraction devices. This report identified numerous low cost manufacturers of soil solution extraction devices. Growers need to be able to understand and interpret soil solution result data. An opportunity exists to; 1) develop an extension package on how to use and interpret soil solution analysis 2) work with agronomic consultants to assist in the adoption of soil solution analysis technology and 3) establish a group to manage and facilitate the adoption of soil solution analysis.

Introduction

Soil solution extraction is steadily increasing in popularity as a tool to assist growers in salinity and nutrition management. Traditionally crop nutrient management largely focused on the observations and measurements of the canopy of plants. The soil and root zone were often overlooked mainly because of the difficulty and cost in taking measurements. Soil tests were the preferred option available, however in most situations only the soil surface was measured because of the difficulty in obtaining numerous soil samples from deeper depths. Soil tests were normally conducted on an irregular basis, (i.e. once every 3 to 8 years). Growers often assume that once fertiliser is applied to the soil, the nutrition program was complete and the soil would hold and provide the nutrients to the plant when required. Growers did not know if the fertiliser was available to the plant nor the efficiency of uptake, until nutrient deficiencies or toxicities were apparent in the plant.

In situations where soil salinity is an issue, soil tests are traditionally conducted annually to provide an indication of soil salinity levels. With this information irrigation application volumes could be manipulated to leach the desired amount of salts out of the root zone. Annual soil tests cannot identify peaks or troughs in salts and nutrient levels within the root zone.

Analysing soil solution provides a quick easy and economical way to measure salt and nutrient levels in the soil throughout the season. Rather than detecting a problem at the end of the season when crop loss or damage may have already occurred, soil solution analysis allows the early detection of the problems and corrective action to be implemented before the crop is seriously affected.

Soil solution analysis is also a valuable environmental tool because it can be used to detect excess nutrients moving below the plant's rootzone. This allows the operator to modify fertiliser and irrigation practices to reduce waste and reduce nutrients leaching into waterways.

The following report provides an overview on the use of soil solution monitoring in Australia and a background to the technology. It summarises various research projects and commercial uses. The report attempts to capture some of the real life experiences and outcomes so others can assess the use of this technology. Contact details and a reference list are included with each report. Appendix A provides the contact details for the equipment mentioned including DIY construction contacts. Appendix B provides the complete list of references mentioned in the report**.**

Use of soil solution extraction tools in Australia

Extracting water from the soil using a ceramic suction device has been used for over 30 years in Australia. Internationally the concept was developed in the early 1900's by Briggs and McCall (1904) and developed further to early models of ceramic tube samplers (Wallihan, 1940, Wagner, 1962, Reeve *et al.* 1965, Adams *et al.* 1973 and Wood 1973) (Figures 1 and 2).

In Australia, Talsma *et al*. (1979) constructed a 5 mm soil water ceramic tipped extraction tube (Figure 3) for use in a study of nutrient mobilisation in the Australian Capital Territory (ACT) native forest water supply catchments. In 1985 Warren Bond and Ian Willett (Willett *et al*., 1984) of CSIRO used the Talsma design in a project on the application of sewage sludge in pastures and then again in 1988 to investigate the fate of mine waste at the Ranger uranium mine (Willett et al., 1993). In 1992 visiting CSIRO research scientist Rolland Poss conducted a review of the ceramic tip technology (Poss et al., 1995) (Figure 4). In collaboration with Dr Chris Smith, Gordon McLachlan and Frank Dunin (CSIRO) Poss constructed a 40mm wide ceramic soil solution extraction tube (SSET). This 40mm wide tube was then used in projects on soil acidification (Poss et al., 1995), leaching under cereal crops (Smith et al., 1998), the automation of sampling using a TDR trigger (unpublished) and the onsite treatment of household sewage (Smith and Bond, 1997; Bond and Smith, 1999). Gordon McLachlan was involved in building the Poss style tubes for various CSIRO projects and in 1998 wrote a draft SSET construction and installation report. This draft report was used by David Deery and Paul Hutchinson (CSIRO) to construct a modified SSET in 2003 (Figure 5) for a CRC Viticulture project. Deery revised the draft SSET construction and installation report (Deery *et al*. 2004). Tapas Biswas (SARDI) used the CSIRO design as a basis to construct a SSET for the Tri State Salinity project (Figure 6). The SARDI SSET was improved during the project and commercialised by Sentek in 2007 (SoluSAMPLER™). Over 1200 SARDI/Sentek SSET have been built since 2004 for use in both projects and commercial applications.

Independently of CSIRO, Tony Wells (NSW DPI, Gosford) also constructed a similar 40mm extraction tube in 1993 (Figure 7) for monitoring soil solution nitrate levels in a vegetable project. Dale and McClure (1994) manufactured a simple and inexpensive narrow ceramic cylinder sampler (100mm x 10mm) in 1992 (Figure 8) to use on a nitrogen management project in Sunraysia. The cylinder samplers were commercialised by Fonz Racioppo (Terra Tech) (Figure 9).

Mottes 20mm SSET (Figure 10) have been used in Australia since 2000 by Horticultural consultant Lawrence Kirton. Mottes SSET were developed in Israel by Mr. Jacob Mottes in 1975. Over 1600 have been sold in Australia since the late 1990's and 10,000 world wide. Peter Ryan (Agriexchange, Mildura) has also constructed and commercialised a 20mm SSET (Figure 11) similar to the Mottes tube and Klaus Gottwald (J.K.G. Tech) has also recently commenced manufacturing a 20mm SSET (Figure 12).

An alternative method to ceramic cup samplers is to collect soil solution samples using a FullStop wetting front detector (Stirzaker 2003, Stirzaker and Hutchinson 2005) (Figure 13). The FullStop wetting front detector is comprised of a specially shaped funnel, filter, float and indicator mechanism. The funnel is buried in the root zone, with the indicator visible above the soil surface. The FullStop gives a signal to the irrigator when water, percolating through the soil, moves past it. The detector works on the principle of flow line convergence. Water from rain or irrigation percolates through the soil and is intercepted by the funnel. As the water moves down into the funnel, the soil becomes wetter as the cross-sectional area decreases. The funnel shape has been designed so that the soil at its base reaches saturation when the soil outside the funnel is around 3 kPa suction, which corresponds to a relatively 'strong' wetting front. Once saturation has occurred at the base of the funnel, free water flows through a filter into a small reservoir and activates a float. The float trips a magnetically latched indicator, visible to the irrigator. A micro tube is attached the small reservoir and soil water can be extracted by using a syringe. The FullStop wetting front detector became as commercial device in 2004, and around 12 000 units have been sold around the world.

Several other soil water extraction devices are imported into Australia; Irrometer 20mm SSET sold by HR Products (Figure 14), the Soil Moisture Equipment SSET sold by ICT International (Figure 15), the UMS SSET sold by MEA (Figure 16) and Soil Measurement Systems stainless steel SSET (Figure 17). DIY (do it yourself) construction information will soon be available (Figure 18).

Suppliers of Australian and overseas soil water extraction devices are provided in Appendix A.

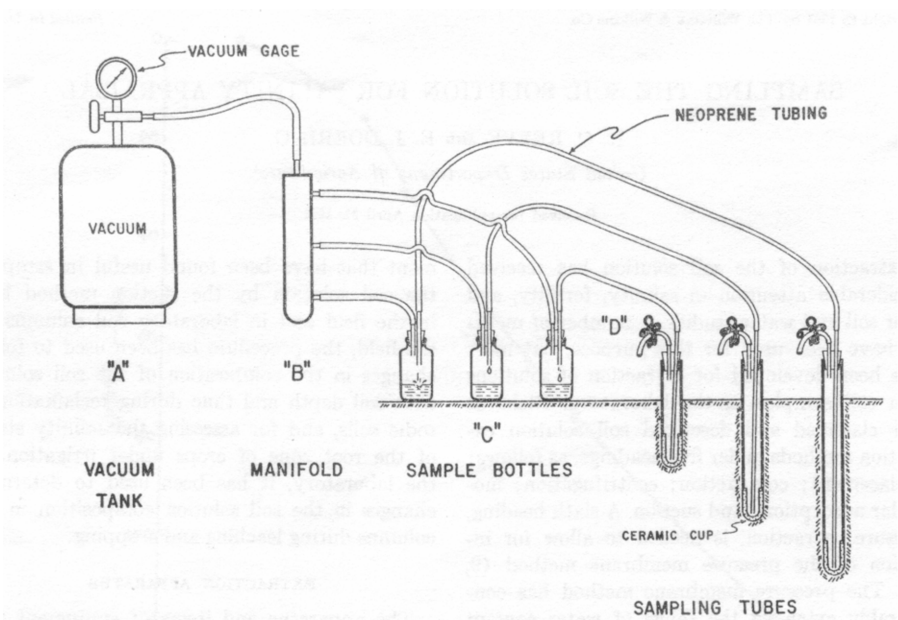
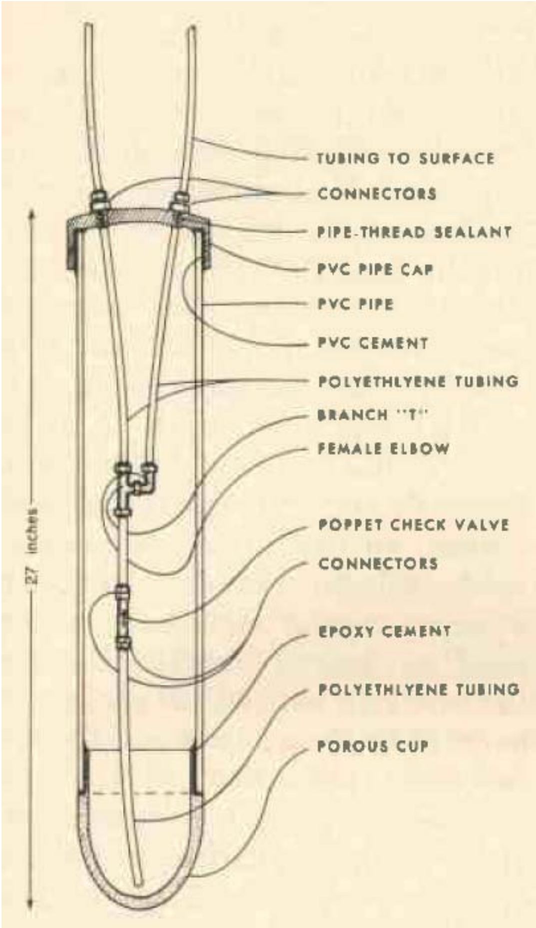


Figure 1 : Excerpt of a diagram of the paper (Reeve *et al*, 1965) describing the use of soil solution sampling from a ceramic sampler for salinity monitoring. Reproduced by permission of Lippincott Williams & Wilkins.

Figure 2 : Excerpt of a diagram from the paper (Wood, 1973), describing the technique of using for soil solution sampling . Reproduced by permission of American Geophysical Union. Copyright 1973 American Geophysical Union.



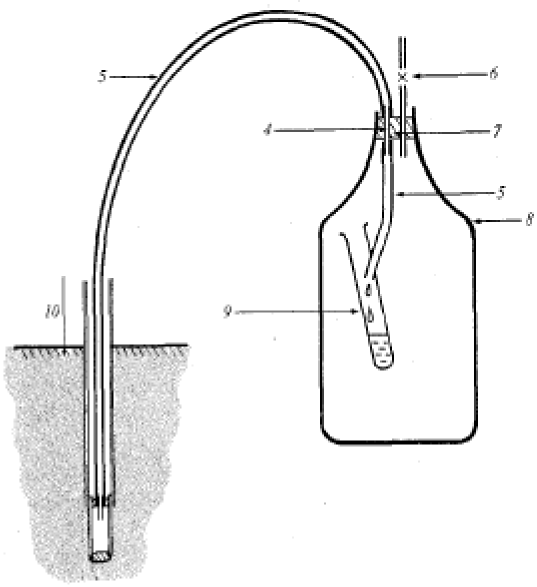


Figure 3 : Excerpts of a diagram from the paper evaluating porous cup soil -water extractors from Talsma et al, 1979. Copyright CSIRO 1979. Reproduced by permission of CSIRO Publishing, Melbourne Australia - http://www.publish.csiro.au/nid/85/ issue/1843.htm.

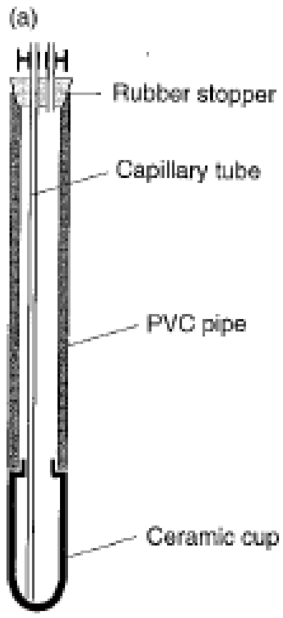
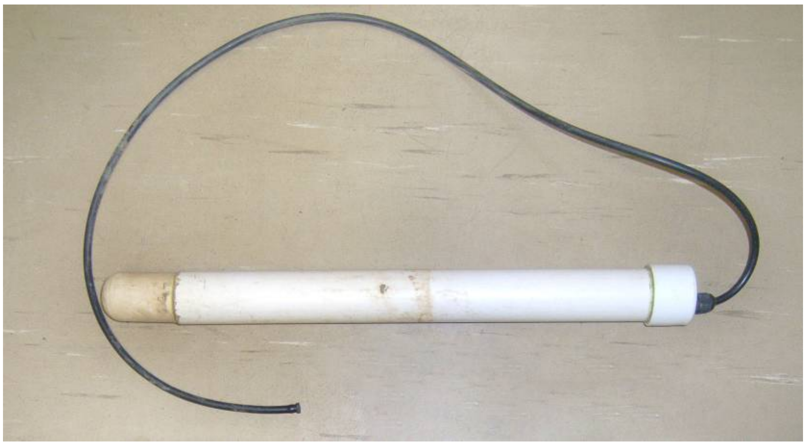


Figure 4 : Excerpt of a diagram from a review of various ceramic cup samplers by Poss *et al.* 1995 . Reproduced by permission of Wiley-Blackwell Publishing.

Figure 5: CSIRO 40mm SSET constructed since 1995 (Poss, 1995 & Deery et al, 2004). The sampler has an installation cap (grey) attached to the tube.

Figure 6 : SARDI/Sentec 40mm SSET

(SoluSAMPLER™ - www.sentek.com.au).



a) b)

Figure 7 : a) 40mm SSET constructed by Tony Wells. b) Close-up of the end cap showing the irrigation riser tube entering the SSET via an "electrical gland".

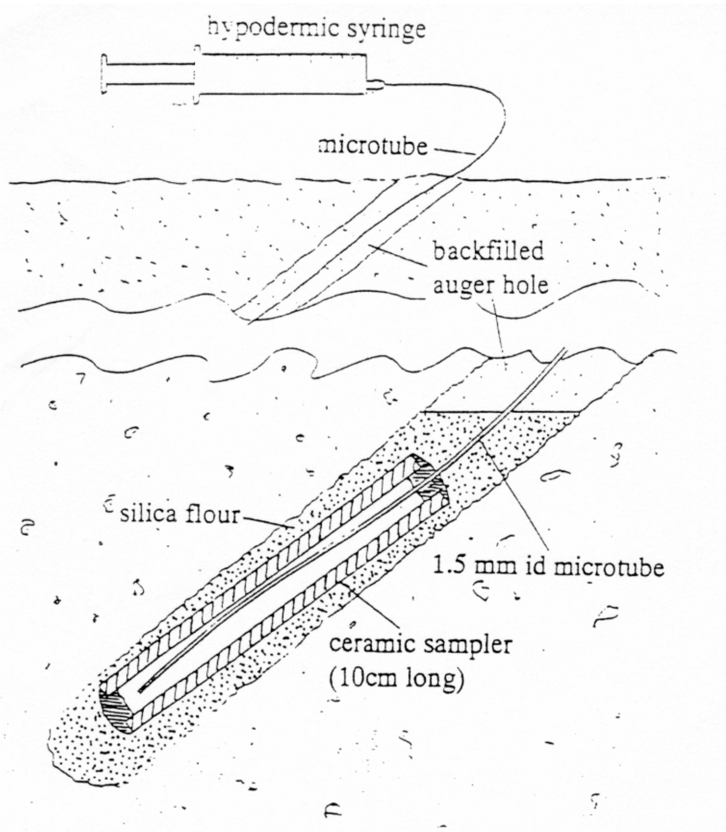


Figure 8 : Ceramic cylinder sampler used by Peter McClure and Mark Dale in a 1993-94 viticulture project (Dale and McClure, 1996). Reproduced by permission of the Australian Dried Fruits Association.

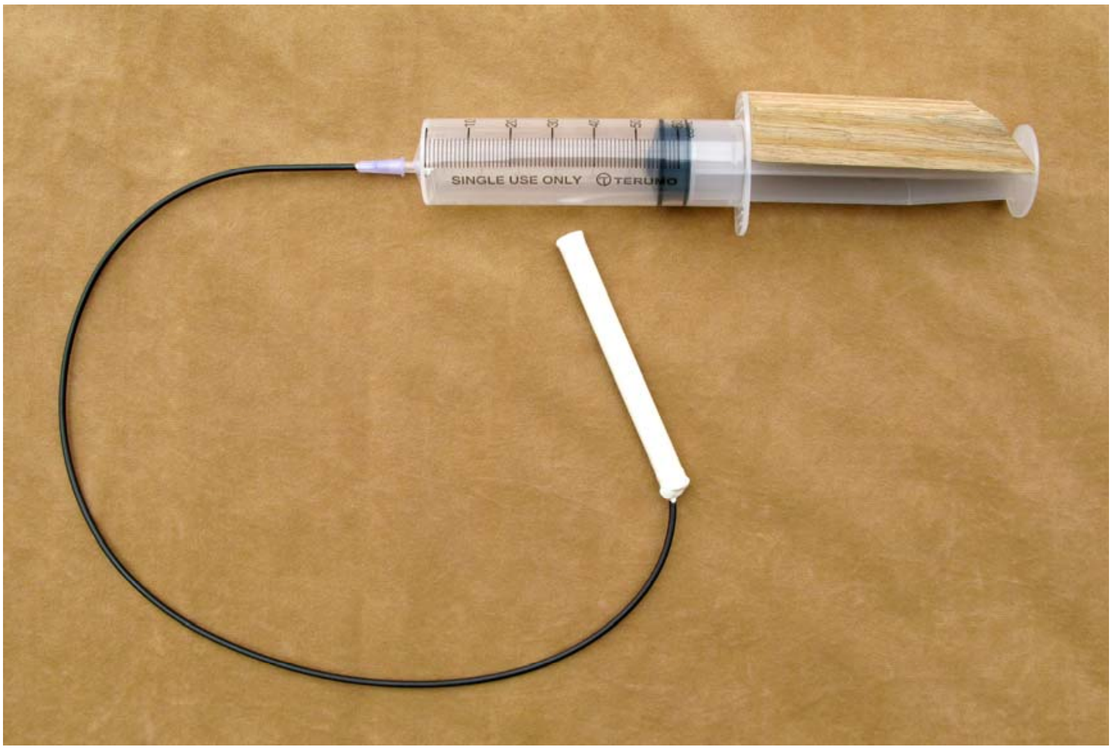


Figure 9 : Ceramic cylinder sampler manufactured by Fonz Racioppo since 1994. The ceramic tip is a 100mm x 10mm cylinder sealed at both ends with epoxy mastic.

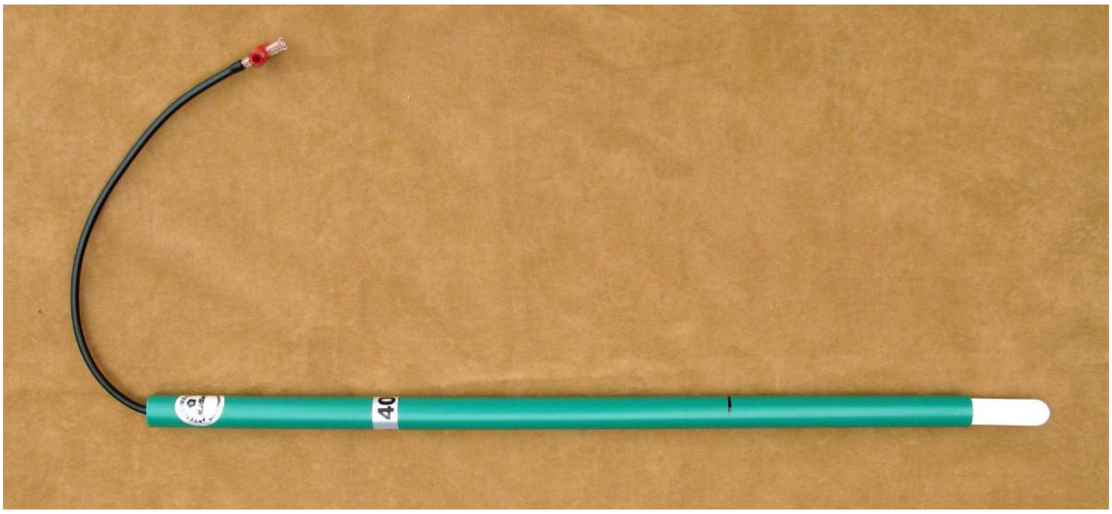


Figure 10 : Mottes 20mm SSET - www.mottestens.com : www.rootzonesolutions.com)

Figure 11 : Agriexchange 20mm SSET.

Figure 12 : Soil Spec 20mm SSET manufactured by J.K.G Tech.

Figure 13 : FullStop wetting front detector

(www.fullstop.com.au, www.mea.com.au)

Figure 14 : Irrometer SSET (www.Irrometer.com , www.hrproducts.com.au)

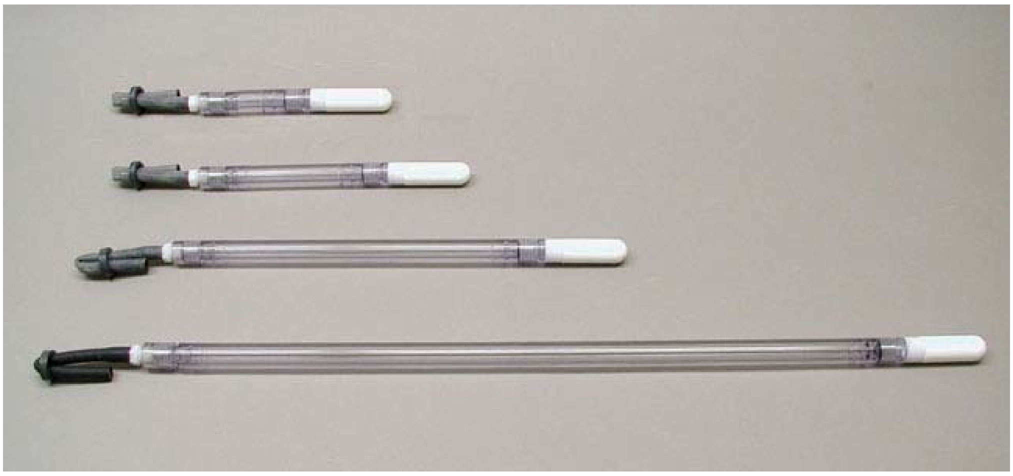
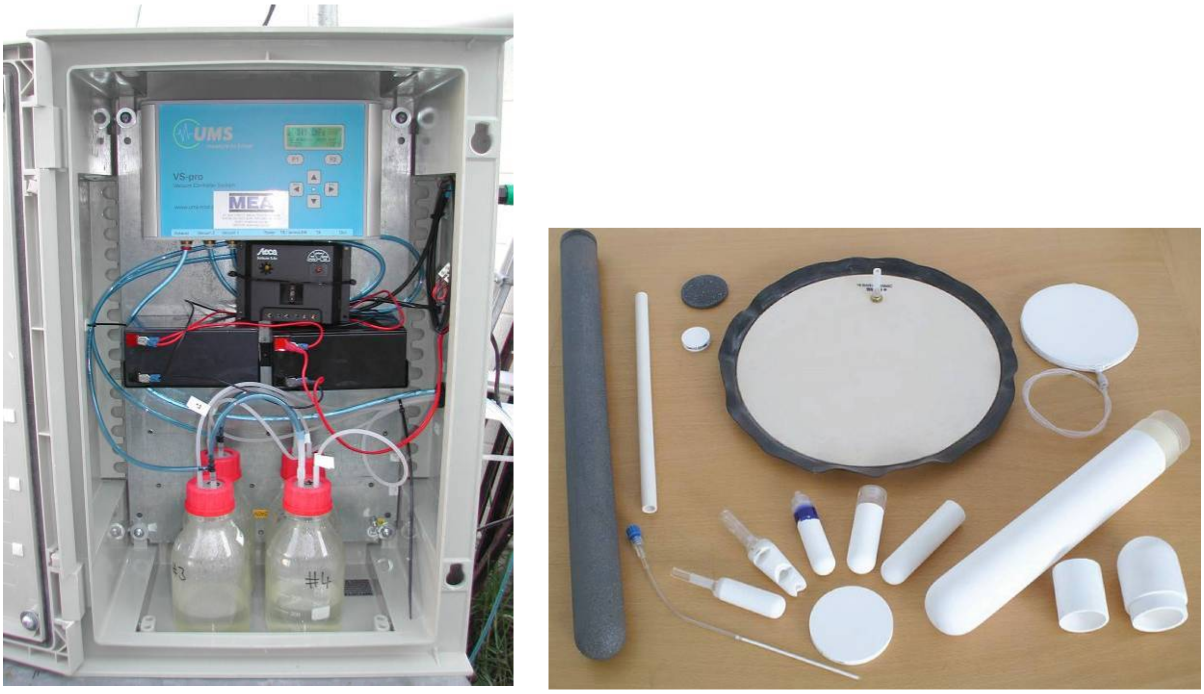


Figure 15: Soil Moisture Equipment SSET (www.soilmoisture.com, www.ictinternational.com.au)



(a) **(b)**

Figure 16 : A scientific soil water extraction system manufactured by UMS and distributed in Australia by MEA. (a) Soil solution collection jars of a automated collection system. (b) Various models of suction cups. (www.mea.com.au , www.ums-muc.de/en/products/suctioncups)

Figure 17 : Soil Measurement Systems (USA) stainless steel porous membrane SSET (www.soilmeasurement.com)

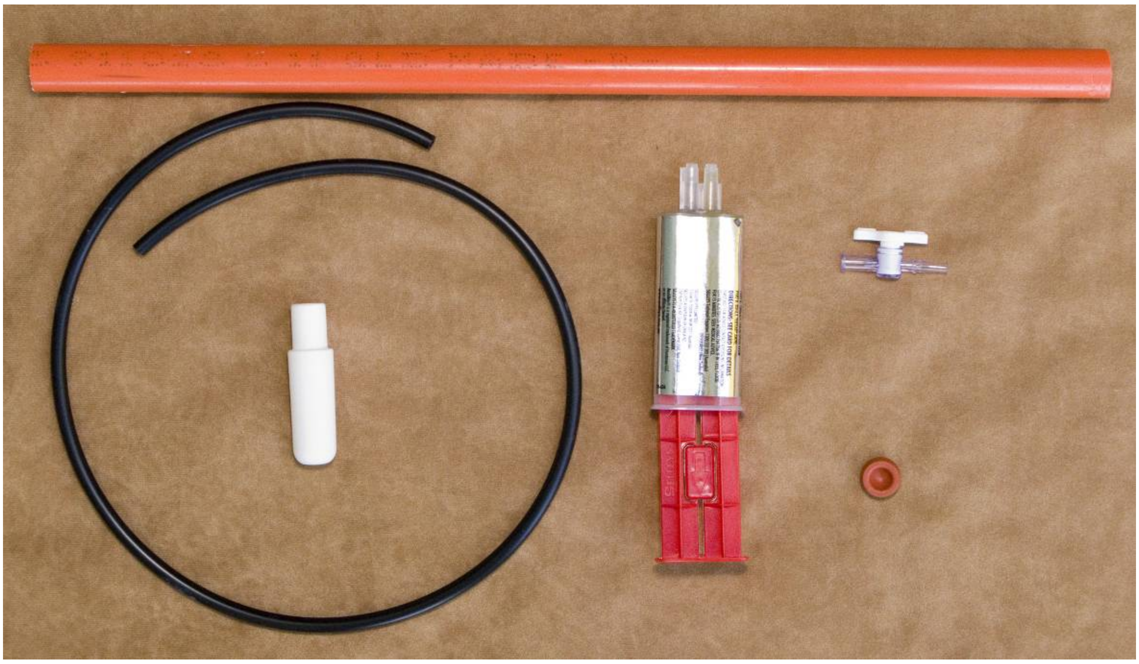


Figure 18 : Parts and equipment to build a 20mm DIY SSET ; 20mm ceramic tip (Cooinda Ceramics or ICT International), electrical conduit (15mm I.D.), irrigation riser tube, rubber bung, polycarbonate stopcock and epoxy glue (Appendix B)

Soil Solution Extraction Devices

Active lysimeters and passive lysimeters are the two types of in-field soil solution samplers that are currently used in Australia. Ceramic suction cups are active lysimeters, which draw water out of the soil through negative air pressure (suction) exerted within the ceramic cup. Passive lysimeters collect water by distorting the downward flow of water (wetting front) during an irrigation or rainfall event, and direct it into a collection vessel. The FullStop Wetting Front Detector is an example of a passive lysimeter. Both active and passive lysimeters are good at providing soil solution extracts, but they have different installation and operational procedures. According to the interviews carried out in this study, both have worked well in sprinkler and drip irrigation. Users should assess which type of device best suits their needs and management style.

Ceramic Cup Samplers

Advantages

- Easy to install and only disturb a small area of soil
- Reliable sampling can occur after a couple weeks of irrigation cycles
- Samples can be taken at drier soil moisture levels than the FullStop wetting front detector
- Can be placed at any depth
- Can be inexpensive if you build yourself (DIY)

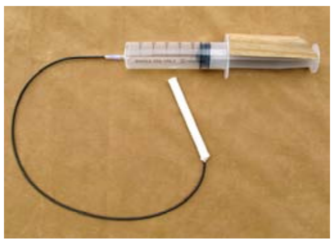
Disadvantages

- Needs to be primed (suction applied) a day or so before the sample is extracted
- The device will not operate if the ceramic tip loses contact with the soil (poor installation procedure and/or soil drying events) or leaks air (cracked tip, poor manufacture).
- Ceramic tip can clog up in clay or loam soils (e.g. silting)
- Some ceramic cups can adsorb particular nutrients and may provide inaccurate results

There are two main designs of ceramic cup samplers, soil solution extraction tubes (SSET) and ceramic cylinder samplers. The ceramic tips can be high flow or low flow models. High flow tips are for sandy/loam soils and low flow tips are for clay soil types. Automated ceramic samplers are also available for scientific applications (Figure 16).

a)

b)



c)

Figure 19 : Examples of : a) 40mm wide SSET b) 20mm wide SSET c) Ceramic cylinder sampler

SSET (PVC Tube)

Soil solution extraction tubes (SSET) are generally supplied in two widths; 40 and 20 mm (figures 19a & 19b) and both widths have operated well. Some people have favoured the 20 mm wide tube because the PVC tube protrudes out of the ground and therefore is easy to remove from the ground if problems occur. The 20 mm wide tubes are also slightly easier to install and disturb slightly less soil. There has been no evidence to suggest that the 20 mm wide tubes provide less volume of soil solution extract than the 40 mm wide tube models. SSET can be hand made (DIY).

Ceramic Cylinder Samplers

These are the easiest and cheapest ceramic cup samplers available from commercial manufacturers (Appendix A) and to hand make (manufacture instructions available in 2009). The volume of air in the ceramic cylinder is too small to maintain enough negative air pressure to extract an adequate amount of water from the soil, so the syringe is used as the pressure chamber. To take a sample, the syringe is attached to the microtube, the plunger is pulled back to cause a negative air pressure and held in place with a small wooden block or dowel. One possible disadvantage is if the soil solution was stored in the syringe for an extended period (7 days), microbial growth may occur and distort the results. In most circumstances the soil solution from the syringe would be removed within a couple of days of priming and this would not be a problem. Samplers are made using 1.5mm microtube or 6mm irrigation riser tube. The 1.5 mm microtube models are about half the cost of 6mm riser tube models because a cheaper narrower ceramic tip (100mm x 10mm) is used and the syringe is attached to the microtube using an inexpensive hypodermic needle securely inserted into the microtube. The 6mm riser tube models use a more expensive larger sized ceramic tip (i.e. tensiometer tip) and the syringe is attached to the riser tube by a laboratory grade one way stopcock.

Wetting Front Detector (FullStop)

The FullStop wetting front detector is simple in design and application. It can be used to monitor the infiltration depth of irrigation and soil solution.

Advantages

- Does not require priming to collect a sample
- Takes and stores a sample at the same soil moisture content range (0 to -3 Kpa)
- Can be used as an irrigation management and soil solution monitoring tool
- Links water monitoring (wetting front depth) and solute monitoring
- Samples of up to 50 mls can be obtained straight after a strong wetting front moves past the device. A 5 ml sample is stored in the device after it drains which is enough to conduct a salinity and nitrate test.

Figure 20: FullStop (www.fullstop.com.au)

Disadvantages

- Generally not used deeper than 60 cm for drip and 40 cm for sprinkler systems (not suitable for deep applications)
- A large hole (20cm diameter) needs to be dug to install the device
- One to two months of settling is required before reliable results can be taken.
- Only collects a sample when the soil tension is -3 kPa or wetter

Data Interpretation

Saturated paste extract (EC_{se}) is the laboratory method used for the analysis of a soil solution. Laboratory analysis can be expensive and time consuming. Extracting soil solution from devices installed in the field is a much quicker method of obtaining a soil solution extract and provides for more regular sampling to monitor salinity and nutrition levels throughout the season.

Very little information is available on the interpretation of soil solution results. One source for nutrients is published on the Web by Mottestens Tensiometers (www.mottestens.com), but these thresholds have been developed for Israel growing conditions and may not be suitable for Australian growing conditions. The thresholds for most nutrients outlined by Mottestens are significantly higher than soil solution results observed in various projects in Australia. The high thresholds might be reflective of Israel's soil characteristics, irrigation water quality (high EC) and intensive management programs. The background information and discussion to the development of these thresholds have not been published so it is difficult to modify these thresholds to suit other situations.

Information on salinity thresholds is available on saturated paste extracts (EC_e) (Mass & Hoffman 1977, Mass 1990). However the relationship between the results of saturated paste extracts and field sampling of the soil solution for salinity (EC_s) is not straight forward. Saturated paste extracts require the addition of distilled water to the sample to bring it to about -1 kPa (glistening point). So the ion concentrations in the extracted soil solution sample will always be lower than in the field. The relationship between saturated paste extract solutions and solutions derived from in-field extraction devices will depend on the soil water content at which the soil solution was extracted. Ceramic samplers can extract soil solution up to about -20 kPa. Wetting front detectors (FullStop) provided a sample only if the soil is wetter than -3 kPa. The equilibration time between the irrigation water and soil solution is much less in FullStop sample. This suggests that the FullStop device will provide results that are closer to the saturated paste extract test. Biswas *et al*. (2007) suggest that salinity measurements for ceramic cup sampling is in a ratio of about two to one (i.e. 2 dS/m ceramic cup reading is approximately equivalent to 1 dS/m saturate paste extract). A similar conversion factor is also suggested by Boland *et.al.* (1997) for ceramic cylinder samplers.

The literature suggests that saturated paste extract salinity thresholds for most irrigated crops are between 1.5 to 2.5 dS/m (Mass & Hoffman 1977, Mass 1990). Therefore most users of soil solution analysis adopt a soil solution salinity (EC_s) threshold of 3 to 5 dS/m. Continually high results should be investigated further using soil analysis.

Figure 21 : Measurement of the salinity of soil solution with a EC meter

Samples from ceramic cups and FullStop WFDs tend to be similar, with the FullStop giving slightly lower readings because the sample is taken from wetter soil. However, there are occasions when the EC and nitrate levels are much higher in the FullStop. This typically occurs when strong wetting fronts have not been moving past the FullStop. A solute front (band of concentrated salts) develops above the Fullstop, which is eventually sampled when there is a large irrigation or rainfall event that moves that band into the FullStop. This solute front moves quickly through the soil and may not be captured by a ceramic sampler, unless it was primed at the commencement of the irrigation or rainfall event (Richard Stirzaker pers comm.).

Another difference and possible source of error between the results of saturated paste extract sampling and in-field ceramic sampler is the possibility of adhesion of nutrients to the ceramic cup, which may reduce the concentration of ions in the sample. The inert quality of the ceramic tip is an important factor in this error and no independent detailed comparative studies of manufactured ceramic tips has been conducted.

Interpretation guidelines or standards for nitrate and other nutrients are being developed by users of soil solution analysis. These "optimum" guidelines are mainly being developed from personal experience of soil solution analysis for the specific crops (i.e. crop type, crop stage, crop responses, comparison of low and high productivity crops) and site conditions (i.e. soil type, irrigation method, fertiliser management program). The guidelines developed are highly subjective and should only be considered as an “approximate” guideline. Data interpretation is a combination of comparing results to optimum guideline levels, comparing cation ratios (milliequivalents) and observing the trends. Since optimum nutrient guidelines have not been extensively studied or formally field validated, more emphasis is placed on observation of trends.

Sometimes anomalies occur and so interpreting one point of data could be misleading. High levels of other ions (sodium, chloride) can sometimes interfere with the analysis of other ions (e.g. high chloride might artificially elevate nitrate readings using some measurement methods) and contamination of samples can sometimes occur. Thus observing trends can be a more reliable method of interpretation. Trends also indicate plant nutrient use, leaching or nutrient accumulation. An increase in the concentration of a nutrient in the soil solution can indicate that the nutrient is being applied at a higher rate than plant use. A decrease in the nutrient concentration can indicate high plant use, soil adhesion or adsorption, or leaching. The installation of soil solution extraction devices below the rootzone helps to provide a better understanding of the nutrient-soil-plant interaction. For example if nitrogen is being depleted within the rootzone and no nitrogen is being detected below the rootzone, this might indicate plant use. However if nitrogen is being detected in the deeper probes below the rootzone, this might indicate leaching.

The growing site can also have an influence on soil solution readings (e.g. clay content of soils). Nitrogen analysis at weekly intervals is recommended during the main part of the growing season and/or when significant nitrogen application occurs. Nitrogen is very mobile and can rapidly increase or decrease weekly. Weekly sampling is required to obtain enough data to observe important nitrogen trends. Increasing sampling to two week intervals is acceptable, however it might miss important data points. A significant nitrogen leaching event can occur within a two week period. Cations are generally more stable and may only require analysis at two to four week intervals depending on the site situation. It is best to initially conduct cation analysis at two week intervals and use the data to determine a suitable analysis interval for the next season.

Crop soil solution interpretation guidelines could be developed in the future, however they would probably have a broad range of optimum nutrient concentrations to cover the wide range of growing conditions and crop management methods. Meaningful interpretation guidelines are best developed to suit site situation based upon historical trends of soil solution results and other important factors (eg fertiliser application program, application method – foliar or ground applied, soil type, rootstock, root depth, crop stage etc).

Soil solution analysis should be used in conjunction with other monitoring tools (visual symptoms, soil and leaf test etc). Spatial variability (i.e. change in soil type within the block) may not provide a true representation of the site and lead to inappropriate management decisions. Installing multiple sets (i.e. three sets) of soil solution extraction devices within a block can help to assess spatial variability in a block and identify the need to maintain one or more sampling sites. Before any major changes to management are made as a result of soil solution information, the data should be carefully assessed and cross-referenced with other monitoring methods to ensure confidence in the data, Interpreting soil solution analysis is a skill based on understanding nutrient-soil-plant interactions in combination with other monitoring methods, rather than looking up a chart.

Nitrate is not greatly influenced by the cation exchange capacity of soil, so in most situations a good relationship between nitrogen application rates and soil solution extraction results can be observed. The optimum ranges currently used by agronomists on irrigated horticultural crops are 10 to 100 ppm nitrate nitrogen (NO_3-N). Narrower ranges are being used for site specific situations (crop type, crop stage, soil type etc). Soil solution analysis has been an effective tool to demonstrate environmental sustainability. The measurement of nitrate below the rootzone is an indicator of nitrogen loss that can potentially contaminate the environment. Soil solution nitrate levels provide an indication of the nitrogen concentration, but not the movement of nitrogen (flux) out into the environment. Measuring deep drainage is required to get a better understanding of nitrogen loss. This is done by using soil moisture monitoring devices above and below the rootzone and calculating a drainage flux. A high nitrogen reading below the rootzone is alarming, but it might be a consequence of gradual and static accumulation over time. Another indicator of a nitrogen flux is to measure soil moisture at all depths (e.g. a low water flux would occur at dry sub soil moisture) and to place soil solution extraction devices further below the rootzone. If corresponding changes in nutrient trends can be observed in all probes then this could be an indicator of nitrogen movement.

The safe level of nitrate in drinking water is 10 ppm NO_3-N (World Health Organisation). This has been used by some agronomists as an upper threshold for nitrate for environmental sustainability. However the CRC Viticulture Project (Hutton *et.al.* 2008) indicated trigger values on the concentration of nitrate and phosphate in water levels that can be an adverse risk in lowland rivers as being 0.5 mg/L (ppm) total nitrogen and 0.05 mg/L (ppm) total phosphorus (ANZECC. 1992 & ANZECC and ARMCANZ. 2000). The ANZECC trigger values indicated are for the river system, not the subsoil nitrate content. It is unknown if the nitrogen leached below the rootzone of an agricultural crop denitrifies as it moves through the subsoil to the river, nor the dilution effect of mixing with the river. An acceptable sub soil nitrate concentration might be different for each district (e.g. distance from the river, sub soil characteristics) and river systems (e.g. rate of flow). A rigorous study would need to be conducted to develop sub soil nitrate concentration threshold guidelines.

Some users of soil solution analysis also measure potassium, calcium, magnesium and sodium. Interpretation of cation data often requires a basic understanding of soil science and knowledge of site conditions. Interpretation of cation data is not straightforward and results are sometimes confounding. Additionally there is little information available and the interaction of the soil solution ions with clay particles is a complex subject. Interpretion of cation data has been easier in soils with low clay content. The optimum ranges currently used by agronomists on irrigated horticultural crops are 15 to 100 ppm potassium, 5 to 40 ppm phosphate and 20 to 150 ppm calcium. Similar to nitrate interpretation, more emphasis is placed on the observation of trends rather than a single point reading. If all of the major cations are measured then a milli-equivalent ratio can be calculated. Interpretation guidelines for soil analysis have been used to assist in the interpretation of cation soil solution ratios.

Further discussion on interpretation of soil solution extracts will be provided in CRCIF Soil Solution Master Class workshops to be presented in 2009.

Case Study Summary Table

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Alan Blight	Avocado grower	FullStop & 40 mm SSET	Avocado	Perth, W.A.	2000-2008	24
Anne-Maree Boland	Former VIC DPI research officer	Ceramic cylinder and tensiometer tip samplers	Stonefruit	Tatura, VIC	Mid 1990's	26
Warren Bond	CSIRO, Research officer	7mm & 40 mm SSET	Sewage reuse, dryland pastures, viticulture	ACT	1983 – mid 2000	28
Andrew Creek	NSW DPI, extension officer	40 mm SSET	Citrus	Riverina, NSW	2006-ongoing	31
Mark Dale & Paul McClure	Former VIC DPI	Ceramic cylinder sampler	Stonefruit	Sunraysia, VIC	1992-94	34
Steven Falivene	NSW DPI Extension officer	20 mm SSET	Citrus	Sunraysia VIC & NSW	2005-07	36
Ian Goodwin	VIC DPI Research officer	40 mm SSET and FullStop	Stonefruit	Tatura, VIC	2007 - ongoing	39
Peter Jerie & Stuart McNab	VIC DPI research officers	Ceramic sampler	Stone & pome fruit	Cobram & Shepparton, VIC	Early 1990's	41
Paul Jones	Horticultural Crop Pest Monitoring, Consultant	20 mm SSET	Strawberries	Sunshine Coast, QLD	2005 - ongoing	43
Lawrence Kirton	Rootzone Solutions, Consultant	20 mm SSET	Various horticultural crops	Western Australia	1980's - ongoing	45
Trevor Lake	Consultant	20 mm SSET	Citrus. Stone & pome fruit	S.E. QLD	2001 - 2007	48
Peter Ryan & Trevor Sluggett	Agriexchange, Consultants	20mm & 40 mm SSET	Citrus, almonds, pistachio & vines	S.E. Australia, Sunraysia & Riverland	2005 - ongoing	50

Graeme Sanderson	NSW DPI, Research Officer	40 mm SSET & ceramic cylinder sampler	Citrus & vines	Sunraysia , NSW	1994-2008	53
Gerrit Schrale & Tapas Biswas	SARDI, Research Officers	40 mm SSET	Citrus & vines	Sunraysia & Riverland	2004 - ongoing	55
Chris Smith & Roland Poss	CSIRO, ACT	40 mm SSET	Dryland, sewage effluent and woodlots	ACT	Mid to lalte 1990’s	58
Tony Thompson & Richard Stirzaker	DWLBC of SA & CSIRO	FullStop	Grapevines, Lucerne hay & potatoes	Angas Bremer, South Australia	2000 - ongoing	60
Tony Wells	NSW DPI	40 mm SSET	Vegetables	Sydney basin and NSW Central coast	1995 - ongoing	62
Joyce Wilkie	Organic vegetable grower	FullStop	Vegetables	Gunneroo , NSW	2000 - ongoing	65

SSET = Soil solution extraction tube

Alan Blight (Avocado grower)

Crop : Avocados
Tool: FullStop and SARDI SSET
Region : Perth, W.A.
Contact : 08 9407 5100

Background

Alan Blight is the manager of a 20 ha avocado orchard at Wanneroo (50km north of Perth). The orchard is sprinkler irrigated and has a sandy soil. Bores are used to supply irrigation water. In recent years there has been a decline in ground water levels resulting in a steady increase in salinisation. Bore water salinity levels are about 1 to 1.3 dS/m. The bore water has also been increasing in nitrate levels to between 30-80ppm. Since nitrate levels are high, nitrogen fertiliser is not used in the orchard unless trees show distinct signs of nitrogen deficiency. The high nitrate levels are a result of farmers applying chicken manure in winter when rainfall is high and nutrient uptake is low.

Research programs were indicating that this property was using more water than the trees required. As a result Alan reduced his irrigation application volumes, however this resulted in trees showing symptoms of salt toxicity. To better manage his irrigation and monitor the soil salinity Alan purchased twelve FullStop wetting front detectors in 2000.

Equipment & Use

In 2000 Alan installed twelve FullStop wetting front detectors. He waited about two to three months for the FullStops to settle down (roots to re-establish in the disturbed soil) and then began to monitor them two to three times per week. Alan was very pleased with the performance of the FullStops and in 2003 and 2005 Alan increased the number of FullStops installed in the orchard to fifty. The FullStops were initially installed at 30 and 60 cm, however now Alan has installed FullStops at a 15 cm soil depth on all sites.

Alan monitors all the FullStops at least once a week and collects the leachate to measure EC and occasionally pH, nitrate, chloride, and potassium levels. Alan uses a portable pH meter to measure pH, Horiba Cardy meter to measure nitrate, a specific ion electrode to measure chloride and the Horiba Cardy meter to measure potassium. Alan mainly uses the FullStops to monitor salinity and to assist with irrigation monitoring, whilst nutrient monitoring is a lower priority.

Experience / Case studies

After using the FullStops over a season Alan recognised a trend of soil solution leachate salinity starting at about 1 dS/m at the end of winter and increasing to 3-5 dS/m during the main part of the growing season. Alan tries to maintain the salinity of the leachate below 3 dS/m by increasing irrigation application rates. The 60 cm FullStops do not trigger as often as the 30 cm FullStops. Alan believes the irrigation wetting front reaching the 60 cm FullStop is not normally strong enough to trigger the device. Information from his soil capacitance probes also indicates that only a weak wetting front reaches 60 cm soil depth.

The FullStops can also highlight the degree of irrigation variability within the orchard. Some FullStops were regularly triggered whilst others were never triggered, so Alan conducted a sprinkler variability test using cups and discovered that the sprinkler efficiency was poor. Alan believes it is critical to conduct a sprinkler efficiency test before installing a FullStop. The FullStops were installed in places receiving an average water application rate. Due to the high variability of irrigation application efficiency Alan believes he is better off having fifty FullStops rather than just a few soil capacitance probes. There is a high-risk of the soil capacitance probes being installed in the wrong position and providing misleading information.

Alan also installed eight SARDI soil solution extraction tubes (SSET) at the 60 cm depth in 2005 to enable him to obtain soil solution leachate for assessment. Alan primes and collects soil leachate once a week from the tubes. The SSET yield soil solution leachate more reliably than the FullStops at this depth. Alan places more emphasis on the results from the 15 and 30 cm FullStops., he does not place too much emphasis on the 60 cm SSET because there are very few roots at this depth.

Benefits & Comments

Alan believes that the FullStops are a very good, inexpensive and simple tool to give growers an indication of appropriate irrigation application amounts, soil nutrient levels and as an alert to potential salt toxicities. The FullStops have helped Alan to better manage his soil salinity and irrigation management to improve the health and productivity of his orchard.

Anne-Maree Boland

Crop : Stonefruit
Tool: Ceramic cylinder and tensiometer tip sampler
Region : Tatura, VIC

Background

Dr Anne-Maree Boland, Stephen Martin and Dr Peter Jerie (VIC DPI) conducted a project “Evaluation of Critical Irrigation Qualities for Perennial Horticulture” in the mid 1990’s (Boland *et.al.* 1997). The studies were conducted on peach and nectarine trees. The project aimed to “*determine threshold salinity levels at which a reduction of fruit yield occurs and seek ways to maximise horticulture productivity while minimising environmental impacts*”.

The project included the evaluation of two types of ceramic sampler tips and the use of soil solution analysis for salinity management.

Equipment & Use

The project used a ceramic cylinder sampler (ceramic tip 100mm X 10 mm) similar to the samplers used in the Dale and McClure project (Figure 9) and also a sampler of similar design but using a common 1.9 cm wide tensiometer tip. The tensiometer tip design was previously used with success in the Jerie and McNab fertilser management project.

Experience / Case studies

The project identified that the current threshold irrigation water salinity for peach and nectarines can be increased from 0.37 dS/m to 0.5dS/m. However the threshold is only a guide and on-farm irrigation management and physical constraints (i.e. tile drainage, soil type and irrigation system) are critical factors in determining tree response. Soil salinity (EC_e) provided a good indication of salinity stress and the results confirmed the suitability of adopting the Mass (1990) soil salinity versus yield relationship for Australian conditions (2 dS/m EC_e threshold).

Soil pot trials were also used to evaluate the ceramic samplers that were used in field trials. The following discussion relates to the pot trial results.

A suction test on the tips established -90 kPa suction was achieved after the syringe was pulled back by more than 20ml. Suction did not vary much when the syringe was pulled back between 20 to 60 ml.

The tensiometer tip design collected more soil water over varying soil moisture levels as compared to the ceramic cylinder design. The sample collection rate for the tensiometer tip design significantly decreased as soil water tension increased from -5 to -30 KPa (45ml to 10mls respectively). The ceramic cylinder design sample collection rate remained constant at about 1-4 mls throughout the soil drying process. The tensiometer model could only extract small amounts of soil solution (2-3 mls) at -27 to -30 kPa, whilst the ceramic cylinder sampler ceased to yield samples after - 20 kPa. The tensiometer design yielded about 7mls of soil solution at about -20 kPa.

The tensiometer tip design demonstrated an increase in soil solution sample salinity of about 2 dS/m as soil water tension increased from -5 kPa to -30 kPa, however the ceramic cylinder sampler did not vary much. There was no significant difference in the soil solution sample salinity levels for either design when soil moisture ranged between -5 to -10 kPa.

The tensiometer tip sampler extracted 4 to 20 times more soil solution than the ceramic cylinder sampler. The surface area of the tensiometer tip was 1.3 times larger than the ceramic cylinder, however with a surface area correction factor applied, this did not account for the differences. It was concluded that the main difference in the ability of the samplers to extract soil solution was the ceramic's intrinsic hydraulic conductivity. The tensiometer tip model had a significantly higher hydraulic conductivity (larger ceramic pore size) than the cylinder model. An opportunity may exist to improve the performance of ceramic samplers by altering the ceramic pore size.

Benefits & Comments

The study indicated that ceramic samplers were *"extremely useful"* as an indicator of soil salinity and "*had a number of advantages over soil sampling for salinity assessment*".

Warren Bond (CSIRO)

Crop : pastures, cereal crops, vineyards, native forest, timber plantations & suburban gardens
Tool: CSIRO SSET
Region : Canberra ACT; Riverina and South-west Slopes, NSW
Contact : warren.bond@csiro.au

Background

Warren Bond is a research scientist with CSIRO and, in collaboration with others, has used soil solution sampling techniques since 1983 in a range of projects. These projects included: sewage sludge re-use on dryland pastures (Willett et al, 1984), the fate of contaminants following land application of contaminated runoff water from the Ranger Uranium mine onto the surrounding bushland (Willett et al, 1993), irrigation of woodlots with sewage effluent (see Smith & Poss report), onsite treatment and disposal of household sewage (see Smith & Poss report) and the movement of nitrogen in flood and drip irrigated vineyards (Barlow, 2008 & Hutton 2008).

Equipment & Use

In the first two projects listed above, Bond used a 6 mm diameter soil solution extraction tube (SSET), based on the design by Talsma et al. (1979, Figure 3). The sampler was made by gluing a hollow ceramic cylinder (4.6 mm in diameter and 50 mm long) into one end of a suitable length of 6 mm diameter stainless steel tube. The other end of the ceramic tube was plugged with epoxy resin. The sampler was connected to a four litre sealed glass flask (typically a discarded wine flagon) via micro-tubing. Suction was applied to the glass flask and this extracted water out of the soil via the SSET. The equipment extracted up to 200ml of soil solution during or immediately after rainfall events. Experience showed that a useful sample could be collected down to a soil water tension of about -20 kPa.

For subsequent projects in which Bond was involved, the 40mm diameter SSET (developed by Poss and Smith – see separate report) was used.

In the irrigated vineyard project David Deery (CSIRO) modified the earlier 40 mm design by changing the seals and reducing the length of the tube. The tubes were buried at 0.5, 0.75 and 1 m below the soil surface for flood irrigated vineyards and 0.25, 0.5 and 1m below the soil for drip irrigated vineyards. Samples were extracted when the soil was wetter than -10 kPa and analysed for EC and nitrate.

Experience / Case studies

1. Sewage sludge application to dryland pastures

Soil solution sampling was carried out in two related projects working on the efficacy of surface applied sewage sludge, both before and after incineration, as a fertiliser for pastures in the Canberra region. Soil solution sampling was included to identify the potential leaching of nutrients from the sludge and subsequent off-site effects. The first was a trial study using small (4 m^2) plots established at the CSIRO Black Mountain Site. Following this trial, a more comprehensive project using 40 m^2 plots was established on the CSIRO Ginninderra Experiment Station on the northern outskirts of Canberra.

In the small trial (Willett *et al.* 1984), sewage sludge (20 t/ha) or ammonium sulphate (85 kg N/ha) were applied to the plots and incorporated by cultivation. The three plots were irrigated at the rate of 50 mm/week during the twenty two week measurement period to simulate rainfall events and speed up the leaching process. SSET were installed at depths of 10, 20, 40 and 60 cm. Samples were extracted every 2 weeks mid-way between irrigation events, and analysed for nitrate-N. The measurements clearly showed the downward movement of a nitrate peak in all plots (including the control) following the commencement of irrigation. The size of the peak was largest for the ammonium sulphate treatment and smallest for the control; the sludge treatment was closest to the fertiliser treatment. There was a significant production and movement of nitrogen in the control plots and this was attributed to the mineralisation of soil organic matter in response to cultivation and wetting. It was concluded that there was a risk of nitrate leaching from surface applied sewage sludge (at 20 t/ha), but that it was slightly less than that from application of ammonium sulphate at (85 kg N/ha).

In the larger experiment, four 40 m^2 plots were established on a gently sloping paddock containing improved dryland pasture. Two plots were treated with sewage sludge and two kept as controls. Measurements of soil water storage and gradients, runoff, plant dry matter production, nutrient accumulation, soil nutrient concentrations and soil solution nutrient concentrations were measured over a 3 year period. SSET were installed at depths of 10, 25, 50, 75 and 100 cm at two locations in each plot. Soil solutions were extracted whenever the soil was wet enough (wetter than – 20 kPa).

2. Land application of contaminated mine waste water

In this project, described by Willett et al. (1993), a 60 m^2 plot was cleared from the bush and irrigated with water having an EC of 0.9 dS/m. The water contained contaminants found in runoff water collected at the Ranger Uranium Mine. The aim of the project was to establish the fate of the contaminants, which included radionuclides (^{238}U, ^{226}Ra, ^{210}Pb, ^{54}Mn, ^{22}Na) as well as non-radioactive ions, the most prevalent being magnesium (90 mg/L) and sulphate (510 mg/L). The Talsma et. al. (1979) SSET were used to extract solution from five depths (to 50 cm) at six locations in the plot. Solution samples were extracted weekly; vacuum was applied to the collection flasks until approximately 25 mL of solution was obtained. When the sandy soil was wet it took approximately three hours to extract a sample, however, there were times when the soil was too dry to obtain a sample. The concentrations of the major soluble cations (Na, K, Ca, Mg) and anions (Cl and SO_4) as well as pH and EC were measured on the samples. The radionuclides were expected (and indeed this was confirmed by measurement) to be retained in the surface soil and not move to depth.

The data showed rapid movement of all ions downward through the soil, resulting in water with an EC of approximately 2 dS/m passing through the unsaturated zone towards the groundwater. Consistent with the composition of the input water, the dominant ions moving through the soil were magnesium and sulphate. The soil solution concentration data was combined with independent estimates of vertical soil water flux to calculate ion fluxes as a function of time for the duration of the experiment (thirty eight weeks). This data was used to calculate a solute mass balance for the plot and confirm the fate and pathways of the constituents of the irrigation water.

3. and 4. The use of the SSET in the effluent-irrigated woodlot project and the onsite treatment and disposal of household sewage project
These projects are discussed in the Smith and Poss report.

5. "Influence of Irrigation and Fertilizer Management on Movement of Water and Nutrient within and below the Rootzone of Vines for Sustainable Grape Production"
Bond participated in the CRC Viticulture project (Hutton *et al.* 2008) headed by Ron Hutton (NSW DPI, Wagga Wagga). The project commenced in 2003 and a final report was published in 2008. Part of the project studied the movement of nitrogen in flood and drip irrigated vineyards (Barlow *et al.*, 2008; Hutton *et al*., 2008).

Solution samplers (40 mm diameter) were installed at depths of 0.5, 0.75 and 1 m below the soil surface under furrow irrigated vines, or at depths of 0.25, 0.5 and 1 m under drip irrigated vines. Three replicates were installed. Samples were collected when the soil was wetter than -10 kPa soil water tension. The nitrate concentrations in the soil solution samples were extremely variable, ranging for example at a 1m depth from 0.64-82 mg N/L. The complexity of the vineyard systems, and the existence of many uncontrolled variables across them, meant that it was not possible to conclusively link management actions with concentrations in soil solution. However, some broad conclusions could be extracted, namely that the soil solution nitrate concentrations were higher in furrow irrigated vineyards than drip irrigated ones, and were higher in vineyards with greater fertiliser nitrogen inputs. Furthermore the nitrate concentrations in soil solution frequently exceeded recommended water quality targets, often by large amounts. Combined with the estimation of the number of days on which drainage beneath the rootzone was likely, these large nitrate concentrations suggest that there is a significant risk of export of nitrate to the groundwater.

Benefits & Comments

Soil solution sampling can be a very useful way of non-destructively monitoring the movement of solutes through the soil. As well as keeping the soil intact by avoiding frequent core sampling, it allows repeated measurements at the same location (albeit with some disruption caused by the extracting of solution), and is usually cheaper than repeated soil coring.

However, it is not without its drawbacks. It clearly works best under irrigated or high rainfall conditions when the soil remains much wetter than -20 kPa. Under these conditions the soil solution was easily extracted, but the influence of the extracted sample on the soil process is much less.

In some cases, soil solution sampler data is highly variable and difficult to interpret. This arises, for example, in circumstances with complex source geometries (eg drip or furrow irrigation), complex root distributions, or under alternating dry and wet conditions. In many cases interpretation may be difficult because the processes affecting solute distribution are incompletely understood. In some instances, the addition of data from regular core sampling, or from increasing solution sampling frequency may help. In other cases soil solution data can be on variable and inconsistent as to be uninterpretable.

Andrew Creek (NSW DPI)

Crop : Citrus
Region : Riverina (Griffith & Leeton), NSW
Contact : Andrew.creek@dpi.nsw.gov.au , Ph 02 6960 1300

Background

Andrew is a District Horticulturist with the NSW Department of Primary Industries (NSW DPI). Andrew is based at Griffith and his work is focused mainly on the citrus industry.

Equipment & Use

Andrew has been collaborating with seven Riverina citrus growers who purchased SARDI soil solution extraction tubes (SSET) in September 2006. NSW DPI installed the SSET using a 50mm auger in a variety of soil types including sands, loams, clay loams and heavy clays. The probes were pushed into a mud slurry that was made from sieved soil extracted from the installation hole.

The SSET were installed at varying depths. Some sites have their probes installed at one site at varying depths, whilst other growers chose to install a single SSET at one depth in numerous blocks. The shallow SSET was installed in the main rootzone at about a 25cm soil depth.

Soil solution samples were extracted monthly from the start of September and then every six weeks from January to the end of autumn. (6 to 7 samples per year). The samples from the active root zone were sent to Rootzone Solutions for analysis - pH, EC, Na, N, P, K, Total Hardness, Ca, Mg. Samples from the bottom SSET (90cm) were analysed for pH, EC, nitrate (Quantofix™ strip), and Chloride levels using an Aquaspex titration test kit.

The tubes were primed after irrigation and a sample was taken one to two days later. The two step process is not ideal because it is easy to forget to either prime the SSET, or come back to take a sample before the tubes loose their prime. Some sites can yield samples after eight hours, however 24 hours is more common. Some can take up to 48 hours to yield a sample. Heavier soils tend to require longer suction times.

About 80% of the SSET were replaced soon after installation because of cracks occurring in the ceramic tip. The cracks occurred after installation. This problem was traced back to a faulty batch of ceramic tips. The replacement SSET worked much better but some still did not yield samples. Investigations revealed that on some sites the soil was too dry to extract any soil solution. However some tubes continue to yield little soil solution even though the soil is moist. The reason for this has not yet been established.

One of the growers has purchased two Mottes SSET. The Mottes tubes were installed at a depth of 20cm and have yielded samples consistently.

Experience / Case studies

Sampling issues

The biggest problem has been the reluctance of growers to collect samples. Only two of the seven growers could be relied upon to take samples. The soil solution sampling would probably cease if NSW DPI was not driving the project and encouraging growers continually to take samples.

Andrew believes the main reason for this lack of interest in taking samples is that the growers see little value in the data because they have difficulty in interpreting the soil solution analysis results. To address this issue NSW DPI hosted a soil solution workshop in March 2007, reviewing the 2006-07 data from both the Riverina and Sunraysia. A post workshop survey indicated growers appreciated the opportunity to discuss results and see how their results compared to other sites. All growers indicated their knowledge and understanding of soil solution had increased as a result of the workshop. A soil solution analysis summary of all sites is distributed monthly to growers with their results tabulated.

Impact on Growers

The project had some impact on a few growers with significant issues (nitrate leaching and salinity). One grower was detecting high nitrate levels at depths below the root zone and a decline in tree health. The grower installed tensiometers to assist with irrigation scheduling and as a result nitrate levels from the deep SSET declined and tree health improved. Another grower was failing to extract any soil solution from both shallow and deep SSET and on investigation it was discovered that irrigation water was barely infiltrating the soil. The grower altered his irrigation practices and resolved the problem. Another grower was detecting high salinity levels in most sites. He was mixing drainage water with irrigation water but the ratio of drainage water to irrigation water was too high and the trees were being irrigated with water with high EC water.

However the project did not alter the practices of the other five growers, even though some had continually low or exceptionally high nutrient readings.

Deep probes

The SSET placed in the active root zone (i.e. 25cm) provided data of greatest use. The SSET at the bottom of the root zone is not essential because irrigation monitoring equipment was able to indicate if irrigation events could potentially leach fertiliser. The deep SSET confirmed when leaching had occurred, but did not provide an indication of the degree of leaching.

SSET installed at the 80 to 90cm depths yielded samples inconsistently. These deep SSET were installed to monitor salt levels and nitrate leaching. The chloride levels remain fairly stable for each property, with only one having levels that required careful management and monitoring.

Soil drying as a result of the Drought

During the drought and subsequent reductions in water availability in the 2006/07 season, a number of sites had difficulty yielding samples at the 40-50 cm depths. All sites are usually able to wet the soil below 40 cm, but during the drought some sites were unable to wet below 15 cm. Irrigation frequencies were increased on a clay soil site and the probes were removed and installed at a 10cm depth for the remainder of the season. This year significant rains in May alleviated the soil wetting problem. The probes have been reinstalled at a 20 cm depth and have been regularly yielding samples.

Analysis and reporting

The Quantofix™ nitrate strips did not provide an adequate level of accuracy required for the project. However they are useful as a quick infield test to provide an indication of low, medium, high or excessive nitrate levels.

Merck Nitrate Reflectoquant™ test strips are accurate and yielded similar results to the Laboratory results. The Merck Reflectoquant™ system costs about $1000 (RQ Flex meter™). The cost of the Reflectoquant™ system would not be suitable for growers who conduct only a few tests per year. Test strips, laboratory analysis or the Cardy Nitrate meter might be a better option for growers analysing a low number of samples per year.

The analysis and interpretation reporting to growers needs to be improved. Results are provided in graphical form with an interpretation guide based on the experience of Lawrence Kirton (Rootzone Solutions). Most growers lack the confidence to use the general interpretation guide and prefer a simple format of results such as: deficient, low, optimum, high or excess.

Benefits & Comments

Overall the project did not have a major impact on the grower's orchard nutrition management, but it did result in altering the irrigation management of two of the seven participating growers. Generally the growers found the data interesting but not essential to their orchard management. Further workshops and training may increase the perceived value of soil solution analysis. Further refinement of nutrient guidelines and improved interpretation or reporting formats would also increase the importance of soil solution analysis as another management tool.

Mark Dale & Paul McClure (Agriculture Victoria)

Crop : Vines & citrus
Tool: Ceramic cylinder sampler
Region : Sunraysia, VIC
Contact : Sunraysia TAFE, pmcclure@sunitafe.edu.au

Background

Mark Dale and Paul McClure worked for Agriculture Victoria as Project Officers. From 1992 to 1994 they conducted a project investigating nitrogen losses from irrigated horticulture on Mallee soils. Sites were chosen on grape and citrus properties and included a range of irrigation systems. All sites had subsurface drains installed for at least 10 years. The sites were monitored by a neutron probe, test wells and ceramic samplers. The project monitored the nitrogen content of the soil leachate from ceramic samplers, test wells and subsurface drainage and regular intervals.

Equipment & Use

The ceramic sampler was a 1 cm wide and 10 cm long ceramic cylinder (open at both ends). A 1.5mm (ID) polyethylene tube inserted into the tube and sealed at either end with epoxy resin putty / plastic mastic compound (Figure 8 & 9). At most sites the ceramic samplers were buried at 10 cm intervals to a depth of 60 cm and there after at 20 cm intervals to 160 cm and a final ceramic sampler at 200 cm.

Soil leachate sampling occurred within three days of an irrigation event. Samples were taken by attaching a 50 ml disposable hypodermic syringe and fully extending the plunger to provide a maximum suction of about – 90kpa. The syringe was locked in place once it was fully extended.

Experience / Case studies

The ceramic samplers were only able to yield leachate if the soil was adequately moist. Once a soil tension began to increase, the volume of leachate extracted decreased.

Paul believed that the nitrate results should not be considered highly accurate because of the variation within the orchard and across the region due to soil type, moisture availability, soil structure and type. The data should be grouped into broad categories of Nil, Low, Med and High. The nitrate reading gave a good indication of the general pool of nitrogen and its trends. Paul also found that samplers installed in the carbonate layer of the soil did not reliably yield soil solution extracts, however the addition of silica four at installation improves their performance.

The various studies indicated that most of the nitrogen applied to the citrus and grape orchard were not leached and remained in the upper part of the rootzone. However the growers selected for this project tended to be more progressive and efficient crop managers.

Benefits & Comments

Paul found the ceramic samplers to be an excellent tool to indicate if nitrogen reserves were exhausted or if nitrogen leaching was occurring. Soil solution sampling is time consuming, but cheap, easy to use and can provide quick results.

Steven Falivene (NSW DPI)

Crop : Citrus
Tool: Mottes SSET & SARDI SSET
Region : Riverland (Renmark, SA) & Sunraysia (Dareton, NSW)
Contact : steven.falivene@dpi.nsw.gov.au, Ph 03 50198405

Background

Steven Falivene has been working as a citrus extension officer in the Sunraysia region since 1994. In 2004 Steven attended a citrus study tour to Spain and observed some Spanish growers using a ceramic tipped soil solution extraction tube (SSET) to monitor the nutrient levels of soil solution extracts for the purpose of nutrition management. On returning to Australia Steven developed a small self-funded soil solution analysis project with citrus growers in the Riverland and Sunraysia region. The project was conducted over two years in collaboration with Lawrence Kirton (Rootzone Solutions). Since no data was available for soil solution analysis in citrus, the main objective of the project was to collect some data and make preliminary assessment of the technology. Ten growers purchased and installed sets of SSET. The sites were monitored on a fortnightly to monthly basis. Recently Steven has commenced an Integrated Advanced Fertigation trial (a variant of Open Hydroponics) at Dareton Research Station. The trial will monitor soil solution of the various fertigation treatments using Mottes SSET and CSIRO FullStops.

Equipment & Use

Two tubes were installed at each grower site. The first tube was placed in the middle of the root zone and the second placed at the base of the root zone. The root zone was determined by digging a small trench beside one or two trees. In the following season a one metre tube was installed on all sites to monitor deep drainage.

Samples were analysed by Rootzone Solutions and also using a Horiba Cardy nitrate and potassium meter, Merck RQ Flex meter (nitrate analysis only), nitrate test strips and Aquaspex water analysis kits (calcium and phosphorous analysis). The Cardy nitrate meter was very convenient and reasonably accurate, however after conducting a large number of samples the small nitrate sensor failed and needed to be replaced. The nitrate meter was not very accurate at readings below 30ppm nitrate. The RQ Flex meter has a high initial cost however it provided more accurate results than the Cardy nitrate meter and did not fail. The Cardy Nitrate meter might be suitable for low volume use (i.e. less than 30 tests per year), whilst the RQ Flex meter is more suitable for a larger volume of samples. Nitrate test strips were also valuable and were able to give a good indication of nitrate levels. Steven was able to improve his accuracy of reading the nitrate strips by calibrating against the RQ Flex meter. In most cases Steven was able to estimate test strip results with in (+ -) 15% of RQ Flex meter results. An added feature of the test strips is the ability to measure nitrite. Nitrite is an indicator of waterlogging. The Cardy potassium meter was used extensively and performed reliably. The Aquaspex water test kit provided acceptable results for calcium, phosphorus and total hardness tests (Calcium plus magnesium).

Soil solution pH was difficult to accurately measure. Three portable pH probes were used and all provided different results (up to 1 pH unit) when tested on the same sample.
Measurement of EC was a very reliable and valuable test. It quickly gave an indication of salt levels within the soil solution. It was also a good cross-reference if high results were presented in other nutrient tests. High nutrient test results (i.e. nitrate, potassium) are generally reflected in high EC test results.

Steven has also had some experience with the SARDI 40mm SSET models (work conducted by Graham Sanderson and Andrew Creek (NSW DPI). Steven prefers to use the 20mm wide SSET because less soil is disturbed during installation and no digging is required to remove the tubes if problems occur. The soil can also be re-compacted easily around the narrower ceramic tip during installation. Slightly compacting the soil around the ceramic tip may help to reduce the risk of the tip loosing contact with the soil. Steven has had no issues with the Mottes 20 mm wide SSET. Although Steven favours the 20 mm wide SSET, he believes that both 20 mm and 40 mm wide models are viable options.

Experience / Case studies

Proportional fertigation vs irregular fertiliser application

The results of the grower study demonstrated that proportional fertigation sites had more stable soil solution nutrient levels than sites fertilised every six to eight weeks. When a high single dose of urea was applied on a conventional site, nitrate levels peaked above 500ppm and then dropped back to 60ppm in the following week. Proportional fertigation sites maintained nitrate levels between 30 and 80 ppm throughout the season.

Sandy soil

Most SSET were installed on a sandy loam soil, however one set of SSET was installed on a loamy sand. The loamy sand site was fertigated once every fortnight.   Nearly all soil solution analysis results from this site were significantly lower in all nutrients compared to the sandy loam sites. The trees on this site were exhibiting signs of nutrient deficiencies. The grower realised more frequent fertigation and irrigation was required for the sandy soil conditions.

Heavy soil : late colouring fruit

Fruit from a block of citrus on clay loam soils was failing to reach adequate colour early in the season. Soil solution analysis results indicated that the soil was retaining high levels of nitrate into autumn. High levels of nitrate delayed fruit colour. In the following season all nitrogen application ceased at the end of December. Soil nitrate levels steadily decreased into autumn and the fruit achieved good early fruit colour.

Excessive potassium

A grower continued to fertigate with heavy doses of potassium into autumn. By the middle of April the demand for potassium by fruit significantly declines. Since the grower did not reduce potassium fertigation rates, soil solution potassium levels quickly increased from 30ppmm to 80ppm.

Benefits & Comments

Most growers demonstrated that their fertigation programs were keeping nutrients in the soil solution within reasonable levels and they were not excessively leaching nutrients. This was not surprising since the growers that agreed to participate in the project had a good level of skill in nutrient and irrigation management. However some interesting observations demonstrated that SSET was valuable in identifying some nutritional issues that required corrective action.

After the project ended most growers did not continue to monitor the SSET. The main issue was having the time and commitment to regularly prime tubes, take samples and send them off for analysis. The use of SSET had demonstrated during the two year project that most growers had a good nutrient application program with no salinity issues, so it was not critical for them to continue monitoring. A positive outcome from the project was that it prompted the adoption of SSET by the Mildura branch of Agriexchange crop consultancy and other corporate orchards. Mildura Agriexchange now use SSET as a part of their crop management consultancy services (see Peter Ryan, Agriexchange case study).

Soil solution analysis is an excellent tool to help fine tune nutrition and irrigation programs. The monitoring of EC and nitrate will provide growers with a sufficient amount of information to improve nutrition and irrigation management. Soil solution analysis should be a part of an integrated monitoring tool kit (i.e. soil moisture, leaf analysis, soil pH etc).

Ian Goodwin (VIC DPI)

Crop : Stonefruit
Tool: SARDI SSET and FullStop
Region : Tatura / Shepparton, VIC
Contact : Ian.Goodwin@dpi.vic.gov.au

Background

Dr Ian Goodwin is an irrigation research horticulturist with Agriculture Victoria. Ian has had 25 years of experience in irrigated horticulture. Ian commenced a project in 2007 titled "Open hydroponics : managing the root zone risk". The project consists of a replicated fertigation and irrigation trial on a commercial stone fruit orchard at Tatura. Abdi Qassim is the project officer for the trial. The trial will investigate the effects of Open Hydroponics (OH) on yield, quality, root zone water, nutrients and salt fluxes. The project intends to minimise nutrient leakage from orchards, increasing nutrient efficiency and capacity for farmers to manage root zone risks.

The treatments in the trial include normal grower practice microjet irrigation, OH (drip irrigation), conventional drip irrigation and OH plus conventional drip irrigation with a straw mulch. Irrigation is applied to match crop water requirements. The trial is using various soil moisture monitoring equipment (Netafim telemetry tensiometer and Decagon ECH_20 TE probes), SARDI soil solution extraction tubes (SSET) and FullStops.

The soil is mounded and the topsoil is a red-brown earth with a sandy loam top soil and clay subsoil. Soil mounding was used to maximise the volume of sandy loam topsoil and minimise water logging.

Equipment & Use

SARDI SWE tubes

Twenty sets (one set per plot) of SARDI SSET (40 mm wide ceramic tip) were installed at 30 and 100 cm depth in mid 2007. The SSET were installed approximately 25 cm horizontally from the dripper. The deep tube was positioned below the rootzone.

FullStops

Twenty sets (one set per plot) of FullStop wetting front detectors were installed at the 30 and 45 cm depth in mid 2007. The SSET were installed directly under the dripper.

Experience / Case studies

SARDI SSET.

The SSET initially operated satisfactorily during spring and early summer when adequate amounts of rainfall and irrigation were applied to sufficiently wet the majority of the root zone. During December a change in the irrigation program partially dried out the root zone. From that point the SSET ceased yielding regular soil solution extracts. Even after adequate irrigation was applied to re-wet the deeper parts of the root zone, the SSET still did not yield regular and adequate amounts of soil solution. The SSET are not producing sufficient results for the trial. Possible reasons for the problem are; the non-symmetrical wetting pattern of the red-brown soils in the region, and/or during the drying stage in December, the soil broke contact with the ceramic tip and/or the positioning of the SSET within the rootzone and the positioning horizontally from the dripper.

FullStop

The FullStops required a distinct wetting front to move past the funnel of the device for soil solution to be collected. The FullStops generally yielded soil solution in both microjet and drip irrigation treatments, including the daily/continuous drip irrigation treatment. The FullStops initially operated satisfactorily during spring and early summer when adequate amounts of rainfall and irrigation was applied to sufficiently wet the majority of the root zone. During the soil drying event in December the FullStops ceased to trigger and provide soil solution extracts. However as soon as higher irrigation amounts were applied, the FullStops began to trigger and yield soil solution.

Since a large amount of soil was disturbed during the installation of the FullStops, the first few of months of results were not considered reliable. However by late summer the soil would have settled and roots would have re-established into the disturbed soil to provide a reliable sample.

The soil solution extracts have been tested for nitrate and EC using test strips and an EC meter. Only a few months of reliable results have been collected from the FullStops, therefore it is difficult to draw conclusions at this early stage.

Benefits & Comments

Tensiometers have a history of not operating successfully in the region due to the reasons mentioned above and perhaps this might be a similar conclusion for the 40mm wide ceramic tipped SSET. The FullStops are considered a valuable tool to provide the project with some qualitative data to assist in understanding soil nutrient and salt fluxes.

Peter Jerie & Stuart McNab (VIC DPI)

Crop : Stone & pome fruit
Tool: Ceramic sampler
Region : Cobram and Shepparton, Victoria
Contact : Henry Schneider , henry.schneider@dpi.vic.gov.au

Background

Stuart McNab and Peter Jerie are former Victoria Department of Primary Industries (DPI) research horticulturists. Stuart and Peter, in collaboration with Henry Schneider (VIC DPI), Robert O'Connor (VIC DPI) and Pauline MacDonald (VIC DPI), conducted a five year research program at the Institute of Sustainable Irrigated Agriculture, Victoria, studying soil acidification and nutrient movement in irrigated horticulture in the early 1990's. In one of these studies soil solution ceramic samplers were used to determine the depth of movement of urea and MAP fertiliser down the profile when applied either early or late during an irrigation cycle. The movement of urea was related to changes in soil pH during the season.

Equipment & Use

A ceramic sampler, similar to the design used by Mark Dale, Paul McClure and Graeme Sanderson (Figures 8 & 9), was used in the trial. However a tensiometer tip was used as the ceramic end instead of a double opened ceramic cylinder. The open end of the tensiometer tip had a 1.5 mm (internal diameter) plastic tube inserted into it and then sealed with epoxy resin glue.

The ceramic samplers were installed at 15, 30, 45 and 60 cm soil depths. A hole was augured to the same width of the tensiometer tip (20 mm) on a 45 degree angle. The angled installation technique was used to minimise the chance of preferential water flow through the disturbed soil. The ceramic sampler was pushed into the hole with the aid of a small stick and the hole was gently re-packed with soil. A syringe was attached to the plastic tube protruding out of the ground. The syringe was pulled back and held in this position with a short piece of dowel. The suction caused by the syringe extracted soil solution out of the soil into the syringe. Adequate volumes of samples were obtained within 15 to 30 minutes of priming the ceramic samplers. The samplers were primed immediately after irrigation.

Experience / Case studies

The ceramic samplers were effective in monitoring the movement of urea and mono ammonium phosphate (MAP). The urea trial demonstrated that if urea was fertigated late in the 8 hour microjet irrigation shift most of the urea was distributed in the top 30cm of the soil with no urea reaching the 45cm soil depth. If urea was fertigated at the beginning of the fertigation shift the urea was distributed mainly in the 30 to 45cm soil depth and some urea reached the 60cm depth. Most crops have the majority of feeder roots in the top 30cm of soil, therefore any fertiliser moving below 30cm has a high probability of not being utilised and leaching out into the environment. Similar results of the rapid movement of urea were also found in a trial conducted by Welsh *et.al.* (1994).

Similar results were observed in the MAP trial. When MAP was applied early in the irrigation shift it reached below 45cm. When applied late in the irrigation shift it was mainly concentrated in the top 30cm of the soil. However the concentration of phosphate-P and ammonium-N recorded at all depths was much less (about 3-10%) than the concentration applied in relation to the volume of water stored in the soil. This suggests that the majority of the ammonium and phosphate possibly adhered to soil colloids above the 15 cm depth.

Benefits & Comments

Henry Schnieder believes the ceramic samplers were a robust tool to provide an indication of the movement of fertiliser and nutrients within the soil profile. Previous to the use of this tool it was very difficult to demonstrate the importance of good fertiliser management. This tool provides instant results to help researchers and growers better manage their fertiliser application program.

Paul Jones (Horticultural Crop Monitoring)

Crop: Strawberries
Region : Sunshine Coast, Queensland
Tool: Mottes SSET
Contacts: www.biomites.com.au, 0412714905

Background

Paul Jones is an integrated pest and crop management consultant for macadamias, citrus, and strawberries. Paul has been working for over 15 years on the Sunshine Coast region (Caloundra/Maroochydore) of Queensland. Paul also rears and distributes a number of strawberry predatory insects. In 2005 Paul heard about the Sunraysia citrus soil solution project and decided to try out twenty Mottes soil solution extraction tubes (SSET) at strawberry farms.

Equipment & Use

Over eighty tubes have now been installed in forty strawberry farms throughout the region. The Mottes tubes have been used at all sites and all SSET have performed successfully without any issues. The majority of growers placed one SSET in the main part of the root zone (i.e. 15cm depth) and some growers have included another SSET below the root zone (i.e. 30 cm). Most strawberry farms are on sandy soils and shallow SSET (i.e. 15 cm) installation is easy by pushing the SSET into the ground. Deeper SSET (i.e. 30 cm) are installed by hammering in an undersized pipe to make a hole and pushing the SSET into the hole. Paul monitors SSET weekly during the active part of the growing season. Soil solution extracts are stored in small jars and analysed with an EC meter, Cardy nitrate meter and an Aquaspex soil solution nutrient test kit. Suction is reapplied to the tubes after each sample is taken so a sample will be available in the following week.

The only problem Paul has had with the SSET is hares occasionally chewing the ends of the micro tubing.

Experience / Case studies

Low soil Nutrients from over irrigation

A strawberry block was not responding as expected to the intensive nutrition program. The SSET indicated that a significant proportion of nutrients (mainly nitrate) were moving below the root zone where it is unavailable to the strawberries and also a potential environmental hazard. The suspected cause was over irrigation and rainfall. The grower implemented good scheduling practices and this reduced deep drainage and the leaching of nutrients. The only option to manage nutrient leaching by rainfall is to apply nutrients in smaller and more frequent doses. Paul has noticed an improvement in production where growers have changed from a weekly application of fertiliser to a daily application. Paul believes that the improvements are due to reduced leaching of nutrients.

Excessive soil nutrients induce deficiency

A grower reported low leaf nutrient levels from leaf tests. The plants appeared to be undernourished. Results from the SSET indicated very high levels of nutrients, resulting in very high soil solution EC levels of about 6 dS/m. The high EC levels were interfering with root nutrient uptake. Instead of applying more fertiliser, the fertigation program was stopped and within a few weeks the EC levels returned to normal (i.e. 0.75-2 dS/m). Once the soil solution EC levels returned to normal, the plants recovered and the fertigation program recommenced.

Benefits & Comments

Paul believes the SSET have made a significant contribution in improving his quality of service to his clientele. Paul regards the use of SSET as an important part of a crop management tool kit, but also recognises that the tool does have its limitations and should be used in conjunction with other monitoring tools. When used to complement other crop management information (e.g. leaf tests, soil tests, crop visual symptoms, soil moisture levels), SSET can provide more quantitative data and help with making better informed management decisions.

Growers like soil solution monitoring because it provides them with information that helps to guide their nutrition management program. Prior to the SSET, growers were not able to quantify soil nutrient levels, which made it difficult for them to achieve optimum soil nutrient levels. This tool has helped to give growers an improved level of confidence in nutrient management.

After installing some SSET on loam to clay loam soils, Paul has noticed that the nutrients in soil solution extracts do not respond to potassium, calcium or phosphorous fertiliser application as dramatically as in sandy soils. In sandy soils when calcium, potassium or phosphorus application occurs, similar increases can be detected in the soil solution, however in loamy soils these increases in the soil solution do not occur as significantly, or not at all. Paul believes that the buffering capacity of the loamy soil is interacting with the fertiliser application, so he does not focus on interpreting cations in such soil types and focuses on nitrate and EC levels.

Growers believe they are producing a better product (firmer fruit with a longer shelf life) by ensuring that soil nutrients are maintained at adequate levels.

Lawrence Kirton (Rootzone Solutions)

Crop : Citrus, stone fruit, vegetables & flowers
Tool: Mottes SSET
Region : Western Australia & all states
Contacts: lkirton@wn.com.au , 0427 634 965 & 0438341447

Background

In the late 1980s Lawrence was working in Zimbabwe as a consultant for rose growers. Fertiliser was very expensive and difficult to obtain, therefore growers had to maximise the efficiency of fertiliser application. Lawrence attended a study tour to Israel in 1989 and observed the successful use of Mottes soil solution extraction tubes (SSET) by growers of various crops. A number of these Mottes tubes were then imported into Zimbabwe and installed on several properties. The use of SSET in rose production was very successful and was expanded to tobacco, citrus, field grown flowers, onions and other various vegetable farms. Lawrence emigrated to Western Australia in 2000 and soon after commenced a crop consultancy service (Rootzone Solutions : www.rootzonesolutions.com). The use of the Mottes SSET is an integral part of the consultancy program. Lawrence continues to provide a consultancy service to a variety of horticultural growers, and is now moving into advanced precision fertigation management technologies with strategic partners Rotem Dan – Autoagronom www.rotemdan.com/autoagronom.htm .

Equipment & Use

Whilst working in Zimbabwe Lawrence tried a number of types of SSET. The Mottes 20mm SSET were the only brand to provide reliable results. Other SSET had difficulty in extracting soil solution and the ceramic tips were also interacting with some nutrients (mainly phosphorus) to provide irregular results. The Mottes SSET has had over 35 years of development, over 1600 have already been sold in Australia and 10,000 world wide. Lawrence believes the use of high quality SSET is very important because the additional cost of purchasing a high quality SSET is small compared to the losses in consultancy fees and incorrect crop management recommendations from SSET that do not operate accurately and consistently. The soils in Western Australia are predominantly sands and Lawrence installs the tubes by pushing them into the soil. For the installation of deep probes (i.e. 50cm), Lawrence uses a 22mm auger to reach the desired depth. Clients are recommended to install two probes, one in the middle of the main root zone and another at the base of the root zone. The mid root zone SSET is used to assess the nutrients available to the plant, and the SSET below the root zone is used to assess the nutrients that are moving past the root zone.

Experience / Case studies

Whilst working in Zimbabwe in the early 1990s, Lawrence was able to assist growers in significantly improving yields and the quality of rose, tobacco, vegetable and citrus crops. Since moving to Australia, Lawrence has been working in a variety of horticultural crops and also in environmental monitoring.

Zimbabwe rose production

In 1989 the price of fertiliser was high due to a limited amount of foreign currency. The growers needed to reduce their fertiliser application rates whilst maintaining production. Mottes SSET were installed and the soil solution was monitored on a regular basis. Traditionally the growers were applying large amounts of granular fertilisers in large single dose applications during the season. The fertiliser applications increased the salinity of soil solution to levels that could damage roots. Soil solution results also demonstrated that a considerable amount of fertiliser was leached beyond the root zone causing the plants to experience a nutritional “flood and famine”. A new program was devised whereby nutrients were applied by fertigation on a daily basis and the total fertiliser application rate was cut by 70%. As a result the soil solution samples indicated a more steady level of nutrients within the soil and production increased by 100%.

Zimbabwe tobacco production

Tobacco was a staple export crop for Zimbabwe. Irrigated crops produced more yield than dryland crops, but there was a general perception that irrigated tobacco was lower in quality compared to dryland tobacco. The perception was that irrigated crops were fed too much nitrogen which induced the plants to produce excessive amounts of vegetation. Mottes SSET were installed and the soil solution was monitored on a regular basis. Drip irrigation was also installed instead of the traditional overhead knocker irrigation. A nutritional program was developed to meet the needs (N:P:K) of the crop at key phenological stages. Traditionally growers would apply fertilisers in single large doses using a calendar program. The average yield of irrigated tobacco was about three tonnes per hectare. The drip irrigated advanced nutrition farm yielded tobacco crops up to five tonnes per hectare. The crop was higher in quality and value (similar if not better to dryland quality) compared to traditional irrigated production.

Zimbabwe citrus production

Growers were attempting to export citrus to Europe. However a high level of fruit breakdown was occurring on the six-week voyage to Europe. A significant proportion of the citrus was grown on sandy soils which had low calcium levels. Mottes SSET were installed and the soil solution was monitored on a regular basis. A balanced nutrition program was also developed to ensure that the correct nutrients were applied at the appropriate phenological stage and the application of calcium nitrate was in balance with other nitrogen based fertilisers (excessive nitrogen, especially ammonium forms, can cause poor quality). Growers also began to adopt fertigation. As a result of the fertigation program and the use of SSET, the trees responded with improved canopy growth, improved fruit quality (less albedo breakdown and higher juice brix) and higher yields.

Zimbabwe tomato production

Traditionally tomato growers yielded about 70 to 80 tonnes per hectare. Growers were applying nutrients in bulk applications that were not balanced or linked to key phenological stages. In conjunction with Netafim, a drip irrigated fertigation project was instigated on grower properties. Nutrition programs were revised and potassium application was increased to meet crop demands. The soil solution was monitored with the Mottes SSET to ensure that the soil contained an adequate and balanced nutrient level. The project increased marketable production to about 140 tonnes per hectare.

Australian crop and environmental monitoring

Lawrence has been working as a horticultural consultant for growers in Western Australia and was also involved in the Sunraysia and Riverina citrus soil solution project (Steven Falivene & Andrew Creek NSW DPI). Clients include citrus and vegetable growers. The consultancy service includes the use of Mottes SSET combined with soil moisture monitoring equipment. Soil solution samples are taken every seven to fourteen days. The SSET have been very beneficial in Western Australia because most horticultural production occurs on infertile sands. Nutrients are very easily leached out of the soil profile and nutritional deficiencies can rapidly occur especially under high rainfall conditions.

Lawrence has been recently involved with government catchment management councils and with the Western Australian Department of Agriculture on several environmental projects. Nitrate levels have been increasing in low-level aquifers around the Perth region. Many of these aquifers are used for drinking water. Community, government and the agricultural industry have identified that the pollution of aquifers with nitrate needs to cease and various projects are underway to reduce the nitrification of aquifers. One project involves monitoring the use of chicken manure in vegetable production. Preliminary results indicate that when chicken manure is applied in winter, a significant amount of nitrogen not utilised by crops and is leached down the soil profile. A project is also underway to look at the nutrient requirements of dairy pastures. Trials will compare the use of fertigation with granular fertiliser application. The site will also be monitored with capacitance probes and SSET. The project aims to increase productivity and reduce the movement of nutrients beyond the root zone.

When water licences are granted or renewed in Western Australia growers are required to implement an environmental management plan. SSET are an important part of the plan because they measure and can help to manage nutrient leaching.

Lawrence is currently working in partnership with Elders and the Western Australian Vegetable Growers Association to improve lettuce production. A precision placement lettuce trial was conducted which demonstrated that frequent applications of liquid fertiliser and polyacrylamide soil conditioners are able to increase production and reduce nutrient leaching. Lawrence has also been working with a new advanced fertigation production method developed in Israel called Rotem Dan – Autoagronom (www.rotemdan.com/autoagronom.htm). Autoagronom is a precision management technique that measures soil nitrate, EC and oxygen levels and then applies the appropriate amount of nutrients and water to meet the crop needs. If oxygen levels decrease below threshold levels, irrigation ceases until adequate oxygen levels are re-established in the soil.

Benefits & Comments

The use of SSET have provided many benefits in Zimbabwe and Australia. There is enormous potential to improve agricultural production and environmental sustainability with the use of SSET in combination with soil moisture probes and a balanced nutrition program. All irrigated agricultural growers should consider using these tools. Governments should encourage the adoption of soil solution monitoring to the irrigated cropping industry through extension programs, grants and subsidies.

Trevor Lake (Private consultant)

Crop : Citrus, stone fruit & pome fruit
Tool: Mottes SSET
Region : SE Queensland
Contact : Trevor.lake@oneharvest.com.au

Background

Trevor emigrated from Zimbabwe in 1991 and commenced working with Lawrence Kirton (Rootzone Solutions) in 2001. Trevor worked in the Gayndah region of Queensland providing an irrigation and fertigation consultancy service to growers. The consultancy service included the use of Mottes soil solution extraction tubes (SSET). The service began with about ten sites around Gayndah and expanded to include stone and pome fruit. The SSET information helped growers fine tuning their nutrition program.

Equipment & Use

Trevor has used the Mottes SSET and found the tubes to be very reliable throughout the past seven years. Trevor believes it is important to use a SSET with an inert ceramic tip. Other ceramic tips may retard the movement of nutrients within the tip and provide inaccurate results. In a well irrigated orchard the Mottes SSET always yielded results.

Experience / Case studies

Citrus potassium demand in November

Historically citrus growers apply potassium in December. SSET tubes indicated that in mid-November potassium levels would drop by about 40% (i.e. 25ppm to 15ppm). This drop would not occur every year. The decrease in potassium was dependent on climatic factors including temperature and rainfall. In the southern citrus growing regions of Australia a December potassium application would correspond to the commencement of cell expansion, however crop development is earlier in Queensland and a November application would better correspond to the commencement of cell expansion. Growers now apply potassium in November and dramatic decreases in November potassium SSET levels are no longer observed.

High EC irrigation water

Some orchards irrigate with high EC water (1.8 to 2 dS/m). The SSET have helped growers to manage their soil salinity levels. As soil solution EC levels rose, fertigation application decreased and irrigation application increased.

High fertiliser application rates cause EC spikes

On some table grape and citrus orchards soil solution EC levels were exceeding 2.5 dS/m soon after fertiliser application and then falling to 1 dS/m in the following week. The two areas of concern were root burn from high EC and fertiliser leaching. EC levels above 2 dS/m might be damaging roots and affecting tree growth. The dramatic decrease in EC may indicate that the fertiliser was being leached out of the soil profile. This leaching reduces the availability of nutrients to the tree and poses a possible environmental hazard. Growers began splitting fertiliser applications and subsequent SSET results showed a reduction in EC and nutrient spikes.

Benefits & Comments

The SSET had been critical in helping growers identify salinity and nutritional problems. Without the use of SSET growers may not be aware of soils salinity levels or soil nutrition status. It enabled growers to detect problems early in the season and address any problems. Regular monitoring is required to build enough data to make reliable interpretations.

Peter Ryan & Trevor Sluggett (AgriExchange)

Crop : Citrus, Almonds, avocado & table grapes
Tool: Motttes SSET, SARDI SSET & Agriexchange SSET
Region : Sunraysia & Riverland
Contact : Peter: 03 50187700, Trevor: 08 85861295
Email: peter.ryan@costaexchange.com.au , Trevor.sluggett@costaexchange.com.au

Background

Peter Ryan is the Sunraysia manager and senior agronomist of the Sunraysia branch of AgriExchange consultancy services. The consultancy service provides irrigation and agronomic advice on a variety of crops to growers and it is also a distributor for Sentek soil solution monitoring equipment. Peter has over 10 years of experience providing agronomic advice and sales to citrus, almond, vegetable and avocado horticulturists in the Sunraysia region. Five agronomists work from the Sunraysia office.

Trevor Sluggett is the Irrigation and Agronomy Manager of Agriexchange. Trevor is the company's most senior agronomist providing irrigation and soil consultancy to horticultural growers Australia wide.

Equipment & Use

In 2005 Peter was introduced to soil solution extraction tubes (SSET) by visiting growers participating in the NSW DPI / Rootzone solutions citrus soil solution project (Steven Falivene case study). Peter purchased a set of Mottes SSET and installed them in a block of avocados. Soil solution samples were taken on a regular basis and analysed for pH, EC, and a full range of both macro and micro nutrients. The soil solution samples produced unexpected results which produced more questions than answers. Although the information from the SSET was not conclusive, Peter viewed this information as important because it gave a direct real time indication of the status of the soil solution. Three more sets of SSET were installed in a table grape vineyard, citrus orchard and almond orchard. These sites produced productive information (see case studies) and the grower provided positive feedback on the information provided by the SSET. Peter now manages thirty sites with SSET and the demand for soil solution monitoring is increasing as growers learn more about this technology. The case studies presented are from Peter's experience. Peter regarded the high cost ($200-$250) of SSET as an impediment to adoption and in response Peter is manufacturing and selling 20mm wide SSET at a considerably lower cost. The Agriexchange SSET have performed equally well to Sentek and Mottes SSET in the field and in bucket extraction tests.

Trevor Slugget has been using some of the Sentek SSET (SoluSAMPLER™) on five sites in South Australia installed in 2006. Trevor has had exposure to the Mottes and Peter Ryan's "AgriExchange" tubes in Sunraysia Victoria. Trevor prefers to install the SSET on an angle to minimise soil disturbance above the sampling tip and minimise possible preferential flow of irrigation water/nutrient.

Experience / Case studies

High EC from liquid Urea Ammonium Nitrate (UAN) in Almond

SSET samples detected very high EC levels exceeding 5dS/m early in spring on a Almond orchard. The high EC levels are considered to be potentially damaging to almond tree roots. An initial investigation pointed towards high spring applications of potassium chloride causing the salinity, upon further investigation it was later determined that the high application of liquid UAN was causing the salinity. The application rate was halved resulting in a drop in EC, while still maintaining sufficient nitrate levels. The reduction in fertiliser rates saved the grower $50,000 worth of fertiliser in just one month, and tree growth was extremely good.

No fertiliser in table grapes

A block of Crimson Seedless table grapes was having quality issues that are generally associated with excessive levels of nitrogen. SSET were installed in this block and in other blocks of table grapes. The Crimson seedless had no nitrogen applied throughout the season. The other blocks had 110 units of nitrogen applied in spring. The 110 unit N application caused a spike in soil solution nitrate levels. The soil solution nitrate levels then dropped off to negligible levels (0-2ppm) within two to three weeks. The Crimson seedless with no nitrogen application also showed a spike in nitrate levels as soil temperatures rose in spring. However the spike was only about one quarter that of the blocks with nitrogen application. After two to three weeks the soil solution nitrate levels decreased, but it remained slightly above the nitrogen fertilised block to about five ppm throughout most of the season. The SSET gave the grower confidence to significantly reduce nitrogen application to the Crimson seedless grapes and the grower is now reassessing the application rates, frequency, and timing of nitrogen of other table grape blocks. The grower will continue to use SSET to fine tune nutrition.

EC from heavy soil salinity

A set of SSET were indicating high EC levels (6 dS/m) in soil solution from a site with heavy soil growing wine grapes. The vines had a history of defoliating at harvest and were gradually declining in health. In response the grower applied extra water over a number of irrigations in late winter/early spring. The SSET showed that the extra irrigations reduced soil solution EC levels to normal (2-3dS/m). The vines gradually improved in health, no defoliation occurred at harvest, the crop ripened earlier and yield increased. The grower continues to manage his fertiliser and irrigation application regime to maintain soil solution EC within acceptable limits.

Benefits & Comments

Peter believes that the SSET is an important part of a nutrition and irrigation management tool kit. A leaf analysis once a year provides a good insight into the general nutritional condition of the crop, however if a problem is detected, the damage has already been done and cannot be corrected until next season. SSET can detect problems during the season (depending upon frequency of sampling), and corrective action can be taken within the season to provide the maximum opportunity for a productive harvest. The SSET also provides an indication of soil moisture, because dryer soils tend not to yield any soil solution.

Peter uses the RQ-Flex meter to analyse nitrate and other ions with success, however he has mixed opinions about the Horiba Cardy nitrate meter. The meter is good for occasional sampling however with extensive use the sensor began to provide variable results after a number of months. The varying results indicated that the sensor needed replacing. Probably under moderate use (i.e. a few sites), the Cardy nitrate meter would be adequate. Peter has had very good results with the Cardy potassium meter.

Trevor and Peter prefer the 20 mm wide SSET over the 40 mm wide SSET because;

- they are slightly easier to install using a narrower hole than the wide tube,
- the narrower hole disturbs less soil,
- a firmer soil contact with the narrow tube can be achieved using a tensiometer installation technique as compared to the slurry technique for the 40 mm wide SSET (soil slurry may crack when drying), and
- the narrower tubes are easily removed out of the ground by pulling on the plastic tube protruding out of the ground, whilst the 40 mm wide SSET needs to be dug out of the ground.

Trevor believes that SSET is an excellent tool as a part of a soil, nutrient and salinity monitoring package. Soil and leaf tests conducted annually are still important, however SSET provide real time information of trends so the grower can make active changes during the crop growth period in order to avoid problems and enhance productivity. Growers also have a choice of either analysing the soil solution extracts themselves using a EC meter and test strips or working with a consultant. Although using a consultant is more expensive, it guarantees that samples will be taken on a regular basis and that interpretation will be a part of a nutrition management advisory package.

Graeme Sanderson (NSW DPI)

Crop : Citrus & vines
Tool: SARDI SSET, local manufacture of ceramic tube sampling equipment
Region : Sunraysia (Dareton, NSW)
Contact : graeme.sanderson@dpi.nsw.gov.au

Background

Graeme is a citrus and vine research horticulturist (NSW Department of Primary Industries) who conducted a Dried Fruits Research & Development Council funded project, 'Improving vineyard soil and water management using minimum tillage and drip irrigation', from 1994 to 1999. The trial included drip and sprinkler irrigation, cover cropping and minimum tillage as the main treatments. The aim of the trial was to determine the effects of a legume cover crop on the nitrogen status and yield of sultana grape vines and to also assess the effects of cover cropping management systems on soil structure. The monitoring of soil solution nitrate was included in the trial to help quantify nitrate production from the decomposition of the legume cover crop and determine any nitrate leaching losses below the root zone.

Graeme was a collaborator on the TriState Salinity Project (SARDI) that commenced in 2004. One of the trial sites for the project is located at the Dareton Agricultural Research and Advisory Station and is being used to monitor the movement of salts in sprinkler irrigated citrus.

Equipment & Use

For the minimum tillage project, soil solution was extracted using a small ceramic cylinder attached to a micro tube (Figures 8 and 9). The tubes were designed by P. McClure, Victorian Department of Primary Industries, Irymple (see Dale and McClure case study). The ceramic blocks were buried at 5, 15, 30, 50 and 80 cm. A 60 ml syringe was attached to the micro tube and a suction pressure was applied and maintained on the syringe over a set period following an irrigation event. Water samples were tested by nitrate test strips (0-90mg/kg, 5-225mg/kg) on a Merck RQFlex meter.

For the TriState Salinity Project (Schrale/Biswas report) Graeme was using the SARDI manufactured soil solution extraction tubes (SSET). The SSET were installed at 30cm, 60cm and 90cm depths.

Experience / Case studies

Vineyard Project

Soil solution extraction provided the best indication of nitrate production from the cover crop and its movement in the soil profile. The results indicated that the use of a legume cover crop combined with its incorporation into the soil during spring can provide up to 50% of the nitrogen requirements for the vine. Nitrate was detected in soil solution three weeks after mowing or cultivating the cover crop and persisted over a 5 - 11 week period. This implied that growers could reduce nitrogen application in a legume cover crop management system. Nitrate was not detected in the soil solution at 80 cm suggesting low levels of nitrate leaching past this depth.

The RQFlex meter provided reasonably accurate, inexpensive and immediate results, however the cost of the unit is about $1600. The ceramic blocks performed well in yielding soil solution extracts from all depths provided that sufficient irrigation was applied to maintain adequate soil moisture.

Tri State Salinity Project

For the Tri-State Salinity Project, three different models of SARDI ceramic SSET were installed in the trial. The performance of the original SARDI SSET prototype was variable, sometimes only yielding a low volume sample even though the profile was wet. However, the newer models have an improved ceramic tip and their performance has been more reliable. Results from the SSET indicate that salinity is not a major issue at the Dareton site. This is due to the availability of good quality water (i.e. 0.2 to 0.4 dS/m), scheduled full ground cover mini-sprinkler irrigation and the ability of the sandy loam soil to easily leach salts below the tree rootzone.

Benefits & Comments

The 40mm wide SSET design (i.e. SARDI SSET) is better than the ceramic cylinder sampler design because the SSET did not require a syringe to be kept at pressure during the duration of the soil solution extraction period.

Soil solution analysis provides real time data for soil EC and nitrate that could not be achieved using annual soil tests. The detection and movement of nitrate through a soil profile was easily monitored by SSET and provided a useful tool to monitor the effects of fertiliser practices.

Gerrit Schrale & Tapas Biswas (SARDI)

Crop : Citrus & vines
Tool : SARDI SWE
Region : Riverland (Renmark, SA) & Sunraysia (Dareton, NSW)
Contact :

Background

Gerrit Schrale is a Principal Scientist with the South Australian Research and Development Institute (SARDI). Gerrit has over 35 years experience in irrigation and drainage. Gerrit was the principal investigator in the Land and Water Australia (LWA) Tri State Salinity project led by Dr Tapas Biswas. Tapas has 21 years experience in irrigated agriculture and currently is the principal investigator of two projects; (a) *Root zone water, salinity and nutrient management under precision irrigation* (LWA), and (b) *Impact of open hydroponics (OH) irrigation in the citrus industry* (LWA & Horticulture Australia Ltd). The Tri State Salinity and the root zone projects aim to identify key management practices to improve the management of salts and nutrients in the rootzone. The OH project aims to investigate and reduce the environmental risks of adopting OH. All the projects have a general aim to provide practical tools and strategies to minimise the accumulation of salts in the rootzone whilst at the same time maximising water and nutrient use efficiency.

Twenty sites are being monitored (16 South Australia, 4 Sunraysia). The sites are being intensively studied for soil moisture (i.e. gypsum blocks, and/or soil capacitance probes and log tensiometers), irrigation application, rainfall, crop evapotranspiration, deep drainage and fertiliser application. Multiple sets of soil solution extraction tubes (40 mm wide ceramic tips), called Soil Water Extractor (SWE), developed by SARDI are installed at the sites at various depths. The monitoring of the sites is conducted by local project officers. A total of 6 project officers provide their input on the project on a part time basis. The project is multi-faceted with linkages to various organizations. The project includes work on tracking salts and nutrients within the rootzone, modelling of soil solute movement in soils by using numerical models (e.g., Hydrus), the development of a method to estimate deep drainage and subsequent nitrogen leaching. The salinity project has been instrumental in promoting the use of soil solution extraction as a salinity management tool for grower in Australia.

Equipment & Use

To monitor the movement of salts through the soil profile, the project constructed ceramic tipped soil solution extraction tubes based on Deery (2004) CSIRO 40 mm wide ceramic tip SWE design. During the course of the project Gerrit and Tapas redesigned the SWE by improving the quality specifications for the manufacture of the ceramic tip, a single tube for both the suction and extraction, and more durable parts. Sentek purchased the manufacturing and distribution rights for the SARDI SWE in 2007 and it is currently marketed as the Sentek SoluSAMPLER™. Over 1400 SARDI/Sentek soil solution extraction tubes have been manufactured since the commencement of the Tri-State Salinity project. The SoluSAMPLER™ is marketed by Sentek nationally and through a global distribution network in 35 countries. The product is being promoted as an inexpensive tool targeted for use in irrigated horticultural crops, where soil solution and fertiliser management are critical.

Samples are generally taken at a weekly or fortnightly interval and read instantly in-situ for EC by using a portable EC meter. Samples can be analysed for nitrate and other parameters such as pH, phosphorus and heavy metals.

Experience / Case studies

Soil Salinity in irrigated horticulture is a significant issue in South Australia.
The salinity project and other projects related to soil solution sampling conducted by Gerrit Schrale and Tapas Biswas have made a significant contribution in raising the awareness of the value of SWE as a salinity management tool in South Australia. The projects have also contributed to a better understanding of on-farm salinity and nutrient management. The project provided the SWE to the growers, relevant training and also analysed the results. The growers were provided with copies of their results. The experiences of two of the growers participating in the project are outlined below.

Brian Caddy

Brian (brian7@hotkey.net.au) is a viticulturist in the Riverland region. Brian became involved in the SARDI salinity project in September 2006 when he installed six SWE manufactured by SARDI. The SWE were installed at 30, 60 and 90cm soil depths, in a block of drip irrigated Chardonnay grapes. Several years earlier a FullStop was installed at a 2m soil depth under the dripper point of the vine. The FullStop did not yield soil solution because it was buried too deep below the wetting zone of the dripper.

After priming the SWE, an adequate volume of soil solution was extracted after six hours on a light clay loam soil and about 12 hours on a light clay soil. Brian then tests the EC with an EC meter and tests for nitrate and phosphorus with test strips. The samples are then sent to SARDI for a more accurate laboratory analysis (salinity project). Due to water allocation reductions, Brian had reduced vineyard water application rates. As a result the deeper profile dried during summer and the 60 and 90cm SWE ceased to operate. Even when significant rainfall occurred in January 2007, this was not enough to sufficiently rewet the full profile. Brian uses a leaching irrigation during winter when evapotranspiration is low and when there is little nitrogen in the soil profile. Brian also attempts to leach salts over a number of irrigations, rather than one large, leaching irrigation. Preliminary results from the salinity project support this method of salt leaching because the water has time to penetrate and leach the very small pores (micro pores) in the soil. Once leaching irrigations are applied in winter, supplemented by rainfall, the deep SWE recommenced to yield soil solution samples. The SWE provide a good indication of leaching requirements of the block. If the salinity readings of the SWE samples are too high, then an extra leaching irrigation is applied. If the SWE yield no soil solution samples, this indicates a dry subsoil and more water is required to wet the profile.

Brian believes SWE are an excellent salinity and nutrient management tool. Many growers are not concerned with what they cannot see (soil salinity) and only respond when the crop shows signs of salt damage. However when the crop shows signs of damage, it is too late to fix the problem and crop loss will occur. Many growers have a culture of being “reactive” rather than “preventative”. The SWE is able to alert the grower to a salinity problem before it affects crop production. SWE are also an excellent way to confirm that you are efficiently managing the fertiliser program.

Nitrate levels can be monitored by SWE and leaching of nitrate can easily be detected if deep probes detect increasing levels of nitrate whilst the shallow probes are detecting a rapidly depleting level of nitrate. Brian recognises that he was inefficient in his previous practices and the combination of SWE, soil moisture monitoring tools and other monitoring tools (petiole tests), has lead to significant improvements in his vineyard by reducing wastage (excessive fertiliser and water application) and improving production. Brian believes that all growers would benefit from using these tools.

Kerry Degaris (Constellation Wines)

Kerry Degaris (kerry.degaris@stonehavenvineyards.com.au) is the technical officer for Constellation wines (Padthaway, South Australia). Kerry provides technical viticultural advice to contracted growers and company vineyard managers. Irrigation water is sourced from an underground aquifer that has become more saline over the years. Salinity levels can rise up to 2.5 dS/m. Kerry was introduced to the SWE manufactured by Tapas Biswas at a regional salinity meeting. Kerry agreed to participate in the SARDI salinity project and installed eighteen SWE in a partial rootzone drying (PRD) trial. The SWE were installed at 25, 50 and 75cm soil depths. The SWE were highly valuable in providing a real time reading of salinity levels in the soil. The information helped Kerry decide if a block required a leaching irrigation and the amount of leaching required. The SWE operated successfully when the soil was wet but as the soil became dryer in mid to late summer, the SWE ceased to yield a soil solution. The SWE then commenced to yield soil solution again when the soil became wet in mid to late autumn. Kerry found that pushing water into the SWE helped to re-hydrate the dry ceramic tip. However, first few samples taken from the SWE had to be disregarded to be confident that the SWE was sampling the true soil solution and not the water pushed through the SWE.

The soil type throughout the PRD trial block was generally consistent. The three sets of SWE provided different results (EC), but did follow a similar trend. It was obvious that some variation occurred within the block and it is important to have a number of sites to capture this variation. Kerry thinks (based on current information) that three sets of SWE should be sufficient for a block of similar soil type and more SWE are required if there is a soil type change.

Kerry has been very impressed with the SWE and intends to expand its use on company and grower vineyards. However she regards the high cost of the ceramic samplers currently being used ($200 each) as an impediment to increased adoption.

Benefits & Comments

The SWE helped the growers better manage their salinity and nutrients levels within the plant's rootzone. The SWE is also an excellent tool to assist in the management of leaching irrigations. The use of the SWE enabled an estimate of nitrogen leaching to be calculated when soil moisture data at deep levels was available.

Chris Smith & Roland Poss (CSIRO)

Crop : pastures and domestic household
Tool: CSIRO SSET
Region : Canberra, ACT

Background

Chris Smith is a researcher at CSIRO, and became involved in soil solution sampling with Roland Poss when Roland visited from France for 2 years in the early 1990s. Roland developed and evaluated a soil solution sampling method based on 40 mm diameter porous cups Poss *et al.* (1995).

Roland and Chris used these samplers on a LWRDC project to measure nitrate concentrations under dryland agriculture. At the same time, Chris Smith and Warren Bond used them in a study of the irrigation of woodlots with sewage effluent (Myers *et al.,* 1994), and in an evaluation of the environmental implications of the onsite treatment and disposal of household sewage (Smith and Bond, 1997).

Equipment & Use

In 1991 Roland Poss (CSIRO) in collaboration with Chris Smith and Gordon McLachlan worked on a project to automate soil solution extraction tubes (SSET) in a dryland situation. Roland surveyed international literature to determine the best type of ceramic to be used in SSET in order to minimise interference and/or contamination of soil solution extracts (Poss *et al.* 1995). Roland assessed three types of ceramic soil solution samplers. Two were 40 mm diameter designs using ceramic tips from different manufacturers and the other was a commercial SSET (Tensioc) purchased from France. From this review Roland developed the 40 mm diameter ceramic tipped CSIRO SSET.

Roland and Chris, in collaboration with Frank Dunin and Steve Zegelin (all from CSIRO), worked on a system to automate the extraction of soil solution in dryland situations. This system, which reached a prototype stage, used TDR measurements of soil water to determine when the soil was wet enough to obtain a solution sample and trigger the activation of the sampling mechanism. This work was not published.

During this project Gordon McLachlan (CSIRO, Technical Officer) wrote a draft SSET construction and installation report. This report was revised in 2004 by David Deery (Deery and McLachlan, 2004).

Experience / Case studies

Chris Smith and Gordon McLachlan constructed and assisted with installation and commissioning of the soil solution samplers for the effluent-irrigated woodlot project (Myers et al., 1994), but the collection and analysis of the data was largely done by others (eg Polglase et al., 1995; Snow et al., 1999).

Solution samplers (40 mm diameter) were installed in duplicate in sixteen plots on which different rates of treated effluent were applied and different tree species were grown. They were installed at depths of 0.1, 0.5 and 1.0 m, and were sampled at intervals of approximately twenty eight days. Large increases in both salinity (up to 6 dS/m) and nitrate concentration (up to 150 mg N/L) were observed at 1 m depth under the plots with the recommended irrigation rate. (The effluent used for irrigation has an EC of < 1 dS/m and a total N concentration of < 15 mg/L.)

The urban household effluent re-use project (Smith & Bond, 1997; Bond & Smith, 1999) used the 40 mm soil solution samplers to investigate the potential for nitrate and salt leaching. Measurements were made on a re-use block and a control block at four sites in Canberra's southern suburbs. The solution samplers were installed at three locations on each block at depths of 0.5, 1.0 m, and in one case 1.5 m. Soil solution was extracted at two to four week intervals whenever the soil was wet enough over an eighteen month period. The samples were analysed for pH, EC and nitrate concentration.

Higher nitrate levels were detected at houses using the waste water recycling system as compared to houses not using the system, and it was concluded that domestic water re-use posed a significant risk for nitrate contamination of ground water. Salinity was also identified as a further potential risk. The main problem was that the average domestic garden size was unable to use all of the water produced from the waste water unit resulting in excessive water application. The garden plants were also unable to utilise the entire nitrate applied via the waste water. This was most evident during winter when water requirements for gardens are significantly reduced, but effluent often still had to be applied because of lack of on-site storage. One of the projects recommendations was to pool the water produced from the domestic waste water re-use system and apply it to adjacent gardens and/or parklands.

Tony Thomson (DWLBC of SA) & Richard Stirzaker (CSIRO)

Crop : Grapevines, lucerne hay & potatoes
Tool : FullStop Wetting Front Detector
Region: Australia
Contact: Richard.stirzaker@csiro.au , Thomson.Tony@saugov.sa.gov.au

Background

Richard Stirzaker has worked on plant water use, salinity and irrigation for over 20 years. Work on the FullStop Wetting Front Detector started in 1997. In 2000 the Angas Bremer was one of the first districts to use prototype versions in on-farm trials. The FullStop became a commercial product in 2004.

Tony Thomson is an irrigation engineer with the South Australian Department of Water, Land and Biodiversity Conservation. He has invested 20 years in improving irrigation management on farms across Australia.

Since 1980 the 160 irrigators on the Angas Bremer floodplain have worked closely with their elected Angas Bremer Water Management Committee to lead Australia in developing and implementing innovative water management strategies.

In 2000 Tony introduced a prototype FullStop to the growers who were so impressed with its potential and simplicity that one grower built 20 "improved" copies. These were tested in the district and after this successful trial each of the 160 growers purchased two FullStops which were each hand-made by Richard. Richard and Tony provided growers with a recording sheet on which they recorded each irrigation event, activation of the flag and the salinity of the leachate. The grower's annual results and further information about the project are available from the Angas Bremer website www.angasbremerwater.org.au

Equipment & Use

The FullStop was developed by Richard Stirzaker and Paul Hutchinson (CSIRO). A description of the design and operation of the FullStop is provided in the "Soil solution extraction devices" section of this report. An automated version of the FullStop is being developed. More information about the FullStop is available from www.fullstop.com.au

Wetting fronts weaken or dissipate as they move deeper down into the soil. Since FullStops respond to strong wetting fronts, they should not be placed too deep. For drip irrigation the recommended deepest installation depth is 60 cm. However the Angas Bremer growers chose to place one FullStop at 50cm and second at 100cm.

Growers monitored the FullStops regularly after each irrigation or rainfall event. If the FullStop was triggered, the grower would take a sample of the soil solution from the collection container and measure it for EC and nitrate using an inexpensive EC meter and a nitrate test strip.

Experience / Case studies

Angas Bremer

Data has been collected continuously over 6 seasons, with approximately 80 growers providing complete data sets of irrigation time, amount and FullStop response. Initially some growers were disappointed with results. Twenty five percent of growers reported that FullStops at the 50 cm depth had not responded and 60% reported no response at 100 cm depth. The data showed that the FullStops that responded less often had higher soil solution salt levels. Growers who irrigated ‘little and often’ did not activate their FullStops, and were accumulating salt in the root zone. The shallow FullStops were not being triggered because the irrigation application was insufficient to produce a wetting front that reached as deep as the 50 cm soil depth. Some growers increased irrigation volumes and the 50 cm deep FullStops began triggering more often. The initial soil solution samples contained up to 10,000 ppm (15dS/m) of salt. More FullStops were supplied and buried at 30 cm. Growers gained confidence with the FullStops and increased their monitoring and recording of results. In response to the use of FullStops a number of growers changed their irrigation and leaching practices to keep soil salinity below damaging levels.

It has been over seven years since the project commenced. Initially growers used the tool regularly to re-calibrate their irrigation management programs. This initial re-calibration had a significant impact on irrigation practices. Many of the growers no longer monitor the FullStops every time they irrigate, but they use the tool occasionally to check salinity levels during the season in order to confirm that their irrigation program is adequate to keep the salts in the soil profile below damaging levels. This occasional check provides valuable information that enables growers to adjust their irrigation program to seasonal conditions.

Benefits & Comments

The FullStop is a valuable tool. It provides a simple indication of irrigation efficiency, soil salinity and soil nutrient levels. Growers in the Angas Bremer district use the FullStop as an essential tool to assist them in managing soil salinity.

Tony Wells (NSW DPI)

Crop : Vegetables
Tool: Custom SSET and FullStops
Region : Sydney basin, NSW
Contact : tony.wells@dpi.nsw.gov.au

Background

Tony is a research horticulturist (New South Wales Department of Primary Industries, Gosford). Between 1993 to 2001 Tony worked on a long-term experiment on the economic and environmental sustainability effects of vegetable cropping systems in the Sydney basin (Wells and Chan 1998, Wells *et al*.2000, Wells 2001). This experiment was conducted at Somersby on the NSW Central Coast. Tony has worked with vegetable growers in the Sydney basin from 2002 to 2007 on issues concerned with sustainability and production (soil organic matter, nutrient application rates, soil pH etc). Tony is also working with horticultural producers on the Central Coast on a number of projects involving sustainability-environmental issues. Activities have included establishing on-farm demonstrations, on-farm experiments and soil and water quality monitoring. Tony constructed 40mm wide ceramic-tipped soil solution extraction tubes (SSET) and used FullStops to monitor soil solution.

Equipment & Use

SSET

In 1995 Tony constructed a 40mm wide ceramic-tipped SSET (Figure 7) to monitor soil solution nutrients (N and P) at 60 cm depth under a number of vegetable cropping systems. Tony purchased the ceramic tips from Cooinda (Appendix A) and glued (epoxy glue) the ceramic tips to the PVC pipe. The other end of the SSET was capped off and had an irrigation riser tube (4mm internal diameter) inserted through the cap via a “electrical cable gland” (purchased from electrician supplies). In 1995 it cost about $12 in parts and materials to make a 40mm wide SSET.

Tony tests for leaks by pumping air into the SSET using a bicycle pump and a pressure gauge and immersing the SSET in a bucket of water. The air pressure does not exceed 50 KPa for safety reasons.

Vegetable growers generally maintained soil moisture at high levels throughout the growing season. On farms with a sandy loam soil, small leaks in SSET were not an issue because the SSET were able to quickly extract water samples from the soil. However small leaks were a problem on heavier soil types or where soil moisture tension fell below -20kpa. Heavier soils or drier soils required a higher negative air pressure in the SSET for a longer period of time to extract soil solution.

Initially SSET were installed at a 60 cm soil depth in the long-term experiment to monitor nitrate leaching beyond the root zone. However the SSET used on farms in western Sydney were installed at a 30 cm depth because the duplex soils had a clay sub layer that might cause a perched water table after an over irrigation or rainfall. The focus of the work was more on what was happening in the root zone rather than below it.

Soil solution was extracted every seven to fourteen days during the growing season. After each extraction the SSET were re-set immediately (air extracted out of the tube via a hand-operated suction pump) to commence re-sampling. This sampling method was used to reduce labour costs. There are some issues with this method because the soil solution sample remains in the tube for a period of time and it is difficult to pinpoint the actual day when the sample was extracted from the soil. A more precise sampling technique is to reset the SSET a day or two prior to sampling.

Soil solution samples were analysed using a RQFlex Plus meter (Merck). Test strips were used for the nitrate testing and the colorimetric technique was used for phosphorus and potassium analysis. Tony sent some samples for laboratory analysis and found that the results from the RQFlex meter were consistent with laboratory results.

FullStop

A few FullStops were installed as a part of the Somersby, Western Sydney and Central Coast projects. The majority of the FullStops were installed on vegetable and fruit farms and there were no issues with installation or performance.

Experience / Case studies

SSET

The SSET performed reliably in all projects. Many of the SSET were re-used but eventually the ceramic tips on some SSET broke with repeated re-installation. The clay loam soils on the Western Sydney project needed to be wet to yield soil solution samples. Occasionally the SSET yielded no soil solution samples and it was difficult to determine the actual cause; faulty, poor contact of the ceramic tip with the soil, or dry soil. The use of soil moisture monitoring devices helped to determine if the soil was too dry for soil solution sampling. Most problems were a result of air leaks in the glued components of the SSET. This prompted the use of the bicycle pump test to eventually improve the gluing technique and reduce breakdowns.

Leaching estimates were made by multiplying the nitrate concentrations of the SSET samples by estimates of deep water percolation using a soil water-balance model. The long-term experiment on sandy soil, demonstrated some interesting differences in nitrate leaching from different approaches to vegetable crop nutrition. Three systems were monitored: a conventional high-input system, a “best practice” system and an organic system. Both the conventional and best practice systems lost about 50% of the applied nitrogen through leaching. However, the best practice system lost only 170 kg/ha of N through leaching over an 18 month period, while the conventional system lost 1,150 kg/ha. The best practice system received small regular doses of N through the drip irrigation lines under plastic mulch, while the conventional system had large base and side dressings of fertiliser and large applications of poultry manure. The organic system had similar N leaching losses to the best practice system (~170 kg/ha) but this represented less than 20% of the N inputs to the system (in the form of compost, manure and legume fixation). Rainfall events were the main contributor to nitrate leaching (the Central Coast has an average annual rainfall of around 1300 mm) followed by over irrigation. It is expected that leaching losses would be considerably lower on a heavier soil type.

Full Stop

FullStops were installed in a number of market gardens in western Sydney. The FullStops were installed at a depth of 20 and 40 cm in a clay loam soil with a medium clay subsoil. The 40 cm deep FullStop was positioned just below the change in soil type. The FullStops indicated that the wetting front reached 20 cm within the first 30% to 50% of the irrigation period and up to 70% of the irrigation water moved below the root zone. Initially the growers did not believe the FullStops were working correctly because they were triggering so quickly, most thought they were installed too close to the drip line. They found it difficult to believe that their irrigation practices were inefficient. The interest from growers in using the FullStops steadily decreased over time.

In the Central Coast project the FullStops were installed on a vegetable farm (using drip irrigation) and an avocado farm (using mini-sprinkler irrigation) at depths of 30 and 60 cm on a sandy loam soil. The growers were given a syringe, a record sheet and nitrate test strips to regularly monitor the FullStops. The growers monitored and recorded information for a few weeks but then lost interest and no further information was recorded. They also thought that the FullStops were not operating properly. However after follow-up visits they eventually realised that the FullStops were working properly and that their irrigation practices were inefficient. The FullStops are still being used as a backup for the tensiometers.

Benefits & Comments

SSET and FullStops are excellent technology to monitor and manage salts and nutrients in the root zone. They can potentially have significant impacts in improving production and environmental sustainability. They have been very successful as a research tool, however their adoption by growers has not been as successful. The main issue involved changing the grower's production practice from a calendar program to a monitoring and adjustment program. This attitude change requires an extensive investment in extension that involves regular follow-up on-farm visits.

Joyce Wilkie (Organic vegetable grower)

Crop : Vegetables
Tool : FullStop Wetting Front Detector
Region: Gunneroo, NSW (near Canberra)
Contact: www.allsun.com.au

Background

Joyce Wilkie is a market gardener growing fruit, vegetables & poultry on a small mixed organic farm . Joyce participated in a field testing project of the FullStop in 2000. The results of the project were published in a paper titled "Four lessons from a wetting front detector " (www.fullstop.com.au). FullStops were installed on pumpkin and garlic crops.

Equipment & Use

The FullStops were installed on a mixed organic farm and were buried at 20 and 30cm depth to reflect the shallow rooting depth of the vegetable crops.

Experience / Case studies

Soon after installing the FullStops Joyce realised she was inefficient in her irrigation and nitrogen management. The FullStops indicated that irrigating in winter quickly wet the soil profile whilst in summer a longer irrigation period was required. Water use in vegetable crops can quickly change as canopy area increases, making irrigation scheduling difficult as requirements can change weekly. The FullStop was able to provide a guide on irrigation requirements by indicating the amount of water required to refill the profile.

The FullStops were also used to detect the concentration of nitrogen in the soil by extracting soil solution from the cup at the base of the collection funnel. The FullStops indicated that nitrogen readily leached out of the soil profile after successive drip irrigation cycles. The FullStops also indicated that a high amount of nitrogen was available at planting (when nutrient demand is low) and decreased as the crop grew (when nutrient demand was high). The high level of nitrogen available at planting and early crop growth was in excess of crop needs and was a potential leaching risk. In response to this an organic liquid nitrogen fertiliser was developed and applied by fertigation at the appropriate crop stages to better manage nitrogen supply. Organic fertiliser application was reduced when soil solution nitrogen levels were excessive.

Irrigation water is supplied from a dam and bore. The bore water salinity levels can rise up to 1.5 dS/m and this can cause soil salinity issues. In some situations soil solution extracted from the FullStop can rise up to 5dS/m. The soil solution EC information provided by the FullStops helped Joyce to make better irrigation management decisions. When EC levels rose, irrigation amounts increased to maintain soil salinity at manageable levels.

Benefits & Comments

Joyce believes that the FullStop is an excellent learning tool and every irrigated horticulturist should use it to improve the irrigation, nutrient and salinity management of their enterprise. Although the FullStops may not be as precise as other soil moisture monitoring equipment, they are simple to use and do not require a computer to read results. The FullStops help to guide the grower towards more efficient production. Joyce also believes that more should be done by commercial enterprise and government agencies to market FullStops to growers because water use efficiency and environmental sustainability (through reduced nitrogen leaching) is an Australia wide issue.

Discussion

The highest level of adoption of solute samplers has been from growers facing actual or potential production losses from soil salinity issues (Stirzaker & Thompson case study at Angas Bremer, the Schrale and Biswas case study in South Australian, and the Alan Blight case study in Western Australia). Growers have identified high EC levels and taken appropriate action to avoid crop damage.

There has been some interest and adoption of soil solution analysis by growers of annual crops (i.e. vegetables, strawberries). A temporary imbalance in the nutrition program can reduce crop quality and yield. Traditionally growers would use visual symptoms to detect a problem, but by this time the crop would have already suffered damage. There has been a mixed rate of adoption by these growers to soil solution analysis. Paul Jones reported that strawberry growers that use his consultancy service have a high level of interest and adoption, but vegetable growers in Sydney region (Tony Wells) did not have a good level of adoption.

There has been fair interest and adoption of soil solution analysis by growers of perennial crops, the main benefit being as a fertiliser management tool. These growers were initially interested but after a couple of years, only continued to use the technology if there was a perceived benefit. The majority of growers that participated in the two year citrus project (Falivene) stopped using soil solution analysis because an interpretation service was not continued and the data had demonstrated there were no serious problems with their fertiliser program.

One barrier to adoption by growers is the lack of information on interpretation of results. Soil solution analysis has not been studied as comprehensively as other soil attributes (i.e. pH, CEC, structure, clay content etc) and so information is not extensive. The only set of soil solution interpretation threshold tables are published on the Web by Mottestens Tensiometers (www.mottestens.com), but these thresholds have been developed for Israel growing conditions and may not be suitable for Australia. The threshold tables need to be validated for Australian conditions.

Soil solution salinity (EC_s) results are relatively easy to measure by using an EC meter and interpreting by using saturated paste extract salinity (EC_e) thresholds (Mass & Hoffman 1977, Mass 1990). Nitrate results are moderately easy to interpret because nitrate does not significantly interact with clay colloids and therefore is a good indicator of soil nitrate content. However setting thresholds does require some agronomic skills and experience in soil solution analysis for the selected crop.

Interpretation of cations (i.e. potassium, magnesium calcium, sodium) in sandy soil require a significant level of skill and is very difficult to interpret for other soil types that have a reasonable clay content (loams, clay loams, clay). Part of the problem in interpreting soil solution is the difficulty in understanding the complex interactions of the soil solution with the soil (clay colloids) and crop. Meaningful interpretation guidelines for all situations will be difficult to develop. If a generalised interpretation guide is developed it would probably have a broad range of thresholds. Meaningful interpretation guidelines should to be customised to the specific situation and would be developed by observing historical data trends, recognising site conditions (e.g. soil characteristics), knowledge of the fertiliser program (foliar or soil application) and also having a basic knowledge of crop physiology and soil science.

The majority of growers do not have the time or knowledge to confidently interpret soil solution results. This was highlighted in the case studies by Steven Falivene and Tony Wells. After the projects were completed, the majority of growers stopped using soil solution extraction tubes or only used them occasionally. This issue was also highlighted in Andrew Creek's case study; however a concerted effort is being made to provide extension and training to the growers involved in the project so they can gain more confidence and benefit. This information (workshop and publications) will be published through the CRCIF and NSW DPI.

This report only looked at methods of actually obtaining a soil solution sample from the soil. Most of the case studies used ceramic cup samplers of one type or another, which have been commercially available for several decades. Five case studies covered the use of the FullStop wetting front detector, which became commercially available in 2004. Both methods proved to be successful, but differ in their installation, application and use. The FullStop requires a wetting front in order to collect a sample (i.e. irrigation or rainfall event). The ceramic sampler does not need a wetting front and can be sampled up to a soil tension of -20 kPa (i.e. up to 5 to 7 days after irrigation), however most are used at soil tensions up to -10 kPa (i.e. within 2-3 days after irrigation) in order to provide a larger sample volume . Consultants tend to favour ceramic samplers (especially the 20mm models because of their ease of installation and uninstallation) because it can take a sample on demand (within -20 kPa soil moisture tension) and sample deeper into the soil (i.e. 60 to 90 cm) where strong wetting fronts may not reach (the FullStop should not be buried deeper than 60 cm).

However the FullStop may be a better option for growers conducting their own salinity and nitrate tests (e.g. test strip), because it requires no priming (a 5 ml or more sample from the previous irrigation event will always be stored in the device ready for removal). It also helps improve irrigation management by signalling when water moves past the device. FullStops have been successfully used for drip, sprinkler and furrow irrigation, but it appears to be best suited to drip irrigation.

Figure 22 : Extracting soil solution from a FullStop wetting front detector. The raised yellow spike (white arrow) has signalled that the wetting front has reached 30cm depth.

Some case studies indicated that the 40 mm wide SSET did not provide sufficient soil solution. It is difficult to ascertain if this is a consequence of circumstance (i.e. more 40 mm wide models installed on difficult soils) or performance. Some possible reasons include : the slurry method of installing a 40 mm SSET may increase the risk of the soil cracking around the ceramic tip during dry periods; or the ratio of air volume within the SSET to the surface area of the ceramic tip in contact with the soil.

Figure 23 : Extracting soil solution from a set of 20mm wide soil solution extraction tubes.

Work conducted by Boland et al (1997) demonstrated a four to twenty times difference in the amount of soil solution extracted from two types of ceramic tips (1.9cm wide tensiometer vs 1 cm wide cylinder). The tensiometer tip had a slightly larger surface area than the ceramic cylinder (3:1 ratio) but this did not account for the difference. It was concluded that the ceramic hydraulic conductivity was the main influence on the ability to extract soil solution. The tensiometer ceramic tip model had a significantly higher hydraulic conductivity (larger ceramic pore size) than the ceramic cylinder model (NB: hydraulic conductivities of commercial ceramic tips may have changed since the completion of this project). Manufacturers of ceramic tips are aware of the importance of ceramic tip hydraulic conductivity and some produce high and low flow tips. High flow tips have a higher hydraulic conductivity (larger pore size) and are best suited to sandy/loam soils whilst low flow tips are suited to clay soils.

Some users of SSET have reported occasional clogging of the ceramic tip after a year of field use. The cause may be from clays/silt particles or calcium carbonate deposits blocking the ceramic pores. Flushing the tip with a mild acid (e.g. vinegar) should alleviate calcium carbonate clogging. The 40 mm wide ceramic tip might be less prone to clogging because it has a larger ceramic surface area. The FullStop wetting front detectors should not have clogging problems because the filtering media is sand.

Successful adoption of soil solution analysis has been by growers who use horticultural consultants. Consultants who have included soil solution analysis as a part of their program (i.e. Paul Jones, Peter Ryan) have been reporting a steady increase in adoption. The use of a horticultural consultant overcomes two main adoption barriers; discipline to regularly take samples and difficulty in data interpretation. Normally consultants are contracted to take weekly or fortnightly samples throughout the growing season and interpret the results. The quality of the recommendations will depend on the expertise of the consultant employed. Growers should seriously consider the use of a consultant because it will ensure that enough samples will be taken at regular intervals (i.e. weekly) to provide meaningful (trends) and reliable data (laboratory analysis). Incomplete or irregular sampling may result in a misleading interpretation and inappropriate management decisions.

Soil solution analysis should be used in conjunction with other crop monitoring tools (i.e. leaf analysis, soil analysis, visual crop assessment). Results should be only used as a guide and further investigation undertaken before making significant management changes. As reported by Kerry Degaris (Schrale & Biswas report) and Paul McClure (Dale & McClure report), variation in results between sites within a block can occur and it is important to have at least three monitoring sites in a block to initially assess the block variation. There could also be a variation in results in sampling soil solution with ceramic samplers at different soil moisture contents. Work conducted by Boland *et.al.* (1997) indicated that there could be a 2dS/m difference in soil solution salinity (EC_s) results when sampling a soil between -5kPa to -30kPa soil moisture tension. However there was no significant change in soil solution EC results as soil moisture tension changed between -5 to -10 kpa. This suggests that sampling is best conducted at similar soil moisture conditions throughout the season (i.e. soon after an irrigation). Most users of ceramic samplers tend to sample soon after irrigating (i.e. -5 to -10 kPa soil moisture tension) because of the difficulty in extracting adequate amounts of soil solution at drier soil conditions. The FullStop wetting front detector only collects soil solution within a very narrow band of soil moisture tension (0 to -3kPa) and is not as prone to variation in ECs results at different soil moisture levels.

Up until early 2008 the cost of soil solution extraction devices has been a barrier to adoption. A FullStop costs about $75 (boxed pair $150) and SSET promoted to industry were about $200 each. If a grower were to install a pair of devices at three sites, the FullStops would cost $450 and SSET $1200 and most farms would require more than three sites to undertake adequate monitoring. There was also a lack of awareness about the various manufacturers and distributors of SSET. An outcome of this report has been the identification of numerous soil solution extraction device manufacturers and retailers. Prices for 20 mm soil solution extraction tubes (SSET) can be as low as $45 each, ceramic cylinder samplers at about $15 each and “do it yourself” (DIY) 20 mm wide models at about $15- $20 each (Appendix A).

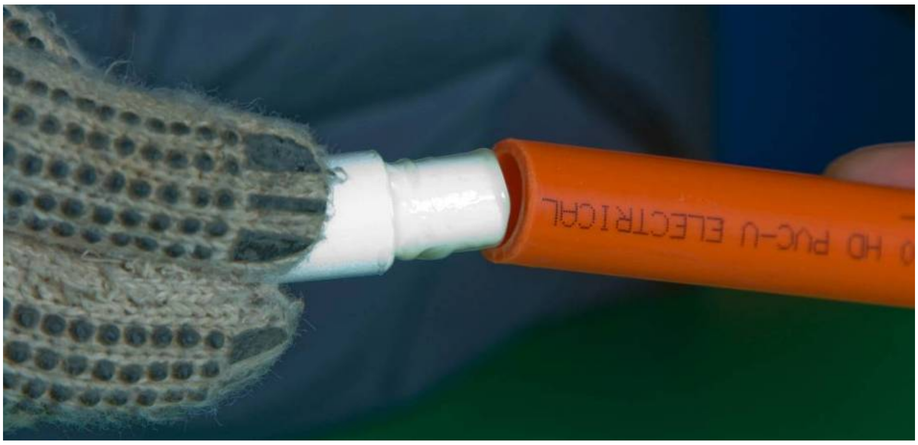

Figure 24 : Making a ceramic sampler; gluing a ceramic tip into electrical conduit

There could be some problems with the reliability of ceramic cup samplers. It has been reported that some ceramic cups hold onto some nutrients (i.e. phosphate and some cations) and may also interfere with pH. If users only intend to measure EC and nitrate, current information suggests that all ceramic sampler options should perform well, however if pH and cation analysis is important, then there may be differences.

There are a number of ways to analyse the nutrient concentration of the soil solution. Laboratory analysis costs about $15 for EC and nitrate, $25 for EC, nitrate, the major cations (K, Ca, Mg) and pH, and over $100 for complete nutrient analysis. Users also have the option of testing nutrients themselves using test kits. The simplest kit is a nitrate test strip that changes colour with nitrate concentration. These are inexpensive (less than $1 per strip), easy to use and provide an indication of very high, high, medium, low or very low levels of nitrate. A better level of accuracy is achieved with a Horiba Cardy nitrate meter. However users of this meter have been reporting that after a period of extended use the readings become erratic. The erratic readings indicate that the sensor needs replacing. Horiba recommends that the sensor should be replaced annually under normal use. The meter costs about $440 (GST Excl) and the replacement sensor cost about $200 (GST Excl). The meters are rated from 62ppm nitrate which might explain the reduced accuracy of the meter below 30ppm as reported by Steven Falivene. For moderate use the Horiba Cardy nitrate meter should be reasonable, however if analysing a large number of samples other options are available. Users of the Horiba Cardy potassium meter have been reporting reliable results for an extended period of time. Horiba also manufacture a sodium meter.

Figure 25 : Reading a nitrite and nitrate result from a test strip

Figure 26 : Horiba Cardy nitrate meter reading a sample

The Merck RQ Flex meter performed well when a good level of accuracy was required and a large number of samples were analysed per year. The meter costs about $1450 (GST Excl), it can measure a wide variety of nutrients, and the test strips to use on the meter cost about 80 cents each. A cheaper option to the RQ Flex meter is the Merck RQEasy Nitrate Meter. The meter cost about $400 (GST Excl), it can only measure nitrate and its test strips cost about 80 cent each. Another option is using wet chemistry kits (eg Aquaspex, Aquamerck). These kits are similar to chlorine pool test kits. They are very easy to use and give an indication of nutrient levels at a slightly better level of accuracy than test strips. A list of suppliers of water analysis tools is provided in Appendix A.

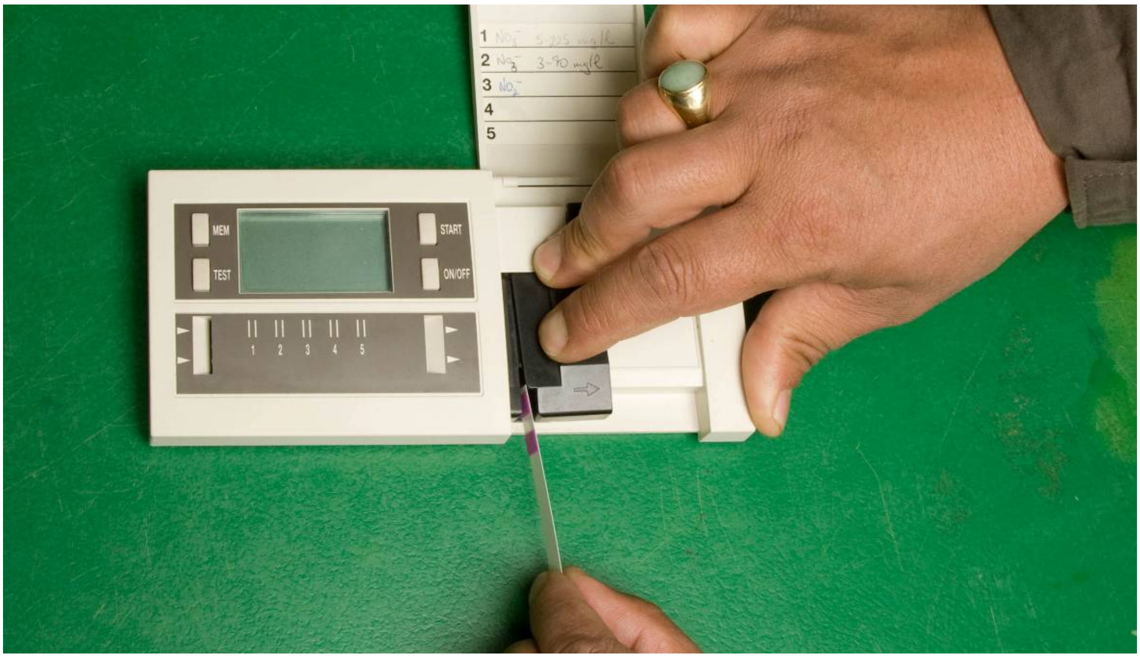

Figure 27 : Inserting a test strip into the Merck RQ Flex meter to take a nitrate reading

Figure 28 : Measuring the total alkalinity using an Aquaspex test kit. Similar colour change test kits are also available for calcium and phosphorus.

Soil solution analysis is an excellent tool to assist growers in the management of salinity and nutrition and to improve the environmental sustainability of irrigated agriculture. The majority of users of soil solution analysis presented in these case studies indicated that it helped them improve their business by improving crop management. However there is an additional benefit. Soil solution analysis can assist growers to reduce the amount of fertiliser leaching into the environment (i.e. rivers, aquifers). In parts of United States of America, guidelines on agricultural management have already been imposed on growers to reduce fertiliser pollution (Falivene 2005). If the Australian government begins to place similar pressure on Australian irrigators to demonstrate low environmental impact, soil solution analysis is a good tool to help address this issue.

Recommendations and Opportunities

Significant opportunities exist to increase the adoption of soil solution analysis as a tool to help growers address salinity issues, better manage their nutrition program and reduce environmental concerns of nutrient leaching.

Growers will only adopt soil solution analysis technology if they have the confidence in themselves or a horticultural consultant to reliably interpret the data. Due to the infancy of soil solution analysis as a crop monitoring tool, it has not been widely promoted. It is only growers involved with specific projects or consultants who have been using soil solution analysis that have been using this technology. There is enough knowledge available to extend soil solution analysis to a wider audience as a salinity and nitrate monitoring tool. Soil solution analysis extension material can be developed and an extension program targeting irrigated agriculture can be conducted. The extension package could be staged in two parts; A) awareness, and B) technical training. The awareness package could include fact-sheets and a training workshop that explain the use and benefits of soil solution analysis. Technical training could target the skills and knowledge required to install devices and interpret results. Although there are still knowledge gaps concerning this technology, updating industry with the current knowledge will significantly contribute to improving interpretation confidence and adoption. The CRCIF has a number of projects that involve soil solution analysis and these projects will develop additional extension material which should be available by 2009

Although soil solution analysis has many benefits for growers and the environment, a 100% adoption rate is an unrealistic objective. If an extension program is developed it must recognised that growers in different districts may adopt soil solution monitoring for different reasons. An extension program should clearly identify the purpose of adoption for a particular district, or grower group, and focus on delivering the appropriate information.

Consultants can incorporate soil solution technology as a part of their agronomic service and make a significant contribution in the adoption and development of soil solution analysis knowledge. An opportunity exists to target horticultural consultants with a technical training program.

CRC Irrigation Futures has been successfully facilitating the extension and development of soil solution analysis through its Toolkits program, however the CRCIF will finish in 2010. An opportunity exists to identify a key group of people and/or an organisation to be responsible for continuing the facilitation and development of soil solution analysis. The group could be a conduit for information exchange so users around Australia can present and discuss their findings.

Summary of opportunities:

- Develop and deliver extension material on soil solution analysis including information leaflets and training workshops

- Provide technical training for horticultural consultants and other technical crop officers or managers
- Identify a key group of people and/or organisation to be responsible for the continuation and development of soil solution analysis
- Independently assess ceramic soil solution sampler devices

Appendix A: Equipment contacts

If any other commercial suppliers wish to be included on this list please send an email to steven.falivene@dpi.nsw.gov.au

Commercial soil solution sampler devices suppliers

- AgriExchange – 20mm **SSET** : Ph 03 5018 7700
- Measurement Engineering Australia (MEA) : Ph 08 8332 9044 – **FullStop** : www.mea.com.au , www.fullstop.com.au , distributor for UMS scientific soil pore water sampling system (http://www.ums-muc.de/en/products/suction_cups)
- Irrometer Co (USA) - 20mm **SSET** : www.Irrometer.com , Australian Distributor : www.hrproducts.com.au (Irrometer soil solution lysimeters)
- J.K.G. Tech – Klaus Gottwald – 20mm Soil Spec **SSET** : Ph 03 5962 1096
- Mottes (Israel) – 20mm **SSET** : www.mottestens.com , Australian retailer : Rootzone Solutions : www.rootzonesolutions.com Ph 0427 634 965, lkirton@wn.com.au
- Sentek Sensor Technologies - SoluSampler 40mm **SSET** : www.sentek.com.au Ph 1-800-736-835
- Terra Tech – Fonz Racioppo : 1.5mm **ceramic cylinder samplers**, Ph 03 5829 9005
- Soil Measurement Systems (USA) – (stainless steel tip extractor "suction lysimeter" **SSET**) www.soilmeasurement.com
- Soil Moisture Equipment Corp. (USA) – 48mm & 22mm **SSET**, ceramic tips. www.soilmoisture.com , Australian Distributor: ICT International, www.ictinternational.com.au Ph 02-6772 6770

DIY construction manuals

- Deery, D., and McLachlan , G. (2004). Soil Solution Sampler Construction and Installation Guide. CSIRO Land and Water Technical Report No. xx/04
- Steven Falivene – DIY SSET manufacturing factsheet & video to be published by 2009
- Basic construction information in Tony Wells and Graeme Sanderson Report

Suppliers of soil solution extraction parts

(A complete list of SSET part suppliers is available from Deery and McLachlan construction guide)

- Cooinda Ceramics - Ceramic tips (cylinders and SSET/tensiometer tips) (minimum order $200) : www.cooinda.com.au : Ph 03 9729 6322 Fax 03 9729 4811, Australian retailers : Terra Tech Ph 03 58299005 and J.K.G. Tech –Ph 03 59621096
- Soil Moisture Equipment Corp. (USA) – 48mm & 22mm ceramic tips. www.soilmoisture.com , Australian Distributor: ICT International, www.ictinternational.com.au Ph 02-6772 6770
- Polycarbonate one way luer stopcock (pack of 10 : No. 36000-01 ; ask for standard postage) B) Australian Scientific Pty Ltd, www.austscientific.com.au Ph: 1800 021083

Suppliers of water analysis tools

- Aquaspex soil solution test kits, - Quantofix test strips, EC & pH meters, Ca, NH_4, NO_3 & PO_4 titration kits, www.aquaspex.com.au Ph (08) 8277 3544
- Cardy Nitrate meter for nitrate and potassium – various suppliers
- Merck RQ flex plus meter, AquaMerck, RQ Easy & test strips, www.merck.com.au Ph 1800 335 571

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