GRAPE AND WINE RESEARCH AND DEVELOPMENT CORPORATION

Salinity Management

Interpretation Guide

A guide for the wine grape industry – SA Central

Salinity Management

Interpretation Guide

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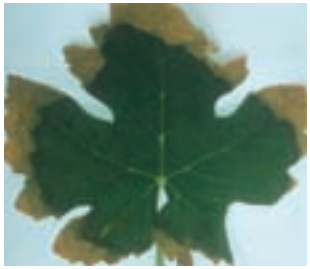

Title

Salinity Management Interpretation Guide

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Front cover:

Measuring salinity of the soil water extract (source: SARDI); Vine leaf showing signs of salinity toxicity (source: Alf Cass).

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1. Aim of the interpretation guide

This Guide is a practical reference for vineyard managers who want to learn more about the principles of 'best management practice' for salinity.

The following questions are addressed:

- What is salinity?
- How is a salinity problem caused?
- What are the affects of salinity on wine grape production?
- How can salinity be identified and monitored in a vineyard?
- How can salinity be managed to minimise future impacts?

If your vineyard is not showing any signs of salinity, this guide will inform you how to monitor your vineyard (vine, soil and water) on an on-going basis to help identify any developing salinity problem.

If salinity has been identified as an issue on your property, this guide will also help you to understand and apply management practices that reduce salinity impacts on your vineyard through a variety of 'best management practice' options. Some of these best management options are well established while others are not and are more based on emerging science in relation to the interaction between the vine and saline conditions (eg intra-seasonal variation in salt accumulation in vines). Hence, any change in management to combat salinity should always be accompanied with a monitoring program to check its effectiveness.

The associated issue of sodicity limitations in vineyards is also discussed. Sodicity is a soil property which is often associated with irrigation with saline or brackish water, as a result of the accumulation of too much sodium leading to structural decline of the soil.

It is important to note that salinity and/or sodicity problems in vineyards are not terminal. The processes involved are reversible, albeit over a period of time (ie years). Like most agronomic problems, prevention is always better than a cure. However, some problems in the vineyard are inherent and require unique solutions (eg shallow duplex soils).

This guide does not set out to be a comprehensive textbook about salinity in vineyards. However, enough information has been provided to allow growers to ask good questions of their advisors and get high-quality vineyard management guidelines for their particular circumstances.

It is recognised that some of the terms used in this guide may not be familiar to some readers. A glossary is provided at the back of this publication that lists terms that are used throughout the interpretation guide and more generally.

2. Background facts about salinity

What is salinity?

The term salinity refers to the presence of soluble salts in water and soil systems. The presence of salinity in the plant root zone can have a major impact on the performance of a crop and is arguably the biggest threat to irrigated agriculture. The sources of soluble salts that can accumulate in the soil water beneath grapevines include;

- Salt imported to a field via irrigation water,
- Saline ground water/water tables,
- Weathering of soil minerals, organic materials and the underlying rock in a vineyard,
- Ocean-derived salts blown inland and carried to ground in rain and/or dust,
- Soluble nutrients and ameliorants such as fertilisers and gypsum that are applied to soil, and
- Cleaning agents added to drip irrigation systems (eg. the use of sodium hypochlorite is a source of chloride that adds to the salt load of the irrigation water).

Salinity is commonly measured as the Electrical Conductivity (EC) of a water solution. EC is a measure of the ability of a liquid to pass an electric current; it increases as the salinity (salt concentration) of a liquid increases. EC is commonly given in units of dS/m (deci-Siemens per metre). Salinity can be measured directly from a sample of irrigation water but is measured in soil using either one of two methods: saturated paste extract (EC_e) or, the inexpensive but less reliable 1:5 soil water extract ($EC_{1:5}$).

A soil is defined as being saline when the level of salinity of soil water (concentration of ions) adversely affects plant growth. However, plants have different susceptibilities to soil salinity. In Australia, soil salinity is predominantly due to salts of sodium: sodium chloride (NaCl), sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$). Whilst all salts contribute to a salinity effect, some salts have beneficial effects to crops outside of salinity like fertilisers and gypsum. Gypsum (calcium sulphate; $CaSO_4.2H_2O$) is regarded as a desirable salt because it is only sparingly soluble and contains beneficial components – particularly calcium and sulphur. Calcium carbonate ($CaCO_3$) is another salt that can be introduced via irrigation water. It is only slightly soluble in water and a valuable source of calcium, but is associated with alkaline conditions that may limit nutrient availability to plants.

Salinity derived from a rising watertable

Salt occurs naturally in the soil but salinity can become a major problem when the groundwater is allowed to rise close to the soil surface. Shallow saline water tables at less than about two metres from the surface can cause salt to accumulate in the root zone of crops. The drier soil surface condition allows capillary action to transport saline ground water to the soil surface. Evaporation and plant transpiration removes soil water leaving the salts behind in the upper layers of soil profile (Figure 2.1).

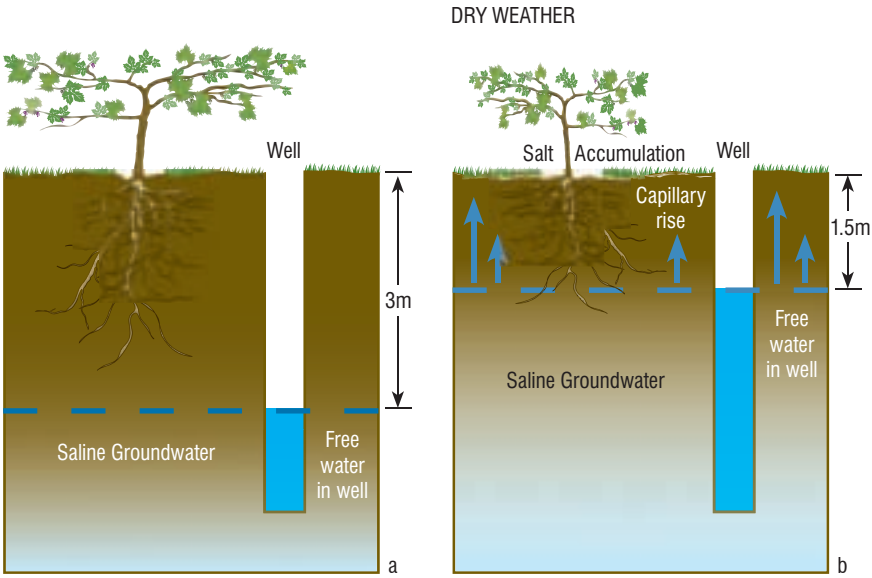


Figure 2.1. Processes associated with the development of salinity problems via capillary rise: (a) Negligible salinisation of the topsoil from capillary rise; (b) Active capillary rise, in response to evaporation during dry weather, from a water table within 2 metres of the soil surface

The degree of salinisation as a result of rising ground water is a function of depth and salinity of ground water, rainfall, the hydraulic properties of soil and the vegetation cover of the soil surface. This form of salinity often results in land scald and the effects are easily visible on the surface.

Transient salinity

Transient salinity (Figure 2.2) is an accumulation of salt in the root-zone that can cause significant productivity losses. This accumulation of salt usually occurs without the influence of rising saline groundwater. The level of salinity under these conditions may not be as high as levels found in salinity caused by shallow groundwater, but it can be sufficient to cause significant crop yield

losses, particularly in dry seasons. Transient salinity is caused by a reduction in the movement of water and salts out of (below) the root-zone. Evapotranspiration removes water from the root zone and leaves behind salt at the same time. It occurs in soils where the movement of water through the soil profile is slow and can fluctuate according to soil depth, irrigation and rainfall.

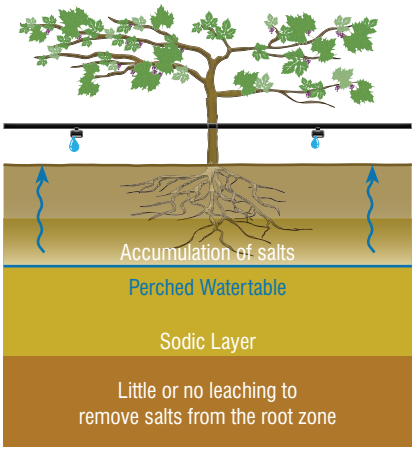


Figure 2.2. Formation of transient salinity as the result of a sub-surface sodic layer with poor hydraulic conductivity. A sodic layer has an excess of sodium ions on the clay particles, which leads to waterlogging when wet and excessive hardness when dry.

The amount of salt that is imported via irrigation has a significant effect on transient salinity. The amount of water applied and quality of the irrigation water determine the amount of salt that is applied to a vineyard (Table 2.1).

Table 2.1. Kilograms of salt applied per hectare for different salinity irrigation water and different irrigation rates

Water Salinity#		Irrigation water applied (mm)*				
dS/m	ppm	20	50	100	150	200
0.2	160	25.6	64	128	192	256
0.5	320	64	160	320	480	640
1	640	128	320	640	960	1280
1.5	960	192	480	960	1440	1920
2	1280	256	640	1280	1920	2560
2.5	1600	320	800	1600	2400	3200

*100 mm of water applied to 1 hectare is equivalent to 1 ML
units conversions are found in the appendix (Table B.2)

What causes salinity damage in plants?

There are two main causes of salinity damage in plants.

1. The osmotic effect, which adversely affects energy expenditure and water uptake by plants. This creates a condition referred to as "chemical drought" – plants wilt because of a shortage of water, even though the soil remains moist.
2. Direct toxicity of salts – particularly from sodium (Na) and chloride (Cl) ions though boron (B) toxicity can also be an issue.

Crops may be affected by either the osmotic effect or salt toxicity or by both. At low salt concentrations toxic ions play a dominant role; at high salt concentrations, it is the osmotic effect that plays a major role.

The osmotic effect

Figure 2.3 shows the osmotic effect in plants. Water moving into roots is slowed down as the concentration of salt in the soil water increases. This reduces the water available to plants for growth and yield.

Soil moisture content can change dramatically between rainfall events. This variation in soil moisture directly affects the salt concentration of the soil water. The higher the soil moisture content (wetter the soil), the lower the concentration of salts, and conversely, the lower the soil moisture content (drier the soil) the higher concentration of salts. As soils become drier there is less water accessible for plants and the soil water becomes increasingly difficult to extract (matric potential effect). In saline soils there is the added complexity that as salt concentration increases as the soil dries then the plant's ability to 'suck' water from the soil is further reduced (osmotic effect). The effect of increasing salt concentration in the soil on plant available water is shown in Table 2.2.

Ionic toxicity

Sodium, chloride and boron are specific components of soil and water salinity that can negatively impact on vine growth. These ions can reduce growth in two ways:

- Direct toxicity
- Indirect effects on nutrient uptake and balance

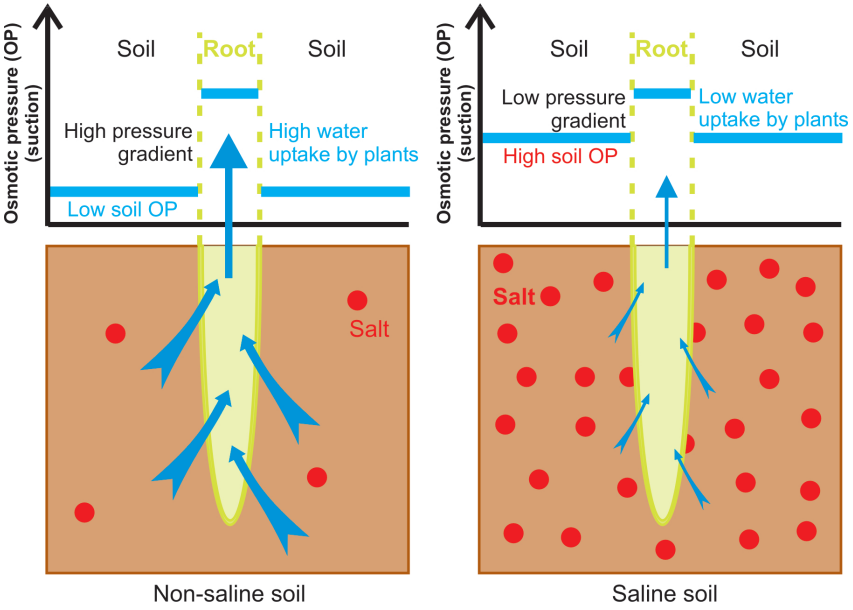
Many of the effects of sodium and chloride are difficult to tell apart and these two elements are commonly found together in soil and water.

Sodium is not an essential element with most plants being natrophobic (sodium hating) and having mechanisms to exclude sodium from uptake by the roots. The use of rootstocks that limit the uptake of sodium can form an effective sodium management strategy.

However, vines that can exclude sodium at the roots may still suffer damage from leaf-absorption of sodium. High levels of sodium in the soil can also interfere with the uptake of potassium and calcium by the vines leading to potential deficiencies in these essential nutrients.

Chloride is an essential plant micro-nutrient and is easily absorbed through the roots and leaves of the vine. However, high concentrations can lead to chloride toxicity and can also reduce production through imbalances with other nutrients. Chloride can compete with nitrate-nitrogen and phosphates for uptake by plant roots leading to deficiencies in these elements at high levels of soil water chloride.

Boron, like chloride, is a negatively charged anion. While low concentrations of boron are essential for plant growth, it becomes toxic at concentrations only slightly higher than that required for optimum growth.



Sourec: Kelly and Rengasamy (2006)

Figure 2.3. The relative water uptake by plants in saline and non-saline soils. In the saline soil the osmotic pressure associated with the salt reduces the pressure gradient between the soil and the root, reducing the flow of water into the root. This reduces the water available to the plant for growth and yield.

Table 2.2. Percentage of available soil water not taken up by plants in different soil types, due to osmotic effect of a given soil salinity.

Laboratory measured soil salinity	Percentage of available soil water not taken up by plants due to osmotic pressure (>1000 kPa) of soil water salinity			
$EC_{1:5}$ (dS/m)	Sand	Sandy loam	Clay loam	Clay
0.11	0	0	0	0
0.25	25	0	0	0
0.39	50	0	0	0
0.50	70	25	0	0
0.72	100	50	15	0
1.00	100	81	40	4
1.11	100	94	50	12
1.25	100	100	63	22
1.50	100	100	85	40
1.64	100	100	98	50
1.75	100	100	100	58
2.00	100	100	100	76
2.33	100	100	100	100

Note: Field soil moisture is on the basis of gravimetric water content. Available soil water is calculated from the field capacity and wilting point for each soil type. It is assumed that soil salinity is due to highly soluble salts such as sodium chloride. These data are not valid when the salts present are sparingly soluble such as gypsum.

How does salinity affect wine grape production?

Grapevines are regarded as moderately sensitive to salinity. Salinity affects wine grape production through both osmotic and ionic processes. The effect of increasing salinity is first observed by a reduction in vine growth followed by a decline in vine yield if saline conditions persist. The reduction in vine growth generally occurs when the average root zone salinity over the growing period exceeds a designated threshold value. Our understanding of thresholds is not comprehensive, so we can only suggest indicative values and is dependent on variety and what rootstock is used. A list of variety and rootstock threshold values is given in Appendix A. A generalised response of own rooted grapevine growth to increasing soil water salinity is given in Figure 2.4.

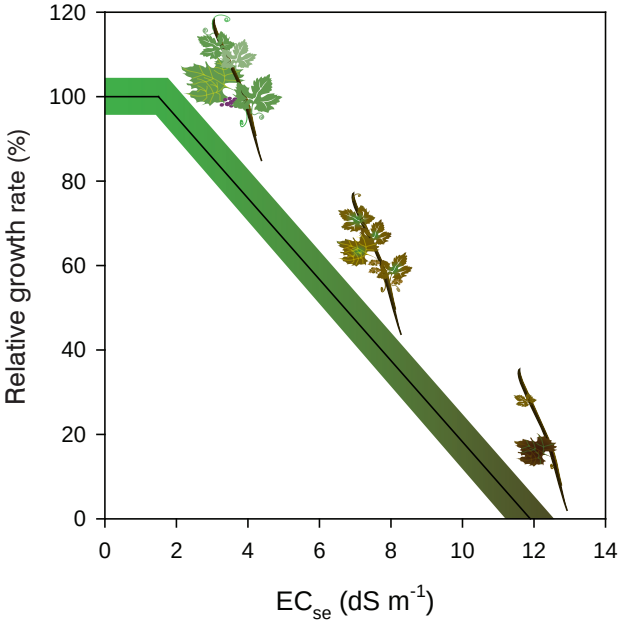
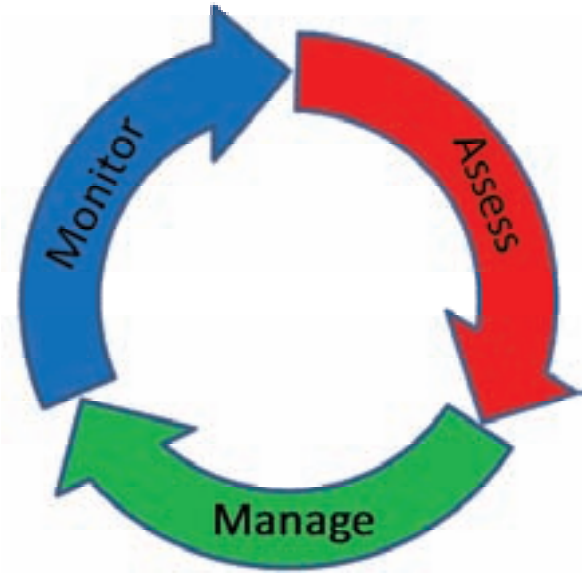


Figure 2.4. The relative response of vine growth to soil salinity (EC_{se}) where EC_{se} is the electrical conductivity of the saturated extract (Source: Mass and Hoffman 1977)

The degree of salinity also affects the amount of ions that accumulate in the vine, grape and ultimately wine. Our understanding of ion accumulation dynamics in grapes is not comprehensive but is dependent on variety and what rootstock is used (see Appendix A). The Australian Food Standards Code (P4) (www.foodstandards.gov.au) specifies an upper limit of 1,000 mg/L soluble chlorides expressed as sodium chloride (606 mg/L of Cl^-). Whilst there is no standard for sodium (Na^+) in Australia, there are some potential export destinations including Canada, Switzerland and Poland that do specify maximums for sodium which range from 60 to 500 mg/L of Na^+.

Saline soil conditions can also cause soil to become sodic. If sodium is present in high amounts in poor quality irrigation water, it may replace calcium attached to clay particles. Soil then becomes sodic causing soil structural decline and is more prone to waterlogging and setting hard when dry. Hence, there is a close relationship between salinity and sodicity.

The following sections detail how to assess the presence of a salinity problem such as visual signs and analytical tests (Section 3), how to monitor changes in vineyard salinity such as routine petiole tests (Section 4), and what management practices can be used to combat the presence and development of saline and related conditions such as sodic soils (Section 5). The key to good salinity management is based on the principles of assess, manage and monitor whereby the effectiveness of a management practice is monitored and assessed and changes made accordingly.



3. Assessment – diagnosis to determine if a problem really is related to salinity

There are many reasons why vines might perform poorly or decline in health. To determine whether a salinity problem is developing or developed you can us a number of visual and analytical methods. It is best not to rely on just one observation but to use a number of different diagnostic tools e.g. visual cues and tissue testing.

Visual signs

There are a number of visual signs of a developing or developed salinity problem. Whilst visual signs of salinity can be dramatic they should always be accompanied with either soil analytical testing or vine tissue testing so that misdiagnosis is avoided (Figure 3.2). Some general visual signs are listed below.

Vine signs

- Shoot growth declines
- Leaves appear smaller and darker than normal
- Marginal and tip burning of leaves, followed by yellowing and bronzing (Figure 3.1a-d). (Visual symptoms of sodium and chloride toxicity are very similar)

Mid-row signs

- Slow germination and growth of inter-row pasture/crop species
- An increase in the variability of inter-row pasture/crop health
- Increasing numbers of salt-tolerant weeds

Soil signs

- A white crust on the soil surface (Figure 3.1e)
- Unusually friable soil structure in low-lying areas
- Flocculation of suspended clay particles to give unusually clear water in puddles and drains
- Damp patches in otherwise dry soil

Site signs

- Death of trees in surrounding areas where severe problems occur (Figure 3.1f)

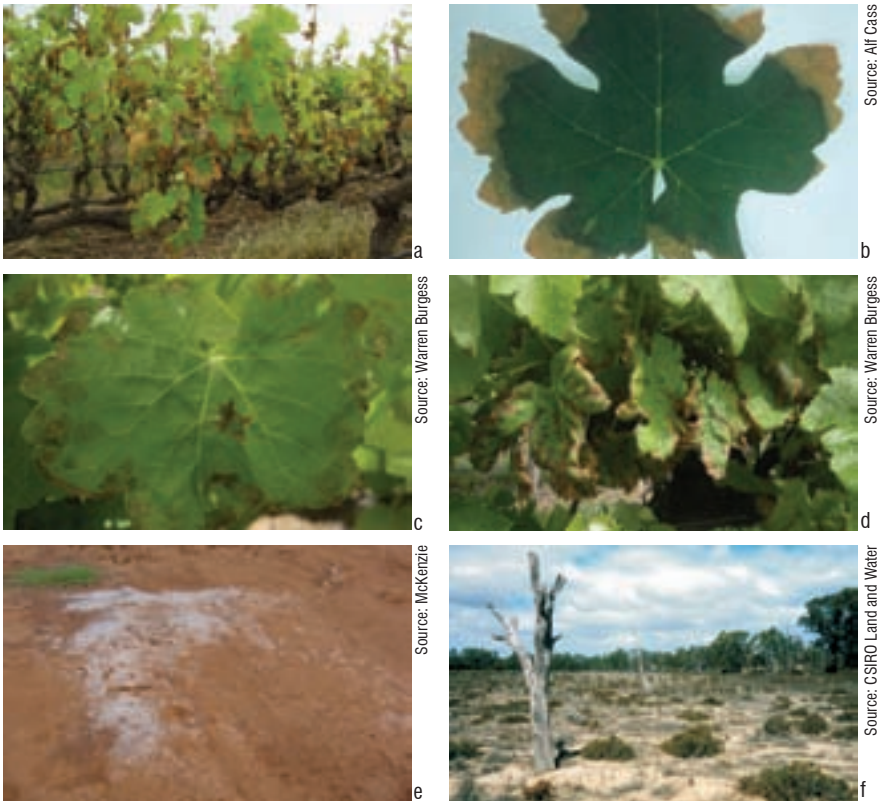


Figure 3.1. Visual symptoms of salinity problems: (a) chloride toxicity on leaves (b), leaf burning on vines, (c&d) sodium toxicity, (e) salt crystals on soil surface, (f) death of nearby trees.

There are also other environmental conditions that cause visual signs that look similar to that caused by salinity. Examples of these include potassium deficiency and heat stress. Potassium deficiency causes leaf edge burning and rolling of older and mid-shoot leaves (Figure 3.2a). The effects of heat stress is caused by elevated leaf temperatures due to stomata closure (evaporation through the stomata cools the leaf) which results in cell death. This usually results in a broad burning/yellowing across the leaf and is not confined to the leaf edges (Figure 3.2).Hence, it is important not to rely on visual symptoms alone but to also check potential salinity problems through either soil or vine analyses.

Source: Marti Longbottom

a

Source: Peter Dry

b

Figure 3.2. Examples of visual symptoms that could be confused with salinity symptoms: (a) potassium deficiency and (b) leaf senescence from heat stress.

Note: The osmotic effect of saline conditions in the soil can cause an increase in the susceptibility of vine to heat stress and the resultant leaf senescence.

Vine analysis

Grapevines integrate a broad range of topsoil and subsoil factors including the quality of the available water in the root zone. Hence, the measurement of salt levels in grapevine tissue offers the most direct method in assessing the presence of problematic saline conditions. This is often done through the collection of petioles at flowering and analysis through a recognised laboratory. Petiole analysis values at flowering of greater than 0.5% sodium and more than 1.0-1.5% chloride are considered to be toxic to vine health and are sure signs of a salinity problem (Robinson 1992). Adapting information from sources such as Robinson 1992, Robinson *et al.* (1997) and references therein simple interpretation charts can be developed to assess the petiole analysis against (Figure 3.3 to Figure 3.6).

Measurements performed later in the season, such as petiole analysis at veraison and juice analysis during vintage, provide little opportunity to initiate management strategies to reduce the effects of salinity within the season and are more suitable for inter seasonal monitoring (Section 4). However, these measures can be used to assess the presence of saline conditions in the vineyard (Figure 3.5 to Figure 3.7) which will be useful for adjusting management practices in subsequent seasons.

Petiole Chloride (%) (Flowering)

Figure 3.3. Interpretation of flowering petiole results for chloride (%) on a dry weight basis

Petiole Sodium (%) (Flowering)

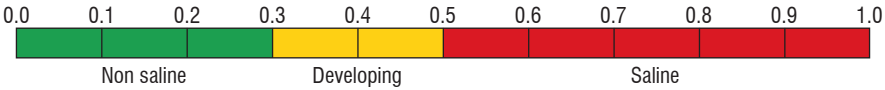


Figure 3.4. Interpretation of flowering petiole results for sodium (%) on a dry weight basis

Petiole Chloride (%) (Veraison)

Figure 3.5. Interpretation of veraison results for chloride (%) on a dry weight basis

Petiole Sodium (%) (Veraison)

Figure 3.6. Interpretation of veraison petiole results for sodium (%) on a dry weight basis

Free run juice Chloride (mg/l)

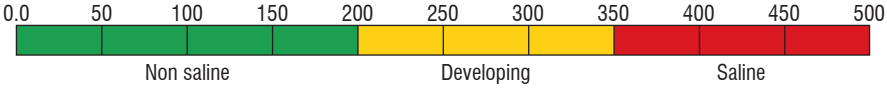


Figure 3.7. Interpretation of free run juice chloride (mg/l)

Note: Vine chloride and sodium uptake and translocation around the vine vary depending on variety and rootstock (Walker et al 2010). Hence, interpretations at different times and organs may lead to differing assessments.

Soil analysis

Soil sampling for salinity analysis is often used as a diagnostic tool to identify the existence of saline soils. However, its use in assessing the cause of vine growth decline should be treated with care. The problem with using a soil analysis is that the soil samples taken do not necessarily represent the root zone in which the vine is growing. In some instances, especially in drip irrigated vineyards, areas in the soil profile can develop significantly high salinity levels but only represent a small portion of the soil volume accessed by the vine roots. This is illustrated in Figure 3.8 showing 4 zones of interest when assessing salinity, as well as associated soil properties and root growth, in an established vineyard. Nevertheless, an overview of the sensitivity of grapevines to average soil salinity in the root zone is presented in Table 3.1. These threshold values are often assessed against soil samples taken along the vine row which have been sent to a recognised laboratory where the EC level is determined by saturated extract (EC_e).

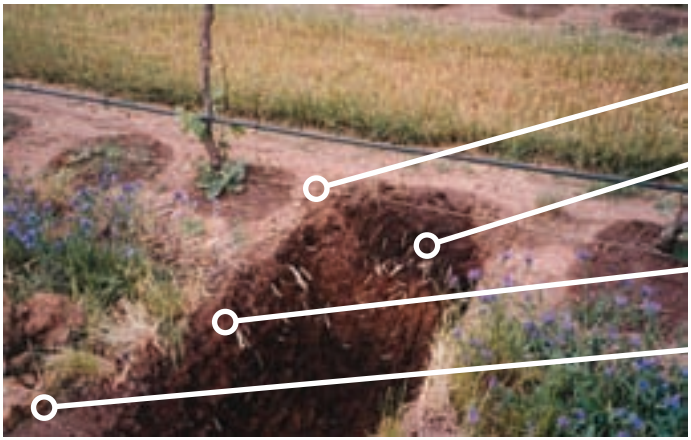


Figure 3.8. Soil sampling positions that take into account the patterns of variation in soil condition induced by a drip irrigation system (Source: McKenzie).

Figure 3.9. Surface soil inspection (0-10 cm)

Table 3.1. Criteria for average root zone soil salinity (EC_e) and potential yield reductions for vines

Salinity hazard	EC_e dS/m	Vine yield reduction (%)	Effects on grapevine growth
Non-saline	< 2	<10	Negligible effect on vines
Slightly saline	2 – 4	10-25	Own-rooted vines begin to be affected
Saline	4 – 8	25-50	Own rooted vines severely affected but some rootstocks are unaffected
Very saline	8 – 16	>50	Grapevines cannot be grown successfully
Highly saline	> 16	0	All grapevines will die

(adapted from Cass *et al.* 1995)

Soil salinity can be tested in the field unlike petiole analysis. Soil salinity is usually measured in the field using a 1:5 soil water suspension ($EC_{1:5}$). Whilst $EC_{1:5}$ is related to the salinity determined by saturated extract (EC_e) the relationship is influenced by soil type. This general relationship is shown in Figure 3.10 as well as its interpretation to salinity severity of the soil. Measuring soil salinity in the field is shown diagrammatically (Figure 3.9) and using the following steps.

To measure $EC_{1:5}$ in the field:

1. Put 50-80 ml of air dried, loose soil into an appropriate sized jar (minimum capacity 500 ml).
2. Add distilled water or clean rainwater into the jar at 5 times the volume of the soil sample. *Example: 50 ml of soil = 250 ml water.* Marking the side of the jar will aid with ratio, (see figure 3.9).
3. Put the lid on and shake the solution for two to five minutes then allow it to settle for five minutes.
4. Dip the EC meter into the top, clear part of the solution and take a reading and note the units.
5. Remember to wash the EC probe in rainwater after using it.

Note: EC meters can give readings in a variety of different units. This is dependant on the brand of meter and the salinity level of the sample. It is important to convert the reading into the correct units before you do any conversion to EC_e or compare your readings to any Soil salinity threshold tables. This test is only approximate and should be followed up by laboratory analysis. However, if on-farm measurements are done properly they can be effective in assessing and benchmarking soil salinity and hence be relied upon when making management decisions.

Loamy sand	0	0.15	0.31	0.46	0.62	0.77	0.92	1.08	1.23	1.38	1.54
Loam	0	0.18	0.36	0.55	0.73	0.91	1.09	1.27	1.45	1.64	1.82
Sandy clay loam	0	0.22	0.44	0.67	0.89	1.11	1.33	1.56	1.78	2.00	2.22
Light clay	0	0.29	0.57	0.86	1.14	1.43	1.71	2.00	2.29	2.57	2.86
Heavy clay	0	0.40	0.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	4.00
	0	2	4	6	8	10	12	14	16	18	20

$EC_{1:5}$

EC_e

Non saline | Slightly saline | Moderately saline | Very saline | Highly saline

Figure 3.10. Interpretation of soil EC (dS/m) measurements determined by 1:5 soil water suspension ($EC_{1:5}$) or by saturated paste extract (EC_e) (adapted from Cass *et al.* 1995)

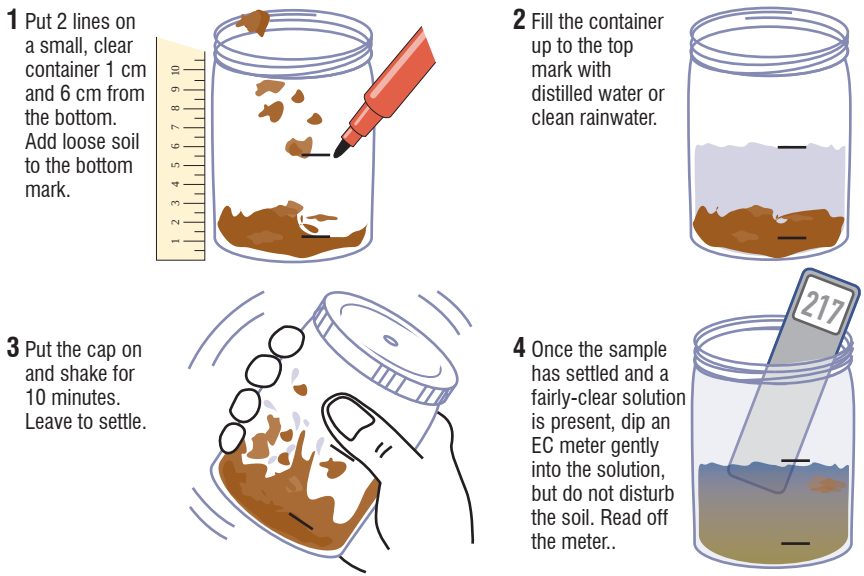


Figure 3.9. Rapid assessment of salinity in the field using a portable EC meter.

Remote sensing

The development of a salinity problem is not usually uniform and is influenced by underlying geology, soil profile properties, position in the landscape and previous land use. Variation in vine performance across a vineyard, often related to vine size, can be assessed using remote sensing technology such aerial imagery (Figure 3.11). Sampling areas or zones of different performance, either vine or soil, can help determine whether the variation in vine performance is related to salinity. An alternative method is the use of electromagnetic induction (EM) devices such as the EM38 (Figure 3.12a). EM38 surveys are often associated with the measurement of salinity however the EM38 device responds to a number of soil factors eg soil moisture, clay content and salinity. If using this device to determine salinity variation soil sampling should always be carried out at each site to calibrate the instruments against measured soil properties. The result maps of the EM38 output (Figure 3.12b) can then be related to the soil property dominating the variation in the EM38 output.

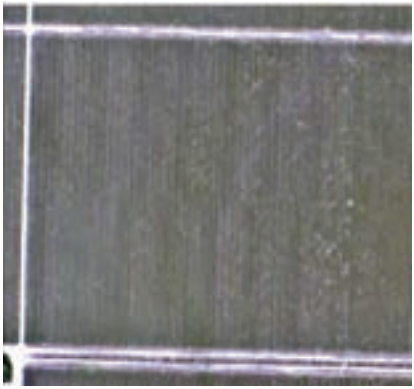


Figure 3.11a. Digital aerial imagery data is used to create maps of indices of vine variations eg PCD

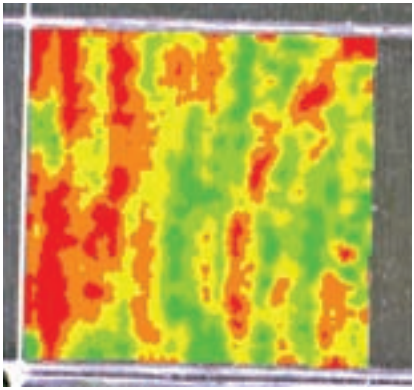


Figure 3.11b. Resultant PCD map from aerial imagery data

Figure 3.12a. EM38 being used to determine potential salinity variation in a vineyard

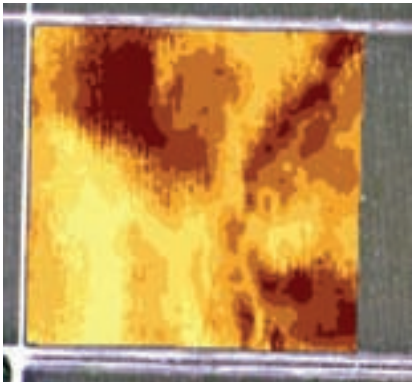


Figure 3.12b. Resultant EM38 map showing the variation in the vineyard

4. Monitoring: Is salinity getting better or worse?

The importance of monitoring

The previous section described options for the assessment of salinity status in vineyards via the consideration of visual cues and vine and soil measurements. These observations represent a snapshot in time and are influenced by seasonal conditions, sampling location and inter seasonal variation. Because of these potential variations it is important to establish a vineyard monitoring program to quantify the trends in vineyard salinity over time. A monitoring program in vineyards allows managers to assess whether management practices are lowering, maintaining or increasing salinity risk in the vineyard. It provides an early warning system of salinity trends that may eventually lead to serious salinity problems. Anticipation of a problem allows preventative action to be taken by vineyard managers in a cost-effective manner. This section outlines a number of monitoring options as well as how to interpret the data you collect.

Irrigation based monitoring

Water quality (e.g. salinity level) must be measured and recorded, as poor quality water can affect fruit quality and create long-term soil problems. Measurement of water quality for potential problems associated with salinity and sodicity will indicate if there is any deterioration of the water supply. Management changes can then be implemented if potential problems with water quality are evident such as extra leaching events and applications of gypsum.

Quality of the irrigation water should be assessed at least 4 times during the growing season.

Salinity

The addition of salts to the soil has both a toxic and osmotic effect on vine growth and health. The osmotic pressure of the irrigation water is often overlooked. Table 4.1 shows that considerable osmotic pressure exists for water qualities greater than 1 dS/m that are outside the readily available water range. The vine is required to work against osmotic potential as well as the matric potential (what is measured when using a tensiometer) when this water is added to the soil.

Table 4.1. Relationship between water EC (dS/m) and the osmotic water potential

Water EC (dS/m)	0.1	0.2	0.5	0.75	1	2	4
Osmotic Potential (kPa)	-5	-10	-24	-36	-48	-96	-192

Note: this table can also be applied to water extracted from the soil (eg SoluSAMPLER™)

Salinity thresholds for irrigation water in vineyards are presented in Table 4.2. To help you to relate to the EC values in Table 4.2, the human taste threshold for salinity is 1.8 dS/m; seawater has an EC value of 63 dS/m. It is suggested that if irrigation water salinity is between 1.0 – 1.8 dS/m, management options such as planting salt tolerant rootstocks, mulching, maintaining ground covers, changing the irrigation system and increasing the leaching fraction should be considered (see section 5).

Table 4.2. Guidelines for interpreting laboratory data on water suitability for grapes. 'Severe' in this table reflects an expected 25% reduction in productivity

Potential Irrigation Problem	Units	None	Degree of Restriction on Use Slight to Moderate	Severe
Osmotic effects[1]				
EC_w	ds/m	< 1	1.0 – 2.7	> 2.7
Toxicity effects				
Sodium (Na^+)[2]	mg/l or ppm	< 460	-	-
Chloride (Cl^-)[2]	mg/l or ppm	< 140	140 – 530	> 530
Boron (B)	mg/l or ppm	< 1	1 – 3	> 3
Nitrate-nitrogen (NO_3-N)	mg/l or ppm	< 5	5 – 30	> 30

(Source: Neja et al. 1978; Ayers and Westcot 1994; Nicholas 2004)
[1] Assumes that rainfall and extra water applied owing to inefficiencies of normal irrigation will supply the crop needs plus about 15 percent extra for salinity control.
[2] With overhead sprinkler irrigation, sodium or chloride in excess of 3 me/l under extreme drying conditions may result in excessive leaf absorption, leaf burn and crop damage. If overhead sprinklers are used for cooling by frequent on-off cycling, damage may occur even at lower concentrations.

Sodicity

Water quality should also be monitored for its likely impact on soil structure through its potential impact on soil sodicity. The amount and type of salts present in the irrigation water have different impacts on the development of soil sodicity. A high sodium adsorption ratio (SAR) can cause the development of sodic soils but the damaging effects of sodicity (dispersion) can be reduced by high salinity which maintains the clay in a flocculated state.

Criteria by which to assess irrigation water as to its potential sodicity hazard are presented in Table 4.3. The potential problems associated with low EC water (either from rain or irrigation) can easily be rectified through the application of gypsum or by the addition of fertiliser. Salts applied in this manner will elevate the EC of the soil solution preventing potential dispersion associated with the development of sodicity.

Table 4.3. Criteria for assessing the sodicity hazard, and hence the likely development of soil sodicity, as a result of irrigating with various water qualities where EC_{iw} is electrical conductivity of the irrigation water (dS/m) and SAR_{iw} is sodium adsorption ratio of the irrigation water.

SAR_{iw}	EC_{iw}	Soil sodicity hazard
0 – 3	>0.7	None
	0.7 – 0.2	Slight to moderate
	<0.2	Severe
3 – 6	>1.2	None
	1.2 – 0.3	Slight to moderate
	<0.3	Severe
6 – 12	>1.9	None
	1.9 – 0.5	Slight to moderate
	<0.5	Severe
12 – 20	>2.9	None
	2.9 – 1.3	Slight to moderate
	<1.3	Severe

(source Ayers 1977)

Vine based monitoring

The use of vine based measurements to assess changes in vineyard salinity levels are the most direct methods to use. Plant based measurements are more representative of 'average' conditions as they can integrate variable saline conditions over time and space. However, vine based measurements should not be used in isolation particularly as some seasonal conditions and lagging vine responses can mask an underlying and developing problem. Over time, vine based measurements will reflect the changes in salinity conditions.

Some vine based measurements are more useful than others depending on what the aim of the measurement is (i.e. intra or inter seasonal management). Vine based measurements should be performed each season within a designated representative zone within the vineyard. Representative zones can be established based on existing soil maps or yield monitoring and aerial imagery data. Whilst there is not an established preferred method to zoning, once a sampling strategy is established it is important to maintain this strategy in order to monitor robust trends.

Petiole testing

Monitoring petiole sodium and chloride during the growing season can potentially be used to change the potential chloride levels in the harvested fruit and the following season. A recent study by Goodwin et al (2009) showed that for own rooted shiraz vines the relationship between petiole sodium levels and juice chloride levels depended on phonological stage and environmental conditions. Whilst sodium petiole levels at flowering were positively correlated with juice chloride levels the relationship varied depending on management practices and climate (rain) post the flowering period (Figure 4.1a). In contrast, the relationship between sodium petiole levels at veraison and juice chloride levels was consistent (Figure 4.1b).

Petiole testing at flowering	Used as an indicator of potential salinity problems that might be looming. Changes in management practices can influence the accumulation of salts in the grape. Also an indicator of effective winter leaching.
Petiole testing at veraison	Used as an indicator of accumulated salts in the grape. Changes in management practices have little effect on salt levels in the grape. Also used to adjust management practices if trending levels are problematic.

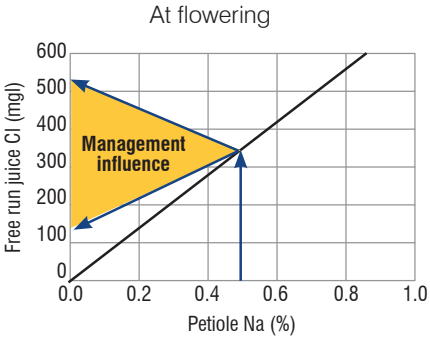


Figure 4.1a. Relationship between Petiole Na (%) levels measured at flowering and the resultant chloride levels in the free run juice (Source: Goodwin *et al* 2009)

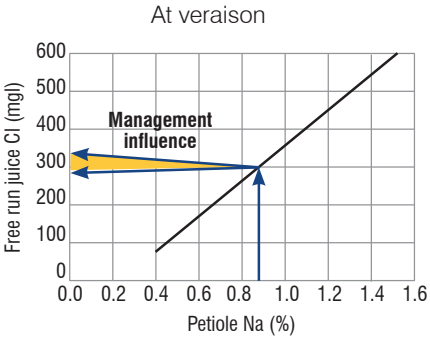


Figure 4.1b. Relationship between Petiole Na (%) levels measured at varaison and the resultant Chloride levels in the free run juice (Source: Goodwin *et al* 2009)

Note: Figure 4.1 should not be used as a universal relationship. It is based on data derived from own root shiraz vines. Vine chloride and sodium uptake varies depending on rootstock and variety (Walker et al 2010).

Grape juice testing

The measurement of grape juice salt levels at harvest reflects seasonal salinity fluctuations and management. Table 4.4 shows the approximate relationship between juice chloride levels and the resultant wine chloride levels. The European Union and Australian bilateral agreement on wine quality requires wine to contain less than 394 mg/l of sodium and 606 mg/l of chloride.

Table 4.4. Relationship between Juice chloride and the resultant wine chloride levels

White varieties	Wine Cl % ≈ Juice Cl %
Red varieties (fermented on skins)	Wine Cl % $\approx \frac{5.\ \text{Juice Cl (\%)}}{3}$

(Source: Walker *et al* 2010)

Soil based monitoring

Soil based monitoring is commonly used to assess changes in soil salinity. However, measurements of soil salinity are not necessarily a good indication of the salinity experienced by the vine. The main reason for this is the heterogeneous nature of soil salinity within and around the root zone and drip emitter in relation to the soil samples taken. When monitoring soil salinity it is important to follow consistent procedures and timing of sampling. It is a direct measure of soil salinity, or sodicity, and will provide a very useful tool in monitoring soil salinity over time (i.e. looking for 'trends' over time).

The timing and frequency of soil based sampling is dependent on the type of monitoring used. Irrespective of the soil based monitoring used the sampling locations or zones should reflect the major soil type of the vineyard and be representative of the vineyard area to be monitored.

Some excellent new options are available to monitor soil salinity. The accuracy of any monitoring program, however, has to be balanced against its cost and likely benefits.

Soil sampling

Soil samples are often used to monitor changes in soil condition over time. Collection is simple but it can be time consuming if deep subsoil samples are required and vine material gets in the way. Specialist soil sampling equipment can be used but in most cases soil augers are all that are required. When taking soil samples you need consider the time and frequency and the sampling location.

Location

For most consistent results soil samples should be collected under the drip emitter. This area, however, may not reflect the average root zone salinity. To reflect

average root zone salinity soil samples should be collected 15-20 cm away from the drip emitter along the vine row. Select 3-4 sites using either pegs or fixed reference points. These areas should be consistent from year to year.

Depths

Soil sampling depths are typically at target depths of 20 cm (major root zone in topsoil), 50 cm (mid subsoil), 80 cm (bottom of root zone). Sampling at these soil depths will typically cover the rooting depth of vines growing on their own roots and on rootstocks.

Figure 4.2. Soil sampling by auger along the vine row and packaging in plastic bags to send to laboratory

Time and frequency

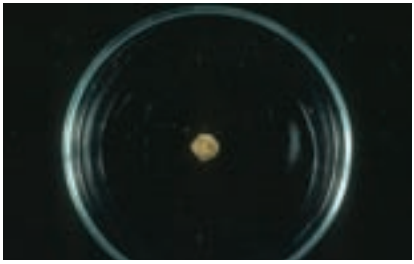
Samples should be taken once yearly. Samples should be collected in early spring (salinity levels at their lowest) or early autumn before opening rains (salinity levels at their highest). Sampling in early spring gives you a snapshot of the soil condition at the start of season whereby action can be taken if needed.

Note: Soil sampling should not occur if either nutrients or gypsum have recently been applied to the soil. Sampling at this time could lead to elevated levels of recorded salinity. Preference is to sample just prior to these additions.

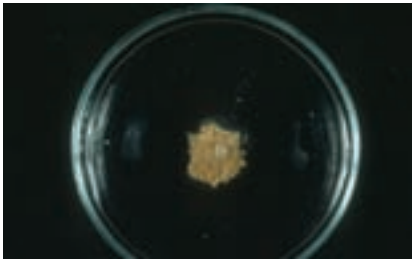
All soil samples from a particular depth should be bulked together, mixed and 500 g sent to a recognised laboratory for analysis or tested on site following good preparation practices (see Figure 3.9). It is not necessary to go to the expense of measuring a saturated paste extraction for EC measurements. The aim of the

sampling program is monitoring and measurements of $EC_{1:5}$ are sufficient so long as the sampling sites are not altered (i.e. remain within the same soil type).

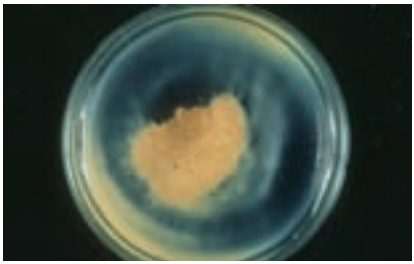
The soil samples can be tested for both salinity and sodicity. Salinity can be tested on each soil layer while sodicity may only be tested on the heaviest clay layer. Dispersion testing (Figure 4.3) provides a simple way of monitoring soil sodicity over time.



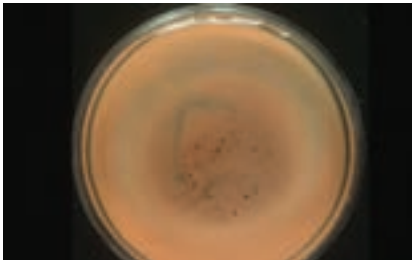
No slaking, no dispersion



Slaking, no dispersion



Slaking, moderate dispersion



Slaking, strong dispersion

Figure 4.3. Assessment of an undisturbed soil crumb after it has been placed in distilled water for a period of 2 hours. Higher the dispersion the higher the sodicity (Source: Cass)

FullStop™

The FullStop™ Wetting Front Detector (FullStop WFD) is a soil water monitoring device which is buried in the soil and captures water as it passes through the soil profile (Figure 4.4). It is a simple device that requires no wires, batteries, computers or loggers. The device consists of a collection funnel at the base and extension tube rising above the soil surface. As water percolates through the soil profile, water 'converges' in the base of the funnel and allows a float to lift the indicator at the top of the extension tube.

A reservoir in the base of the funnel collects and retains a 5 ml sample of soil water. The sample is retained until it is extracted. This soil water sample is manually extracted using a syringe for analysis of salts and/or nutrients in the soil profile.

Location

The preferred location to install the FullStop WFD is directly beneath the drip emitter. Wherever possible, FullStop WFD should be installed in areas that are representative of a block or irrigation zone. However, they may also be used in areas where soil type or other factors make irrigation scheduling difficult. Furthermore, FullStop WFD can be used in areas with known soil salinity issues in order to collect soil water samples.

Depths

The installation depth for FullStop WFD is between 15 cm to 80 cm beneath the soil surface however, in a drip irrigated vineyard situation, the suggested installation depths are 30 cm and 50 cm placed directly beneath the dripper (Figure 4.4). These suggested depths vary depending on dripper output, irrigation duration and root depth. For example, shallower placement is suitable for lower output drippers, shorter irrigation frequency, more infrequent irrigation application or shallow rooted vines. Conversely, deeper placement would suit higher output drippers, longer irrigation duration or more frequent irrigation application. With more experience, placement depths may be altered to suit local conditions and management styles.

Time and frequency

The FullStop WFD should be monitored frequently during the irrigation season (if irrigation volumes allow) and during the winter period. If the indicator is in the up position, it means that more than 20 ml of water was collected by the FullStop WFD. The 'indicator' must be reset manually before it can lift for the next irrigation. After each irrigation, captured water will wick out of the funnel, however, a 5 ml sample of soil water will be retained for nutrient or salt testing. The collected water sample is drawn from the FullStop using a syringe via 4 mm flexible tubing attached to the base of the funnel. The sample should be taken as soon as possible after irrigation as the composition of the water captured in the FullStop can change over time.

Salt and nutrient concentrations tend to be quite variable over short distances. Taking 5 ml from a number of FullStops and bulking the sample can reduce the time and cost of solution monitoring. A soil water sample can be measured using a hand-held salinity meter (Figure 4.4d). Alternatively a water sample can be sent to a laboratory for analysis of salinity and/or nutrient levels. Laboratories usually require at least a 10 ml sample.

Short infrequent irrigations can cause a build up of salt at a particular point in the soil. This build up can potentially occur above the FullStop WFD (usually associated with a lack of extractable water samples). When an irrigation or rainfall event eventually wets the soil past the FullStop WFD the salts that have accumulated above the FullStop WFD will move downwards and form part of the

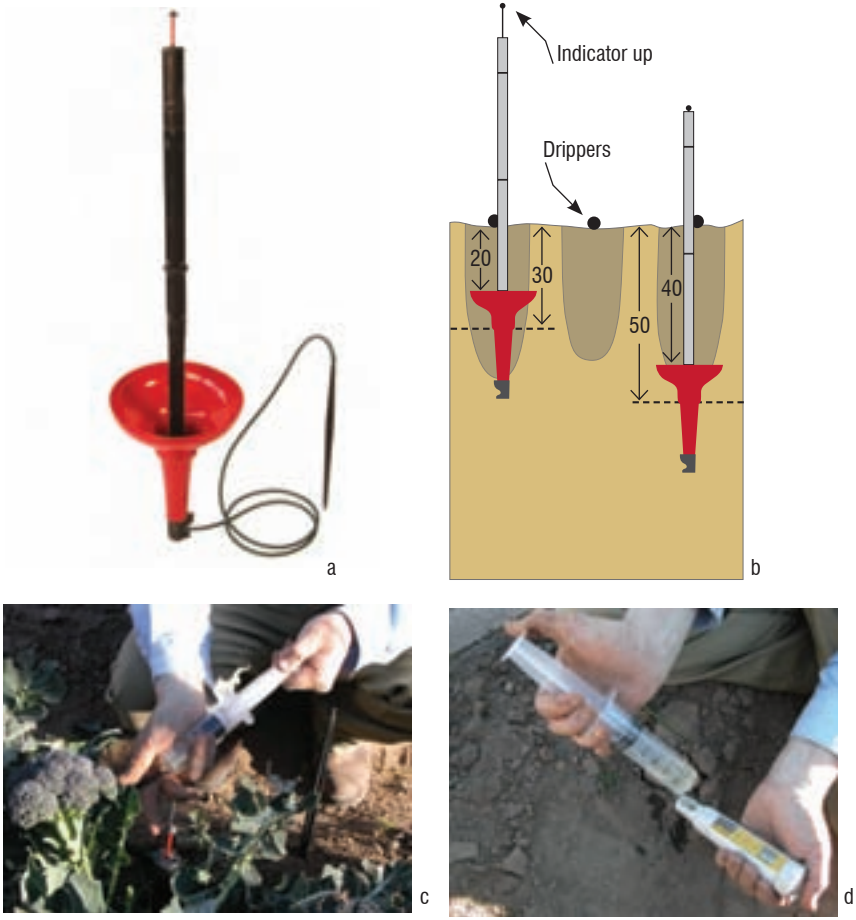


Figure 4.4. a) The FullStop wetting front detector, b) suggested placement of the FullStop wetting front detectors beneath drippers, c) extracting the soil water sample, and d) testing a soil water sample extracted from the FullStop for salts. (Source: CSIRO)

water sample in the FullStop WFD. This can lead to very high salinity readings (Figure 4.5). Whilst this can be alarming it simply indicates that salts were accumulating above the collection point due to shallow irrigation and further leaching by irrigation or rainfall may be required.

Since the FullStop WFD collects water under near or saturated water conditions its interpretation for monitoring purposes is very similar to the soil EC saturated extract (ECe). The interpretation guide (Figure 4.6) relates to the soil salinity condition at that point in time but remember monitoring is about the observation of trends over time.

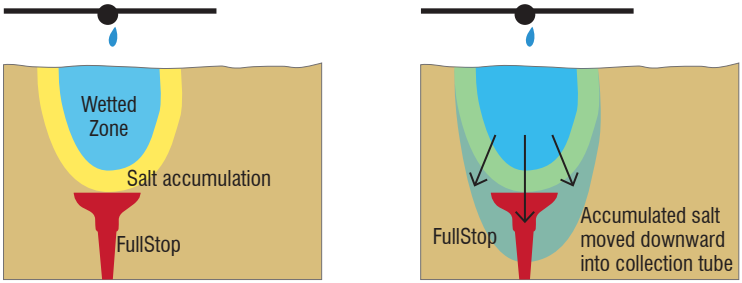


Figure 4.5. The effect of short infrequent irrigation events that can result in the accumulation of salt above the FullStop WFD. Larger wetting events can then migrate these salts into the collection tube resulting in very high salinity readings.

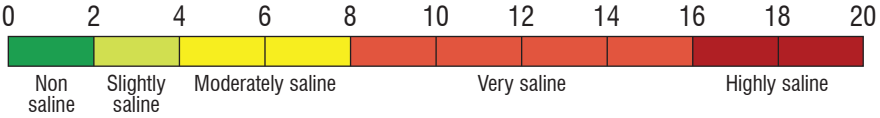


Figure 4.6. Interpretation of EC (dS/m) measurement of the sample extract from the FullStop WFD

Advantages:

- A simple tool for water management and soil water sample collection
- A FullStop does not require any wiring, batteries or loggers
- Detects moderate – strong wetting fronts well
- Stores a 5 ml soil water sample for salt or nutrient analysis and monitoring
- Provide information on depth of irrigation
- Can help detect water logging

Disadvantages:

- Cannot detect weak wetting fronts
- Requires regular monitoring
- Float must be reset manually
- Water sample must be collected manually and soon after wetting event
- Reservoir must be emptied before any additional sample can be taken
- Large soil disturbance on installation. It may take a full season for the site to settle back to its original compaction level and provide accurate samples

For a full description, cost and ordering of the FullStop WFD refer to the website www.fullstop.com.au.

SoluSAMPLER™

The SoluSAMPLER™ is comprised of an inert ceramic cup and sampling tube (Figure 4.7) buried into the soil. Suction is applied and water from surrounding soil enters the void within the ceramic cup via the differential pressure gradient. Water is retained within the SoluSAMPLER™ (approximately 70-75 ml of soil water) and is extracted manually via the sampling tube using a syringe for analysis of salts and/or nutrients in the soil profile. The SoluSAMPLER™ provides an inexpensive way of extracting soil water and monitoring soil salinity throughout the growing season, allowing users to potentially adjust their irrigation management accordingly.

Figure 4.7. SoluSAMPLER™ comprises of an inert ceramic cup and sampling tube buried into the soil.

Location

The SoluSAMPLER™ collects soil water for testing and therefore, should be installed in areas of the vineyard that are of interest for salt or soil nutrients. The ceramic cup should be located 15 cm away from a dripper, directly beneath the dripper line. This will ensure soil water is sampled around the 'drying-wetting' zone margin. When installing the SoluSAMPLER™, particular note should be taken to ensure water falls directly downward from the dripper, rather than running along the dripper tube and falling some distance away.

Depths

It is recommended that three SoluSAMPLER™ units should be inserted in the plant root zone at each sampling site. Common installation depths are 30, 60 and 90 cm within 15 cm of a dripper (or your target soil depths). It should also be noted that the SoluSAMPLER™ should not be operated before irrigation water or rainfall reaches the tip of the ceramic cup, because the suction applied can dissipate quickly and water samples of the wetting front can potentially be collected rather than post irrigation conditions.

Time and frequency

Samples should be taken at least every fortnight during the peak of irrigation and once per month during other times. In normal conditions, suction should be applied to the ceramic cup approximately 1 day after irrigation or rainfall event and a soil water sample can be collected in the next day or two. If the soil is particularly dry, suction should be applied immediately after the irrigation and

Figure 4.8. SoluSAMPLER™ installation and measurement a) augering hole to desired depth, b) insertion of the SoluSAMPLER™, c) placement of a bentonite plug to prevent preferential flow, d) tagged extractor tubes, e) application of suction to collect soil water sample, and f) measurement of the soil water sample using an EC meter. (Source: SARDI)

sample taken soon after. In the case of dry soil, water will redistribute faster prior to the sample being collected and a stronger suction may be needed. Be aware that the collection of soil water samples at different soil water conditions will result in more variability in the readings observed. The important point here is to collect the sample in the same manner each time limiting the variability in the readings which allows trends to be observed more readily.

As previously mentioned short infrequent irrigations can cause a build up of salt at a particular point in the soil (see Figure 4.5). This build up can potentially occur above the SoluSAMPLER™ (usually accompanied by a lack of extractable water samples). This can lead to very high salinity readings when water eventually moves

past the SoluSAMPLER™. However, unlike the FullStop WFD which collects water as the wetting front passes the SoluSAMPLER™ can collect soil water after the salt front has moved past allowing users to monitor the result of irrigation as opposed to activity during irrigation.

Since the SoluSAMPLER™ collects water after a period of drainage and vine water extraction the concentration of salts in the soil water solution will vary depending on the length of time after an irrigation event. Water extraction by vine roots causes an increase in the concentration of salts in the soil water solution. Hence, it is important to try and use the SoluSAMPLER™ at the same time after each irrigation event to minimize this variation. Studies have shown that the SoluSAMPLER™ EC readings are approximately twice that of the soil EC_e. The interpretation guide (Figure 4.9) relates to the soil salinity condition at that point in time but remember monitoring is about the observation of trends over time.

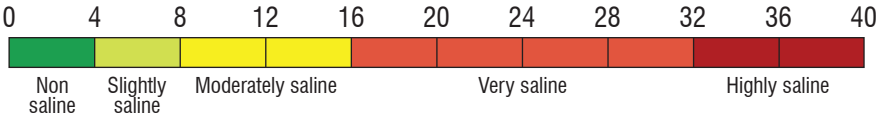


Figure 4.9. Interpretation of EC (dS/m) measurement of a sample extract from a SoluSAMPLER™

Advantage

- Easy to install and use
- Minimal expense and disturbance to root zone
- Delivers relatively small volume samples (up to 70 ml)
- Can be permanently installed and sampled on demand
- Enables soil water to be extracted over a range of soil moisture conditions
- Provides information on the trends of nutrient (e.g. nitrogen) and salt transport through soil profiles

Disadvantage

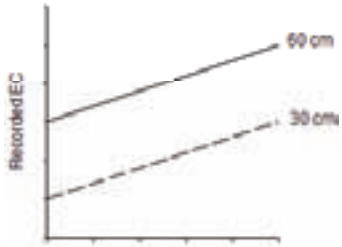
- Requires regular monitoring and maintenance
- Water sample must be collected manually and soon after wetting event
- The ceramic cup must be sterilised in situ against fungi every six months if nutrient measurement of the soil water is required
- Sampling at different soil moisture conditions increases salinity monitoring variability

Further information and instruction manual for the SoluSAMPLER™ can be found on the Sentek website www.sentek.com.au.

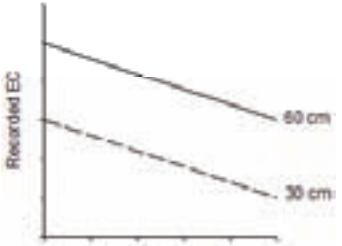
Interpretation of trends

Once a monitoring program is in place it is important to understand how to interpret the data collected. The following schematic diagrams represent an array of trends that can be used to interpret short (monthly) as well as longer (yearly) measured changes in soil profile salinity data (Figure 4.10). It is also important that the interpretation is not based on a few data points but many data points. Field measurements are often variable particularly those that are not taken from the same location (e.g. soil sampling).

Note: The depths indicated in these graphs are arbitrary and the time and EC scale is relative. Trends can be observed intra-seasonal if samples are able to be collected. However, samples collected at the end (autumn) or the beginning of the season (spring) are a more reliable indicator of salinity trends.

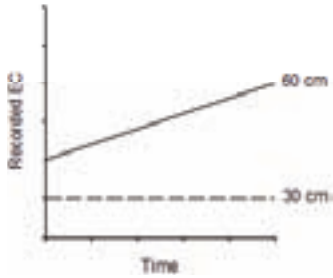


Increasing salinity at both soil depths.
Salinity conditions deteriorating
Usually associated with increasing salinity of irrigation water and irrigation reaching deeper soil layers. Should also see rising vine chloride levels. This is not a sustainable practice. Need to reduce reliance on irrigation water or use better quality water if available.



Decreasing salinity at both soil depths.
Salinity conditions improving
Usually associated with decreasing salinity of irrigation water, good seasonal rainfall and better quality water reaching deeper soil layers.
Be mindful not to over irrigate and induce waterlogging and nutrient leaching.

Steady salinity levels at both soil depths.
Salinity conditions at equilibrium
Current management practices neither increasing nor decreasing salinity levels in the soil profile.
Assess vine chloride levels to decide whether changes to management practices are required.

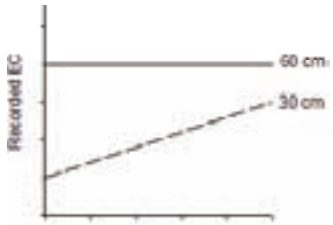


Increasing salinity at 60 cm depth only.

Salinity conditions moderated

Usually associated with deficit irrigation practices, no leaching fraction and irrigation volumes equal to water use and evaporation. Also associated with ineffective leaching by winter rainfall.

Monitor vine chloride and sodium levels to decide whether changes to management practices are required. Will most likely require leaching at some point.

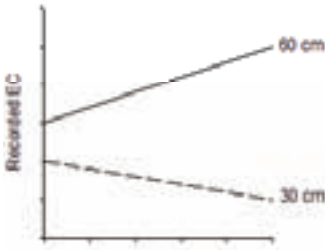


Increasing salinity at 30 cm depth only.

Salinity conditions deteriorating

Usually associated with deficit irrigation and short infrequent irrigation below crop requirement and/or ineffective leaching by winter rainfall.

Should also see rising vine chloride levels. This is not a sustainable practice. Either increase the volume of water applied during the season or run irrigation intervals for longer to leach salts.

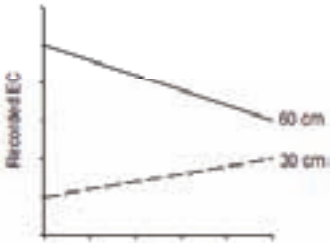


Decreasing salinity at 30 cm and increasing at 60 cm depth.

Salinity conditions improving

Usually associated with deficit irrigation practices, no leaching fraction and irrigation volumes equal to water use and evaporation. Also associated with rainfall moving salts down the soil profile.

Will most likely require leaching at some point but only if evident in vine chloride analysis.

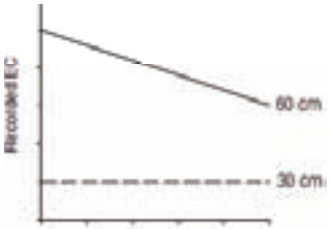


Increasing salinity at 30 cm and decreasing at 60 cm depth.

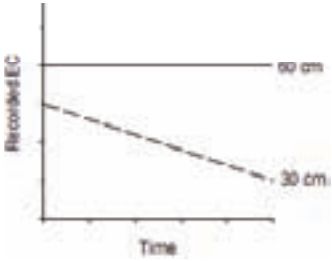
Salinity conditions unknown

Usually associated with bypass flow or poor placement of sensors. Could be the rise of a high quality water table causing the capillary rise of salts to the soil surface.

Check installation of monitoring equipment and groundwater levels.



Decreasing salinity at 60 cm depth.
Salinity conditions improving
Usually associated with increased amounts of water applied and/or more effective winter leaching.
Be mindful not to over irrigate and induce waterlogging and nutrient leaching.



Decreasing salinity at 30 cm depth.
Salinity conditions improving
Usually associated with decreasing salinity of irrigation water, irrigation reaching deeper soil layers, and/or more effective winter leaching.
Monitor vine chloride levels. If levels do not fall then leaching will be required past the 60 cm soil depth.

Figure 4.10. Schematic illustrations of changes in recorded EC levels with time measured at two different soil depths.

5. Management Practices

Irrigation management

The management of salinity is often considered to be an irrigation issue related to water quality and leaching requirements. However, there a number of other factors such as design of the irrigation system that should be considered for effective control of salinity.

Method of irrigation

Our understanding of different irrigation methods for the control of salinity, particularly in relation to buried drip, is not comprehensive. Table 5.1 describes salinity management issues associated with a range of pressurised irrigation systems. The wetting patterns and rates of flow of irrigation water produced by these contrasting systems are also strongly influenced by soil factors, particularly structure, texture, organic matter content and the degree of water repellence.

Table 5.1. Salinity management issues associated with contrasting irrigation system designs.

Irrigation method	Positive salinity features	Negative salinity features
1. Standard above-ground drip with wide spaced emitters (1.0m)	Less surface area wetted than closely spaced emitters using low output drippers. High output emitters can create continuous wetting patterns and uniform wetting.	Where wetting spheres beneath low output emitters do not overlap, salts tend to concentrate on the fringes of the spheres. This salt concentration in zones between the emitters can create problems for root growth, particularly when mobilised by rainfall.
2. Above-ground drip with closely spaced emitters (0.5m)	Where the wetting spheres beneath each emitter overlap, a continuous wetting front is created that allows a relatively uniform flushing of salts from the root zone.	More expensive than Option 1 Likely to have greater surface evaporation losses than Option 1.
3. Buried drip	Minimal evaporation losses mean that more water is available per unit of applied water. This provides more leaching of unwanted salts from the root zone.	Maintenance can be difficult (e.g. root intrusion, damage by soil fauna); blocked emitters can be difficult to detect. If the irrigation water is saline, substantial amounts of salt can migrate upwards from the drip line and concentrate in harmful concentrations in the topsoil.
4.Microjets or mini-sprinklers	A relatively uniform wetting front is created that allows a thorough flushing of salts from the root zone.	Water losses via evaporation tend to be greater with spray systems than with drip systems. The resultant increase in near-ground humidity can encourage vine growth in dry weather, but there may be a greater risk of fungal outbreaks with sprinklers under moist conditions.

Leaching of salts

Leaching of salts from the root-zone remains the most effective technique for salt management. Irrigation scheduling strategies such as 'regulated deficit irrigation' and 'partial root-zone drying' minimise deep leaching and tend to accumulate imported salts in the root-zone. The leaching fraction refers to the amount of water that needs to be applied in excess of vine evapotranspiration requirements to flush out accumulated salt. The extra water applied can come from irrigation or by rainfall. Low leaching fractions, caused by little rainfall or low irrigation allocations, increases the net salinity retained in the root zone leading to a potential requirement to use salt tolerant rootstocks (Appendix A).

The application of leaching irrigation events has commonly been associated with the management of salt in the root zone. The common suggestion was that leaching of salts can be done either as part of each irrigation, or it can be achieved via a single large irrigation soon after harvest. The use of leaching events during periods of high transpiration demand is less effective and efficient as leaching events during low transpiration demand (Figure 5.1). Best leaching of salts from the topsoil occurs when the soil profile is near saturation and the water applied has little salt and water is applied slowly and evenly, either by rainfall or irrigation.

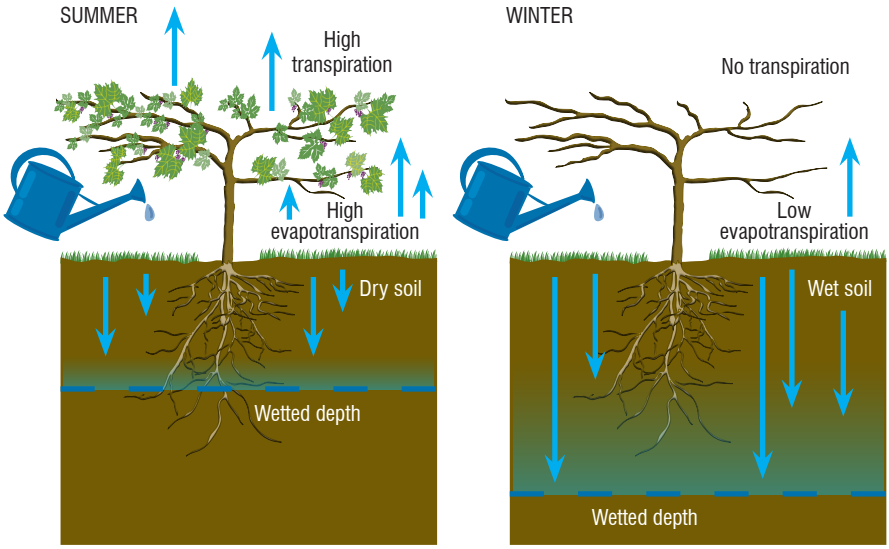


Figure 5.1. Difference in water movement through the soil profile for the same quantity of water applied during summer and winter (either through irrigation or rainfall)

Table 5.2 shows the importance of rainfall in the salt leaching process. As rainfall increases (e.g. moving from the Langhorne Creek region to the Adelaide Hills), there is a decrease in the number of leaching irrigation events that need to be applied to prevent salt build-up in the root zone of grapevines.

The effectiveness of rainfall assumes that rainfall enters the soil rather than runs off, hence the term 'effective rainfall'. This table also assumes that the water entering the soil is 100% effective in leaching salts.

Table 5.2. Leaching requirements (the extra irrigation water required in %) to maintain average root zone salinity less than 2 dS/m (grapevine tolerance), where the total irrigation requirement for the season is 0.5, 2 and 5 megalitres1, for a range of effective annual rainfall totals. (Source Tanji and Kielen 2002)

Water quality, dS/m	Effective annual rainfall, mm											
	0.5 Ml				2.0 Ml				5.0 Ml			
	0	200	400	600	0	200	400	600	0	200	400	600
1	11%	2%	1%	1%	11%	5%	3%	3%	11%	8%	6%	5%
2	25%	4%	2%	2%	25%	11%	7%	5%	25%	17%	13%	10%
3	43%	6%	3%	2%	43%	18%	11%	8%	43%	27%	20%	16%
4	67%	9%	5%	3%	67%	25%	15%	11%	67%	40%	29%	22%

[1] assumes that the amount of irrigation applied equates to the water demand of the vineyard. Irrigation volumes less than the water demand of the vineyard will result in a greater reliance on effective rainfall to leach salts than indicated in this table.

Recent research has shown that the leaching process is not always completely efficient. This is thought to be due to the presence of preferred pathways of water movement through the soil, which results in salt build-up in other parts of the root-zone. In some situations where shrinkage cracks form in saline clay soil, salt crystals form on the crack faces in response to evaporation losses. If runoff water can be directed down these cracks before they close up, substantial amounts of salt can be leached quickly and deeply.

Application of leaching fractions is only effective if the water table is deep enough to receive the extra water without adversely affecting vine growth. Hence, monitoring the water table using test wells and/or piezometers is recommended. Subsoil drains may have to be installed if the water table is high enough to adversely affect vine performance.

A common practice in determining the depth of irrigation for leaching purposes is through soil water monitoring. Water monitoring allows objective measurement of factors such as depth of penetration of rainwater or flood water – a key factor when assessing the effectiveness of salt leaching programs in vineyards. Salinity is usually monitored in conjunction with soil water content using devises such as capacitance probes and neutron probes.

Scheduling water resources

When growing wine grapes under drip irrigation it is necessary to be mindful of irrigation frequencies to reduce the salt uptake by the vine. Soils should not be allowed to dry out too much, as the salts become concentrated in the soil solution as the soil dries and the vine may take up the salt. This will harm the vine, wine grapes and finally the wine quality. Frequent irrigations in drip will keep the soils

close to field capacity and move salts to the edge of the wetted zone away from the bulk of the root system. However, with limited water supply this may not be possible.

Where a range of water supplies is available that are of variable quality (i.e. level of salinity), it is desirable that these water resources be scheduled according to phenological stage. Whilst our understanding of variable water quality applications within a growing season is still developing, recent research suggests that chloride accumulation in the grape berries is more related to the environmental conditions leading up to veraison than after veraison. This suggests that it may be best to use the better quality water (e.g. runoff water stored in a dam) early in the season to maintain a low saline soil conditions during the period of rapid cell growth and division and then apply the poorer quality water (eg. from a bore or a salt-affected river) after veraison during fruit development and maturity. This is a topic that requires further research.

Soil management

The use of soil management practices to control salinity is often not considered. However, there are a number of management practices that can be used to mitigate and control the effects of salinity.

Mulching soil surface

Water dripping onto bare soil is undesirable for several reasons:

- It is prone to loss by evaporation, particularly when the soil surface is very hot.
- Surface sealing may occur beneath each dripper, leading to reduced infiltration rates.
- Surface soil chemical properties tend to become very heterogeneous, with strong salt concentration gradients along the vine rows (mid-way between the drippers tends to be more saline than directly under the drippers).

Organic mulches/composts (e.g. Figure 5.2) can overcome these problems:

- The mulch/compost can act as a wick, which tends to produce a more uniform downward flow of irrigation water and dissolved salts.
- Burrow-forming soil fauna tend to become active at the soil-compost boundary; this improves soil structure (Figure 5.3), infiltration rates and rootzone aeration.
- Rapid percolation of water into the cool subsoil beneath the protective mulch/compost reduces the risk of loss by evaporation and encourages the leaching of unwanted salts in the topsoil.

When applying mulch, however, the wine grape grower must know what they are applying. They need to ensure that the imported mulch is free of contaminants and that the nutrient content is taken into account when planning vineyard fertiliser strategies.

Figure 5.2. Compost a) and straw mulch b) applied along the vine rows to improve the physical fertility of a poorly structured topsoil

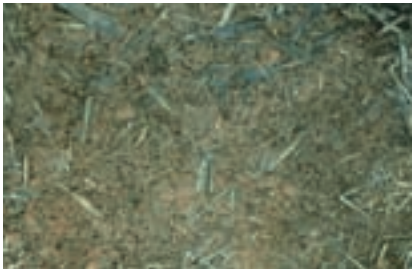


Figure 5.3. Vertical biopores created by soil fauna beneath straw mulch along vine rows.

Sodicity management in a saline environment

Gypsum is itself a salt, albeit only sparingly soluble. It provides two distinct soil structural benefits when applied to sodic soils:

1. Gypsum provides calcium cations, which replace sodium and magnesium cations associated with the dispersion of negatively charged clay particles.
2. The gypsum also provides a mildly saline soil solution that suppresses dispersion. However, this "electrolyte effect" of dissolved gypsum only persists while a supply of undissolved gypsum is available in the soil. The use of coarse-crystalline mined gypsum (solubility approximately 0.4 dS/m) maintains the electrolyte effect for longer than finely divided gypsum (solubility approximately 1.9 dS/m). Where the soil already is moderately saline, avoid the use of finely divided gypsum that may push up the salinity stress on plants substantially – instead, use a coarse-grade gypsum if a sodic layer requires treatment under these circumstances.

Figure 5.4 shows the combined effects of gypsum application on soil stability and salinity hazard. A gypsum treated soil without residual gypsum particles can become dispersive and poorly drained if large amounts of low-salinity water (ie. rainfall, flooding) flow through the soil and reduce topsoil $EC_{1:5}$ values to less than about 0.1 dS/m.

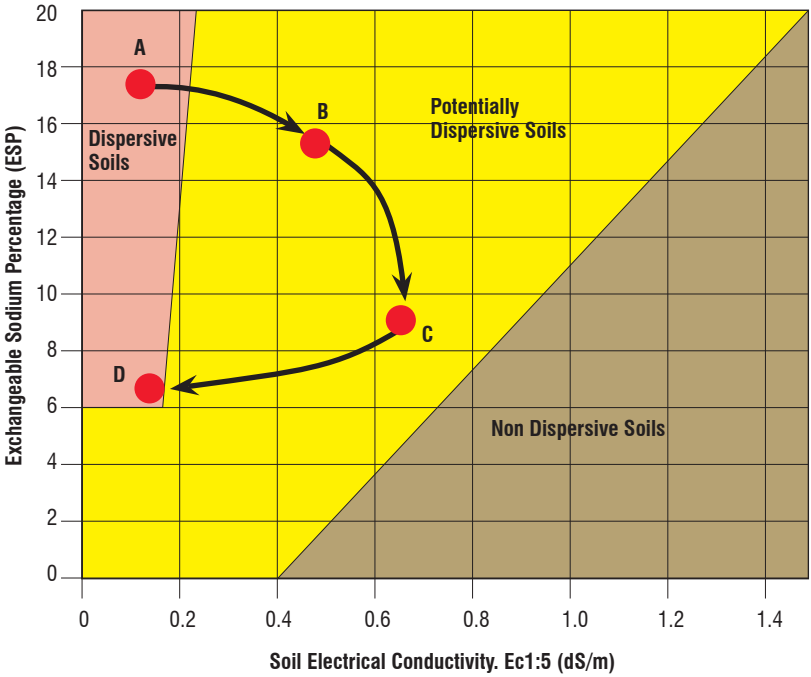


Figure 5.4. Prediction of the changes in dispersion and salinity characteristics with time after the initial application of 5 t/ha gypsum to the soil (adapted from Rengasamy *et al.* 1984). A. Initial condition of the soil, B. Increasing soil EC as gypsum dissolves into the soil water solution, C. Gypsum solubility reaches maximum and displaces the sodium ions with calcium ions leaving the sodium ions in solution, D. Winter rains leach the sodium ions from the soil profile thereby reducing salinity.

There are three main ways of applying gypsum to a vineyard soil:

1. A spreader towed by a tractor is an effective way of adding gypsum to the zones requiring treatment. Mechanical incorporation is not essential – the gypsum will dissolve and travel with the wetting front the next time it rains and/or irrigation water is applied.
2. Gypsum can be applied to a field via an aircraft in situations where the ground is too boggy for ground spreaders and application is required urgently.
3. The gypsum can be dissolved in irrigation water and then be applied through the irrigation system.

Mid-row management

The management of water from rainfall is critical for vineyard salinity management plans. The more rainwater that can be captured in a vineyard, the less irrigation

water is required. Any reduction in irrigation water application will therefore reduce the total amount of salt imported via that water. Rainwater usually has a much lower salt load than irrigation water, so as much of it as possible needs to be captured and stored within vineyards.

One method of increasing stored rain water in the vineyard is good management of the inter-row soil. If serious compaction is present and the soil has a poor inherent ability to regenerate soil structure through shrink-swell processes, ripping will improve the ability of that soil to accept and then store rain water. The transformation of a compacted soil into friable soil can double its water holding capacity.

Once the properties of the inter-row are able to accept and store rainwater through appropriate soil remediation, it is important to ensure that the vine roots are able to grow through the wheel compaction zone. This will allow the vine roots to access the stored water in the inter-row readily.

Ripping

Biological loosening

Where the soil has an inherent ability to shrink and swell (cation exchange capacity greater than about 15 cmol($^+$)/kg for those familiar with the terminology), loosening of compacted layers can be achieved through wetting and drying cycles in the inter-row. The use of inter-row species such as chicory can also provide deep macropores (created by deep taproots) that improve the ability of a soil to transmit water. Increasing the transmission of water improves the effectiveness of leaching during periods of high rainfall or rainfall intensities.

Mechanical loosening

When treating soil compaction mechanically, ensure that the following issues are taken into account:

- The soil needs to be at its plastic limit (ability to hand roll a 3 mm diameter rod before breaking – but no smaller)
- Select a tyne design that maximises subsoil disturbance in a cost-effective fashion without lifting subsoil fragments to the surface (e.g. Figure 5.5)

When ripping the inter-row in established vineyards, consider the possibility of only ripping every second inter-row if there is concern about excessive vine root pruning. If the soil is prone to dispersion, the benefits from ripping will soon be lost unless it is treated with gypsum or a gypsum-lime blend to prevent slumping and hard setting.

Figure 5.5. Disrupting compaction zones from vineyard wheel tracks to improve accessibility of the inter-row soil by grapevine roots.

Nutrition

Nutrient application to overcome salinity problems

Although studies have shown that salinity reduces nutrient uptake within plants, the addition of nutrients in excess of amounts considered optimal under non-saline conditions tends not to improve yields. However, where chloride toxicity is a problem, application of nitrate compounds (e.g. calcium nitrate) can improve crop performance but only in nitrogen limited situations.

Aggravation of salinity problems

Fertilizers, manures, and soil amendments include many soluble salts in high concentrations. If placed too close to the growing plant, the fertilizer may cause or aggravate a salinity or toxicity problem. Care, therefore, should be taken in placement as well as timing of fertilization. The lower the salt index of the fertilizer, the less danger there is of salt burn and damage to seedlings or young plants. Salt indices for various fertilizers are shown in the appendix Table C.1. If fertiliser is to be applied in a high saline environment, it is best to apply a little often rather than apply the fertiliser in one application.

Nutrient deficiencies caused by irrigation water

Water high in calcium or magnesium carbonates/bicarbonate salts, such as bore water from limestone aquifers, can cause a lime precipitation in the soil adjacent to drip system emitters. This can cause the soil to become more alkaline over time. The associated increase in alkalinity may lead to a decrease in availability of nutrients such as zinc, iron and copper.

Glossary

Acidic soil soil with a pH value less than 7.0.

Aggregate a group of soil particles that cohere to each other (also known as a ped or clod). Soil aggregates are the small clumps soil breaks into when you dig it; small aggregates (microaggregates) clump together to form aggregates. The size, shape and percentage of aggregates are indicators of structural form.

Alkaline soil soil with a pH value greater than 7.0.

Ameliorate to improve.

Anion an ion with a negative charge.

Aquifer a water-bearing rock formation capable of yielding useful quantities of water to bores or springs.

Biopore a large pore created by biological activity in the soil, e.g. old root channels and earthworm tunnels.

Calcareous a soil containing significant amounts of naturally occurring calcium carbonate (CaCO3 – lime), which fizzes when dilute acid is added.

Cation exchange capacity the total amount of exchangeable cation, or the ability of negatively-charged clay minerals to hold cations, often referred to as the CEC. A guide to the nutrient status and structural resilience of a soil.

Capillary rise the rise of water through the soil pore system from a free water surface.

Cation an ion with a positive charge.

Clay soil particles smaller than 0.002 mm in diameter. Clay particles hold water and exchangeable cations.

Compaction compression of soil into a smaller volume so that porosity is decreased.

Crusts hard surface layer up to 1 cm thick, which occur mainly on bare soil when soil aggregates have dispersed.

Deep tillage any tillage deeper than that needed to produce loose soil for a seedbed, or deeper than needed to kill weeds. Its usual purpose is to loosen a compacted subsoil.

Dispersion disintegration of soil aggregates into single soil particles upon wetting; the opposite of flocculation.

Duplex soil a soil which shows a clear or abrupt change in soil texture between the topsoil and the subsoil, e.g. a loam topsoil overlying a clay subsoil.

EC is electrical conductivity.

$EC_{1:5}$ the electrical conductivity of a 1:5 soil:water extract.

EC_e the electrical conductivity of a saturated soil paste; the preferred measure of electrical conductivity as it is not dependent on soil texture and best reflects how salinity will affect plant growth.

Exchangeable cations the positively charged cations calcium, magnesium, potassium, sodium and aluminium.

Exchangeable sodium percentage (ESP) the amount of sodium in a soil expressed as a percentage of the total cation exchange capacity.

Fertility the capacity of a soil to support plant growth. It has three components: chemical, biological and physical fertility.

Field capacity the content of water remaining in a soil after free drainage is negligible (following rain or irrigation where the soil is saturated or full of water).

Flocculation clustering of clay particles into microaggregates; the opposite of dispersion.

Gravitational Potential (ψ_h) the hydraulic potential determined by the height of the point relative to some reference plane. A point higher than the reference point has a positive gravitational potential.

Gypsum calcium sulfate, used to reduce swelling and dispersion in sodic soil.

Hardsetting describes soil which dries very hard so that air and water movement, root penetration and seedling establishment are adversely affected.

Infiltration the movement of water into a soil.

Ion atomic or molecular particle carrying an electrical charge.

Leaching downward movement of dissolved materials.

Lime calcium carbonate, used to increase the pH of the soil (reduce acidity) and to improve structural stability in soil which is both acidic and dispersive.

Matric Potential (ψ_m) the hydraulic potential determined by the height of the water column of the point of interest. The matric potential of unsaturated soil is negative.

Nutrients required for good plant growth, e.g. nitrogen, phosphorus and potassium.

Organic matter living and dead plant and animal material.

Osmotic Potential (ψ_o) the pressure potential created by different concentrations of solutes on opposite sides of a semi-permeable membrane.

Percolation the movement of water through the soil.

Permanent wilting point the water content of a soil at which plant roots cannot extract water, and plants wilt and cannot recover.

Permeability ability of a soil to transmit water and gases.

pH a measure of how acidic or alkaline a soil is.

Plant available water water held between field capacity and permanent wilting point.

Plastic limit the water content of soil above which it can be remoulded (is plastic) and below which it cannot be remoulded (is brittle). Soil with a water content just below the plastic limit is said to be at the ideal soil water content for cultivation.

Pore the space between soil particles and soil aggregates.

Porosity the degree to which a soil is permeated with pores.

Readily available water water held between field capacity and refill point, often referred to as RAW.

Refill point the water content of a soil where it becomes difficult for plants to extract water and more water is required to maintain growth rates.

Remote sensing an activity that involves observing or measuring characteristics of a certain feature or target from a distance.

Root zone that part of a soil where the majority of live plant roots are located.

Salinity an excess of water-soluble salts (dominantly sodium chloride in Australia) that restricts plant growth, indicated by electrical conductivity.

Sand soil particles between 0.02 mm and 2 mm in diameter.

Saturated soil soil which is so wet that it contains no air.

Silt soil particles between 0.002 mm and 0.02 mm in diameter, intermediate between clay and sand.

Slaking collapse of aggregates into microaggregates upon wetting.

Sodicity an excess of exchangeable sodium causing dispersion to occur.

Sodic layer a layer in the soil profile that exhibits sodicity.

Sodium adsorption ratio (SAR) is the ratio of sodium (detrimental element) to the combination of calcium and magnesium (beneficial elements).

Soil profile the vertical sequence of layers in the soil. The three main horizons are the A (topsoil), B (subsoil) and C (parent rock) horizons.

Soil structure soil structure is the arrangement of the solid component of soil and the spaces in between (pores). Sometimes referred to as structural form.

Structural form the arrangement of the solid component of soil and the spaces in between (pores).

Structural stability a measure of aggregate collapse (slaking and dispersion) upon wetting that changes structural form.

Structural resilience the ability of a soil to regain desirable structural form after damage (e.g. compaction caused by heavy machinery).

Soil texture the proportion of sand, silt and clay in a soil, estimated by the behaviour of a small handful of soil when moistened and kneaded into a ball and pressed out between the thumb and forefinger.

Soil water water stored in, or in transit by drainage through, the soil.

Subsoil soil between the depths 30–120 cm.

Subsurface soil soil between the depths of 10–30 cm.

Topsoil soil between the depths of 0–10 cm.

Total Potential (Ψ_T) the sum of matric, gravitational and osmotic potentials.

Toxicity the upper limit of an elemental concentration after which plant growth declines.

Unavailable water water stored in very small pores or held tightly around soil particles that cannot be extracted by plant roots.

Waterlogging saturation of a soil with water caused by the application of excessive amounts of water and /or poor drainage.

Watertable upper surface of groundwater, below which the layers of soil, rock, sand or gravel are saturated with water.

Appendixes

A. Rootstock/variety salinity tolerances

Table A1.: A guide to salt tolerance of a range of varieties and rootstocks.

Salt-tolerance classification	Soil salinity threshold (ECe) for % yield loss			Grapevine Variety or Rootstock
	0%	25%	50%	
Sensitive	1.8 dS/m	4.1 dS/m	6.7 dS/m	**Own Roots:** Sultana, Shiraz, Chardonnay, Pinot Noir, Riesling, Semillon, Merlot, Cabernet Franc, Cabernet Sauvignon, Grenache **Rootstocks:** 3309, 1202C, K51-40
Moderately sensitive	2.5 dS/m	4.8 dS/m	7.4 dS/m	**Own Roots:** Colombard **Rootstocks:** Kober 5BB, 5C Teleki, Richter 110, Richter 99, K51-32, SO4
Moderately tolerant	3.3 dS/m	5.6 dS/m	8.2 dS/m	**Rootstocks:** Rupestris St. George, Ruggeri 140, Schwarzmann, 101-14, Ramsey
Tolerant	5.6 dS/m	7.9 dS/m	10.5 dS/m	**Rootstocks:** 1103 Paulsen

(Source: Walker *et al.* 2002, Tee *et al.* 2003, Zhang *et al.* 2002 and Adams *et al.* 2006)
Note: These values are based on field trials over a 4-6 year period. More recent studies suggest that longer term exposure to saline conditions results in greater and more sustained yield losses at lower salinity levels.

B. Salinity conversion tables

Table B1.: Multiplier factors for different soil textures to convert $EC_{1:5}$ to EC_e

Texture	Factor (R)	Clay content	Factor (R)
Sand, loamy sand	13	0 – 10	12.4
Silty loam	12	11 – 20	10.2
Sandy loam, loam	11	21 – 30	8.8
Sandy clay loam, clay loam, silt clay loam	9	31 – 40	7.7
Sandy clay, silty clay, loamy clay	7	41 – 50	6.6
Medium, clay, heavy clay	5	51 – 60	5.7
		61 – 70	4.9
		71 – 80	4.2

(Source: Cass *et al.* 1996)
Note: If the salt in the soil is dominated by gypsum these conversions are unreliable.

Example: A loam with a $EC_{1:5}$ of 0.1 dS m^{-1} = 1.1 dS m^{-1} EC_e (0.1 x 11)

Table B2.: Relationship between electrical conductivity units and approximate salt concentrations

deciSiemens per metre (dS/m)		milliSiemens per centimetre (mS/cm)		microSiemens per centimetre (µS/cm)		EC units (EC)		parts per million ^ (ppm)		milliequivalence per litre (m.equiv/L)
0.1	=	0.1	=	100	=	100	=	64	=	1
1	=	1	=	1000	=	1000	=	640	=	10
10	=	10	=	10000	=	10000	=	6400	=	100

^equivalent to mg L^{-1}

C. Fertiliser effects on soil salinity

Table C1. Relative effect of fertilizer materials on the soil solution[1]

Material	Salt Index[2]
Anhydrous ammonia (NH_3)	47.1
Ammonium nitrate (NH_4NO_3)	104.7
Ammonium sulphate ($(NH_4)_2SO_4$)	69.0
Ammonium dihydrogen phosphate ($NH_4H_2PO_4$)	29.9
Ammonium thiosulphate ($(NH_4)_2S_2O_3$)	90.4
Calcium carbonate (limestone) ($CaCO_3$)	4.7
Calcium nitrate ($Ca(NO_3)_2$)	52.5
Calcium sulphate or gypsum ($CaSO_4.2H_2O$)	8.1
Diammonium hydrogen phosphate ($(NH_4)_2HPO_4$)	34.2
Dipotassium hydrogen phosphate (K_2HPO_4)	17.4
Dolomite ($CaCO_3$ and magnesium carbonates)	0.8
Monocalcium phosphate ($Ca(H_2PO_4)_2$)	15.4
Nitrate of soda ($NaNO_3$)	100.0
Potassium chloride, 50% (KCl)	109.4
Potassium chloride, 60% (KCl)	116.3
Potassium chloride, 63% (KCl)	114.3
Potassium dihydrogen phosphate (KH_2PO_4)	8.4
Potassium nitrate (KNO_3)	73.6
Potassium sulphate (K_2SO_4)	46.1
Potassium thiosulfate ($K_2S_2O_3$)	136.0
Sulphate of potash-magnesia ($2MgSO_4.K_2SO_4$)	43.2
Superphosphate, 16% ($Ca(H_2PO_4)_2 2CaSO_4$)	7.8
Triple superphosphate, 48% ($Ca(H_2PO_4)_2$)	10.1
Urea ($CO(NH_2)_2$)	75.4

[1] Data taken from Rader (1943) and Kambrova and Kirilov (2008).
[2] The salt index is for various fertilizer materials when applied at equal weights. Sodium nitrate, with a salt index of 100, is used as a base for the index

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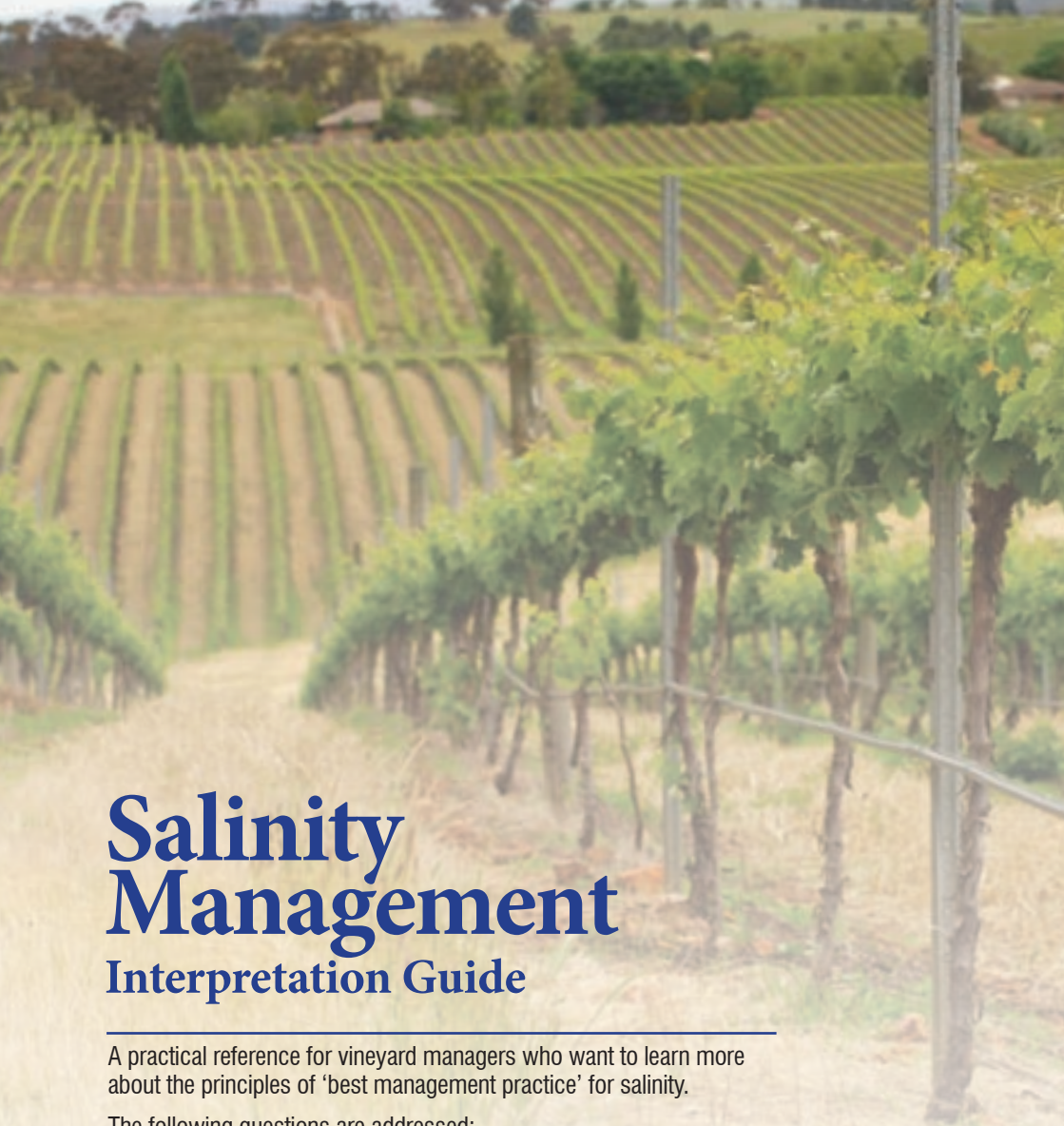

Salinity Management

Interpretation Guide

A practical reference for vineyard managers who want to learn more about the principles of 'best management practice' for salinity.

The following questions are addressed:

- What is salinity?
- How is a salinity problem caused?
- What are the affects of salinity on wine grape production?
- How can salinity be identified and monitored in a vineyard?
- How can salinity be managed to minimise future impacts?

If your vineyard is not showing any signs of salinity, this guide will inform you how to monitor your vineyard (vine, soil and water) on an on-going basis to help identify any developing salinity problem.