Interpretation of electrical conductivity measurements from ceramic suction cups, wetting front detectors and ECH2O-TE sensors

M. van der Laan[1#*], R.J. Stirzaker[1,2], J.G. Annandale[1], K.L. Bristow[1,2] and C.C. du Preez[3]

[1]University of Pretoria Water Institute and Department of Plant Production and Soil Science, University of Pretoria, Private Bag X20, Hatfield, Pretoria 0028, South Africa
[2]CSIRO Sustainable Agriculture National Research Flagship and Cooperative Research Centre for Irrigation Futures, Australia
[3]Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein 9300, South Africa
[#]Current address: South African Sugarcane Research Institute, Private Bag X02, Mount Edgecombe 4300, South Africa

2 December 2012

Electrical conductivity (EC) measurements are often used to identify and address soil salinity issues in irrigated cropping systems. In this study, measurements of soil solution EC (EC-sol) collected in ceramic suction cups (SCs), wetting front EC (EC-wf) collected in Fullstop wetting front detectors (WFDs) and soil bulk EC (EC-bulk) measurements made using ECH2O-TE sensors and converted to EC-sol, were compared. As a result of differentmethods of measurement and different components of soil waterflow being sampled, variations in EC measurement between SCs and WFDs were observed. EC-sol was usually higher than EC-wf, as expected for this system, due to incomplete mixing between the draining and resident soil water during infiltration. For periods of high solute leaching, however, the opposite can occur, indicating that WFDs are sampling when solutes are first mobilised at the beginning of the leaching event. The ECH2O-TE sensors were less effective in measuring the short-term EC dynamics but were able to detect general changes in soil salinity. This could reflect difficulties estimating soil EC-sol from measured EC-bulk, especially at low soil water contents. Each of these instruments show good potential for application to guide salinity management practices, but a more detailed study on a range of soils subjected to different watering regimes is needed to further improve interpretation of EC measurements and their application.

Keywords: Active sampler, irrigation, passive sampler, soil salinity, swiss chard

*To whom correspondence should be addressed (E-mail: michael.vanderlaan@sugar.org.za)

Electrical conductivity (EC) is a simple measurement that can be made on a soil or soil water sample to indicate solute concentration, and is commonly used to inform salinity management practices in irrigated cropping systems. High salinity can reduce crop growth through osmotic and/or toxic effects (Pasternak, 1987; Maas & Grattan, 1999), and through the reduction of root cell membrane permeability and nutrient uptake (Mansour, 1997; Hopmans & Bristow, 2002). The standard method for measuring soil EC is via a saturated paste extract, but this is a laboratory procedure which is not suited to routine field use. Measuring soil solution EC (EC-sol) is straightforward, but water samples collected by active and passive samplers under what appear to be similar field conditions can yield very different EC values (Litaor, 1988; Paramasivam *et al*., 1997). Identifying and understanding the reasons for these differences is important to ensure the measurements are interpreted and used correctly.

Active samplers, such as ceramic suction cups (SCs), require a vacuum to be applied by the user before water will be sampled by the device from the surrounding soil. Suctions of 60 to 80 kPa are commonly applied, signifying that any water held at a lower suction in the soil can theoretically be collected by the device. In practice, low unsaturated soil hydraulic conductivity limits the collection of samples at suctions closer to field capacity. In addition to the suction applied, the initial water content, the time period of the applied suction, the porous material used for the cup and the size of the cup will influence the solute composition of the sample collected (Litaor, 1988; Paramasivam *et al*., 1997).

Passive samplers, such as Fullstop wetting front detectors (WFDs) (Stirzaker, 2003), automatically collect a water sample from the wetting front under specific conditions. In the case of a WFD, the funnel-shaped base is buried in the soil at the depth of interest. During a rainfall or irrigation event, flow lines from the wetting front converge in the funnel creating a saturated condition, and free water collects in a small reservoir which can be used for analysis (Stirzaker, 2003). WFDs therefore collect over an even narrower range (0 to 3 kPa) than SCs, but always during the event and under the same conditions.

Over recent years, capacitance and dielectric sensors that measure volumetric soil water content (VWC), soil temperature and bulk soil EC (EC-bulk) have become available, with the major advantage that EC can be measured across a wide range of water contents and these readings can be continuously logged. ECH2O-TE sensors (Decagon Devices Inc., Pullman, USA), for example, make use of a four-probe electrical array to obtain EC-bulk which is converted to EC-sol using the Hilhorst equation (Hilhorst, 2000):

$$\sigma_p = \frac{\varepsilon'_p \sigma_b}{\varepsilon'_b - \varepsilon'_{\sigma b = 0}} \qquad (1)$$

where

σ_p = EC of the pore water
ε'_p = electrical permittivity of pore water (real, non-imaginary term)
σ_b = EC of the bulk soil
ε'_b = electrical permittivity of the bulk soil (real, non-imaginary term)
$\varepsilon'_{b=0}$ = permittivity for dry soil

At low water contents the method becomes sensitive to the term ε'_b-$\varepsilon'_{b=0}$ in Equation 1, and in general the equation only applies for soil water contents greater than 0.1 m^3 m^{-3} (Hilhorst, 2000).

Generally, as passive samplers collect water samples under very wet conditions, they are more indicative of soil water moving through the root zone, as opposed to active samplers which are more indicative of the water held in the soil and available for uptake by the crop (Magid & Christensen, 1993; Simmons & Baker, 1993).

We compare and interpret EC measurements from soil water samples collected by SCs, WFDs (EC-wf) and ECH2O-TE sensors. The data are from three large 6.1 m^3 drainage lysimeters containing a sandy loam with 12% clay (SL12), a sandy clay loam with 18% clay (SCL18) and a sandy clay loam with 26% clay (SCL26) (Stirzaker *et al.*, 2010). SCs, WFDs and ECH2O-TEs were placed at depths of 150, 300, 450 and 600 mm in each lysimeter. A vacuum was applied to the SCs using a 60 ml syringe immediately following irrigation/rainfall and samples for SCs and WFDs were collected 24 hours after the irrigation/rainfall event. Sample EC was measured using an ECScan-High EC meter (Eutech Instruments, Malaysia).

The vegetable crop swiss chard (*Beta vulgaris* ssp. *cicla*) cultivar 'Lucullus' was grown. Irrigation was manually applied using a watering can to maximise application uniformity and irrigation water EC ranged between 20 and 30 mS m^{-1}. Initially, small frequent irrigations ensured seedling establishment and thereafter irrigation was applied until the WFD at either 150 or 300 mm responded, depending on estimated crop water demand. Rainfall was the same for all lysimeters while irrigation was applied on the same dates for each lysimeter but differed slightly in the volume applied based on WFD response. Cumulative irrigation for the SL12, SCL18 and SCL26 soil was 425, 458 and 495 mm, respectively. Rainfall and irrigation data and soil VWC measured by the ECH2O-TEs at depths of 300 and 600 mm for the SCL18 lysimeter are shown in Figure 1.

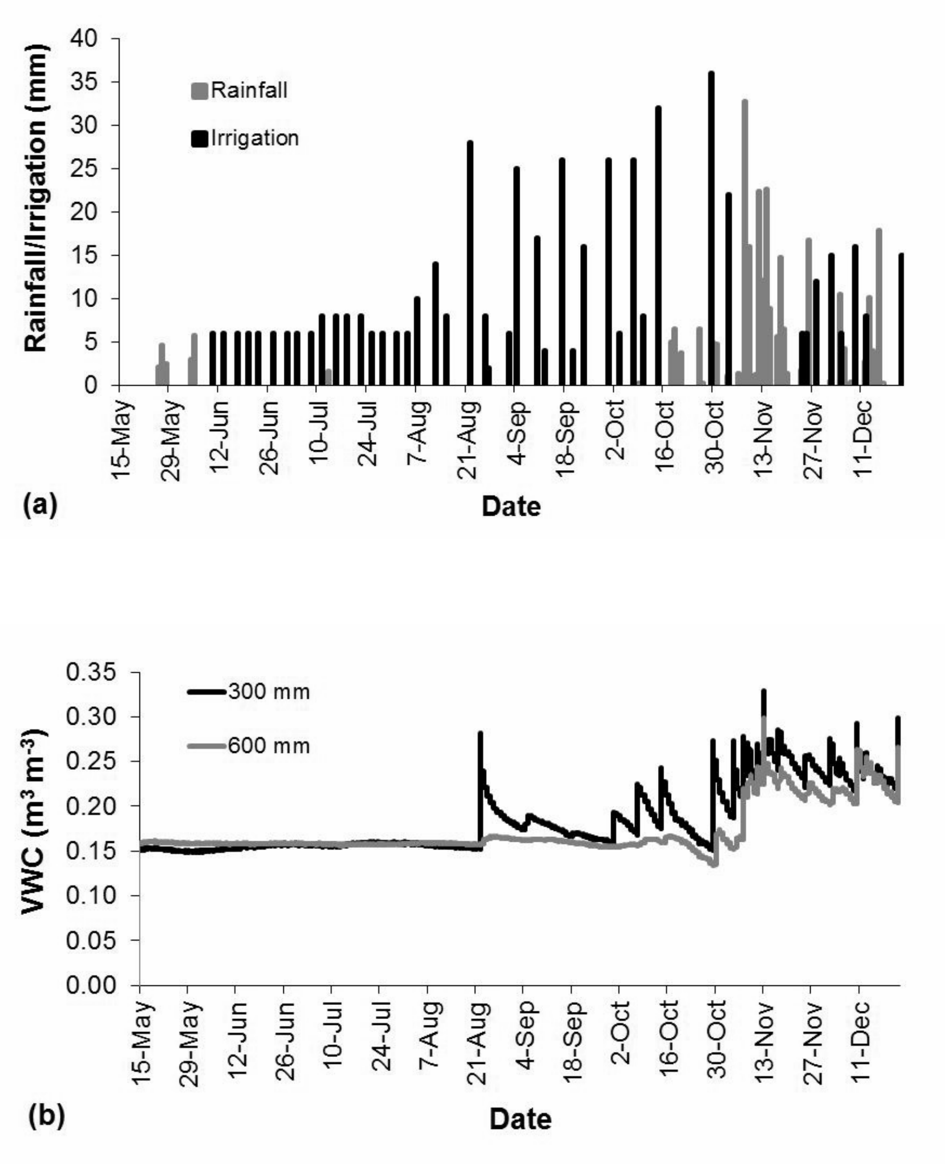

Figure 1 Rainfall and irrigation (a) and measured soil volumetric water content (VWC) at depths of 300 and 600 mm (b) for the 2008 growing season of swiss chard for the SCL18 lysimeter.

Lower EC values were often measured in the WFDs compared to the SCs (Figure 2). This indicates that solute concentrations in the draining soil water originating from rainfall or irrigation (as sampled by the WFDs) was lower than the resident soil water because of incomplete mixing during infiltration. This was not always the case, however, with EC-wf greater than EC-sol at certain times during the season. This was most notable in all three lysimeters at the 150 and 300 mm depths. Interestingly, this occurrence also coincided with periods in which the EC-sol values were observed to decrease with time as a result of high rainfall (250 mm between 2008/10/18 and 2008/12/17). It therefore appears that the greater EC values measured reflect mobilised salt sampled by the WFDs at the beginning of the leaching event. These transient salt fronts have largely dissipated by the time the SCs are sampled. The data also show smaller differences between EC-sol and EC-wf with depth, indicating that the processes responsible for the differences are damped deeper in the soil profile.

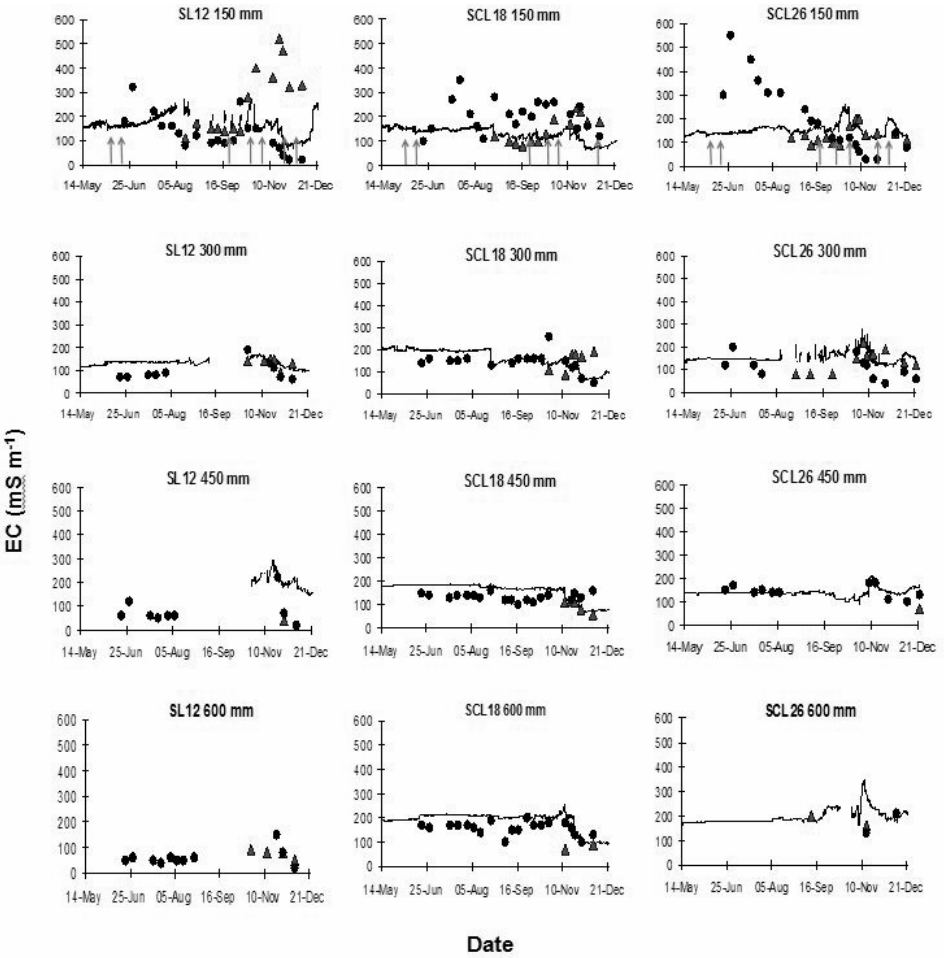

Figure 2 Suction cup (solid dots), wetting front detector (triangles) and ECH2O-TE sensor (solid curve) electrical conductivity (EC) measurementsfor the 2008 swiss chard growing season at depths of 150, 300, 450 and 600 mm (↑ = fertilisation event; SL12 = sandy loam with 12% clay, SCL18 = sandy clay loam with 18% clay, SCL26 = sandy clay loam with 26% clay).

In some cases, good alignment was observed between EC measured by the ECH2O-TEs and SCs (SL12 150 mm, SCL18 300 and 600 mm, SCL26 450 mm), and EC measured by the ECH2O-TEs and WFDs (SL12 300 mm, SCL18 450 mm, SCL26 150 and 300 mm) (Figure 2). There was generally improved agreement between EC values measured by the ECH2O-TEs and SCs compared to that for ECH2O-TEs and WFDs. This was expected since the ECH2O-TEs, at least theoretically, measure across a similar soil water pore spectrum to the SCs. For the samplers, EC values as high as 520, 350 and 550 mS m^{-1} were observed for the SL12 (WFD 150 mm), SCL18 (SC 150 mm) and SCL26 (SC 150 mm) soils, respectively. These high EC levels were not detected by the ECH2O-TEs, whose measurements never exceeded 300 mS m^{-1}, except briefly for the SCL26 soil at 600 mm. Given the Hilhorst equation only applies for soil water contents greater than 0.1 m^3 m^{-3}, the ECH2O-TEs were not able to estimate EC-sol for the SL12 soil for certain periods at depths of 150 and 300 mm and not at all for the 450 and 600 mm depths because measured VWCs were below this threshold. The manufacturers have since this experiment produced a new version of the ECH2O-TEs that should be re-tested. From this study, however, the data shows that measuring soil water EC with sensors that make use of the Hilhorst equation in sandy soils forVWC less than 0.1 m^3 m^{-3} can be problematic.

Regular measurement of EC at different depths in the soil profile can provide useful insights into solute movement for improving irrigation management. Both SCs and WFDs showed good potential for use in regular monitoring of soil water EC to guide management practices. ECH2O-TEs were less effective but were still able to indicate general changes in soil salinity.

As SCs and WFDs employ different sampling methods and sample different components of soil water flow, measurements need to be interpreted accordingly. The amount of solute present in the different components of soil water flow also varies with management practice and time of sampling, with-high EC values measured in WFDs compared with SCs usually reflecting active solute leaching. Further work on understanding and interpreting EC measurements from SCs and WFDs as influenced by soil type and different watering regimes, and using these measurements to inform improved management practices, is recommended.

Acknowledgements

The authors gratefully acknowledge the Water Research Commission (Project 1574), the National Research Foundation, the Cooperative Research Centre for Irrigation Futures and CSIRO for supporting this research.

References

HILHORST, M.A., 2000. A pore water conductivity sensor. *Soil Sci. Soc. Am. J.* 64, 1922-1925.

HOPMANS, J.W. & BRISTOW, K.L., 2002. Current capabilities and future needs of root water and nutrient uptake modelling. *Adv. Agron.* 103, 103-183.

LITAOR, M.I., 1988. Review of soil solution samplers. *Water Resour. Res.* 24, 727-733.

MAAS, E.V. & GRATTAN, S.R., 1999. Crop yields as affected by salinity. *In*: R.W. Skaggs & J. van Schilfgaarde (eds.). Drainage of Agricultural Lands. Am. Soc. of Agron. Monograph No. 38, Madison, WI, USA.

MAGID, J. & CHRISTENSEN, N., 1993. Soil solution samples with and without tension in arable and heathland soils. *Soil Sci. Soc. Am. J.* 57, 1463-1469.

MANSOUR, M.M.F., 1997. Cell permeability under salt stress. *In*: P.K. Jaiwal, R.P. Singh & A. Gulati (eds.). Strategies for Improving Salt Tolerance in Higher Plants. Science Publishers, Enfield, NH, USA.

PARAMASIVAM, S., ALVA, A.K. & FARES, A., 1997. Vadose zone soil solution sampling techniques to investigate pollutant transport in soils. *Trend. Soil Sci.* 2, 115-136.

PASTERNAK, D., 1987. Salt tolerance and crop production – a comprehensive approach. *Ann. Rev. Phytopath.* 25, 271-291.

SIMMONS, K.E. & BAKER, D.E., 1993. A zero-tension sampler for the collection of soil water in macropore systems. *J. Environ. Qual.* 22, 207-212.

STIRZAKER, R.J., 2003. When to turn the water off: scheduling micro-irrigation with a wetting front detector. *Irrig. Sci.* 22, 177-185.

STIRZAKER, R.J., STEYN, J.M., ANNANDALE, J.G., ADHANOM, G.T., VAN DER LAAN, M. & M'MARETE, C., 2010. Adapting the wetting front detector to small-scale furrow irrigation and providing a basis for the interpretation of salt and nutrient measurements from the water sample. Water Research Commission Report No. 1574/1/10, Pretoria, South Africa (ISBN no. 978-1-77005-957-3).