Separating the Effects of Foliar and Root Salt Uptake on Growth and Mineral Composition of Four Grapevine Cultivars on their Own Roots and on ‘Ramsey’ Rootstock

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Abstract. The effect of foliar salt uptake on potted grapevine growth and ionic composition was investigated in a split plot trial. The main plot was a 2×2 factorial consisting of separately irrigating the roots and foliage with nonsaline or saline (25 mM NaCl) solutions. The subplot was a 4×2 factorial consisting of four grape (*Vitis vinifera*) cultivars on their own roots or ‘Ramsey’ (*Vitis champini*) rootstock. Saline foliar irrigation over 27 weeks reduced total vine growth by 14% while saline root irrigation had no effect. Leaf Na and Cl concentrations were elevated by saline foliar and saline root irrigation. The increases in concentrations with saline foliar irrigation were four times those with saline root irrigation. Leaf K concentration was reduced by saline foliar irrigation and increased by saline root irrigation. With saline irrigation of roots and foliage the Cl and Na levels were highest in the leaves of ‘Shiraz’, but with saline irrigation of only the roots ‘Sultana’ had the higher levels of leaf Cl and ‘Shiraz’ the highest leaf Na. Saline foliar irrigation had no effect on the concentrations of Na, Cl, and K in the roots. In ‘Sultana’, saline foliar irrigation did not affect the leaf concentrations of N, $\text{NO}_3\text{-N}$, P, Mg, Zn, and Cu. It increased the leaf concentration of Fe, and decreased that of Mn. Rootstock modified the effect of salinity on Fe concentrations. The B concentration was decreased by saline irrigation of either the foliage or the roots, but not by saline irrigation of both. In roots, saline foliar irrigation increased B in own-rooted vines, but not in those on ‘Ramsey’ rootstock.

The Murray Darling Basin is a major horticultural production area in Australia and in its southern portion the irrigation water salinity reaches 1.0 dS/m with a NaCl concentration of about 8 mM (McKay et al., 1988). Seasonal overhead sprinkler operations are in excess of 120 hours. Under these conditions, it is likely that the foliar uptake of salt contributes to salinity damage.

Prior et al. (1992a) suggested that the yield loss in salinized vines was caused by a decrease in photosynthesis. They found that leaf photosynthesis was strongly negatively correlated with leaf Cl concentration. Ehlig (1960) demonstrated that the accumulation of Cl in leaves caused foliar damage. Along the River Murray, Prior and Grieve (1985) found the leaf Cl concentration in vineyards irrigated with overhead sprinklers was 16% higher than that in vineyards where irrigation was applied by under canopy methods.

Francois and Clark (1979) found the leaf Cl and Na concentrations in vines sprinkled with saline water were directly proportional to the total sprinkling time. After 54 h of sprinkling with 10 mM NaCl, the leaf concentrations of Na and Cl approached toxic levels.

Amongst table grape cultivars, Francois and Clark (1979) found foliar Na and Cl uptake varied with cultivar. Downton

(1977) found that Na and Cl uptake by the roots was dependent on the rootstock species.

This study aimed to separate the effects on grapevine growth and tissue composition of salt uptake by the foliar pathway from those by the root pathway and to determine the effects of four winegrape cultivars on their own roots and on ‘Ramsey’ rootstock on this apportionment.

Materials and Method

Plant material and culture. Cuttings of own-rooted ‘Chardonnay’, ‘Sultana’, ‘Ruby Cabernet’, and ‘Shiraz’ vines and scions of these same four cultivars, which had been bench grafted onto ‘Ramsey’ rootstock, were planted in 2-liter pots and grown in shadehouse in the 1991–92 season (southern hemisphere).

In mid-August 1992, the dormant vines were pruned to two bud spurs and the potting soil was teased away from the roots while they were immersed in water. Five randomly selected vines from each cultivar–rootstock combination were harvested, divided into root and stem, and dried to a constant weight at 70°C. The remaining vines were repotted in 4-liter pots filled with steam sterilized coarse washed sand and placed in a 70% shaded glasshouse where the temperature was maintained between 15 and 30°C. Budburst occurred on 8 Sept. and after a single shoot of six leaves had established, the other buds were rubbed off. The shoot was trellised to a string suspended between the bench base and a mesh 2 m above. By mid-October, the vines had grown to a height of 1.5 m. Subsequent growth above this height and lateral shoots greater than two nodes in length were pruned monthly and retained for measurement of dry weight.

The vine roots were irrigated by a dripper in each pot with each

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vine receiving 0.17 liter of irrigation five times per day. The irrigation was well in excess of the soil water deficit and pots began to drain before the end of each irrigation. Irrigation water consisted of water drawn from the River Murray to which a commercial hydroponic solution (Hydroponic Nutrients, Top Australia, Adelaide, Australia) was added to bring the nutrient concentration to one-tenth of that recommended by the manufacturer. The resultant concentrations of N, P, K, Ca, Mg, and S in the irrigation water were 1.5, 0.1, 0.6, 0.8, 0.7, and 0.6 mM, respectively. Iron concentration was raised to 1 mg·liter⁻¹ by addition of sodium ferric ethylenediamine di (O-hydroxy phenylacetate). In mid-November the vines received a foliar spray consisting of 0.4 and 0.3 g·liter⁻¹ of Zn and Mn as sulphate salts, and 6 g·liter⁻¹ of urea. Growth increased with the onset of longer days and in November the nutrient additions to the irrigation water were doubled.

Vine foliage was irrigated with inverted microjet sprinklers suspended 2 m above the bench. Overhead irrigation was scheduled with a frequency and duration similar to that found in local commercial vineyards i.e., a 10.5 h irrigation being applied every 14 days with irrigation beginning at 1600 HR. The volumes of irrigation water were measured by in-line flow meters.

Treatment. The trial was a split plot design with the main plot a two by two factorial of irrigation treatments (combinations of plus (+S) or minus (-S) salt in the foliar (F) and root (R) irrigation solutions) and the subplot a four by two factorial (combinations of four cultivars, 'Chardonnay', 'Shiraz', 'Ruby Cabernet' and 'Sultana', on their own-roots or 'Ramsey' rootstock). The trial consisted of five replicates. Each replicate occupied a bench with a row of barrier vines placed around its perimeter.

Both the foliar and root irrigation solutions were salinised by addition of a sodium and calcium chloride brine to bring the irrigation solution NaCl concentration to 25 mM and the Na : Ca molar ratio to 17:1. Root saline irrigation began at budburst and saline foliar irrigation began 1 day after budburst – both continued until harvest.

Contamination of the rootzone by foliar solution was prevented by two barriers to water movement attached to the base of each stem. Each barrier consisted of a collar made from a strip of 2 mm closed cell foam wrapped four times around the stem and held in place with waterproof double sided tape to which was attached a plastic sheet fabricated into a cone. The top of the cone was attached to the collar with waterproof cloth tape. The plastic cone flared downward to below the top of the pot. On the top barrier, a waterproof pruning paint was applied as an additional seal against water movement between the collar and the stem. In the grafted

vines, the graft and the stem of the rootstock, which protruded above the collar, were also coated with waterproof pruning paint to prevent salt entry via these sites.

Cross contamination of plots during overhead sprinkling was prevented by inserting movable 2-m-deep plastic curtains, which fell from the top of the trellis to the base of the pots, between the plots.

Water samples were collected by continuously bleeding the supply line through a microcapillary tube into a 4-liter jar. These samples were bulked on a monthly basis and analysed for Na and Cl following methods described for analysis of tissue.

Measurements. In mid-March, the vines were harvested and the shoots divided into leaves and stems. Roots were separated from the potting sand by submerging the pots in water and teasing the sand away from the root balls. Roots that broke away from the balls were retrieved from the washing water with a sieve. All material was dried to a constant weight at 70°C. The stem and root portions included growth from the preceding season. So that the weights represented only growth that occurred during the trial, the weights of these two portions were corrected by subtracting the mean weights of the root and stem samples taken at the beginning of the trial before budburst.

Chemical analyses were performed on the lamina of leaves inserted between nodes three and eleven, and on a subsample of roots removed after the entire root sample was coarsely ground. At harvest, the leaves were rinsed in three 5-liter baths of distilled water to remove salt from their surface. Two drops of 5 N nitric acid and two drops of phosphate-free detergent were added to the first bath. The water was changed whenever the electrical conductivity of the first bath rose above 0.1 dS·m⁻¹. After drying, the material was ground in a hammer mill to pass a 0.8 mm mesh. Chloride content of a cold water extract was measured with a chloridometer. The remaining material was ashed, dissolved in 6 N HCl, and the Na and K was measured by atomic absorption spectrophotometry (Leece and Short, 1967). For 'Sultana', leaf lamina and root concentrations of N, NO₃-N, P, Mg, Ca, Fe, Zn, Mn, Cu, and B were also determined. The determination of cations followed the method already described. Nitrate-N was determined by an ion selective electrode in a cold water extract buffered with Al₂(SO₄)₃; nitrogen was measured on a modified Kjeldahl digest; phosphorus was measured by the molybdenum blue method (Murphy and Riley, 1962); boron was measured by the carminic acid method (Hatcher and Wilcox, 1950).

Statistical analysis. The significance of difference between treatments was tested by analysis of variance. Least significant differences were only calculated when the F test for treatments was

Table 1. The effects of saline (+S) foliar (F) and root (R) irrigation on the net grapevine growth (g/vine).

	Irrigation treatment				LSD (<i>P</i> = 0.05)		
	F-S, R-S	F-S, R+S	F+S, R-S	F+S, R+S	F	R	F × R
Root ^z	16.1	14.4	12.5	9.2	1.9	1.9	NS
Stem ^y		46.7		40.9	3.3	NS	NS
Leaf ^x	34.5	40.1	32.4	34.2	***	***	4.3
Total ^y		100.1		85.8	6.3	NS	NS

^zThe effect of each factor was significant, but the interaction between them was not, the individual treatment means are shown and application of the LSD requires calculation of the mean appropriate to the comparison.

^yThe effect of saline foliar irrigation was significant and the mean appropriate for comparison is shown.

^xThe effect of each factor and the interaction between factors were significant; the significance of the effect of individual factors, and the LSD and means appropriate to comparison based on the interaction between factors are shown.

significant. Tukey's one degree of freedom test for non-additivity was used to test for the assumption of additivity, and the assumption of normality was checked by inspection of the plot of fitted values against residuals. Where necessary, the data were log transformed to meet assumptions of normality and additivity.

Results

The mean concentrations of NaCl were 3.3 and 26.0 mM for the nonsaline and saline solution, respectively. Analysis of the variance amongst the sets of samples collected on a monthly basis showed that the Na and Cl concentrations in the foliar and root irrigation were equivalent.

Growth. The effects of saline irrigation on the growth of whole vine and individual organs were independent of vine cultivar and rootstock. Saline foliar irrigation depressed total vine growth by 14%, root growth by 28% (F+S vs. F-S), stem growth by 12% (F+S vs. F-S) and leaf growth by 11% (Table 1). Saline root irrigation did not affect the total vine growth. It depressed root growth by 17% (R+S vs. R-S), did not affect stem growth and stimulated leaf growth by 11% (R+S vs. R-S). The 11% increase was due to the positive effect that saline root irrigation had on leaf growth when foliar irrigation was nonsaline (F-S,R+S vs. F-S,R-S).

Leaf Cl, Na, and K concentrations. In the treatment combining saline foliar irrigation with nonsaline root irrigation, the Cl and Na concentrations were 208% and 519%, respectively greater than those in the nonsaline control (Table 2). Saline root irrigation caused smaller increases relative to the control. In the treatment combining nonsaline foliar with saline root irrigation, the Cl and Na concentrations were 59% and 109%, respectively, greater than those in the nonsaline control. The rises in Cl and Na concentrations caused by saline foliar irrigation were 3.7 and 4.7 times those caused by saline root irrigation.

'Ramsey' rootstock reduced the Cl concentration in all irrigation treatments (Table 2). The reduction of 48% achieved under nonsaline conditions was much greater than that of 18% and 10% achieved under saline root and saline foliar irrigation treatments, respectively. 'Ramsey' rootstock reduced the Na concentration in the nonsaline control, had no effect in irrigation treatments that received saline foliar irrigation, and increased the Na concentration in the treatment combining saline root irrigation with nonsaline foliar irrigation.

Table 2. The effects of saline (+S) foliar (F) and root (R) irrigation on the concentrations of Cl and Na in the leaves of grapevines on their own-roots and 'Ramsey' rootstock. Data were log transformed for analysis and the untransformed values of concentration (mmol·kg⁻¹ dry weight) are enclosed in parenthesis.

	Irrigation treatment			
	F-S,R-S	F-S,R+S	F+S,R-S	F+S,R+S
<i>Chloride</i>				
Own-rooted	2.29 (198)	2.40 (260)	2.68 (487)	2.70 (502)
Ramsey	2.01 (103)	2.31 (212)	2.64 (437)	2.66 (468)
LSD 0.03 (<i>P</i> = 0.05) for comparison between rootstock species receiving the same irrigation treatments and for comparison between different irrigation treatments with the same or different rootstock species.				
<i>Sodium</i>				
Own-rooted	1.63 (48)	1.81 (77)	2.37 (261)	2.48 (336)
Ramsey	1.55 (37)	1.97 (102)	2.38 (270)	2.52 (355)
LSD 0.05 (<i>P</i> = 0.05) for comparison between rootstock species receiving the same irrigation treatments: 0.07 (<i>P</i> = 0.05) for comparison between different irrigation treatments with the same or different rootstock species.				

Table 3. The effects of saline (+S) foliar (F) and root (R) irrigation on the concentrations of Cl and Na in the leaves of four grapevine cultivars. Data was log transformed for analysis and the untransformed values of concentration (mmol·kg⁻¹ dry weight) are enclosed in parenthesis.

	Irrigation treatment			
	F-S, R-S	F-S, R+S	F+S, R-S	F+S, R+S
<i>Chloride</i>				
Chardonnay	2.14 (144)	2.30 (205)	2.57 (372)	2.63 (432)
Sultana	2.17 (166)	2.46 (294)	2.70 (499)	2.66 (463)
Ruby Cabernet	2.18 (153)	2.36 (238)	2.64 (434)	2.66 (457)
Shiraz	2.11 (139)	2.31 (206)	2.73 (542)	2.77 (590)
LSD 0.10 (<i>P</i> = 0.05) for comparison between cultivars in the same irrigation treatment: 0.05 (<i>P</i> = 0.05) for comparison between irrigation treatments with the same or different cultivar.				
<i>Sodium</i>				
Chardonnay	1.43 (28)	1.73 (56)	2.23 (173)	2.39 (256)
Sultana	1.63 (44)	1.92 (86)	2.42 (268)	2.50 (317)
Ruby Cabernet	1.57 (44)	1.75 (60)	2.21 (165)	2.37 (239)
Shiraz	1.73 (54)	2.17 (156)	2.65 (453)	2.74 (569)
LSD 0.12 (<i>P</i> = 0.05) for comparison between irrigation treatments with the same or different cultivar: 0.10 (<i>P</i> = 0.05) for comparison between cultivars receiving the same irrigation treatment.				

There were significant interactions between irrigation and cultivars for the Cl and Na concentrations. With saline irrigation of the foliage and the roots, the Cl concentration in 'Shiraz' vines was greater than the other cultivars. With the treatment that combined saline root irrigation and nonsaline foliar irrigation, the Cl concentration in 'Sultana' was greater than all other cultivars. With nonsaline irrigation all cultivars were equivalent (Table 3).

In all irrigation treatments, the Na concentration in 'Shiraz' was higher than in 'Sultana', which in turn was higher than in 'Chardonnay' and 'Ruby Cabernet', which were equivalent excepting the nonsaline treatment (Table 3). With the combination of saline foliar and saline root irrigation the greatest increase (linear scale) in Na occurred in 'Shiraz' and 'Chardonnay', 954% and 814% respectively. Even though a large increase in Na occurred in 'Chardonnay', the concentration was equivalent to that in 'Sultana', the cultivar with the lowest concentration, because the base level of Na in 'Chardonnay' was the lowest amongst cultivars. In the treatment that combined saline root irrigation with nonsaline foliar irrigation, the greatest increase in Na concentration, 189%, occurred in 'Shiraz'. With saline foliar irrigation, the addition of saline root irrigation caused a rise in the Na concentrations of 'Chardonnay' and 'Ruby Cabernet', but had no effect on those of 'Sultana' and 'Shiraz'.

Saline foliar irrigation decreased (*P* < 0.001) the K concentration by 15% from 351 to 297 mmol·kg⁻¹ dry weight. This effect was independent of the root irrigation treatment, cultivar, and rootstock. Saline root irrigation increased the K concentration by 60% from 250 to 397 mmol·kg⁻¹ dry weight, and altered the ranking of cultivars by K concentration (Table 4). With saline root irrigation the K concentrations in 'Sultana' and 'Ruby Cabernet' were higher than those in 'Chardonnay' and 'Shiraz'. Under nonsaline root irrigation the K concentration in 'Sultana' was higher than those in other cultivars. The interaction term between foliar and root irrigation was not significant, however there was a trend (*P* < 0.10) for the K concentrations in the treatment combining saline root irrigation with nonsaline foliar irrigation, 436 mmol·kg⁻¹ dry weight, and the treatment receiving saline irrigation of the foliage and roots, 360 mmol·kg⁻¹ dry weight, to be higher than that in the

Table 4. The effect of saline (+S) root irrigation treatment on the K concentration (mmol·kg⁻¹ dry weight) in the leaves of four grapevine cultivars

Root irrigation treatment	R - S	R + S
Chardonnay	227	361
Sultana	287	441
Ruby Cabernet	240	437
Shiraz	246	352

LSD 42 ($P = 0.05$) for comparison between different root irrigation treatments with the same or different cultivars: 38 ($P = 0.05$) for comparison between two cultivars receiving the same root irrigation treatment.

nonsaline control treatment, 266 mmol·kg⁻¹ dry weight.

Root Cl, Na, and K concentrations. The salinity of foliar irrigation did not affect the concentrations of Na, Cl, and K in the root (data not shown).

Saline root irrigation increased the concentration of Cl and this effect was modified by rootstock and cultivar. In 'Sultana' and 'Shiraz', the use of 'Ramsey' rootstock reduced the Cl concentration regardless of root irrigation treatment. With 'Chardonnay' the rootstock only reduced the Cl concentration under saline irrigation. In contrast, the use of 'Ramsey' rootstock with 'Ruby Cabernet' increased the Cl concentration under saline conditions (Table 5).

With saline root irrigation the use of 'Ramsey' rootstock decreased the root concentration of Na in 'Sultana', had no effect in 'Chardonnay', and increased it in 'Ruby Cabernet' and 'Shiraz' (Table 5). With nonsaline root irrigation, 'Ramsey' rootstock did not affect Na.

Saline root irrigation decreased ($P = 0.0001$) the K concentration in 'Shiraz' from 230 to 157 mmol·kg⁻¹ dry weight. It did not affect the concentrations in 'Sultana', 'Ruby Cabernet', and 'Chardonnay', which were 263, 196, and 208 mmol·kg⁻¹ dry weight, respectively. In own-rooted vines, saline root irrigation decreased ($P = 0.01$) the concentration of K from 263 to 223 mmol·kg⁻¹ dry weight. The K concentration in 'Ramsey' rootstock did not respond to saline irrigation and had a mean value of 198 mmol·kg⁻¹ dry weight.

Leaf P, Mg, Mn, B, Fe, Ca, N, NO₃-N, Zn, and Cu concentrations. Saline foliar irrigation decreased ($P = 0.02$) the concentration of Mn from 15.3 to 13.7 mmol·kg⁻¹ dry weight and increased ($P < 0.0001$) the concentration of Fe from 0.54 to 0.71 mmol·kg⁻¹ dry weight. With nonsaline foliar irrigation, the use of 'Ramsey' rootstock decreased ($P < 0.01$) Fe concentration from 0.45 to 0.30 mmol·kg⁻¹ dry weight.

In own-rooted vines, saline foliar irrigation increased ($P < 0.05$) the concentration of Ca from 591 to 664 mmol·kg⁻¹ dry weight. This increase may have been caused by the addition of Ca to the saline irrigation solutions, however with vines on 'Ramsey' rootstock the Ca concentration was not affected by the salinity of irrigation and had a mean value of 676 mmol·kg⁻¹ dry weight.

In the nonsaline control treatment and that receiving saline irrigation of the foliage and roots, the B concentrations were equivalent with a mean value of 8.4 mmol·kg⁻¹ dry weight. In the treatments where saline irrigation was only applied to the foliage or to the roots, B was reduced ($P < 0.002$) to 7.5 and 7.1 mmol·kg⁻¹ dry weight for saline foliar and saline root irrigation, respectively. The concentrations of B in these two treatments were equivalent.

Saline root irrigation decreased ($P < 0.001$) the concentration of Mg from 205.0 to 168.0 mmol·kg⁻¹ dry weight and increased ($P = 0.001$) the concentration of P from 191 to 398 mmol·kg⁻¹ dry weight.

The irrigation treatments did not affect the concentrations of N, NO₃-N, Zn and Cu and their means were 2075, 36, 4.9, and 0.3

mmol·kg⁻¹ dry weight, respectively.

Root P, Mg, Mn, B, Fe, Ca, N, NO₃-N, Zn, and Cu concentrations. In own-rooted vines, saline foliar irrigation increased the concentration of B from 1.3 to 1.7 mmol·kg⁻¹ dry weight ($P = 0.05$). The concentration in 'Ramsey' rootstock was not affected by the salinity of irrigation and had a mean value of 1.7 mmol·kg⁻¹ dry weight.

Saline root irrigation increased ($P = 0.01$) the concentration of P from 93 to 141 mmol·kg⁻¹ dry weight and 85 to 108 mmol·kg⁻¹ dry weight in 'Sultana' roots and 'Ramsey' rootstock, respectively. With saline root irrigation the P concentration in 'Sultana' roots was greater ($P = 0.01$) than that in 'Ramsey' rootstock.

Saline root irrigation increased the concentrations of Mn ($P < 0.0001$) and Fe ($P = 0.02$) from 3 to 6 mmol·kg⁻¹ dry weight and 28 to 37 mmol·kg⁻¹ dry weight, respectively. The concentration of Mg was reduced ($P = 0.0001$) from 99 to 80 mmol·kg⁻¹ dry weight by saline root irrigation.

The irrigation treatments did not affect the concentrations of N, NO₃-N, Ca, Zn, and Cu and their mean concentrations were 1329, 75, 139, 3.1, and 0.6 mmol·kg⁻¹ g dry weight, respectively.

Discussion

Growth. The effects of salinity on growth have been ascribed to osmotic and toxic ion stresses, and nutrient imbalance (Marschner, 1986). Saline root irrigation did not reduce vine growth and therefore the growth loss in the present study could not be attributed to a fall in the osmotic potential of the soil solution.

Saline foliar irrigation decreased the leaf Mn and K concentrations by 10% and 15%, respectively, and increased the Fe concentration by 32%. While saline foliar irrigation decreased K in the leaf, there was a trend in the treatment combining saline root with saline foliar irrigation for the concentration to be greater than that in the nonsaline control treatment which suggests that a reduction in leaf K cannot explain the loss in growth. In own-rooted vines, but not those on 'Ramsey' rootstock, saline foliar irrigation increased the lamina concentration of Ca and the root concentration of B. The growth loss was unresponsive to rootstock and this suggests that alterations to the Ca content of the lamina and the B content of the roots did not affect growth. Saline foliar irrigation decreased the B concentration of leaves in the absence of saline root irrigation, but not in its presence. The loss of growth was insensitive to the salinity of root irrigation suggesting that the growth loss could not be attributed to alteration of the B concentration.

By elimination, the remaining potential causative agents of growth decline are the toxic effects of Na and Cl and the nutritional disorders caused by decreasing Mn or increasing Fe. The percentage changes in the concentrations of Na and Cl (>200%) were much greater than those in the concentrations of Mn and Fe and these differences suggest a toxic effect rather than a nutrient disorder was the more likely cause of the growth loss.

Walker et al. (1981) found that the suppression of shoot growth in 'Sultana' vines by saline irrigation of the rootzone (90 mM NaCl) could be fully reversed by replacing the saline irrigation solution with nonsaline solution. The leaf concentrations of Na and Cl remained high during this recovery. Their observation would support a hypothesis that high tissue concentrations of a Na and Cl are not necessarily toxic and are only associated with a decline in growth when roots are irrigated with saline solutions i.e., the vine is exposed to an osmotic stress due to the lowering of soil water potential by saline irrigation. In the present study, the association between reduced growth, high leaf Na and Cl concentrations, and nonsaline root irrigation found in the treatment combining saline

Table 5. The effect of root irrigation treatment on the concentrations (mmol·kg⁻¹ dry weight) of Cl and Na in the roots of four grapevine cultivars on their own roots and on 'Ramsey' rootstock

	Root irrigation treatment							
	R - S				R + S			
	'Chardonnay'	'Sultana'	'Ruby Cabernet'	'Shiraz'	'Chardonnay'	'Sultana'	'Ruby Cabernet'	'Shiraz'
<i>Chloride</i>								
Own-root	107.8	210.2	107.8	128.9	235.0	309.2	145.0	197.7
Ramsey	86.3	84.6	80.4	87.7	140.8	177.7	198.9	163.3
LSD 33.1 (<i>P</i> = 0.05) for comparison between different root irrigation treatments with the same or different combinations of rootstock and cultivar: 32.6 (<i>P</i> = 0.05) for comparison between two combinations of cultivar and rootstock receiving the same root irrigation treatment.								
<i>Sodium</i>								
Own-root	67.0	110.0	77.0	101.8	159.6	219.7	126.1	130.1
Ramsey	66.1	87.0	73.1	86.6	149.2	179.2	191.4	162.2
LSD 30.6 (<i>P</i> = 0.05) for comparison between different root irrigation treatments with the same or different combinations of rootstock and cultivar: 28.9 (<i>P</i> = 0.05) for comparison between two combinations of cultivar and rootstock receiving the same root irrigation treatment.								

foliar irrigation with nonsaline root irrigation supports a rejection of this hypothesis.

In mature vines, Prior et al. (1992a, 1992b) found that over six seasons the effects of salinity on vine growth and the tissue concentrations of Na and Cl were cumulative. This suggests that Na and Cl were carried over between season in the over-wintering organs of the vine. In immature potted vines, the potential over-wintering organs are the root and stem. In the stem (data not presented), the Na and Cl concentrations in the treatment combining saline foliar irrigation with nonsaline root irrigation (F+S, R-S) were equivalent to those in the treatment combining nonsaline foliar irrigation with saline root irrigation (F-S, R+S). In the root the Na and Cl concentrations in the F-S, R+S treatment were 1.7 and 1.5 times, respectively, those in the F+S, R-S treatment. In the leaf, the Na and Cl concentrations in the F+S, R-S treatment were 3.0 and 1.9 times those in the F-S, R+S treatment. This pattern of ion distribution indicates that if given leaf Na and Cl concentrations were acquired via foliar uptake then the concentrations of these ions in the over-wintering organs will be less than if the same leaf concentrations were acquired via root uptake. This suggests that the carryover, across seasons, of Na and Cl acquired via foliar uptake will be less than that of the same ions acquired via root uptake.

Tissue Cl, Na, and K concentration. Cultivar differences in the rate of leaf Na and Cl uptake under saline irrigation suggest that 'Shiraz' vines would be most at risk of high leaf Cl and Na with saline overhead irrigation. With saline under-vine irrigation, 'Sultana' vines would be most at risk of high leaf Cl and 'Shiraz' of high leaf Na.

Groot Obbink, and Alexander (1973) found that with saline root irrigation only, the Cl concentration in the leaf petiole of 'Shiraz' was lower than that in 'Sultana'. The present study, where the Cl concentration in the leaf blade was highly correlated with that in the petiole (*r* = 0.77, data not presented). Based on this difference Groot Obbink, and Alexander (1973) suggest that 'Shiraz' should have a greater tolerance to Cl in irrigation water than 'Sultana'. In the present study, with saline foliar and root irrigation, the order was reversed, i.e., the Cl concentration of 'Shiraz' was greater than that of 'Sultana', which suggests that 'Sultana' should have a greater tolerance to Cl in irrigation water than 'Shiraz' under overhead irrigation.

The addition of saline root irrigation to saline foliar irrigation did not increase the leaf Cl concentration and only increased the leaf Na in the two cultivars with the lowest concentrations of Na. Chloride concentrations in the leaf were at least a 100 mmol·kg⁻¹

dry weight higher than Na. This suggests that uptake of Na and Cl via the root pathway may be controlled by the concentrations present in the leaf.

The Na to Cl ratios in the saline and nonsaline irrigation water were both unity. The values of the same ratio in the root and stem (between nodes 1 and 4) were 0.9 and 1.7 (Stevens and Harvey, unpublished data). Neither value was affected by the irrigation treatments. In the leaf lamina of the nonsaline control treatment, Na exclusion reduced the Na to Cl ratio to 0.4. Saline irrigation of the roots increased the ratio to 0.5 and saline irrigation of the foliage increased the ratio to 0.6. The increase in the value of the ratio with saline root irrigation was associated with a rise in leaf lamina K concentration, whereas the increase with saline foliar irrigation was associated with a fall in the concentration of K in the leaf.

The stimulation of leaf growth in the treatment which combined nonsaline foliar irrigation with saline root irrigation was associated with a high leaf K concentration (436 mmol·kg⁻¹ dry weight as against 266 mmol·kg⁻¹ dry weight in the nonsaline control). In the root, the K concentration in this treatment was 7% lower than that in the nonsaline control. These results suggest that the high concentration of K in the leaf was due to elevated transport from the root.

This association suggests that the exclusion of Na from the leaves may in part be accomplished by exchanging K for Na as the ions move from the root to the shoot. In so far as salinity tolerance is based on a Na-K exchange then the enhanced exchange where salt uptake is via the root, suggests that tolerance to soil salinity is based on a different mechanism to that which confers tolerance to saline overhead irrigation.

Our finding that saline root irrigation caused a rise in leaf K agrees with Hawker and Walker (1978), who worked on Cabernet Sauvignon, and Joolka et al. (1977) who worked with a number of cultivars including 'Sultana', but contrasts with the fall in K concentration found by Prior et al. (1992b) and Downton (1985) who both worked with 'Sultana', and Sourail et al. (1985) who worked with a number of cultivars including 'Sultana'.

With saline root irrigation, the root Cl concentration in the own-rooted 'Ruby Cabernet' scion was lower than in 'Ramsey' rootstock, whereas in the other three cultivars the root Cl concentrations in own rooted vines was higher than in those on 'Ramsey' rootstock. The rootstock effect on leaf Cl was independent of cultivar.

Other nutrients. In the present study, saline root irrigation decreased the leaf concentrations of K and Mg, and increased leaf P without reducing growth. We can conclude that salinity induced

changes in the concentrations of K, Mg, and P similar in magnitude to those of the present study, do not affect vine growth.

Implications for the field. The relative effects of root and foliar salt uptake on growth determined under our experimental conditions probably do not translate to the field. In the field, the concentration of salts in the soil is higher than that in the irrigation water. Between irrigations, the processes of evaporation and transpiration concentrate salts in the soil water. In the present study, which was irrigated five times per day, the effect of these processes was probably negligible, however it becomes significant when the irrigation frequency is reduced to once every 14 days. Blesing and Tuffley (1977) and Ayers and Westcot (1985) proposed that after an equilibrium has been reached between salt concentration in the irrigation water and the soil solution, the electrical conductivity of soil water was 3-fold- and 5-fold, respectively, greater than that in the irrigation water. Application of these propositions to irrigation water with a NaCl concentration of 25 mM gives a corresponding NaCl concentrations in the soil water of between 75 and 125 mM. Stevens and Harvey (1995) drip irrigated the rootzone of 'Sultana' vines between three and seven times per day for 16 weeks with 60 mM NaCl. In own-rooted 'Sultana' this caused shoot mass to decline by 42%. In the present trial, increasing the NaCl concentration of the foliar irrigation from 3 to 26 mM caused shoot mass to decline by 12% in own-rooted 'Sultana'. Comparison between the growth losses in these two studies suggests that, after an equilibrium has been established between salt concentration in the irrigation water and the soil solution, the growth loss in field grown vines from salt uptake via the roots would be more than three times that caused by salt uptake via the foliage. However, the allocation of loss against the two pathways is strongly dependent on whether an equilibrium establishes between salt concentration in the irrigation water and the soil solution. In the second season of a field salinity experiment, Prior et al. (1992c) found the ratio of salt concentration in the saturated soil solution to that in the irrigation water was 1:1 and rose to 5:1 after 6 years of saline irrigation. This suggests under conditions where irrigation water salinity changes from season to season the application of Blesing and Tuffley (1977) or Ayers and Westcot (1985) propositions regarding equilibrium conditions would overestimate the contributions that root uptake of Na and Cl make to the growth loss.

Studies of Downton (1985) and Bernstein et al. (1969) have established that 'Ramsey' rootstock excludes chloride from 'Sultana' scions. This property was demonstrated in experiments where only the roots were irrigated. Downton (1985) salinized potted 'Sultana' scions on their own roots and on 'Ramsey' rootstock by irrigating with a 25 mM mixed cation (sodium dominant) chloride solution. In own-rooted vines the Cl concentration in the lamina of a leaf sample taken in March was 140 mmol·kg⁻¹ dry weight and the ratio of the lamina Cl concentration in scions on 'Ramsey' rootstock to those own-rooted vines was 0.4. In the present experiment, the Cl concentration in the lamina of a leaf sample taken in March from own-rooted 'Sultana' vines which had their roots and foliage irrigated with 26 mM NaCl was 480 mmol·kg⁻¹ dry weight and the ratio of the lamina Cl concentration in scions on 'Ramsey' rootstock to those own-rooted vines was 0.9. In the present experiment, foliar uptake was a major pathway for Cl entry into the vine and as this bypasses the rootstock the reduction in the efficacy of Cl exclusion by 'Ramsey' rootstock is to be expected. Under field conditions, the concentration of salts in the soil solution of vines irrigated with 26 mM NaCl solution by over canopy sprinklers would probably be greater than that in the present experiment. This increase in concentration

would increase the proportion of salt entering the vine via the root. For this reason the reduction in the Cl exclusion efficacy of 'Ramsey' rootstock observed in the present experiment probably overestimates that likely to be observed under field conditions. The degree of overestimation may be minor.

The results of Downton (1985) suggest that increasing the concentration of chloride in the rootzone, and coincidentally the total salt concentration, is associated with a fall in the efficacy of Cl exclusion by 'Ramsey' rootstock. He found that in vines irrigated with 12.5, 25, 50, and 75 mM Cl solutions the ratios of lamina Cl concentration in scions on 'Ramsey' rootstock to those own-rooted vines were 0.3, 0.4, 0.8, and 0.7. In contrast, Bernstein et al. (1969) found that increasing the concentration of chloride in the rootzone from 12 to 50 mM did not affect the ratios of lamina Cl concentration in 'Sultana' (synonymous with 'Thompson Seedless') scions on 'Ramsey' rootstock to those own-rooted vines, which remained constant at 0.2. However, unlike the study of Downton (1985), that of Bernstein et al. (1969) maintained a constant total salt concentration in the rootzone and produced a variation in the chloride concentration by varying the proportion of chloride and sulphate salts in a 50 mM mixed cation (sodium dominant) solution. Downton's (1985) model, i.e., an association between increases in the concentrations of chloride and total salt, bears more resemblance to field conditions in the Murray-Darling Basin.

While the use of over-canopy irrigation exposes vines to the risk of salt uptake via the foliage and predisposes the vines to fungal foliage infection (Emmett et al., 1992) this method of irrigation also offers some advantages. Compared with other methods of improved irrigation, e.g., drippers and under-vine sprinklers, overhead sprinklers provide a means of frost protection, have less stringent water filtration requirements because of a larger nozzle diameter, have less emitters to monitor per area covered, allow the use of irrigation to establish cover crops, and have a sprinkler distribution pattern that is insensitive to weed problems. These advantages must be weighed against the increased likelihood of losses to salinity and fungal disease.

In horticultural tree crops, Ehlig and Bernstein (1959) found that the application of saline foliar irrigation at midday caused more leaf damage and greater salt uptake than its application in the evening. Recent findings with barley suggest that variation in climatic parameters other than light, temperature, and humidity may also affect foliar salt uptake. Aragüés et al. (1994) and Gorham et al. (1994) have found that foliar uptake of Cl and Na by barley from saline overhead irrigation can be reduced by a short period of irrigation with nonsaline water applied before saline irrigation. These results suggest that salt uptake via foliage from overhead irrigation may be reduced when irrigations immediately follow morning dew or a non-effective rainfall event.

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