VINEYARD IRRIGATION

Interactions between irrigation, salinity, leaching efficiency, salinity tolerance and sustainability

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Introduction

Most vineyards in Australia receive some irrigation. For what purpose? At first glance, the purpose could be stated 'to replace water used by the crop'. The degree to which this purpose has been achieved can be assessed by calculating the irrigation efficiency:

$$\text{Irrigation efficiency (\%)} = \frac{\text{amount of irrigation water used by the crop}}{\text{amount of irrigation water}} \times 100$$

In an ideal situation, the irrigation efficiency should equal 100%. For the ideal situation to occur, the irrigation water would have to contain no salts. Under less than ideal conditions, irrigation has a second purpose, 'to prevent salts introduced with irrigation water from building up in the soil to levels deleterious to plant growth'. This purpose is achieved by leaching the salts left behind when the crop extracts water.

The second purpose of irrigation is the subject of this article. Whilst the discussion will draw heavily on experiences in the irrigated areas along the lower part of the Murray River, the principles behind it are applicable in many other locations. This area, centred on the Riverland and Sunraysia regions, has had a long history of investigations into irrigation, salinity and drainage.

Irrigation water and soil salinity

In most circumstances, irrigation water is the major source of salt in the rootzone soils of irrigated vineyards. Along the River Murray, the salinity of irrigation water is generally quantified by measuring the electrical conductivity (EC) of the water, with salinity expressed in EC units (micro-Siemens per centimetre abbreviated as μS/cm). The weight of salt contained in irrigation water in milligrams per litre (mg/L) is equal to the product of the water EC and 0.55 (Phil Thomas, SA Water, pers comm.). Table 1 shows the amount of salt added per year for a range of irrigation water salinities and irrigation application volumes. Irrigation waters contain much more salt than rain. At Loxton, the average annual rainfall of 278mm (2.8ML/ha) adds salt at rate of 0.07t/ha (Kernich, 1984; Blackburn and McLeod, 1983). By way of comparison, a grapegrower who annually applies 7 megalitres per hectare (ML/ha) of moderate salinity water will add between one and two tonnes of salt to each hectare per year. Reducing annual irrigation volumes decreases the amount of salt added.

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Most types of salt in river water are highly soluble and remain dissolved when irrigation water percolates into the soil. Grapevines remove only a very small portion of the salt added in irrigation water. Therefore, we can estimate the effect that adding salt will have on the soil salinity, measured as the salinity of the saturated soil paste extract (ECe), from the values of the soil saturation percentage and the amount of salt added. Sandy clay loam soil, which is common in Riverland vineyards, has a saturation percentage

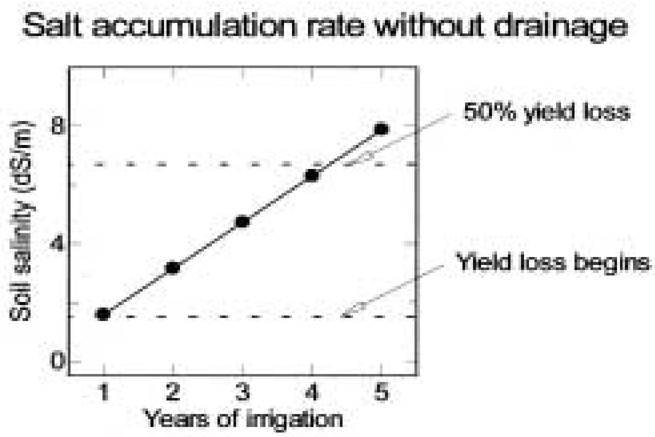

Fig. 1. The effect of annually applying 7ML of irrigation (450μS/cm) on soil salinity if no water drains from the rootzone. Dashed lines correspond to the soil salinity values at which salinity begins to reduce grapevine yield and where loss reaches 50%.

Table 1. Tonnes of salt added per hectare by irrigating with different volumes of water at range of salinities (1 ML = 100mm depth of water spread over an area of one hectare).

Irrigation water salinity (EC units, μS/cm)*	Annual irrigation volume (ML/ha) 5	7	11
300	0.8	1.2	1.8
450	1.2	1.7	2.7
600	1.6	2.3	3.6
900	2.5	3.5	5.4

* Salinity is usually expressed in micro-Siemens per centimetre (μS/cm) in water and in deci-Siemens per metre (dS/m) in soil; 1dS/m = 1000μS/cm.

of 40% (Cock, 1984). Figure 1 (pg.69) shows the effect that the annual addition of salts in 7ML of irrigation water would have on the salinity of a 0.5m deep rootzone of this soil, if no water drains from the rootzone.

The effect that a build up in soil salinity has on vine yield can be estimated using a relationship developed by the United States of America Dept. of Agriculture Salinity Laboratory (Maas and Hoffman, 1977). This relationship has been used to calculate soil salinities corresponding to the onset of yield decline and 50% yield decline. These values are indicated in Figure 1 by the use of dashed lines. By the end of the first season, the build up in soil salinity would have begun to decrease grapevine yield, and by the end of the fourth season the build up in soil salinity would be causing a 50% yield loss.

Irrigated viticulture is only sustainable if the salt added by irrigation is removed from the rootzone. Soluble salts can be removed from the rootzone by flushing it with water. Flushing occurs when the amount of water (either irrigation or rainfall) added to the rootzone is in excess of the soil's water-holding capacity. The excess drains out of the rootzone base carrying salts with it. This process of salt removal is known as leaching. The primary purpose of producing drainage water is to control soil salinity.

Drainage water and river salinity

The drainage water collects in subsurface drains or it flows downward to the underlying groundwater. Water will flow into subsurface drains whenever the surface of the perched or permanent watertable is above the drains. In the 1980s, a study of water balances of vineyards with subsurface drains in the Riverland showed that at many sites the drains collected only a small proportion of the water draining from the rootzone base (Cock *et al*., 1991). Since the 1980s, the prevalence of perched watertables has decreased. Therefore, drains are collecting less of the water flowing out of the rootzone base and a greater proportion is flowing as an accession (additions to groundwater are referred to as accessions) to groundwater.

Locally, it is the volume rather than salinity of drainage water which has received most attention. The volume is indicative of the hydraulic loading (the weight of water added to the top of an aquifer) that an accession of drainage water places on groundwater. In the Riverland, the River Murray cuts through an aquifer (a strata of porous rock which holds water and allows water to percolate through it) which contains highly saline groundwater. The salinity of the groundwater, above 40,000µS/cm, is much greater than that of drainage water, between 1800 and 4500µS/cm (Smith, 2002). An increase in the hydraulic loading on the aquifer increases the rate at which groundwater discharges into the River Murray. Irrigation increases the salinity of the River Murray by increasing the rate that this aquifer discharges into the river.

Drainage water volumes

How much drainage is being produced? Over the last decade there has been a number of irrigation benchmarking studies conducted in the Riverland and Sunraysia regions. Most studies have been based on calculations of vineyard water balances.

Under suitable field conditions, water balances can be derived for each irrigation or significant rainfall event from measurements of the depth of water applied and the soil water deficit just prior to application. Water applications in excess of the soil water deficit produce drainage with the amount equal to the depth of irrigation minus the pre-irrigation soil water deficit. The pre-irrigation soil water deficit represents crop water use since the previous irrigation. Estimates of irrigation efficiency (see earlier) are derived by expressing the seasonal crop water use as a percentage of seasonal application depth. The percentage of the application depth draining below the rootzone is equal to 100 minus the percentage irrigation efficiency.

A recent study of vineyards with pressurised irrigation systems found that the average irrigation efficiency was 82% (Giddings, NSW Agriculture, pers comm.). This value is the same as the average found amongst a group of peer-identified good irrigation managers by Skewes and Meissner (1997). Many irrigators in the Riverland-Sunraysia region are probably achieving efficiencies between 70 and 85%.

Leaching efficiency

The sole purpose of producing drainage is to leach salts. How efficient is our present leaching practice? In common with our assessment of irrigation efficiency we can describe the efficiency of the leaching process in terms of the ideal achievable.

Under ideal conditions, water added to the rootzone soil completely inter-mixes with water and soluble salts already present in rootzone soil before it drains out of the rootzone's base. Using a mathematical model based on this assumption, the ratio of salinity of the rootzone soil to salinity of applied water can be calculated from a knowledge of the percentage of applied irrigation water draining from the rootzone base (Ayers and Westcot, 1985). With average irrigation efficiencies ranging from 70-85%, the average percentage of applied water draining ranges from 30-15%, respectively. For irrigation practices where 30, 22 and 15% of applied water drains below the rootzone, Figure 2 shows the average rootzone salinities predicted by the model when irrigating with water salinities ranging from 200-900µS/cm.

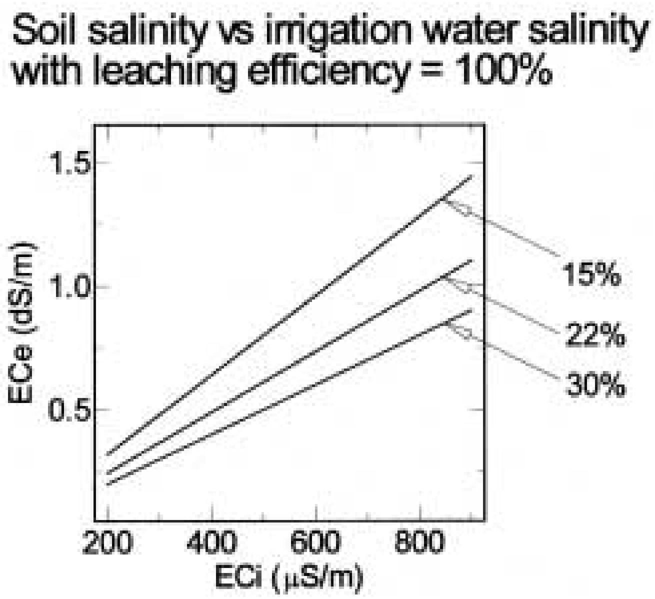

Fig. 2. The soil salinity (ECe) with 15, 22 and 30% of applied water draining for irrigation water salinities (ECi) between 200 and 900_S/cm under ideal leaching conditions.

From Figure 2 it can be seen that if the average irrigation efficiency lies somewhere between 70 and 85% and if leaching was occurring under near ideal conditions, then with irrigation water salinity at about 400µS/cm most values of soil salinity should lie below 0.6dS/m. In the Riverland during years when average irrigation water salinity is about 400µS/cm, surveys of vineyard soil salinity (ECe) frequently return values greater than 1dS/m with a value of 1.3dS/m (equal to 1300µS/cm) being common.

The mathematical model used to generate Figure 2 can be applied in reverse so that the percentage of applied irrigation water draining from the rootzone base under ideal conditions can be calculated from measurements of irrigation water and soil salinity. Applying the model in this manner to irrigation water and soil salinity values of 400 and 1300µS/cm, respectively (concentrations of Cl- at 6.4 and 2.1mmol/L, respectively), produces an estimate that 6% of applied water drains from the rootzone. That is, in such a vineyard, 6% of applied water is draining under ideal conditions.

The efficiency of leaching can be expressed by calculating how closely the amount of water draining under ideal conditions approaches the actual amount draining as follows:

$$\text{Leaching efficiency (\%)} = \frac{\text{proportion of irrigation water draining under ideal conditions}}{\text{proportion of irrigation water draining}} \times 100$$

If a vineyard such as that just discussed was achieving an irrigation efficiency of 85%, giving 15% of applied water draining below the rootzone, then with 6% of the water draining under ideal condition, the leaching efficiency equals 6/15 = 0.40 or 40%. Alternatively, if such a vineyard was only achieving an irrigation efficiency of 70%, then the leaching efficiency equals 6/30 = 0.20 or 20%.

How does leaching efficiency effect irrigation sustainability?

For irrigation to be sustainable in the long term its salinity impact on the river must be reduced. One of the major works being undertaken to reduce this impact is the construction of salt interception schemes. These consist of a series of wells that extract water from the aquifer between the points of accession and points of discharge. The water is pumped to evaporation basins that are hydrologically isolated from the river. The extraction lowers the hydrostatic pressure on the aquifer and thereby reduces the rate at which it discharges into the river, which in turn reduces the salinity impact of irrigation on the river.

What volume of water should the salt interception schemes aim to intercept? The present target for irrigation efficiency is 85%. If this target is met, then 15% of water applied will drain below the rootzone. In order to sustain irrigation, the wells will have to extract water at a rate that returns the hydrostatic pressure to a value associated with an acceptable rate of aquifer discharge into the river. It is likely that one of the design criteria for the schemes will be an upper limit on accessions equal to 15% of applied water.

A further criteria for sustainability of irrigation is that leaching rates must be high enough to prevent crop losses due to a build up of soil salt. Thus, for sustainability to be achieved we need to strike a balance between reducing the effect of accessions on river salinity and preventing salt building up to deleterious levels in the crop rootzone. Grapevines begin to lose yield at soil salinities above 1.5dS/m (Maas and Hoffman, 1977). Figure 3 shows the effect that irrigation water salinity and leaching efficiency have on the maximum irrigation efficiency achievable without soil salinity rising above 1.5dS/m. At irrigation water salinities below 300µS/cm, irrigators with leaching efficiencies at or above 30% will maintain soil salinities below 1.5dS/m with irrigation efficiencies greater than 85%. With irrigation water salinities below 600µS/cm, irrigators with leaching efficiencies at or above 60% will maintain soil salinities below 1.5dS/m with irrigation efficiencies above 85%. At water salinities below 900µS/cm, irrigators with leaching efficiencies at or above 90% will be able to maintain soil salinities below 1.5dS/m with irrigation efficiency above 85%. At a water salinity of 900µS/cm, irrigators with leaching efficiencies of 30 and 60% will only prevent salt build up in soil if they drop their irrigation efficiencies below 54 and 77%, respectively. Next year, river salinity in the lower reaches is likely to rise above 900µS/cm unless the drought breaks in the eastern portion of the Murray Darling Basin.

Present approaches to sustaining irrigation and the River Murray assume that irrigation efficiency can reach 85% without loss of yield due to soil salt build up. Whenever river salinities rise above 600µS/cm, this goal will not be reached unless leaching efficiencies are greater than 60%.

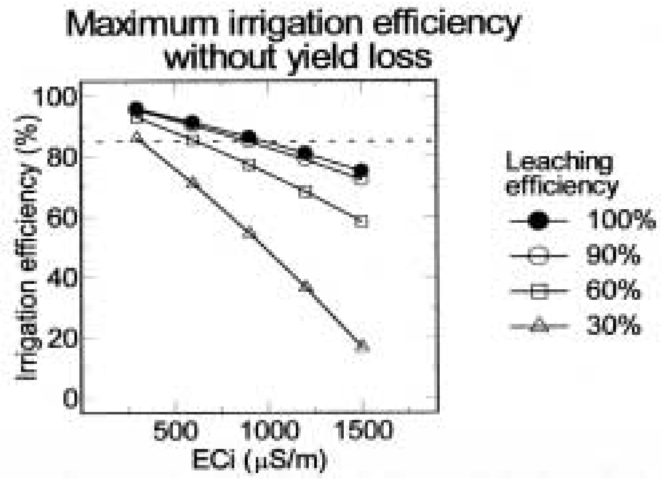

Fig. 3. The maximum irrigation efficiency at which the rootzone salinity remains below 1.5dS/m for a range of irrigation water salinities and four leaching efficiencies. Dotted line indicates 85%.

The role of salt tolerance in sustaining irrigation

The use of rootstocks can increase the salt tolerance of grapevines (Zhang *et al*., 2002). Let us consider a rootstock grapevine that does not begin to lose yield until soil salinity rises above 2.5dS/m, as opposed to a threshold salinity of 1.5dS/m for own-rooted vines. Figure 4 shows the effect that irrigation water salinity and leaching efficiency have on the maximum irrigation efficiency achievable without soil salinity rising above 2.5dS/m. At irrigation water salinities below 500µS/cm, irrigators with leaching efficiencies at or above 30% will maintain soil salinities below 2.5dS/m with irrigation efficiencies above 85%. Irrigators with leaching efficiencies greater than or equal to 60% will maintain soil salinities below 2.5dS/m with irrigation efficiencies above 85% for water with a salinity of up to 1000µS/cm.

With salt tolerant vines, the present approach to sustaining both irrigation and the River Murray by irrigating with an efficiency greater than 85% can be reached with leaching efficiencies greater than 60% at river salinities below 1000µS/cm.

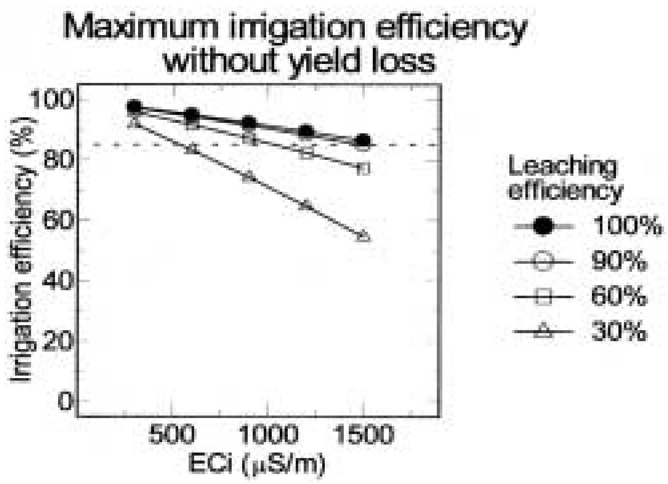

Fig. 4. The maximum irrigation efficiency at which the rootzone salinity remains below 2.5dS/m for a range of irrigation water salinities and four leaching efficiencies. Dotted line indicates 85%.

Why is leaching not 100% efficient?

In vineyards with leaching efficiencies less than 100%, some of the water added by irrigation inter-mixes with water and soluble salts already present in rootzone soil before it drains out of the rootzone's base and the rest drains under less ideal conditions. This water bypasses the inter-mixing process and in doing so fails to pick up salt as it moves out of the rootzone base (see van der Molen, 1972, for discussion on bypass flow).

Can irrigation management effect leaching efficiency? It has been known for a long time that the amount of fresh water needed to reclaim saline soils is dependent on the method used to apply the water to the soil surface. If the water is applied by intermittent sprinkling, then much less is required than if it is applied by ponding on the soil surface (Hoffman *et al*., 1980). This observation indicates that the application method can produce a large variation in leaching efficiency.

Why haven't we heard much about leaching efficiency?

At low irrigation efficiencies, leaching efficiency is unlikely to limit control of soil salinity. Twenty years ago, a study of vineyard water balances in the Riverland found that the average irrigation efficiency was 51% (Cock *et al*., 1991). Over the last two decades, the widespread provision of training in irrigation management, conversion of supply infrastructure to support scheduling that matches application rates to soil water storage capacity and crop water requirements, and the introduction of pressurised irrigation have all been associated with a significant rise in vineyard irrigation efficiency. With this rise in irrigation efficiencies, leaching efficiency could become an important factor limiting control of soil salinity.

The development of regulatory linkages between irrigation and its off-site salinity effects began in the late 1980s with the Murray Darling Basin Commission Salinity and Drainage Strategy. Since this time, there has been a progression to draw more and more irrigators under the ambit of legislation that makes them responsible for their salinity impact on the River Murray, for example, water allocation plans or salinity management plans. It is likely that this responsibility may require the purchase of an off-set to the salinity impact, for example, the purchase of salinity credits generated by a scheme that intercepts saline groundwater inflows and diverts them to an evaporation basin some distance from the river. The cost of credits will be proportional to the volume of drainage. Producing drainage with high leaching efficiency will minimise this cost.

A rise in irrigation efficiency coupled with the development of linkage between the cost of irrigation's salinity impact and drainage production will probably provide the impetus for increased interest in leaching efficiency.

Conclusions

- Irrigation water contains a significant amount of salt and in order to sustain irrigated horticulture, salts must be leached from the soil.
- Drainage water generated by leaching increases the rate that a highly saline aquifer discharges into the Murray River and this discharge increases river salinity.
- About 20% of the water applied to vineyards drains below the rootzone and ad hoc measures of soil salinity suggest that less than half of the draining water is involved in leaching salts.
- Low leaching efficiency may confound efforts to achieve the twin goals of sustaining the River Murray through reducing drainage-induced rises in river salinity and sustaining irrigated horticulture through preventing the build up of soil salts.
- Investigations into the causes of variation in leaching efficiency and the use of salt-tolerant cultivars may assist in realising these sustainability goals.

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Industry award for irrigation technique

The research team behind partial rootzone drying (PRD) has been presented with an Excellence in Natural Resource Management Science Award by the board of Land & Water Australia.

An irrigation technique now familiar to many winegrape growers, PRD involves imposing a watering regime that allows part of a plant's root system to dry up. Roots that are in the drying zone send signals to the leaves to slow down the rate of water use. The plant behaves as though it is in drought and directs its resources into the ripening of fruit rather than putting on more leaf and cane growth, resulting in a significant reduction in water use without suffering the usual problems associated with reduced irrigation.

CSIRO Plant Industry researcher, Dr. Brian Loveys, accepted the award on behalf of his research team, which also includes Professor Peter Dry, from the University of Adelaide, and Dr. Michael McCarthy, from the South Australian Research and Development Institute.

The board of Land & Water Australia said PRD represented "a quantum leap in sustainability and improved water management for the Australian irrigation industry".

Loveys said recent increased interest in the area had resulted in several successful collaborations with researchers, viticulturists, wine companies and growers in Australia and overseas.

"It is very gratifying that this work - which essentially arose from a simple plant physiology question - has led not only to a much better understanding of the way plants control their use of water, but also to a commercial outcome," he said.

Land & Water Australia board chairman, Bobbie Brazil, said presentations of Excellence in Natural Resource Management Science awards were not made often or lightly.

"This is not an annual or regular award but on rare occasions the board takes the opportunity to recognise an outstanding research contribution," Brazil said. "This is just such an occasion, reflecting exceptional research that should lead to great benefits for water management in Australia."

PRD was the only water-based technological innovation selected in the top 100 innovations of the last century by the Australian Academy of Technological Sciences and Engineering and the Powerhouse Museum last year. ■