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Response of Six Grape Cultivars to the Combined Effects of High Salinity and Rootzone Waterlogging

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Abstract. **The effect of rootzone salinity (0 to 90 mM NaCl) on shoot growth of 6 grape cultivars ['Sultana' (syn. 'Thompson Seedless'), 'Carbernet Sauvignon', 'Crouchen', 'Shiraz', 'Doradillo' and 'Palomino'] grown as rooted cuttings was determined in sand cultures. Relative shoot growth values over 23 days with salt were 'Palomino' 100, 'Sultana' 94, 'Shiraz' 87, 'Crouchen' 83, 'Cabernet Sauvignon' 63, and 'Doradillo' 59. Application of concurrent waterlogging (anaerobiosis) stress on the root system depressed shoot growth more than salt stress alone and changed the ranking for shoot growth. Waterlogging increased total uptake of Na and Cl, increased the amount of Na and Cl transported into the shoots, and resulted in visible leaf damage within 5 days of the onset of the waterlogging.**

Plant species differ in tolerance to rootzone waterlogging (anaerobiosis) (15) or to rootzone salinization (14), and these differences are important when selecting plants adapted to these conditions. Plant performance under well drained saline conditions has been reviewed extensively (6, 11, 14), and there are several reviews of plant response to rootzone waterlogging (10, 15, 16). There is little information, however, on plant performance under the combined stress, a condition which occurs frequently in the field.

With high salinity and low oxygen, plant growth is reduced severely (1, 4, 19) and salt uptake and transport to the shoots are greatly increased compared with a nonwaterlogged condition (17, 18, 19, 20). Adverse effects may occur even while only parts of the rootzone are waterlogged (17) or where waterlogging occurs intermittently (18). Ion distribution patterns within the plant are altered so that many plant species, which normally depend for salt tolerance upon exclusion of high concentrations of salts from the shoots, (11) and which therefore respond largely to the osmotic potential of the rootzone solution (14), may be subjected to toxic concentrations of Na and Cl in the shoots. Most agronomically important crops seem to lack adaptation to grow successfully when both high salinity and anaerobiosis occur together, although barley and rice may be somewhat tolerant of the combined stress (13).

Grape has been classed as moderately sensitive to salt (14), although studies have shown cultivar differences in sensitivity (2, 3, 5, 9, 12). The use of salt-excluding rootstocks also is important for saline situations (5, 8). Grapes also are classed as tolerant of waterlogging (15). Viticulture is practiced in areas of South Eastern Australia (Murray River Valley) where soils or irrigation waters are somewhat saline and where irrigation may result in at least temporary waterlogging for periods of 3 to 4 days.

This paper examines some effects on growth, salt uptake, and distribution and tolerance of 6 grape cultivars to salinity and anaerobiosis as single stresses and in combination.

Materials and Methods

Cuttings of 6 grape cultivars were rooted in sand with bottom heat. The cultivars 'Sultana' (syn 'Thompson Seedless'), 'Cabernet Sauvignon', 'Crouchen', 'Shiraz', 'Doradillo' and 'Palomino' are all *Vitis vinifera*. Uniform single-shoot plants were grown in sand in a shadehouse for one month. Lateral shoots were removed as they appeared. Every 3 days the plants were irrigated with nutrient solution (K 3 mM, N 7.5 mM, Ca 5 mM, Mg 2 mM, S 2 mM, P 0.5 mM, B 46 μM, Mn 9 μM, Zn 0.8 μM, Cu 0.3 μM, Mo 0.1 μM, Fe 100 μM as Fe EDTA) (14). The plants were selected further for uniformity of shoot length within each cultivar after 4 and 8 weeks.

All selected plants were repotted into 16 cm diameter plastic pots (2.5 liter capacity) of coarse sand and were transferred to a temperature controlled greenhouse (15 hr day 33° ± 2°C, 9 hr night 17° ± 2°). Plants were irrigated 3 times daily from peristaltic pumps through a calibrated microtube dripper placed in each pot. Sufficient solution was applied to each pot at each irrigation to produce some drainage. Volumes measured on only 8 test pots averaged 100 ml at each irrigation indicating a leaching fraction of about 0.3.

After 25 days in the greenhouse, shoot measurements began and were taken every 3 days. Mean shoot length of each cultivar at this time was: 'Sultana' 59 cm, 'Palomino' 94 cm, 'Shiraz' 81 cm, 'Crouchen' 57 cm, 'Cabernet' 47 cm, and 'Doradillo' 35 cm. After the 2nd set of measurements, the 1st stage of salinity treatments was applied. Sodium chloride was added to the nutrient solution in increments of 30 mM every 2 days to final concentrations of 0, 30, 60, and 90 mM NaCl. Solutions then had electrical conductivity values (Kw) of 1.2, 4.7, 8.1, and 11.0 dS m^{-1}, respectively. Each treatment was replicated 12 times with plants arranged in a randomized block design.

After 12 days of the full salt concentrations, rootzones of half the plants of each cultivar were waterlogged by standing the pots in plastic buckets filled with the appropriate irrigation solution. Solution oxygen concentrations were measured with a membrane covered electrode in an access tube installed into the sand in each waterlogged pot.

All plants were harvested 7 days later, i.e., a total of 25 days after the start of incremental additions of NaCl. Plants of the cultivars 'Sultana' and 'Crouchen' were sampled completely. Shoots were divided into 3 equal length sections; leaves, petioles, and stems were harvested separately. The original scion wood and all roots trimmed from the scion were collected separately. The other 4 cultivars were subsampled, but not harvested fully. Each plant was divided into 6 sections: top one-third of shoot, (leaves, petioles, and stem), mid shoot leaf, mid

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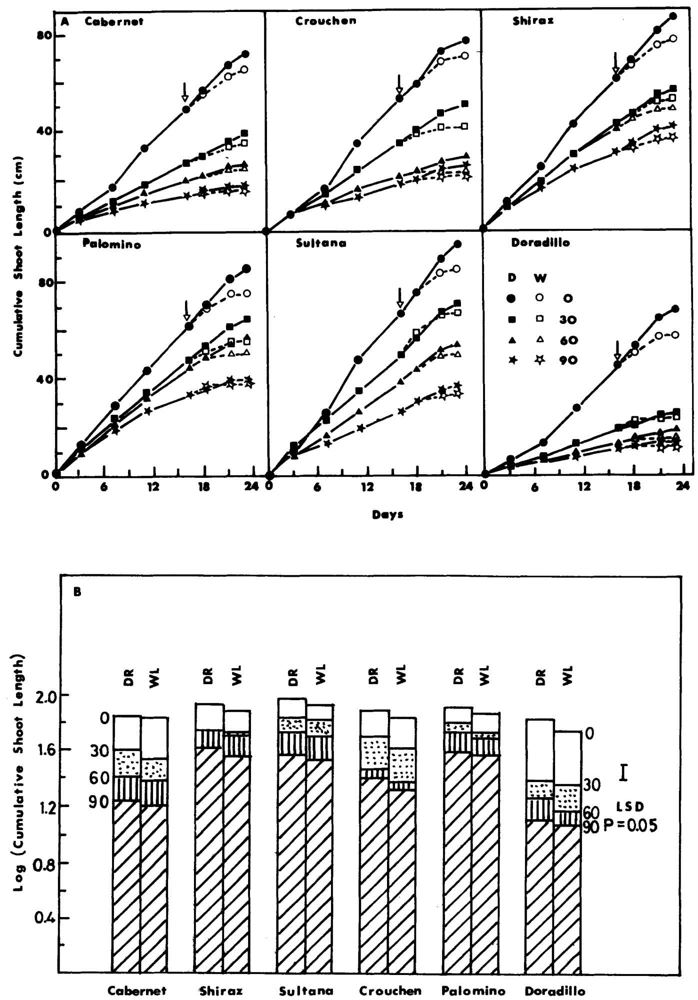

Fig. 1. **A**) Cumulative shoot growth (cm) for 6 cultivars of grape grown with external NaCl concentrations of 0, 30, 60, or 90 mM in nutrient solution and with drained (D) or waterlogged (W) rootzones. Waterlogging treatments were applied on day 16 (indicated by arrow) to half the plants of each cultivar. First salt applied at day 0. **B**) Cumulative shoot growth at harvest (log values) for the plants in part A.

shoot petiole, basal ⅔stem, scion wood, and roots. Roots were washed thoroughly in 3 changes of distilled water to remove sand and external salt. All tissues were oven dried (72°C) to constant weight, weighed, and milled. A subsample then was ashed (450° for 16 hr) and analysed for Na by atomic absorption spectrophotometry and for Cl^- by the method of Best (7).

Results and Discussion

Rootzone waterlogging treatments. The flooding treatments reduced solution oxygen concentrations to a mean of 15% of the air saturated value within 24 hr. After 48 hr of waterlogging, oxygen concentration was 2% of the air saturated value, and this level was maintained for the rest of the treatment period. Such levels of oxygen in other plants are sufficiently low to result in changes in growth, ion uptake, and distribution. (20, 21).

Shoot growth. All cultivars showed a rapid decrease in cumulative shoot growth with application of the NaCl treatments. Reductions occurred in amounts and rate of growth of all cultivars with each increase in external NaCl (Fig. 1A). Absolute shoot growth rate over the 16-day period of drained treatment was constant at each salt level for all cultivars. For the drained treatments, final cumulative shoot length was reduced significantly ($P = 0.05$) with each increase in external NaCl for 'Cabernet Sauvignon' and 'Crouchen'; with the lowest and highest increments of NaCl for 'Shiraz', 'Sultana' and 'Doradillo'; and with the highest increment in NaCl with 'Palomino'.

Those plants which had waterlogged rootzones for 7 days before harvest showed further declines in cumulative growth and in rate of growth. Yet because the combined waterlogging-salinity treatments were applied for a relatively short time, final cumulative shoot length attained was not reduced significantly relative to the drained treatments at the same salt concentrations. The data for shoot growth were converted to a log scale for analyses. To allow for comparison of treatments and cultivars for significance of differences, the values of final cumulative shoot growth also have been plotted as log values (Fig. 1B).

A comparison of the shoot growth rate over the last 5 days before harvest shows the response to waterlogging. Significant differences occurred among cultivars ($P = 0.01$), between drainage treatments ($P = 0.01$), and among salt treatments($P = 0.01$) (Table 1). In addition, there was a statistically significant interaction between cultivar and drainage treatment. For all salt levels combined, waterlogging caused a significant ($P = 0.01$) reduction in shoot growth compared with drained plants for every cultivar. The interaction between cultivar and salt level also was significant but not between drainage treatment and salinity (all cultivars combined). There was no significant 3rd order interaction (cultivar × salinity × drainage treatments).

Table 1. Shoot growth (cm) over last 5 days before harvest for 6 grape cultivars as a function of rootzone salinity and drainage treatment. Data transformed to log (× + 1) scale for analysis, values in parenthesis are retransformed means.

	Salt concentration (mM NaCl)							
	0		30		60		90	
Cultivar	DR[z]	WL	DR	WL	DR	WL	DR	WL
Cabernet Sauvignon	1.198 (14.8)[y]	1.074 (10.9)	0.982 (8.6)	0.744 (4.6)	0.655 (3.5)	0.480 (2.0)	0.407 (1.6)	0.321 (1.1)
Shiraz	1.268 (17.6)	1.073 (10.8)	0.990 (8.8)	0.815 (5.5)	0.966 (8.3)	0.695 (4.0)	0.876 (6.5)	0.578 (2.8)
Sultana	1.276 (17.9)	0.998 (9.0)	1.152 (13.2)	0.964 (8.2)	1.016 (9.4)	0.810 (5.5)	0.717 (4.2)	0.659 (3.6)
Crouchen	1.262 (17.3)	1.067 (10.7)	1.051 (10.3)	0.574 (2.8)	0.793 (5.2)	0.244 (0.8)	0.794 (5.2)	0.398 (1.5)
Palomino	1.152 (13.2)	0.916 (7.2)	1.076 (10.9)	0.618 (3.1)	0.905 (7.0)	0.416 (1.6)	0.631 (3.3)	0.449 (1.8)
Doradillo	1.189 (14.5)	0.847 (6.0)	0.528 (2.4)	0.286 (0.9)	0.619 (3.2)	0.219 (1.0)	0.417 (1.6)	0.191 (0.6)

[z]DR = drained rootzones. WL = waterlogged rootzones.
[y]LSD 0.05 = 0.20; 0.01 = 0.263: LSD of differences (cultivar × drainage treatment; cultivar × salt level interactions) 0.05 = 0.283; 0.01 = 0.373.

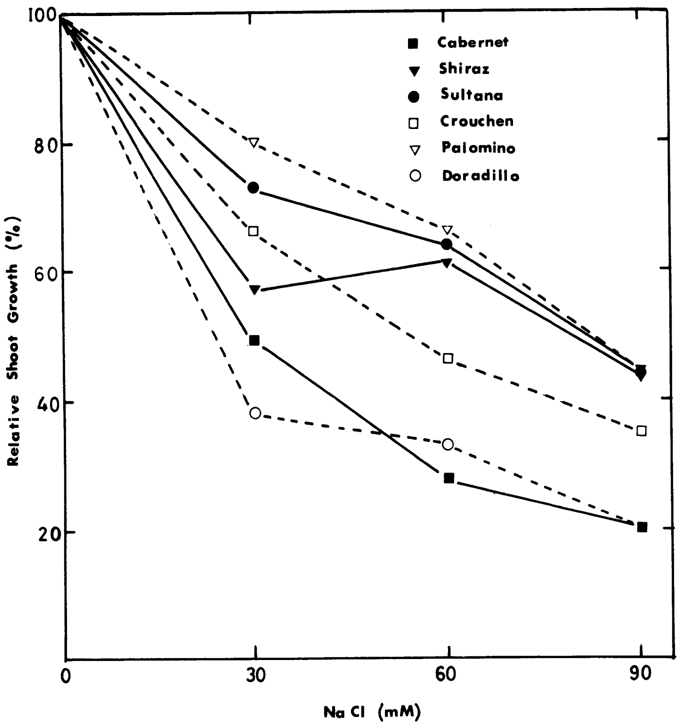

Fig. 2. Relative shoot growth of 6 cultivars of grape grown with salinized, drained rootzones for 23 days.

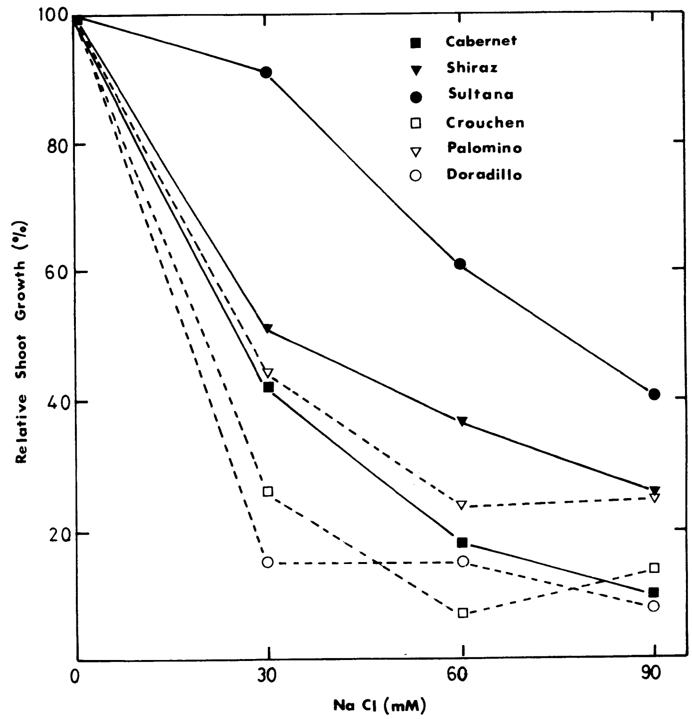

Fig. 3. Relative shoot growth over 5 days for 6 cultivars of grape grown with salinized, waterlogged rootzones.

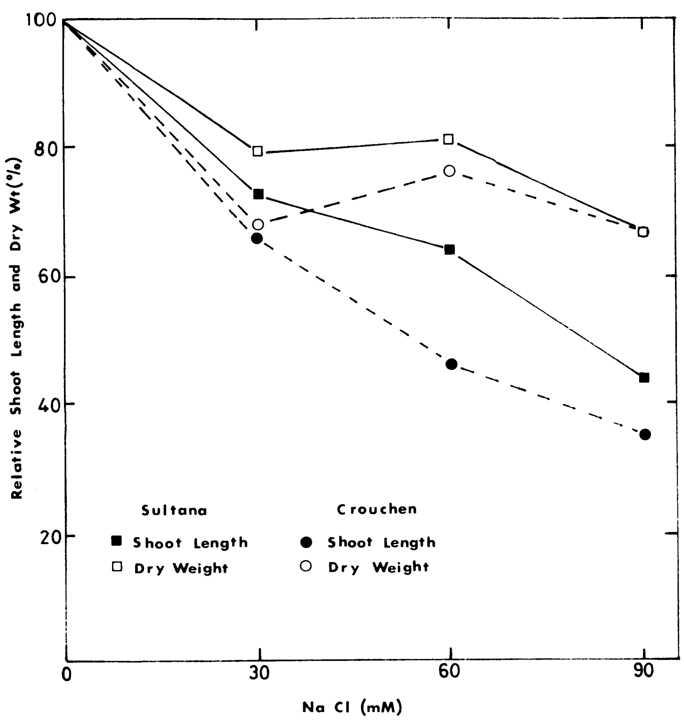

Fig. 4. Relative shoot length and relative plant dry weight of 'Sultana' and 'Crouchen' grapes with drained rootzones at a range of external NaCl concentrations.

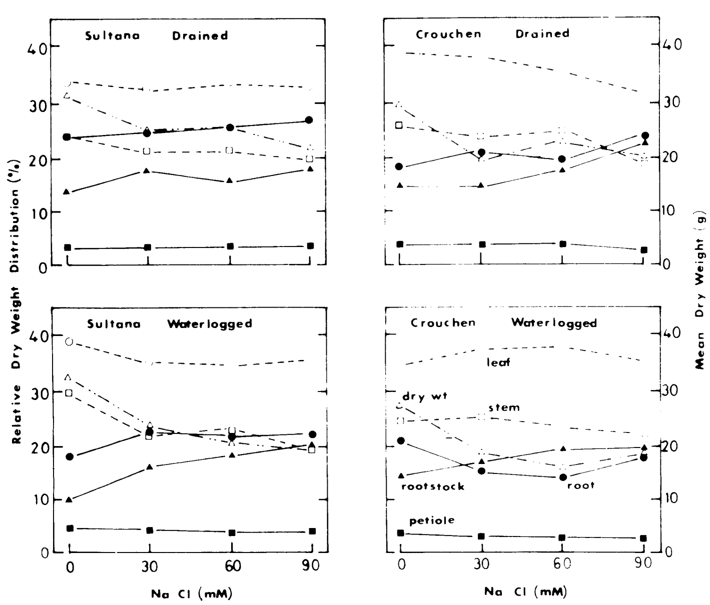

Fig. 5. Relative dry weight distribution (percentage) and mean plant dry weight (g) for 'Sultana' and 'Crouchen' grapes grown with drained or waterlogged rootzones at a range of external NaCl concentrations.

These interactions indicate that different cultivars responded at different rates to the increments of salt concentration or to the imposition of rootzone flooding on the NaCl treatments. Total shoot growth (length) over the last 5 days was not significantly different among cultivars for the control treatments (drained, NaCl = 0).

Cumulative shoot growth in drained treatments for each cultivar over the full 23 days of salinity stress was used to rank

Table 2. Sodium and chloride in different parts of 'Sultana' vines as a function of rootzone salinity and drainage treatment (mM·kg^{-1} dry weight).

Part of vine sampled	Salt concentration (mM NaCl) 0 DR[z]	0 WL	30 DR	30 WL	60 DR	60 WL	90 DR	90 WL
	Sodium (mM·kg^{-1} dry weight)							
Top 1/3 Laminae	143.5[y]	156.6	395.8	530.7	687.3	1383.2	830.8	1391.9
Petiole	130.5	117.4	656.8	1231.0	1100.5	1774.7	1326.7	2074.8
Stem	139.2	65.3	452.4	652.5	661.2	1213.6	726.4	1474.6
Mid 1/3 Laminae	74.0	39.2	217.5	334.9	343.6	769.9	435.0	891.7
Petiole	174.0	130.5	917.8	1139.6	1248.4	1705.1	1300.6	2005.2
Stem	117.4	113.1	448.0	800.4	687.3	1274.5	681.2	1474.6
Lower 1/3 Laminae	43.5	30.5	82.6	265.3	126.1	609.0	230.5	665.5
Petiole	343.6	304.5	565.5	848.2	769.9	1061.3	939.5	1431.1
Stem	126.1	82.6	200.1	265.3	217.5	378.4	234.9	465.4
Stock	26.1	65.3	108.7	208.8	178.3	287.1	213.1	395.8
Root	182.7	213.1	482.8	543.7	604.6	740.5	730.8	869.9
	Chloride (mM·kg dry wt)							
Top 1/3 Laminae	17.2[x]	24.3	79.8	225.3	188.1	678.2	306.5	649.7
Petiole	74.5	43.1	230.4	637.1	453.2	984.8	654.3	1243.4
Stem	20.3	18.9	84.0	205.6	147.2	500.0	226.2	567.1
Mid 1/3 Laminae	33.0	22.3	178.2	271.3	343.2	632.8	402.4	728.7
Petiole	198.0	119.9	430.3	715.7	615.1	1180.5	687.3	1221.7
Stem	23.1	46.5	97.6	179.4	157.4	346.9	165.3	406.4
Lower 1/3 Laminae	55.8	38.9	127.2	286.2	229.6	598.4	337.6	567.4
Petiole	250.7	200.8	409.8	601.8	393.7	850.0	590.8	926.7
Stem	44.0	41.5	106.9	124.1	115.3	188.4	105.2	212.4
Stock	11.3	33.2	40.0	72.0	66.0	84.0	121.8	152.0
Root	153.4	112.0	346.0	333.3	515.2	520.0	608.3	492.4

[z]DR = drained rootzones. WL = waterlogged rootzones.
[y]LSD 0.05 = 191.4; 0.01 = 247.9.
[x]LSD 0.05 = 145.0; 0.01 = 190.6.

Table 3. Increases in Na and Cl (%) in plants with waterlogged rootzones relative to plants with drained rootzones. Data are means for all salt concentrations.

Part of vine sampled	'Sultana' Na	'Sultana' Cl	'Crouchen' Na	'Crouchen' Cl
Top 1/3 lamina	66.5	187.7	88.3	138.6
petiole	56.3	107.1	217.2	152.9
stem	71.4	166.5	277.9	193.0
Mid 1/3 lamina	99.2	75.1	166.1	101.4
petiole	29.4	75.3	87.1	81.5
stem	89.9	136.8	143.9	78.4
Basal 1/3 lamina	271.5	109.6	137.9	128.1
petiole	37.1	52.8	74.7	61.2
stem	58.0	40.4	120.5	70.9
Stock	76.6	58.1	63.0	163.8
Roots	16.1	−10.2	26.6	−78.3

the cultivars for tolerance to salt. For each cultivar shoot growth at each salt concentration was expressed relative to growth of the control treatment for the cultivar given a value of 100, (Fig. 2). The area under each of the lines (Fig. 2) then was calculated, and these values were converted to a relative scale with 'Palomino' being given a value of 100. The other cultivars then had the following values: 'Sultana' 94, 'Shiraz' 87, 'Crouchen' 83, 'Caberbet Sauvignon' 63, and 'Doradíllo' 59. This ranking is different from that reported elsewhere for the same cultivars grown on their own roots for 28 days under salt stress (12). In that report, tolerance to high salt was highest for 'Cabernet Sauvignon', followed by 'Shiraz', 'Sultana', 'Crouchen', 'Palomino', and 'Doradillo'. The difference in ranking could be due to genetic differences in the material (the cultivars in each trial being from different clones) or to different environmental conditions for the 2 experiments (14). This ranking, with respect to shoot growth, also could be different to a ranking for fruit set and production (14).

Each cultivar also was ranked for tolerance to the combined stress of salinity and waterlogging (Fig. 3). This ranking was done using shoot growth relative to growth of the control treatments (waterlogged NaCl 0) for each cultivar individually. Tolerance was calculated as described for drained treatments. This ranking ('Sultana' 100, 'Shiraz' 67, 'Palomino' 59, 'Cabernet Sauvignon' 52, 'Crouchen' 41, and 'Doradillo' 38) was quite different to that obtained for drained treatments. Although the same cultivars occurred in the upper and lower 50% of each list the order was changed. With waterlogging, there was a much greater range of response (100% to 35%) compared to that within the ranking of drained treatments. There was a nonsignificant correlation between relative shoot growth with drainage and relative shoot growth with waterlogging. A plot of these values showed 5 cultivars ('Shiraz', 'Cabernet Sauvignon', 'Crouchen', 'Doradillo' and 'Palomino') to be closely grouped, whereas,

Table 4. Sodium and chloride in different parts of 'Crouchen' vines as a function of rootzone salinity and drainage (mM·kg^{-1} dry weight).

Part of vine sampled	Salt concentration (mM NaCl)							
	0		30		60		90	
	DR[z]	WL	DR	WL	DR	WL	DR	WL
	Sodium (mM·kg^{-1} dry wt)							
Top 1/3 Lamina	124.4[y]	175.7	160.5	188.8	144.8	344.5	189.6	436.3
Petiole	225.8	48.7	131.4	400.2	367.6	1418.9	498.9	1457.6
Stem	79.2	53.9	72.6	178.8	121.8	710.7	214.0	732.5
Mid 1/3 Lamina	64.8	57.9	54.4	119.6	117.9	411.5	216.6	486.3
Petiole	94.0	59.6	371.5	1006.1	1120.9	2094.0	1574.2	2225.8
Stem	75.7	73.1	224.9	620.7	502.0	1405.0	690.3	1132.7
Lower 1/3 Lamina	54.4	76.1	95.3	214.0	148.3	448.5	227.5	530.2
Petiole	209.7	274.0	796.4	1467.2	1186.2	1959.1	1310.6	2134.0
Stem	80.9	134.8	215.3	523.3	312.7	675.1	273.6	573.3
Stock	31.8	69.2	143.1	247.9	193.1	371.5	240.5	336.7
Roots	109.6	156.6	486.7	648.5	709.0	826.0	714.2	1040.9
	Chloride (mM·kg^{-1} dry wt)							
Top 1/3 Lamina[x]	9.6	27.1	131.4	96.2	109.4	427.5	199.4	438.2
Petiole	33.3	48.8	167.5	366.9	383.8	1103.5	615.6	1262.8
Stem	21.4	18.0	50.5	132.3	125.8	432.3	174.6	428.9
Mid 1/3 Lamina	16.6	15.5	100.4	181.3	221.4	520.0	315.3	562.0
Petiole	69.7	81.5	340.9	616.2	557.5	1121.8	691.8	1173.2
Stem	40.6	13.0	94.2	165.5	141.8	316.7	141.0	242.5
Lower 1/3 Lamina	17.5	29.3	102.1	232.1	192.3	493.2	305.7	572.8
Petiole	196.0	161.9	428.9	644.7	569.7	966.4	598.1	1038.4
Stem	36.1	40.6	87.1	132.5	109.7	257.8	112.8	212.6
Stock	20.0	25.7	30.2	65.1	59.5	133.7	87.1	116.5
Roots	66.3	175.7	438.0	385.2	559.8	479.4	605.5	653.1

[z]DR = drained rootzones; WL = waterlogged rootzones.
[y]LSD 0.05 = 165.3; 0.01 = 217.5.
[x]LSD 0.05 = 101.7; 0.01 = 133.8

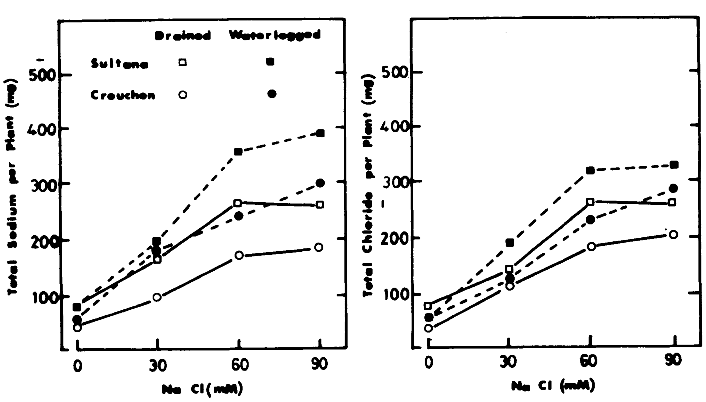

Fig. 6. Total contents of Na and Cl in 'Sultana' and 'Crouchen' grapes grown with drained or waterlogged rootzones at a range of external NaCl concentrations.

'Sultana' showed a much higher relative shoot growth under waterlogging than was obtained with the other cultivars.

'Sultana' and 'Crouchen', which were closely ranked among drained treatments but separate in the ranking for waterlogging, were analyzed for total dry weight in different parts of the plant. Dry weight was reduced less than shoot length at each salt concentration (Fig. 4). It is common for salinity to have a different effect on different components of growth and development of a plant (14). Although total dry weight declined significantly with increasing salinity, the relative distribution of dry weight among leaves, petioles, stems, stock, and roots was almost constant over all treatments (Fig. 5). In all cases, as expected, the proportion of dry weight contributed by the stock increased slightly with increasing salinity.

Sodium distribution in tissues of 'Sultana' and 'Crouchen'. In all parts of the 'Sultana' plants from the drained treatments there was a linear increase in Na concentration with increasing external NaCl. The highest rates of increase occurred in mid- and topshoot petioles (Table 2), so that petioles had the highest concentrations at harvest. Sodium concentration in lamina tissue was reduced basipetally with an increase in leaf age and was relatively low in basal lamina tissue. Stems had Na concentrations similar to those of lamina tissue for each section sampled. Root Na concentrations were significantly higher than in stocks, except in the controls.

After 7 days of waterlogging, Na concentrations in all but the controls increased in all tissues, compared with those of drained treatments. The rate of increase in Na with increasing external NaCl was much higher than for drained rootzones. As for drained treatments, the highest accumulation still occurred in mid- and topshoot petioles. Again, there was a gradient from top to base in Na concentrations in both laminae and stems. The stock tissue had the lowest Na.

The increase in Na and Cl for each section of the plant with waterlogging, when expressed relative to the Na or Cl concen-

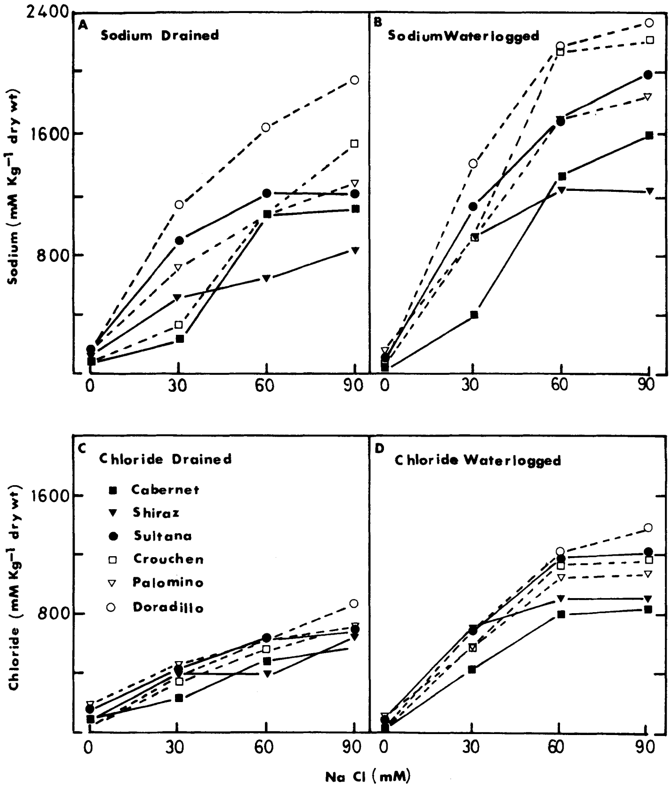

Fig. 7. Mid shoot petiole Na and Cl concentrations (mM kg^{-1} dry wt.) in 6 cultivars of grape grown at a range of NaCl concentrations with drained or waterlogged rootzones.

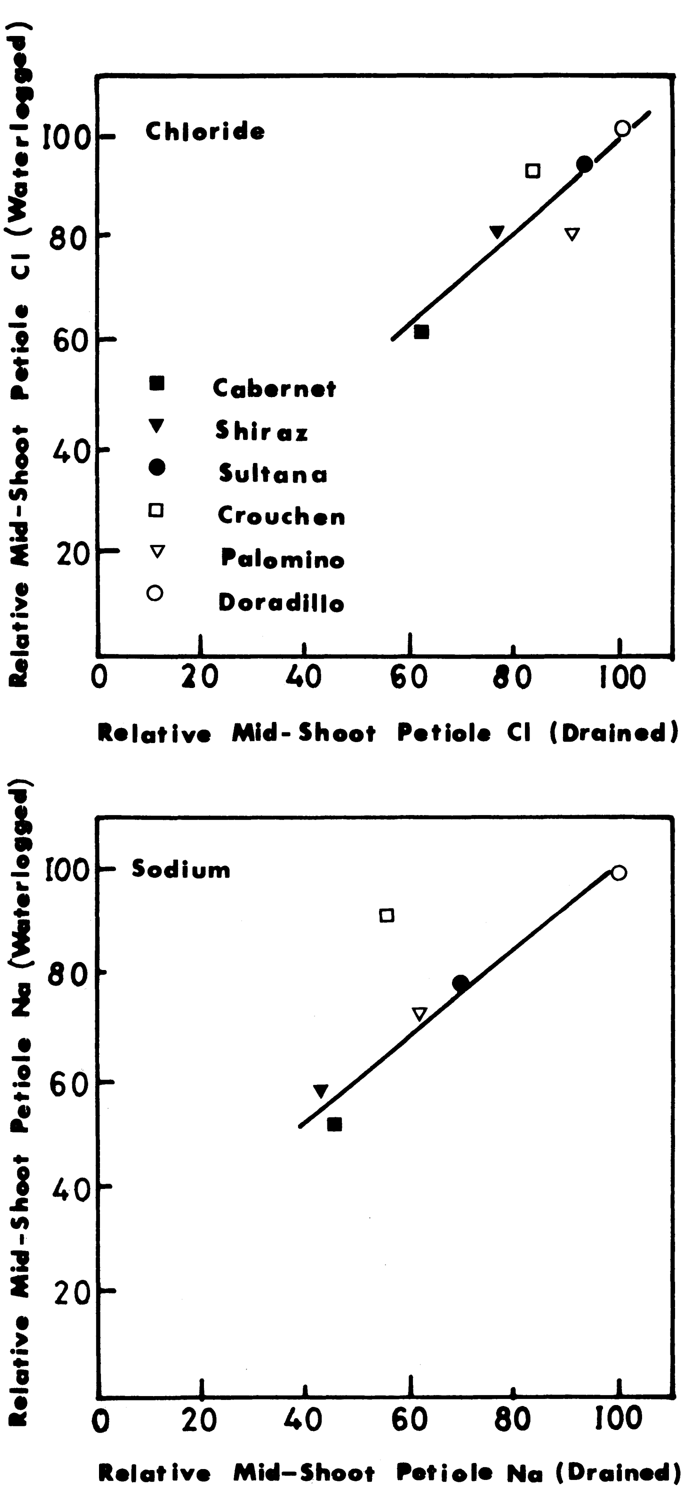

Fig. 8. Midshoot petiole chloride (**8a**) and sodium (**8b**) for drained and waterlogged treatments for 6 cultivars of grape relative to the values for the cultivar 'Doradillo'. The line plotted for sodium does not include the cultivar 'Crouchen'.

tration in that part of the plant under the drained treatment (Table 3), shows the parts of the plant in which the largest relative increases occurred. The largest increase in final Na concentration in 'Sultana' with waterlogging treatments occurred in lamina of basal shoots (Table 3).

In the 2 or 3 days immediately prior to harvest, some plants from all cultivars, except 'Cabernet', with waterlogged rootzones at 60 and 90 mM NaCl showed leaf damage. Interveinal areas appeared pale green, translucent, and blotched. The leaves then wilted, and centers of the lamina started to become necrotic. Areas along the veins remained green, and the symptoms did not start at leaf margins as would be typical of Cl toxicity in grape. It is unlikely that the symptoms were those of waterlogging—typically leaf epinasty, chlorosis, nonpatterned necrosis and wilting, especially of basal leaves—as symptoms occurred only at 60 and 90 mM NaCl and not with waterlogging alone (NaCl = 0). The effects were confined to mid and basal shoot leaves, which also had the largest increases in Na with the change from drained to waterlogged. While the rate of increase was highest, however, the final concentration of Na was much lower than in top shoot laminae of 'Sultana' (Table 2) which showed no visible damage in these top leaves. The rate of increase in Na with the change from drained to waterlogged was reduced in top shoot leaves. It is possible, as suggested for leaf damage in *Phaseolus vulgaris L* (19) that a rapid transport of Na to leaves is more important in the development of damage than is the concentration of ions per se in total leaf tissue. There is no information regarding distribution of Na in leaf tissue, and it is possible that a high rate of transport of Na may allow cytoplasmic concentrations to increase to levels at which damage occurs.

Chloride distribution in tissues of 'Sultana' and 'Crouchen'. The greatest increases in Cl in 'Sultana' with the change from drained to waterlogged treatment occurred in top leaves and stems, but damage was not visible. Although salt toxicity symptoms observed in grapevine usually are thought to be due to chloride toxicity (9), it is possible that these vines were showing

Table 5. Relative values of mid shoot petiole sodium and chloride for 6 grape cultivars.

Cultivar	Na drained	Na waterlogged	Cl drained	Cl waterlogged
Cabernet Sauvignon	46	52	62	62
Shiraz	43	59	76	80
Sultana	69	78	93	93
Crouchen	55	91	83	92
Palomino	62	73	91	80
Doradillo	100	100	100	100

a sodium toxicity. Damage occurred in all cultivars except 'Cabernet Sauvignon', which showed no symptoms.

For drained 'Sultana' plants, there was a linear increase in Cl in all tissues with increasing external NaCl (Table 2), with the highest rates of increase occurring in top and mid shoot petioles, and in roots. Highest final concentrations (means for all salt levels) occurred in mid shoot petioles, with basal and top petioles next highest. Lamina tissues also had high Cl, while the stock remained relatively low. Waterlogging increased the rate of accumulation of Cl and the final concentrations in all tissues, except for stocks and roots which maintained concentrations of chloride very similar to concentrations in drained treatments. Within a given tissue, Na concentrations were almost always higher than Cl concentrations.

The data from analysis of 'Crouchen' (Table 4) generally show similar patterns of distribution of Na and Cl in drained plants, as described for 'Sultana'. Mid and basal section petioles and roots had the highest concentrations of Na. With waterlogging, there was a marked increase in Na in top petiole and stem sections and a very large increase in mid-shoot petiole, mid-shoot stem and basal section petioles. Concentrations of Na did not increase strongly in lamina tissues, and the stock remained low in Na.

Chloride was highest in mid and basal section petiole tissues in drained treatments and in root tissues. Most of the other tissues were relatively low in Cl. The major effect of waterlogging on Cl was to increase Cl concentrations in petiole tissues. Other tissues also increased (with the exception of roots) in Cl but at a much lower level than Na.

The greatest percentage increase in tissue Cl over all salt levels occurred in stem, lamina, and petiole tissues in the top 3rd of the plant (Table 3). With the change from drained to waterlogged, 'Sultana' tended to accumulate Na in the lower part of the shoot and Cl in the upper part of the shoot, whereas 'Crouchen' accumulated both Na and Cl into the upper part of the shoot.

The increased concentrations of both Na and Cl that occurred with waterlogging were the result of increased uptake of Na and Cl. Figure 6 shows the increase in total plant Na and Cl with increasing external NaCl in drained and waterlogged treatments. Plant dry weights, at any rootzone NaCl concentration, were not significantly different for waterlogged or drained treatments.

The ranking of the 2 cultivars for shoot growth showed 'Sultana' to be superior to 'Crouchen' for both drained (94% vs. 83% relative to 'Palomino' 100) and waterlogged (100% vs. 41%) treatments. 'Sultana' had higher total amounts of Na and Cl in the plant than did 'Crouchen' under both drained and waterlogged treatments (Fig. 6). Also, concentrations of Na and Cl in most tissues in the top two-thirds of the shoots, at equivalent external NaCl concentrations, were higher for 'Sultana' than for 'Crouchen' (Table 2 compared with Table 4).

'Sultana' showed better shoot growth than 'Crouchen. Either 'Sultana' had a higher physiological cytoplasmic tolerance to salt than does 'Crouchen' or it had an ion localizing mechanism that operates at a level of distribution which is not revealed by ion analysis on bulk tissues and which complements petiole interception of ions (8, 21).

Since as mid or top shoot petiole tissues in 'Crouchen' and 'Sultana' were indeed usually highest in Na and Cl, and mid shoot petioles are the most common tissues for sampling to characterize levels of Na and Cl in grapevines (21), the 6 cultivars were compared on the basis of mid shoot petiole Na and Cl (Fig. 7).

There were almost linear increases in both Na and Cl uptake with increasing rootzone NaCl up to 60 mM NaCl, and the relative areas under the lines in Fig. 7 are shown in Table 5. 'Doradillo' had the highest Na and Cl for both rootzone conditions.

Plots of relative mid shoot petiole Cl for drained versus waterlogged treatments (Fig. 8a) showed a significant correlation ($r = 0.8826$, $P = 0.05$) between the values for the 6 cultivars. A similar plot for mid shoot Na (Fig. 8b) resulted in a nonsignificant correlation ($r = 0.8040$) between the values. All cultivars except 'Crouchen' were well grouped, however, and if this cultivar had been excluded from the analysis, the correlation was significant ($r = 0.9795$, $P = 0.01$). 'Crouchen' was isolated from the other cultivars due to a much higher relative Na under waterlogging than occurred with the other cultivars; i.e., 'Crouchen' responded to waterlogging with a substantial increase in mid shoot petiole Na. There were no significant correlations between these values of mid shoot petiole Na or Cl and the relative shoot growth for drained treatments over 23 days (Fig. 2) or waterlogged treatments over the last 5 days (Fig. 3).

The ranking of these cultivars for salt tolerance is not of major importance in the present work and is certainly not absolute, as shown by differences between this ranking and another for the same cultivars (12). Salt tolerance depends upon many soil, plant, and environmental factors, and therefore, it can only be a relative value with reference to a particular set of cultural conditions. Large differences in the ability of grape rootstocks to exclude salt (5, 8) are more important in situations with saline soil water and tend to override the relatively small differences in tolerance of scion cultivars.

More important than relative tolerance under drained conditions is the effect of rootzone waterlogging on growth, increased Na and Cl uptake, and development of toxicity symptoms. Salt exclusion in rootstocks should be reduced by waterlogging just as it is in rooted cuttings. Even if rootstocks of different salt tolerances maintained their relative ranking under waterlogging, as occurred for rooted cuttings with the change from drained to waterlogged roots (Fig. 8), the advantages of using rootstocks in saline situation would be largely lost. Clearly, it is important to avoid or minimize any rootzone waterlogging when salinity is a factor in the cultural, environmental system; it greatly increases the potential for salt toxicity.

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Quality of Citrus Fruit Following Cold Treatment as a Method of Disinfestation against the Caribbean Fruit Fly

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Abstract. **Fruit of 'Valencia' orange *(Citrus sinensis* Osbeck) and 'Murcott' tangerine *(Citrus reticulata* Blanco) were subjected to cold treatment at 1.1°C for 17 days as prescribed for the disinfestation of citrus of the Caribbean fruit fly *(Anastrepha suspensa* (Loew) in the plant protection and quarantine treatment manual. Fruit quality was evaluated during subsequent storage at 4.4°C for one week followed by 2 weeks at 21.1°. Fruit under cold treatment did not develop any physiological disorders. Fruit color and general appearance remained unaffected. Loss due to decay was 2.3% for 'Murcott' tangerine and 7.2% for 'Valencia' orange. Moisture loss for both varieties was about 5%. Fruit quality, including flavor, was found to be acceptable in 'Murcott' during subsequent storage. Yet the quality of 'Valencia' remained acceptable for one week only at 4.4°. Cartons used for packing fruit and stored at 1.1° absorbed more moisture when transferred to 21.1° than the cartons at 4.4° or 21.1° because of moisture condensation on fruit.**

Quarantine treatments for the disinfestation of fruit and vegetables from insect pests include chemical fumigation, cold treatment, and treatment with vapor heat (8). Citrus fruit shipped from Florida to other citrus producing states were fumigated with ethylene dibromide (EDB) to protect against the spread of Caribbean fruit fly [*Anastrepha suspensa* (Loew)] from infested to noninfested regions (6). The Environmental Protection Agency (EPA) had proposed to "phase-out" the use of EDB in postharvest quarantine fumigation of citrus and tropical fruits and vegetables in 1980, because it induced cancer in laboratory test animals (6). Its use as a postharvest fumigant was later abolished for domestically consumed fruit and vegetables (9). Subjecting fruit and vegetables to low temperatures for specified durations is a viable and approved quarantine treatment method against a

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