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MANAGING SALINITY IN THE VINEYARD

ROB WALKER : CSIRO PLANT INDUSTRY, WAITE CAMPUS, ADELAIDE

Salinity as a variable

Salinity refers to the amount of dissolved salts in water, soils or landscapes. The amount and types of dissolved salts in water can vary greatly. In Australia, the major ions in irrigation water from the River Murray, for example, and from various ground waters (Walker et al. 2010a), are sodium (Na^+) and chloride (Cl^-). A range of other ions may be present in varying concentrations, the usual ones being anions, sulphate, carbonate and bicarbonate, and cations, Na^+, calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+).

Salinity is measured as total soluble salts (ppm) or more correctly by electrical conductivity ($dS\ m^{-1}$, at a standard temperature of 25°C). Depending on the electrical conductivity (EC) value, it is possible to classify irrigation waters as low (0 - 0.28 $dS\ m^{-1}$), medium (0.28 - 0.80 $dS\ m^{-1}$), high (0.80 - 2.30 $dS\ m^{-1}$), very high (2.30 - 5.50 $dS\ m^{-1}$) or extreme (> 5.50 $dS\ m^{-1}$) salinity (Hart, 1974). For comparison, 1 $dS\ m^{-1}$ = 625 ppm.

The interaction between irrigation water and soil determines the soil solution salinity. The extent to which ionic constituents enter the soil solution, remain available to plants or become fixed and unavailable depends largely on the soil characteristics.

Proximity of a water table to the soil surface is another consideration. During and immediately following periods of rainfall or irrigation, water moves downwards through the soil to the water table, if present. At other times, depending on the depth to the water table, evaporation may reverse the direction of flow in the soil so that water moves up from the water table by capillary action. If the water table is saline, capillary rise can lead to an increase in the salinity of the soil solution in the surface layers.

Grapevine physiological responses to salinity

Grapevines show decreasing rates of photosynthesis with increasing salinity (Downton 1977a and Walker et al. 1981, 1997). The photosynthetic reduction is primarily associated with reduced stomatal aperture and increased resistance to CO^2 diffusion. At lamina concentrations higher than about 150 mM Cl^- in the tissue water, irreversible damage may occur. Leaves containing up to 150 mM Cl^- generally retain the capacity to recover normal physiological function once the salt stress is removed (Walker et al. 1981).

The symptoms of Cl^- toxicity in grapevine leaves are different from the symptoms of Na^+ toxicity.

Chloride toxicity

Sodium toxicity

Salinity effects on growth and development

Numerous studies have reported grapevine growth reductions in response to salinity, for example in the glasshouse (Downton 1977a); and in the field, as reduced pruning weights (Walker et al. 2002).

Salinity also affects the timing of budburst (Downton and Crompton 1979), timing of veraison (Downton and Loveys 1978), bunch number, fruitfulness and cane number (Prior et al. 1992), and berry size and sugar content (Hawker and Walker 1978; Prior et al. 1992; Walker et al. 2002). Prior et al. (1992) reported reductions in bunch numbers, % fruitful nodes, % fruitful shoots, bunches per node, bunches per cane and cane numbers of own-rooted, field-grown

Sultana vines at the higher salinity treatments (up to 3.5 dS m-1). Affects on yield are influenced by rootstock type. Severely salt-affected vines fail to mature fruit.

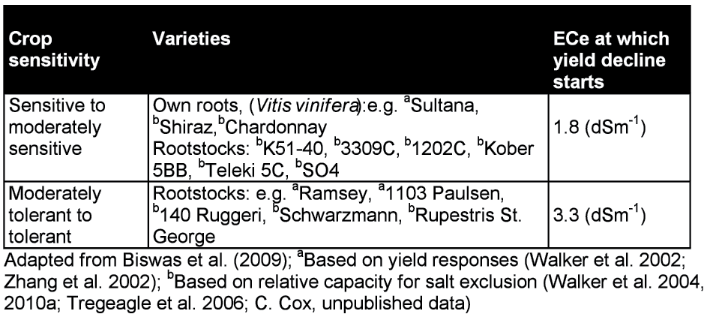
Severe Salt Damage

Yield-salinity relationship

Grapevines (*Vitis vinifera*), by comparison with other crop types, are classified as moderately sensitive to salinity (Maas and Hoffman, 1977). Maas and Hoffman (1977) suggested a threshold soil saturation paste electrical conductivity (EC$_e$.) of 1.5 dS m^{-1}, beyond which yield could be expected to decrease. They proposed a 9.6% reduction in yield for every 1 dS m^{-1} increase in EC$_e$.

The relationship was re-examined using data from a 5 year field trial involving *Vitis vinifera* cv Sultana vines on their own roots, and grafted to a range of rootstocks including Ramsey (*V. champinii*) and 1103 Paulsen (*V. rupestris* x *V. berlandieri*) (Walker et al. 2002). Data from two other 5-6 year duration field trials involving Sultana on own roots (Prior et al. 1992) and Colombard on Ramsey (Stevens et al. 1999) were also examined. All three trials involved irrigation water with EC in the range 0.4 dS m^{-1} to 3.5 dS m^{-1}. The yield threshold EC$_e$. for Sultana grapevines on their own roots was in the range 2.1 - 2.3 dS m^{-1}, while for Sultana on Ramsey it was in the range 3.3 - 3.8 dS m^{-1}. (Zhang et al. 2002). The most sensitive rootstock in that study had a 'yield threshold' EC$_e$ of 1.8 dS m^{-1}. Sultana on 1103 Paulsen did not experience a significant yield reduction over the duration of the trial (Walker et al. 2002). The yield decrease for every 1 dS m^{-1} increase in EC$_e$ beyond the threshold ranged from 9 to 15% for Sultana on own roots, while for Colombard and Sultana on Ramsey rootstock, it was approximately 6%.

Based on the above information, the following table may be considered an approximate guide for root zone salinity management. The very salt sensitive rootstocks K51-40 and 3309C may have a lower yield threshold than 1.8 dS m^{-1}.



Crop sensitivity	Varieties	ECe at which yield decline starts
Sensitive to moderately sensitive	Own roots, (*Vitis vinifera*):e.g. [a]Sultana, [b]Shiraz,[b]Chardonnay Rootstocks: [b]K51-40, [b]3309C, [b]1202C, [b]Kober 5BB, [b]Teleki 5C, [b]SO4	1.8 (dSm^{-1})
Moderately tolerant to tolerant	Rootstocks: e.g. [a]Ramsey, [a]1103 Paulsen, [b]140 Ruggeri, [b]Schwarzmann, [b]Rupestris St. George	3.3 (dSm^{-1})

Adapted from Biswas et al. (2009); [a]Based on yield responses (Walker et al. 2002; Zhang et al. 2002); [b]Based on relative capacity for salt exclusion (Walker et al. 2004, 2010a; Tregeagle et al. 2006; C. Cox, unpublished data)

Factors contributing to grapevine salt tolerance.

There are many factors that may contribute to grapevine salt tolerance, but the main ones are rootstock vigour and capacity for salt exclusion (Walker et al. 2002 and 2004). Salt exclusion is defined as the capacity of a plant to restrict uptake and/or root to shoot transport of dissolved salts.

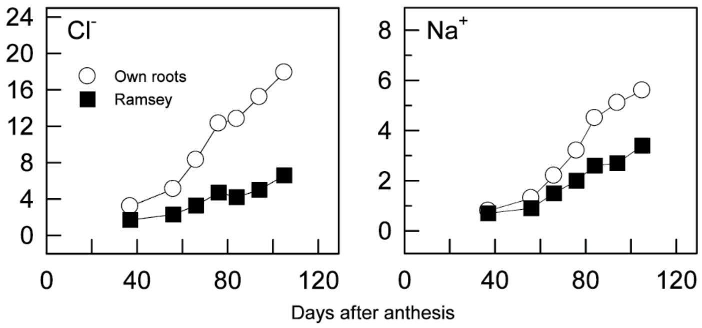
A positive linear relationship has been obtained between yield and rootstock vigour under both non-saline and saline conditions (Walker et al. 2002). Yield was poorly correlated with Cl$^-$ exclusion capacity (Walker et al. 2004), however, it is clear that rootstocks with poor capacity for Cl$^-$ exclusion e.g. K 51-40 may accumulate so much Cl$^-$ and Na$^+$ over time that considerable plant damage occurs leading to severe reductions in growth and yield and in many cases to plant death (Tregeagle et al. 2006; Walker et al. 2010a).

Different grapevine species vary widely in their capacity for salt exclusion. For example, Downton (1977d) analysed the harvest time petiole Cl$^-$ status of a range of self-rooted field grown grapevine species at Merbein, Victoria (irrigated with River Murray water), and ranked them as follows:- *V. rupestris* < *V. berlandieri*, *V. riparia* , *V. candicans*, *V. champinii*, *V. longii* < *V. cinerea*, *V. cordifolia* < *V. vinifera*.

Scions grafted to the better Cl$^-$ excluding species and hybrids as rootstocks under irrigation with River Murray water accumulate lower concentrations of Cl$^-$ in the petioles than the scions on their own roots, demonstrating that the Cl$^-$ exclusion characteristic is associated primarily with the rootstock (Sauer 1968; Walker et al. 2004 and 2010a). However, the scion can also have an effect, e.g. Shiraz tends to accumulate more Cl$^-$ than Chardonnay, irrespective of rootstock type (Walker et al. 2010a).

Sodium and chloride concentrations in grape berries

Sodium and Cl$^-$ concentrations in grape berries are affected by salinity level (Downton 1977b), by rootstock type (Downton 1977c) and by scion type (Walker et al. 2010a). The increase in Cl- and Na+ concentrations in grape berries is initially slow but then accelerates as the berry develops (Walker et al. 2000), e.g. for Shiraz, drip-irrigated with water of EC 2.1 dSm^{-1}(below).



Sodium and Cl$^-$ accumulate mainly in pulp and skin of the berry. Concentrations of Cl$^-$ in skin of Chardonnay on own roots and grafted to Ramsey, 1103 Paulsen and 140 Ruggeri were on average 10.1 fold higher than concentrations in pulp (Gong et al. 2010). For Shiraz, skin Cl$^-$ concentrations were 11.5 fold higher than in pulp. Concentrations of Na$^+$ in skin of Chardonnay on own roots and grafted to Ramsey, 1103 Paulsen and 140 Ruggeri were on average 1.9 fold higher than concentrations in pulp. For Shiraz, skin Na$^+$ concentrations were 2.3 fold higher than in pulp (Gong et al. 2010). This shows that Cl$^-$ accumulates to higher concentrations in skin than Na$^+$.

Sodium and chloride concentrations in wines

The maximum concentration of Cl$^-$ permitted in Australian wine is 607 mg/L (equivalent to 1000 mg/L when expressed as NaCl) (Commonwealth of Australia 2009). Some countries have lower limits for Cl$^-$ in wine, e.g. Turkey, where the limit is 303 mg/L (equivalent to 500 mg/L when expressed as NaCl). Australia does not have a maximum limit for Na$^+$ in wine. While many countries have no imposed limit for Na$^+$ in wine, a small range of countries have limits that vary considerably e.g. Canada (500 mg/L), Argentina (230 mg/L, as 'excess' or 'free' Na$^+$ i.e. the concentration of Na$^+$ in wine in excess of the concentration of Cl$^-$, based on equivalents), South Africa (100 mg/L) and Switzerland (60 mg/kg) (Stockley and Lloyd-Davies 2001).

Concentrations of Cl$^-$ in wine of Chardonnay are similar to or slightly higher than concentrations in grape juice (Walker et al. 2010a). More recently, however, mean increases (Chardonnay juice to wine) of 1.67 fold have been recorded for Cl$^-$ and 1.14 fold for Na$^+$ (Walker et al. 2010b). Concentrations of Cl$^-$ in wine of Shiraz are higher than concentrations in grape juice (Walker et al. 2010a, see table opposite). More recently, mean increases (Shiraz juice to wine) of 2.26 fold have been reported for Cl$^-$ and 1.20 fold for Na$^+$ (Walker et al. 2010b). The higher concentration of Cl$^-$ in wine of Shiraz than in wine of Chardonnay reflects extraction from Shiraz skins during red wine fermentation. The higher extraction of Cl$^-$ than Na$^+$ into wine of Shiraz reflects higher skin to pulp ratio for Cl$^-$ than for Na$^+$ in Shiraz grape berries (Gong et al. 2010).

Salty taste in wines

In studies involving Shiraz wines made from grapes from six rootstocks differing in capacity for salt exclusion and grown in a salt affected vineyard, a panel of experienced tasters detected statistically significant and substantial differences among the wines in 'salty' ratings. 'Salty taste' ratings correlated ($r > 0.94$) with the Na$^+$, Cl$^-$ and K$^+$ concentrations of the wines (Walker et al. 2003). The tasters also scored an attribute 'soapy', which was defined as a slimy or soft mouthfeel character. This attribute was closely correlated with the 'salty' scores of the wines. A high 'salty' score was related to relatively low scores for perceived acidity, fruit flavour, astringency and fruit persistence. Wine from K 51-40 rootstock, for example, which contained a Cl$^-$ concentration of 1750 mg/L, was rated significantly lower for each of these attributes than the wine made from 140 Ruggeri rootstock, which contained only 200 mg/L Cl$^-$ (Walker et al. 2003).

Rootstocks to reduce Cl$^-$ and Na$^+$ concentrations in wines

There are a range of rootstocks that demonstrate good capacity of Cl$^-$ and Na$^+$ exclusion (Walker et al. 2010a). The data shown below are for Shiraz vines at Merbein, planted in 1992 and assessed in seasons 1996 and 1997. The vines were drip irrigated, at approximately 6.5 ML/ha, with water having a salinity level of 2.1 dS m^{-1}. The poorest Cl$^-$ and Na$^+$ excluders are shown in bold type. Wine Na+ concentrations are not shown in the table because in that study (Walker et al. 2010a) sodium metabisulphite was used in winemaking which would have affected the relationship between juice Na$^+$ and wine Na$^+$.

Parameter	**Cl$^-$ (mg/L)**		**Na$^+$ (mg/L)**
Shiraz/ rootstock	**Harvest grape juice**	**Wine**	**Harvest grape juice**
Own roots	**378^{b}**	**622^{c}**	**81^{a}**
Ramsey	91^{c}	173^{d}	32de
1103 Paulsen	49^{c}	114^{e}	28^{e}
140 Ruggeri	48^{c}	127^{e}	39^{bcde}
K51-40	**516^{a}**	**809^{a}**	54^{b}
Schwarzmann	81^{c}	ND	45^{bcde}
101-14	71^{c}	ND	33^{cde}
R. St George	51^{c}	ND	46^{bcd}
1202C	**475^{a}**	**711^{b}**	**85^{a}**
LSD$_R$	88	34	18

ND = not determined

Sustainability of rootstock capacity for salt exclusion

The Cl$^-$ exclusion capacity of some rootstocks in some situations appears to diminish over time. For example, mean increases in Shiraz grape juice Cl$^-$ concentration between seasons 1996 and 1997 and seasons 2003 and 2004, were 6.3 fold with 1103 Paulsen as rootstock, 3.7 fold with Ramsey, 2.9 fold with 140 Ruggeri and 1.3 fold for Shiraz on own roots (Tregeagle et al. 2006). Current research is aimed at identifying rootstocks with sustained capacity for both Cl- and Na+ exclusion.

Water and soil management to reduce salinity impacts

A guide for root zone salinity management based on threshold soil saturation paste EC (EC_e) for yield decline was presented earlier. Root zone salinity should be regularly monitored and ideally maintained below the threshold values. This requires careful attention to irrigation management, soil type and leaching efficiency to ensure appropriate leaching fractions are applied (Walker et al. 2005). The efficiency of leaching depends on the level of intermixing between irrigation water and the water and soluble salts already in the root zone (Stevens 2002). Soils with a high leaching efficiency will require a lower leaching fraction to achieve a specific soil saturation paste EC than soils with a low leaching efficiency (Stevens 2002; Walker et al. 2005).

Irrigation with water containing a relatively high concentration of Na^+ relative to Ca^{2+} and Mg^{2+} may result in some soil types becoming sodic, which requires careful irrigation management to avoid fine particle dispersion, blocking of soil pores and decreases in hydraulic conductivity (Hart 1974).

The sodium adsorption ratio (SAR), or relative proportion of Na^+ to Ca^{2+} plus Mg^{2+} (Hart 1974), of the irrigation water (SAR_{iw}) and 1:5 soil water extract ($SAR_{1:5}$), provides a means of monitoring the potential sodium hazard. In general terms, for sensitive fruits, the tolerance limit for SAR_{iw} is about 4, but for general crops, slightly higher values may be tolerable depending on soil type, concentration of salts in the water and other variables (Hart 1974). Soils with $SAR_{1:5}$ values of 0 - 3 and exchangeable sodium percentage (ESP) values of 0 - 6 are considered non-sodic, while soils with $SAR_{1:5}$ values of 3 -10 and ESP values of 6 -15 are regarded as sodic (Cass et al. 2002).

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