

Real-time vineyard root zone salinity monitoring with a modified suction cup

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Introduction

Many grape growers irrigating with lower Murray River water in southern Australia have converted to pressurized irrigation systems in order to improve wine grape quality, yield consistency and improve water use efficiency. As growers become more efficient in their irrigation water use they are, however, confronted with rootzone salinisation (Stevens 2002). This problem is exacerbated by high irrigation water salinity (eg Padthaway, Langhorne Creek) and also the current drought. Having accurate measurements of soil salinity in the rootzone during the growing season is essential to obtain reliable salt tolerance data. This requires monitoring salinity at several depths at various times during the season in order to manage the salinity risk of high value horticultural crops.

Soil salinity is conventionally estimated from the electrical conductivity (EC) of water extracted from the soil at some reference water content, (e.g. saturated soil-paste or soil suspension). The EC of the saturated-soil extract (ECe) is commonly used to express the salinity of the soil. It is a reproducible value that is directly proportional to the salt concentration of the soil water (Maas 1996). Other extraction ratios, such as 1:1, 1:5, etc., are easier to use than that of the saturation paste but they are less well-related to meaningful soil water chemistry and are more subject to errors resulting from hydrolysis, cation exchange and mineral dissolution (Rhoades *et al.*, 1999). Despite this, the EC of 1:5 soil:water ratio (EC1:5) is widely used as an industry standard in Australia.

Theoretically, the electrical conductivity of the soil solution or soil water (referred hereafter as EC_{sw}) is a better index of soil salinity than is the traditional index (ECe). This is so because the plant roots actually experience the soil solution; they extract their nutrients from it, absorb other solutes from it and they consume this water through the process of transpiration. Most importantly, EC_{sw} has not been widely adopted for routine appraisals of soil salinity because methods for obtaining soil water samples are not practical at typical field soil water contents. Two means of measuring EC_{sw} in undisturbed soils exist: [i] extract soil water using an in-situ extractor and then measure its EC; [ii] measure EC_{sw} directly in the soil using in-situ salinity sensors. Although there are several devices available (eg., resistance, capacitance, passive and suction lysimeters), these are often expensive and require specialised skills to install and operate.

Recognising the need for real time monitoring of irrigated rootzone salinity for EC_{sw}, (Biswas 2006) developed SoluSAMPLER™ for collecting soil pore water up to 1 bar (100 kPa) suction created by using a plastic syringe. The irrigation trigger value for most of the crops along the lower Murray is around 40-60 kPa. This inexpensive device, when permanently installed, enables growers to track the salinity within the rooting depth throughout the year by sampling at any time.

SoluSAMPLER™ - a grower tool for monitoring root zone salinity

The SoluSAMPLER™ (Fig. 1) is a modified porous suction cup designed to extract a soil pore water sample of up to 70mL at 60-70 kPa suction as created by using a plastic syringe (Biswas 2006). The soil water samples can be analysed in-situ for electrical conductivity (termed hereafter as EC_{sw}) as well as other parameters such as pH and nutrient composition.

It is recommended that the SoluSAMPLER™ be installed in nests of three, positioned at depths of 0.3m, 0.6m and 0.9m within 0.15m of a dripper (assuming dripper spacing of 0.6m) or at a representative site within the wetting zone of a sprinkler. Replication of depths across a vineyard will enhance the accuracy of data produced. Installing at multiple depths permits the tracking of salts as they move through the profile over time. EC_{sw} values can then be

averaged to estimate the average annual soil water salinity encountered by the crop at each depth. This device also permits the tracking of nutrient status in the profile during the growing season. Whilst there are other devices and techniques available to monitor root zone salinity, the permanently installed SoluSAMPLER™ provides real-time EC_{sw} with minimal effort, expense or disturbance to the root zone. Such information will assist irrigators in make informed decisions on the requirement for and effect of leaching irrigations.

There are currently two designs of SoluSAMPLER™, the ‘Low Flow’ and the ‘High Flow’. The Low Flow SoluSAMPLER™, which is recommended for universal use, has porosity between 24-28% (v/v), air entry value of 150 kPa and can withstand a positive pressure of up to 700 kPa (i.e. 7 bar pressure). The greatest advantages of the SoluSAMPLER™ are its convenience to install and that the results are instantly available to the irrigators. They can extract the soil water sample and, with the aid of a simple hand held EC meter, measure its salinity in the field. Analysing soil water samples and plotting the results on a timeline allows the irrigator to view trends in salt and nutrient transport through the profile.

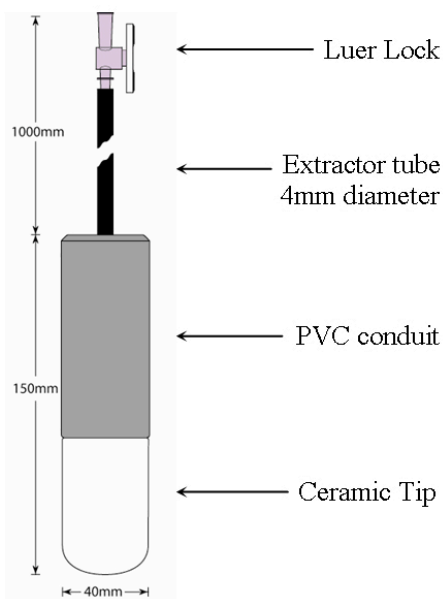


Figure 1. SoluSAMPLER™ Diagram

Benchmarking of SoluSAMPLER™ EC_{sw} with E_{Ce} and EC_{1:5}

Soil salinity is conventionally related to the EC of water extracted from the soil at reference water content (e.g. saturated soil-paste or soil suspension). The EC of the saturated soil-paste extract (E_{Ce}) is widely used because it is a reproducible value that is directly proportional to the salt concentration of the soil water (Maas 1996). Other extraction ratios, such as EC of 1:5 soil:water ratio is widely used as an industry standard in Australia. It is easier to use than that of the saturation paste E_{Ce} but less well related to meaningful soil chemistry and is more subject to errors resulting from hydrolysis, cation exchange, and mineral dissolution (Rhoades et al., 1999).

Theoretically, the EC_{sw} of the soil solution or soil water is an improved indicator of soil salinity than the traditional E_{Ce} or EC_{1:5} measurements. Plant roots experience the soil solution rather than E_{Ce} or EC_{1:5}. They extract water, nutrients and other solutes from soil solution. However, EC_{sw} has not historically been used for routine appraisals of soil salinity, as samples have not been practical to obtain at typical field water contents. The SoluSAMPLER™ presents an opportunity for uncomplicated soil water extraction and a possible alternative to traditional techniques of monitoring soil salinity.

Crop tolerance to salinity is generally expressed in terms of E_{Ce} (Maas and Hoffman 1977), (Maas 1996). Hence, it is vital that the relationship between

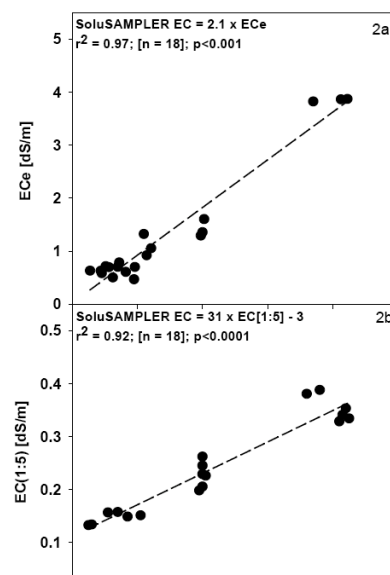


Figure 2. Relationship between EC_{sw} and Saturated paste extract E_{Ce} (a) and EC(1:5) soil : water ratio (b) (after Biswas *et al.*, 2007a).

SoluSAMPLER™ EC_{sw} and EC_e is established before this tool can be reliably used for interpreting rootzone salinity risks for irrigated crops.

The relationship between EC_{sw} and EC_e has been derived by taking SoluSAMPLER™ water samples and soil cores from around the SoluSAMPLER™ from a number of properties in the Riverland of SA. Biswas *et al.* (2007a) reported a strong positive correlation between EC_e and EC_{sw}, where SoluSAMPLER™ EC (EC_{sw}) was found to be twice the EC_e (Fig. 2a) and about 30 times the EC_(1:5) (Fig 2b).

Many empirical relationships have been proposed to relate soil water EC_{sw} to the saturated paste EC_e. Hoffman and van Genuchten (1983) reported the soil water content, close to field capacity, to be half the saturation extract water content and assumed the value of EC_{sw} is about twice EC_e. In this study the soil water suction varied between 8 kPa and 40 kPa when the field capacity of these soils ranged between 10 to 20 kPa. Congruent to the Hoffman and van Genuchten (1983) prediction, the EC_{sw} measured by SoluSAMPLER™ was found to be about twice that in the saturated paste extract where the saturated paste salinity was less than 10 dS/m.

Interpretation of SoluSAMPLER™ reading for salt tolerance of horticultural crops

The SoluSAMPLER™ EC_{sw} data can easily be linked to salinity threshold values when yield begins to decline for many irrigated crops. For example, Maas and Hoffman (1977) calculated that the threshold EC_e for grapes on their own roots was 1.5 dS/m while (Zhang *et al.* 2002) reported 1.8 dS/m as the new salinity threshold value for own rooted vines in Australian conditions. EC_{sw} being twice the EC_e, the salinity threshold for grapes on their own roots, as measured by SoluSAMPLER™, can be reported as 3.6 dS/m. A general salt tolerance level measured for wine grapes and other horticultural crops, expressed as EC_{sw} of samples extracted by SoluSAMPLER™, is reported in Tables 1 and 2. These values should be used as a guide only. EC_{sw} values may require adjustment depending on agronomic management, irrigation salinity, soil moisture content, variety, soil type and leaching efficiency.

Table 1 Rootzone salinity threshold for grapes when measured in SoluSAMPLER™ solution

Crop sensitivity	Varieties	EC _{sw} at which yield decline starts (dS/m)
Grape- Sensitive to Moderately Sensitive	Own roots (<i>Vitis vinifera</i>): e.g. Sultana, Shiraz, Chardonnay. Rootstocks: 1202C, Kober 5BB, Teleki 5C, S04	3.6
Grape- Moderately tolerant to Tolerant	Rootstocks: e.g. Ramsey, 1103 Paulsen, Ruggeri 140, Schwarzmann, 101-14, Rupestris St. George.	6.6

EC_{sw} modified from Zhang *et al.* (2002)

Table 2 Rootzone salinity threshold for tree crops when measured in SoluSAMPLER™ solution

Tree crops	Threshold EC _{sw} (dS/m) for maximum production	Threshold EC _{sw} (dS/m) for reduced yield levels [Impact of higher salinity]	
	100% yield	75% yield	50% yield
Orange	3.4	6.6	9.6
Grapefruit	3.4	6.6	9.6
Lemon	3.4	6.6	9.6
Apricot	3.2	5.2	7.4
Peach	3.4	5.8	8.2

Modified after (Maas and Hoffman 1977; GHD1999)

Field Testing of SoluSAMPLER™ in a South Australian vineyard

Soil water samples were collected fortnightly from 0.3, 0.6 and 0.9m depths for EC_{sw}. From early 2006 till late 2007, over 250 soil water samples were collected from a 10 year old vineyard (*Vitis vinifera* L. cv Shiraz on own roots) irrigated with Willunga reclaimed water with an annual average EC of 1.3 dS/m. Soil was a loamy sand to clay over medium clay soil which had substantial amounts of fragmented limestone in subsoil. Two drip systems were used, a conventional surface drip in one area and subsurface drip lines (buried at 0.25m) in nother area. Average annual irrigation, rainfall and ETo at the site were 194 mm, 550mm and 1200 mm, respectively.

Detailed records of irrigation, rainfall, ETo and SoluSAMPLER™ EC_{sw} from both the treatments are presented in Fig 3. Lack of EC_{sw} data during the summer irrigation, particularly under conventional drip relates to insufficient soil moisture which influenced the success of getting samples in the SoluSAMPLER™. Moisture data from the Watermark™ (GBLite) sensors collected from the same depths and at the same time showed that each time tension dropped below 50 kPa the SoluSAMPLER™ yielded samples. Soil moisture data clearly justified the functioning of the SoluSAMPLER™ which worked well in the range of 0-50kPa suction.

Under the conventional surface irrigation the 0.3m deep SoluSAMPLER™ produced the highest frequency of samples. Soil moisture content was low throughout the summer months which led to gaps in EC_{sw} data and the unavailability of 0.6m and 0.9m data until winter 2007. EC_{sw} readings from 0.3m SoluSAMPLER™ installed in within conventional surface drip irrigation consistently produced salinity greater than the theoretical production threshold for own rooted vines of 3.6 dS/m. This was particularly noticeable in late January 2007 when 50mm of rainfall over three days mobilised salts, from both the vine line and the mid-row, to produce an EC_{sw} of 11.9 dS/m. Subsequent irrigation and rainfall events from March through to June 2007 were associated with EC_{sw} drop to approximately 6.2 dS/m as salt gradually moved out of the 0.3m region of the root zone. Rainfall events through winter 2007 increased soil moisture sufficiently to allow sampling both at 0.6 and 0.9m from July onward, to the end of data collection. Patterns of EC_{sw} from these depths suggested that residual salts from the irrigation season are gradually moving deeper with the rainfall but are yet to be flushed out of the root zone.

In case of subsurface irrigation, higher frequencies of samples were retrieved during the summer months as compared to surface irrigated site. This is likely due to the subsurface drip being buried at 0.25m and therefore less influenced by evapotranspiration allowing increased soil moisture. This increase in soil moisture content not only allowed more consistent sampling from the SoluSAMPLER™ but also tended to reduce salinity at all three soil layers. All 0.3m soil water samples were below the theoretical production threshold of 3.6 dS/m. Soil water salinities at both the 0.6 and 0.9m although followed similar trends to that at 0.3m but were higher than the theoretical production threshold of wine grapes. Until soil moisture increased after the winter 2007 rainfall, no soil water samples could be collected at 0.9m depth. This suggested that irrigation in this vineyard was not sufficient to push the wetting fronts below 0.6m and hence was deficient.

Table 3 has listed mean salinities, as read by SoluSAMPLER™, from conventional and

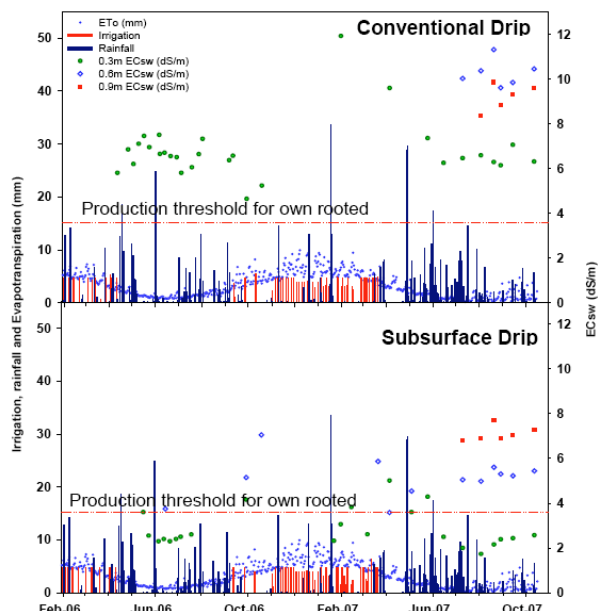


Figure 3. Changes in SoluSAMPLER™ EC_{sw} at 0.3, 0.6 and 0.9m depths in a conventional and subsurface drip irrigated vineyard. Red bar for irrigation, blue bar for rainfall and blue dot for evapotranspiration (ETo). EC_{sw} at 0.3m is presented as green dots, 0.6m as blue/white diamonds and 0.9m as red squares.

subsurface drip during the testing period. Data suggested that the subsurface drip recorded half the soil water salinity as compared to the conventional surface drip system. This is particularly observed at the 0.3 and 0.6m depths, from which the vines are likely to extract most of the water.

Table 3 Influence of conventional drip and sub-surface drip on mean soil water salinity at McLaren Vale Shiraz vineyard irrigated with reclaimed water

Depth of SoluSAMPLER™	Conventional Surface Drip EC _{sw} (dS/m)	Sub Surface Drip EC _{sw} (dS/m)
0.3m	6.4 ^{72##}	3 ⁵²
0.6m	9.8 ²¹	4.9 ³²
0.9m	8.3 ¹⁴	6.6 ¹⁹

Superscript represents population size, (after Biswas *et al.*, 2007b)

Although the mean rootzone soil water salinities were much higher than the theoretical production threshold of 3.6 dS/m, plants did not display symptoms typically associated with exposure to saline conditions. In particular, the soil water salinity of the conventional drip irrigated vine rootzone recorded was as high as 10-12 dS/m. It is likely that lower berry yields were linked to the vines tolerance to high salinity spikes during the growing season. This suggested that there is a critical need for a revision or redefining of the current salinity thresholds for wine grapes grown for quality yields under precision irrigation management.

Conclusion

There has been significant research and educational inputs into improving water use efficiency over the past 20 years. Highly efficient irrigation with moderately saline water often results in insufficient leaching of residual salts, which in-turn threatens the sustainability of irrigated horticulture. Many Australian grape growers in south eastern Australia have reported elevated levels of sodium and chloride in leaves and berries. It is now very critical to put effort into managing root-zone salinity.

By using SoluSAMPLER™ and a simple salinity meter, irrigators can see whether or not they are adding extra salt to the root zone at levels to reduce yield and quality of many high value horticultural crops. The SoluSAMPLER™ is an inexpensive tool suitable for usage in typical irrigation zones where soil water management occurs between 40 – 60kPa. It is easy to install, can be used in a wide range of soil types and moisture conditions, and does not affect the chemical composition of the soil pore water.

Soil salinity is normally defined and measured on aqueous extracts of so-called, saturated soil-pastes. It is related in a predictable way to soil-water content under field conditions. For these same reasons, crop tolerance to salinity is also most often expressed in terms of EC_e. The EC_{sw} measured by SoluSAMPLER™ was found to be about twice that in the saturated paste extract salinity (EC_e) in the Riverland irrigated soils. Readings from SoluSAMPLER™ can now be linked to salt tolerance threshold values of horticultural crops. However, like any other new tools, this device requires further ground truthing for heavier texture and/or duplex soil types.

SoluSAMPLER™ data showed that subsurface drip irrigated vineyard recorded rootzone salinities two times lower than that under a conventional surface drip system. This was particularly observed at the 0.3 and 0.6m depths, from which the vines were likely to extract most of the water. The mean rootzone soil water salinities were much higher than the theoretical production threshold of 3.6 dS/m without showing symptoms typically associated with exposure to saline conditions. Soil water salinity observed at 0.6m depth was as high as 10-12 dS/m. It is likely that the traditional lower yields at this site were associated with the vines tolerance to these high salinity spikes. This suggests that there is a critical need for a revision or redefining of the current salinity thresholds for wine grapes grown for quality wine.

The SoluSAMPLER™ is also an excellent tool for monitoring the movement of nutrients through the soil profile. Soil water samples collected periodically after a fertiliser event can be analysed for nitrogen content. This helps irrigators to manage the nitrogen within the profile to meet crop needs.

Acknowledgments

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