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Root Zone Salinity Risks in the Lower Murray Districts

Tapas Biswas[1], Rob Stevens[2], and Gerrit Schrale[1]

[1]SARDI/PIRSA, PO Box 397, Adelaide 5001 schrale.gerrit@saugov.sa.gov.au Phone: (08) 83039334
[2] SARDI/PIRSA P O Box 411 Loxton SA 5333

Abstract

Due to improved irrigation management and system upgrades, the field application efficiency (FAE) in the Lower Murray horticultural districts has risen from about 50 to 85% during the past 2 decades. Consequently, the drainage volumes have reduced from about 50 % to 15% of water applied. Under steady state conditions, the salinity in the root zone can be estimated from salinities of the irrigation water and the leachate (i.e. extra irrigation water applied which drains out of the base of the root zone). For this estimate it is assumed that the leaching water uniformly displaces the (saline) soil water in a 'piston' flow manner.

Despite the relatively low salinity of the River Murray flows in the past five years, growers practicing 'precision' irrigation expressed concern about the gradual, but visual accumulation of salinity in the root zone of drip irrigated vineyards in particular. A 'Tri-State Salinity' syndicate of Government agencies from western NSW, Victoria and South Australia (with support from federal agencies) was formed to generate new knowledge for managing root zone salinity hazards by undertaking a 3 year laboratory and field scale studies. Besides assessing the risk of salinity accumulation under precision irrigation, the project team is working on strategies for minimising production losses.

Field data from conventional drip in the Riverland and Sunraysia regions showed that only less than 10% of applied water was found to leave the root zone during the grape growing season, which resulted in salt build up in root zone. This is particularly of concern when the average leaching efficiency at the 14 surveyed properties was 63% and where only <5% of total applied water is flushing the root zone during the irrigation season.

Using the data from a drip irrigation vineyard at Loxton in Bookpurnong Lock-4 district, the output of a two-dimensional numerical flow/transport model (LEACHM-TRANSMIT) showed that during summer about 2 t of salt /ha would accumulate in the root zone if the River water salinity is 0.8 dS/m. However, even at the currently River salinity of 0.3 dS/m and 95% FAE, crop losses due to gradual salinity build up may be inevitable in the Riverland/Sunraysia districts.

Introduction

As a result of improved irrigation management and systems, growers in the Lower Murray (Riverland-Sunraysia) horticultural region have improved their water use efficiency (WUE) over the past two decades from about 50% to about 80%. However a negative consequence of this achievement is the emerging risk of salinity build-up in the root zone, threatening the sustainability of the region (Biswas *et al.* 2005a; Biswas *et al.* 2005b). The amount of irrigation applied must account for both the crop water use and some extra water (the leaching fraction) to flush periodically the residual salt out of the root zone. For example, when the average river water salinity is about 0.4 dS/m, a 15% leaching fraction (15% more than the crop needs) should give root zone salinity around 0.6 dS/m. However field surveys indicate that the root zone salinity, though very variable, is often greater than 1.3 dS/m. The discrepancy between observed and expected soil salinity may be due to a portion of the leaching water moving rapidly through the larger soil pores without displacing soil soluble salts from the root zone. As a result, the leachate is a mixture of irrigation water that has passed unchanged and of displaced soil solution. Van der Molen (1956) described this by-path water and salt transport process and used the term 'leaching efficiency' to describe the ratio of the volume of drainage flowing by piston flow to the total volume of drainage (Bouwer 1969).

The River Murray Catchment Water Management Board has sought to manage the impact of return flows of irrigation drainage water on river water quality and health of the floodplains by introducing a target of WUE of 85% in the current Water Allocation Plan. Insufficient leaching at this target may result in high levels of root zone salinity and subsequent yield losses for the local horticultural crops (Stevens 2002).

Since the end of 2003 a tri-state syndicate of government agencies from western NSW, Victoria and South Australia has been working on a strategy to manage this salinity hazard. This paper reports some of the findings to date, focusing on results of monitoring root zone salinity and deep drainage in sprinkler and drip-irrigated citrus orchards and vineyards.

Measuring root zone salinity

Measurement of the electrical conductivity (EC) of soil began in 2002/03 irrigation seasons at 3 properties in the Lower Murray and during 2003/04 another 11 properties were added to this measurement regime. The seasonal depth of water applied for the citrus crops ranged from 588 to 1646 mm; the associated total rainfall ranged from 235-284 mm. The vines had seasonal irrigation depths ranging from 440 to 1133 mm and total rainfall from 153 to 303 mm. This survey indicates that the mean measured value of soil salinity (Cl_{sw}) was at least 2-fold higher than the values estimated by application of a range of irrigation water to soil salinity conversion formulae (GHD, 1999, Hoffman and van Genuchten, 1983, and Ayers and Westcot, 1985). As presented in Table 1, the mean leaching efficiency of 63% at these sites was significantly less than unity ($P < 0.01$) and had a large coefficient of variation (77%). Leaching efficiency is the efficiency with which the drainage water mixes with the soil solution and is accepted as 100% when every mm of water passing below the root zone carries its full quota of salt.

Table 1. Volume weighted Cl concentration in water (Clw) applied in 12 months preceding soil sampling, Cl concentrations in the soil solution at base of root zone (Clswb), leaching fraction and leaching efficiency.

No of farms surveyed	Years under irrigation	Clw mmol/L	Clsw mmol/L	Leaching Fraction =1-FAE or Clw/Clswb	Predicted Clsw mmol/L	Leaching Efficiency
14	>45	1.2	12	0.2	4.1 –5.1**	63%

[*]estimated as twice the Cl concentration in the saturated paste extracts **P=0.01 paired t-test between Clsw and predicted Clsw

The leaching in-efficiency and its large variation are likely due to local characteristics and their spatial variability. In order to gain temporal variation of both leaching fraction and leaching efficiency four representative vineyard and citrus farms across the Riverland and Sunraysia irrigation areas were selected. The major criteria were that the sites should have had at least 12 years of irrigation and the water table should be more that 3 meters below the surface depths (Schrale and Biswas, 2004; Biswas *et al.* 2005a; Biswas *et al.* 2005b).

At each of these sites an EM38 survey was undertaken, which uses electromagnetic resonance imaging, to map the paddocks into units of greater or lesser salinity (Figure 1). The results showed great variation between core samples and between farms, but generally salinity increased with depth (Figure 2). This is expected because evaporation and absorption by the plant roots reduces the amount of free water and therefore concentrates the salt in the substrata.

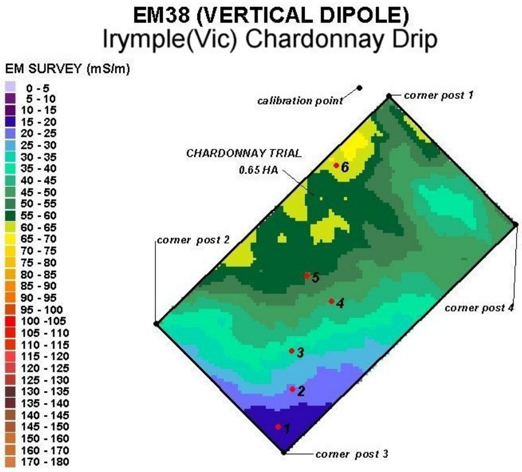

Figure 1. Map of apparent salinity (ECa for the drip irrigated Chardonnay block, and location of core samples. The colours show the variability in salinity across the paddock, ranging from 0.2 to 0.75 dS/m. 1 mS/m = 0.01 dS/m.

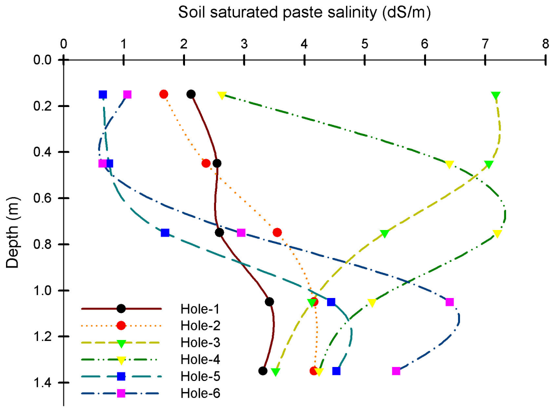

Figure 2. Variation in salinity (x axis dS/m) with soil depth (y axis in m) for each of the core samples in Fig 1

Soil solution salinity was monitored at each sites at depths of 0.3m, 0.6m and 0.9m. Following each irrigation or rainfall event, solutions were extracted under a suction of 70 kPa. ECsw measurement was used as surrogate measure for Cle.

The salinity of soil water (ECsw) peaked at 20 dS/m at 90 cm root zone depth under drip irrigated vineyard, but was rarely more than 1.5 dS/m in an undercover sprinkler citrus orchard (Figure 3). According to (Maas and Hoffman 1977) and (Ayers and Westcot 1976) the threshold ECsw for yield reduction is 4.2 dS/m for grape and 2 dS/m for citrus respectively. Although the salinity of the entire root zone at the citrus farm (irrigated by under-cover sprinklers) is kept well below the threshold salinity, the salinity of the lower root zone strata in the drip irrigated vineyard was above the threshold for most of the season.

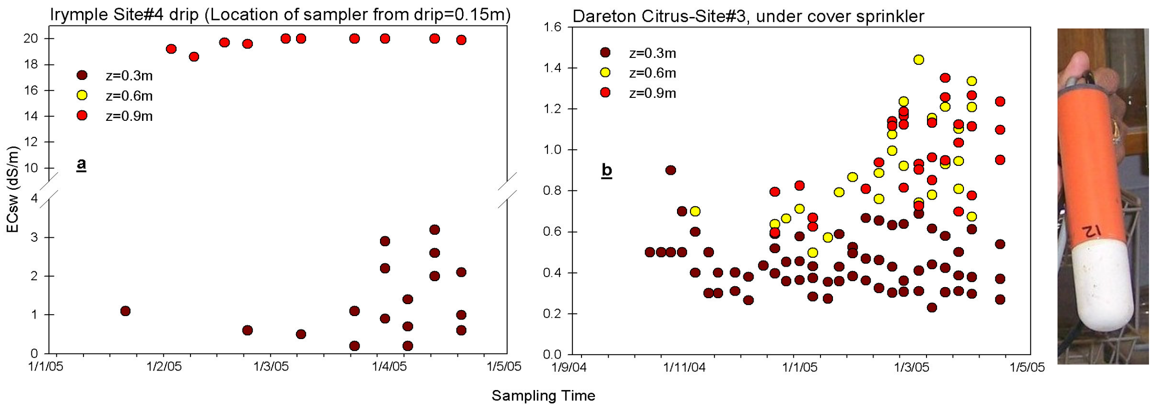

*Figure 3. Electrical conductivity of soil water (ECsw) under (**a**) a drip irrigated vine and (**b**) an under-cover sprinkler citrus tree. On the right: solution extractor.*

Deep drainage estimation

Four methods were used to try to determine the amount of water draining from the root zone. These were:

1. estimation of water balance throughout the season;
2. using chloride as a tracer;
3. seasonal water balance, validated by capacitance probe logs;
4. capacitance probe method using Darcy equation.

Method 1 involves estimating changes in soil water storage from soil texture, irrigation records, crop types, climatic data and crop coefficients. Water applied in excess of water holding capacity of the root zone is attributed to deep drainage.

Method 2 assumes that the ratio of deep drainage to the amount of water applied is equivalent to the ratio of the chloride (Cl) concentration in irrigation water to the Cl concentration Cl in drainage water. By monitoring these concentrations in the field, a seasonal picture of deep drainage can be built up. If a Soil Solution Extractor is used, soil water can be extracted from the root zone at a standard suction pressure similar to that applied by the plant roots.

Method 3 uses capacitance probe logs for measuring total root zone water content, estimates of the field capacity of the soil, and rainfall and irrigation data to determine deep drainage (Edraki *et al.* 2004). Whereas Method 1 uses crop coefficients to predict the crop's average water use at various stages of development, Method 3 makes no such assumptions, but simply derives the amount of water leaving the profile.

Method 4 uses the van-Genuchten function to smooth hourly capacitance probe soil water content data into soil matric potentials. Using Darcy function these results along with the soil hydraulic functions are converted into the deep drainage volume. Detailed methodology is presented in Biswas *et al*. (2005c).

Using Method 1, it is estimated that 4-10% deep drainage is occurring under drip irrigated vines and citrus compared to 24% and 35% respectively for citrus and grapes irrigated by undercover sprinkler. This means that the WUE under drip is 90-95% with consequently high risk of long-term salt accumulation in the root zone and associated yield losses.

Using Method 2, drip irrigation would not have produced any leachate at one site, and produced only 1% of applied water at the other. With undercover sprinklers the estimates were 21 ± 3 % and 17 ± 4 % of deep drainage. The results are summarised in Table 2.

Table 2. Estimated Deep Drainage (Sep 04-Apr 05) from soil Cl tracing technique (Method 2)

Site	Irrigation (mm)	Rainfall (mm)	Deep Drainage (%)
Loxton vine drip	510	177	ND[a]
Irymple vine drip	343	116	1 (±0.02; n=10)[b]
Loxton vine uc sprinkler	735	177	21 (±3; n=53)
Dareton citrus uc sprinkler	912	102	17 (±4; n=31)

[a]ND=Not detected
[b]value in parenthesis indicates standard deviation (SD) and n = sample size

Using Method 3 estimates of deep drainage ranged from 7-16% and 13-17% for drip irrigation and for undercover sprinkler irrigation respectively. The results are presented in Table 3. This confirms the method 1 result that the WUE under precision drip is often more than 90%.

Table 3. Deep Drainage estimated from field capacity and real time capacitance probe data (Method 3)*

Site	Period	Apparent Field Capacity (%)	Deep Drainage (%)
Loxton vine drip	10 Dec 04-23 Jun 05	31	7
Irymple vine drip	22 Dec 04-23 Jun 05	30	16
Loxton vine uc sprinkler	6 Jan -23 Jun 05	20	13
Dareton citrus uc sprinkler	30 Jan-1 Aug 05	19	17

* based on non-calibrated enviroscan data

Using Method 4 during summer irrigation, under a drip irrigated vine the drainage estimates resulted in negligible deep drainage (1%) whereas under sprinkler irrigated citrus deep drainage was 17%, which confirm the Method 2 findings.

What do the results mean?

Although the results from the 4 methods vary considerably, they suggest that, in summer, negligible leaching is occurring under drip irrigation compared to the uniform under canopy sprinkler irrigation, regardless of the crops grown. Consequently, the general concern for precision drip irrigation is that if winter rainfall does not provide effective leaching, accumulation of residual salt in the root zone is going to be a major concern.

To develop a strategy for root zone salinity management, a two dimensional solute transport model (LEACHM-TRANSMIT) (Hutson and Wagenet, 1995) simulation was run for 278 days to estimate the salt accumulation in the root zone for irrigation salinities of 0.3 dS/m (current river water salinity at Loxton) and 0.8 dS/m (the Morgan benchmark). The scenarios are shown in Figure 4. Under the scenario of drip irrigation with 10% root zone drainage and 0.3 dS/m water, about 130 kg/ha of salt (is this chloride or salt – if salt then 0.3 dS/m ~ 165 mg/L and if 8 ML/ha then cumulative salt in equates to 1.320 Mg/ha equates to 132g/m2) would accumulate in the root zone during first irrigation season. Under the 0.8 dS/m water scenario, 2000 kg/ha of salt would accumulate in a 1 m root zone during a normal grape growing season.

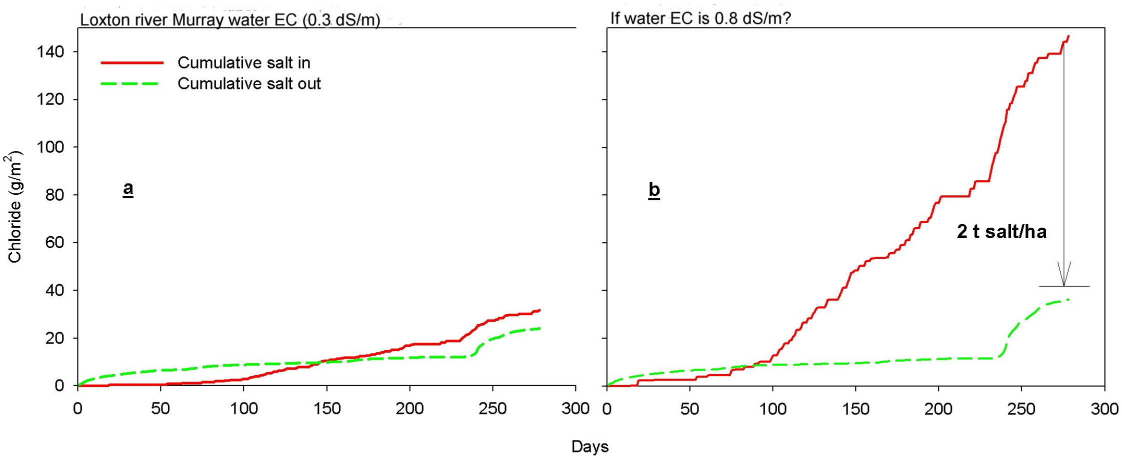

***Figure 4**. Results of a two dimensional salt transport model that predicts salt build up in the root zone with two different salinities of River water, the 0.3 dS/m (current level), and 0.8 dS/m the Morgan benchmark*

It is important to note that the fruit and leaf analysis for the 0.3 dS/m scenario showed no significant salt problem for either grapes or citrus except at one site.

Future direction

With more field data and calibration of capacitance probes, the team plans to further investigate the variations in deep drainage estimates that the different methods have shown. The detailed monitoring of daily and hourly changes in unsaturated hydraulic conductivity is proving critical to the estimation of deep drainage, as wetting periods are not homogeneous events. However the results to date suggest that deep drainage may have been over-estimated by the traditional water balance methods (Methods 1 and 3).

We plan to measure leaching efficiency and model the scenarios of different levels of River Murray salinities on root zone salinity accumulation for the current irrigation system and management practices. The aim is to develop a user-friendly root zone monitoring toolkit for growers and a modelling tool and field validation system for water managers to assess the risk of excessive root zone salinity for the Lower Murray irrigation districts.

We also plan to undertake an economic assessment of grower losses across the region under different River salinity scenarios by using previously developed salinity-yield relationships for different horticultural crops. This information is keenly sought by State government agencies who, through the Murray-Darling Basin Ministerial Council, are investing multi-million dollars in salinity mitigation works to reduce salinity in both the drinking and irrigation water in the Lower Murray region.

The outcomes of the 3 year project will be compiled in Salinity Management Guidelines with salinity triggers that will assist the different investors to identify their temporal and spatial options for salinity management from the perspective of irrigation water salinity management for the Lower Murray region. This information, combined with the environmental and socio-economic requirements, will lead to the best 'triple bottom line' outcomes for this important horticultural region of Australia.

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