Salt tolerant rootstocks for long-term sustainability in the Limestone Coast





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1. ABSTRACT

This project extends our knowledge about the use of rootstocks in the Limestone Coast and the Riverland. In a Shiraz vineyard at Coonawarra with vines of 3-6 years age, the yields from vines grafted to non-*vinifera* rootstocks were equivalent to those from vines on their own roots. But, at 24-25 years of age the yields from vines on 5C Teleki A6V18 and own roots were nearly double those from vines grafted to 5C Teleki 8344, 101-14, 5C Teleki 8343, 420A, and 1616. In a Chardonnay vineyard at Padthaway, measurement of juice sodium and chloride concentrations and yields showed that the salt exclusion performance and yields of vines on the well characterised rootstocks, Ramsey and Schwarzmann, could be equalled or bettered by vines on the lesser known rootstocks, Fercal and SO4. In a Shiraz vineyard at Kingston-on-Murray which was growing on saline soils, but receiving non-saline irrigation, a 30% reduction in irrigation raised juice chloride concentrations by 24% in vines on Ramsey, 110 Richter, Schwarzmann, 140 Ruggeri and 1103 Paulsen, but only raised juice sodium concentration in vines on 1103 Paulsen. In a Chardonnay vineyard at Barmera, the tolerance of grafted vines to a 98% reduction in irrigation was assessed with measurements of vine vegetative growth and inflorescence number. The assessment showed that vines on Ramsey and 110 Richter were more tolerant than those on 1103 Paulsen and K51-40. This project has identified aging and irrigation as factors which affect rootstock performance and has broadened the range of rootstocks shown to have salt exclusion properties.

2. EXECUTIVE SUMMARY

Long term drought in the first decade of the 21st century coincided with rises in the salinity of ground waters used for irrigation in some supplementary irrigated regions and has forced an abandonment of the premise that underpinned the establishment of many of the fully irrigated areas; that is that in 99 out of 100 years the water resource will be able to provide 100% of full irrigation allocation. Vineyard sustainability will depend in part on the ability of plantings to weather these variations in the quality and quantity of irrigation waters. Rootstocks can enhance sustainability by conferring tolerance to reductions in water quality and quantity. This project was developed to address these issues in a supplementary irrigated region, the Limestone Coast of SA. A variation to the project in 2010 supported its extension into a fully irrigated region, the Riverland of SA. The project addresses these issues by assessing whether the stability of a fundamental property of grafted vines, yield, is affected by aging; by increasing the range of rootstocks for which we have information on salt exclusion properties; by determining whether rootstock salt exclusion properties are modified by reduction in irrigation allocations; and by assessing rootstocks tolerance to conditions of near zero irrigation.

In a SARDI Shiraz rootstock trial at Coonawarra, a comparison between vine yields measured in 2010 and 2011 and those recorded in 1989 through to 1992 showed that aging had affected the relative performance of rootstock genotypes. At age three to six years the yield from own rooted vines was equivalent to those from vines grafted to non-*vinifera* rootstocks. In contrast, the yields at 24 and 25 years of age from vines on 5C Teleki A6V18 and own roots were nearly double those from vines grafted to 5C Teleki 8344, 101-14, 5C Teleki 8343, 420A, and 1616. Given the large shift with aging in such a fundamental property as yield, it is unclear whether other properties, such as salt exclusion, are also change with aging.

In a 24 year old SARDI Chardonnay rootstock trial at Padthaway, measurement of yield and juice chloride concentrations showed that yield from vines on Ramsey rootstock was equivalent to that from own rooted vines and that chloride concentrations in juice from vines on Ramsey was less than half that in juice from own rooted vines. The site was located on deep sandy soils in the Padthaway Ranges. Yields at this site were similar to those found in a previous assessment of salt exclusion in a Chardonnay rootstock trial located on the shallow loamy clay on calcrete soils of the Padthaway Flats. Ramsey had the lowest juice chloride concentrations at the Padthaway Flat site. The site on the Ranges also included rootstocks that had not previously been assessed in the district. Of these different rootstocks, the yields of vines on Fercal and SO4 were equal to or better than those of vines on Ramsey, and sodium and chloride concentrations in juice were less than or equal to those on Ramsey.

During the recent drought, irrigation waters in the middle reaches of the Murray River remained non-saline, but there were still reports of undesirable levels of salt in fruit. It was unclear whether a reduction in irrigation allocations was diminishing the capacity of rootstocks to exclude salt. In a SARDI Shiraz rootstock trial at Kingston-on-Murray which was growing on saline soil (4 dS/m), but receiving non-saline irrigation, comparison between vines receiving 100% and 70% of irrigation allocations showed that a 30% reduction in irrigation raised juice chloride concentrations from 67 to 83 mg/L, but did not affect juice sodium concentrations except in vines on 1103 Paulsen where it doubled. At this site, the use of four of the five rootstocks, 140 Ruggeri, Schwarzmann, 1103 Paulsen and 110 Richter, prevented the (estimated) concentrations of chloride and sodium in wine rising

above 80 and 53 mg/L, respectively. These concentrations are below the levels at which a salty taste has been detected.

In a SARDI Chardonnay rootstock trial at Barmera, comparing measurements of vine vegetative growth and inflorescence number made when vineyard was in receipt of 100% irrigation allocation with those made when it was in receipt of 2% of allocation showed that vines on Ramsey and 110 Richter were more tolerant of the 98% reduction in irrigation than those on 1103 Paulsen and K51-40. Tolerance to such low levels may be relevant if vineyard “mothballing” is used to sustain vineyards through future droughts.

3. BACKGROUND

Most vineyards in Australia receive irrigation. Their sustainability depends in part on the ability of plantings to weather variation in the quality and quantity of irrigation waters. Rootstocks can play an important role in underpinning the sustainability of Australian viticulture by conferring tolerance to reductions in water quality caused by salinity and reductions in water quantity caused by drought.

The deleterious effects of saline irrigation on vine yield are due to an osmotic effect in which the increase in soluble salt concentration of the soil solution imposes an osmotic drought on the plant and a toxic effect in which the tissue concentrations of chloride (Cl^-) and sodium (Na^+) increase to toxic levels. Measurements of Na^+ and Cl^- concentrations in leaf petioles sampled at full bloom have proved to be robust indicators of whether the salinity pressure on the vine has been sufficient to cause yield loss (Robinson et al. 1997, Prior et al. 1992, Stevens et al. 2011a). However, the economic sustainability of a vineyard is determined not only by yield, but also by fruit quality. One determinant of quality is the level of Cl^- in the juice. The relationship between juice and wine concentration depends on processing during vinification. The production of white wine does not cause much change in the Cl^- concentration and the ratio of its concentration in wine to that in juice is about 1:1, whereas the production of red wine increases the concentration of Cl^- giving wine to juice ratios of about 2:1 (Rankine et al. 1971, Walker et al. 2010b).

Walker et al. (2003) found that scores for salty taste increased as Cl^- concentration in Shiraz wines rose from 151 to 1788 mg/L. This result contrasts with their more recent work in which they found that spiking Shiraz wines with NaCl to produce wines with Cl^- concentrations ranging from 265 to 854 mg/L did not produce a significant variation in the perception of a salty taste (Walker et al. 2010b). It is unclear whether the lower end of this range was too high. Bastian et al. (2010) found more than 50% of tasters could detect salt in Shiraz wine at NaCl concentrations of 200 mg/L or less (equivalent to 121 mg/L of Cl^-). Leske et al. (1997) tabulated the distribution of Cl^- concentration in grape juices sampled from regions across Australia. After adjustment of their data to reflect the concentrating effect of red grape vinification it can be seen that in many regions the mean concentrations of Cl^- in red wine were greater than 500 mg/L. This level is well above the low end of the range for which we are uncertain about the relationship between salty taste and the concentration of Cl^- in wine.

The use of grafted vines reduces the levels of Cl^- in juice and wine (Downton 1977, Cirami et al. 1984). Walker et al. (2010a) reported the salinity status of vines in Chardonnay and Shiraz rootstock trials in the Limestone Coast at Padthaway. They showed that although bloom time petiole concentrations of Na^+ and Cl^- were below levels indicative of yield loss to salinity, the Cl^- concentrations in Shiraz fruit would have produced wines with Cl^- concentrations ranging up to 328 mg/L juice, that is well within the ranges which Bastian et al. (2010) and Walker et al. (2003) found increasing concentrations to elicit an increasing detection or perception of salty taste.

Up until the middle of the first decade of the 21st century, irrigation allocations for most fully irrigated regions were sufficient to meet vine water use. Under these conditions, interest in drought tolerant vines was mainly confined to the supplementary irrigated regions. However, within the fully irrigated areas there was an interest in making irrigation water go further by identifying rootstocks that might be more tolerant of reduced irrigation. In supplementary irrigated areas McCarthy et al. (1997) found that rootstocks varied in their tolerance to drought, whereas in a fully irrigated area Stevens et al. (2008, 2010) found that rootstocks were equally tolerant of 30-35% reductions in irrigation.

Drought in the first decade of the 21st century has affected the sustainability of viticulture in both fully irrigated regions and supplementary irrigated regions. In the Padthaway region, salinity pressure on supplementary irrigated vineyards has increased due to recent rises in the salinity of groundwater used for irrigation combined with a reduction in water available for leaching (caused by the introduction of volumetric allocations and a trend in the last decade for annual rainfall to be about 50 mm less than the long term average). In the Riverland, the recent drought has seen irrigation allocations at the opening of the grape growing season reduced to between 2% and 16 % of full allocation and in mid season reduced to 15% and 48% of full allocation. The fully irrigated regions had been set up with the expectation that irrigation allocations could be met in full in 99 out of 100 years.

In response to the emergence of salinity as an issue of concern for some vineyards in the Limestone Coast Wine region, SARDI developed an interdisciplinary project aimed at delivering a pathway to sustainability for the region's groundwater irrigated vineyards. This project had four objectives:

1. Develop hydro-geology scenarios for the Padthaway district
2. Develop strategies for root zone salinity management
3. Develop strategies for prevention of soil structure decline
4. Select rootstocks for premium grape production at Padthaway

Objective 1 was to be delivered by the Department for Water Land and Biodiversity. SARDI has undertaken to deliver objectives 2 to 4. At the time of project inception it was envisaged that modelling of the vadose zone using Hydrus 2-D would provide an avenue to link objectives 1 and 2. This aspect initially received support from the Caring for Our Country (CFOC) program, however within the first year of the project's life the direction of the CFOC program altered to reflect the change in Federal government. Support for this aspect lapsed. Objectives 2 and 3 have been supported by the SE Natural Resource Management Board (until changes in the Caring for our Country funding program), CRC for Irrigation Futures and the National Program for Sustainable Irrigation. Work on these components runs until May 2012. They will be covered in a report to National Program for Sustainable Irrigation due in May 2012.

The Grape and Wine Research and Development Corporation supported SARDI to address objective 4 and provided a variation to this support to allow the project to address aspects of rootstock usage in the Riverland. This aspect of the project sought to improve the sustainability of viticulture in both supplementary and fully irrigated regions by increasing the range of rootstocks for which we have information on salt exclusion properties, assessing rootstocks tolerance to near zero irrigation, and determining whether rootstock salt exclusion properties are modified by a reduction in irrigation allocations. Our current knowledge base for characterising rootstock salt exclusion and drought tolerance has been generated from trials on either potted immature vines or on field vines in the first decade of life. It is unclear whether rootstock properties change as vines age past their first decade. SARDI has in-house historic data sets of yield from rootstock trials and one of these was used to assess whether aging affects a basic property of grafted vine, yield. Further, the characterisation of rootstock salt exclusion properties in the Limestone Coast region was undertaken with field vines in their third decade of life.

4. PROJECT AIMS

1. Assess the long-term performance (> 20 years) of rootstocks at selected sites in the Limestone Coast.
2. Broaden the range of rootstocks being assessed for salinity tolerance in Limestone Coast vineyards.
3. Determine rootstock performance under a wider range of soil types than currently being assessed.
4. Pro-actively communicate via workshops and publications, the project's progress and outcomes to the Limestone Coast regional and national viticulture industries.

A variation, approved in September 2010, added the following objectives:

5. For hot inland conditions, assess the effect of rootstock on salt exclusion by Shiraz vines during deficit irrigation with non-saline water on saline soils.
6. Present results at a Riverland Wine Industry Development Council workshop and include data in peer reviewed manuscript.

Support for the above variation allowed the inclusion of an additional aim:

7. Investigate rootstock response to extreme water stress caused by near zero irrigation.

Output 1

Assess the long-term performance (> 20 years) of rootstocks at selected sites in the Limestone Coast Wine region, SA.

Performance Targets:

- Assess the effect of rootstock on vine yield and vegetative growth in long-established SARDI trials at Padthaway and Coonawarra.
- Evaluate the stability of yield response to rootstock by comparing current yields at 25 years of age with those recorded from the same vines between three and six years of age in a trial at Coonawarra.

Output 2

Extend the number of rootstocks that have had their salt exclusion properties assessed in the Limestone Coast Wine region, SA.

Performance Targets:

- Conduct these assessments at sites where the set of rootstocks and the soil types are different to those which have already been assessed by CSIRO.
- Assess the effect of rootstock on the exclusion of Na^+ and Cl^- from leaf petiole and fruit in long-established SARDI trials at Padthaway and Coonawarra.

Output 3

Assess the effect of reducing irrigation on salt exclusion from Shiraz vines grafted to a range of rootstocks receiving non-saline irrigation, but growing on saline soils in the Riverland Wine region, SA.

Performance Targets:

- Measure Na^+ and Cl^- concentrations in samples of fruit and leaf petioles, which have been stored since collection in 2004, from a SARDI rootstock by irrigation trial at Kingston-on-Murray.

Output 4

Assess the effect of near-zero irrigation on rootstock performance in a Chardonnay vineyard located in the Riverland Wine region, SA.

Performance Targets:

- Measure the soil water content, salinity and water table depth in a SARDI rootstock trial at Barmera which has had two years of near zero irrigation.
- Assess rootstock tolerance to extreme water stress by comparing measures of fruit and vegetative growth made after two years of near zero irrigation with those made under full irrigation at an earlier time when these vines were in a SARDI rootstock by irrigation trial.

Output 5

Pro-actively communicate outputs.

Performance Targets:

- Establish a steering committee comprising funders, industry representatives from the Limestone Coast and researchers involved in the field of salinity management of grapevines. Provide the committee with project updates and the opportunity for consultation on at least three occasions during the project.
- Use regional workshops and seminars to present project findings to Limestone Coast and Riverland grower groups.
- Use scientific and technical publications and presentations at national conferences to inform the national viticultural industry.

5. LONG TERM PERFORMANCE (>20 YEARS) OF ROOTSTOCKS IN THE LIMESTONE COAST

5.1 Introduction

Most of our knowledge about rootstock properties is based on observations made on young vines either as potted immature vines or as field vines within the first decade of their life.

Trials with potted vines and young field vines have shown that the use of Ramsey as a rootstock reduces the uptake of salt, specifically the chloride ion. Recent field observations on vines older than 10 years have found that as it ages this rootstock becomes less effective at reducing salt uptake (Tregeagle et al. 2006). This finding highlighted a gap in our knowledge; what happens to rootstock properties as vines age past their first decade? We are unsure whether rootstock effects on such a basic vine property as yield are stable across the decades of a vineyard's life.

In the early 1980's, SARDI established 7 rootstock trials in the Limestone Coast region (Cirami and McCarthy 1988). Four of these trials were assessed in the late 1980's to early 1990's (Nicholas 2006). We re-visited all sites in 2009. Only three of the seven trials were still present as planted. The others had either been top-worked to other varieties or removed. The trials which had been top-worked to other varieties were given no further consideration. It is likely that top working may have created an inter-stock by budding the new scion into the stem of the original scion rather than the rootstock. In citrus, inter-stocks have been shown to modify the effect of rootstock on scion under saline conditions (Zapata et al. 2004). Inter-stocks may also have an effect on vine salt exclusion because under saline conditions there are inter-cultivar differences in the Na^+ and Cl^- concentrations in leaves and juice of *V. vinifera* (Stevens et al. 1996, Walker et al. 2002a). Further, the presence of a different scion would have confounded attempts to uncover the effects of aging on relative rootstock performance through comparisons between present yields and those measured during the first decade of vine life.

Of the remaining three trials, one was irrigated with over-canopy sprinklers using saline groundwater. Salt enters the vine more readily via the leaf cuticle than via the roots (Stevens et al. 1996, 2011b). Rootstocks confer an advantage under saline irrigation by excluding salts from the scion. This mechanism is overridden where irrigation wets the foliage with saline water. The other two remaining trials were drip irrigated and therefore suitable for assessment of both long term performance of rootstocks and effects of rootstocks on exclusion of salt from scion. They were a Chardonnay rootstock trial at Padthaway and a Shiraz rootstock trial at Coonawarra. Assessment consisted of measuring mortality, yield, vegetative growth, and fruit composition.

5.2 Materials and methods

5.2.1 Vineyard descriptions

Both trials were located in commercial vineyards. The Padthaway site was located on deep sands on the crest of the Padthaway range lying to the east of the Padthaway flats. The Coonawarra site was located on terra rosa soils, just south of the Coonawarra township. The vineyard properties and soils are described in Table 1. Soil descriptions were sourced from Cass et al. (2002). Soils at both sites were different to those at the site Walker et al. (2010a) rootstock trials on the Padthaway Flats. Cass et al. (2002) described the soils at

this site as a shallow calcareous non-restrictive equating to a Hypervescent Petrocalcic Lithocalcic Calcarosol in the Australian Soil Classification (Isbell 1996).

Table 1. Description of Limestone Coast trial sites at Padthaway and Coonawarra.

	Padthaway	Coonawarra
Location	36° 62' S, 140° 52' E	37° 30' S, 140° 84' E
Planted	1986	1986
Scion (Variety / Clone)	Chardonnay / I10V5	Shiraz / BVRC12
Row by vine spacing (m)	2.75 x 1.8	2.75 x 1.5
Row orientation	N – S	N – S
Trellis type	Vertical	Vertical
Wire number	2	1
Wire height (m)	1.1 and 1.6	0.95
Soil type	Deep uniform sandy soil (Arenic Orthic Tenosol[†])	Shallow loamy over calcareous-rock (Petrocalcic Red Dermosol[†])
Irrigation water source	groundwater	groundwater
Previous planting	non-vine	non-vine

[†] Australian Soil Classification (Isbell 1996)

5.2.2 Trial design and analysis

The trials were laid out as randomised block designs. That at Padthaway contained 6 replicates of 9 rootstock genotypes including own roots. That at Coonawarra contained 10 replicates of 10 rootstock genotypes including own roots. Each plot consisted of three adjacent vines in the same row. All measurements were undertaken on the central vine. Details of the rootstocks are given in (Table 2). In all, sixteen rootstock genotypes (including *V. vinifera* cv Petit Verdot) were assessed in the two trials.

Mortality data (number of missing vines) were analysed by Kruskal-Wallis one-way non-parametric ANOVA using Statistix Version 8 (Analytical Software, Tallahassee, FL). All other data were analysed using GenStat 13th Edition (VSNI, Hemel Hempstead, UK).

5.2.3 Measurements of fruit and vegetative growth and fruit quality

Missing vines were counted in spring 2009.

Vine vegetative growth was assessed in winter by measurement of pruning weight. The vineyards at both sites were mechanically pruned and the hand pruning of treatment vines replicated the approximate dimensions of the hedge created by the commercial, mechanical pruning operation (saws ~20cm from cordon). Pruning weights were measured at the Padthaway site in winter 2011 (year of harvest) and at the Coonawarra site in 2010 and 2011.

Measurement of pruning weights followed the convention of the cooperating corporate grower, that is measurement of all growth removed from their standard unit vine length of 1.2m (0.6 m either side of the crown).

Table 2. Rootstock genotypes in the Padthaway and Coonawarra trials.

Chardonnay Padthaway	Shiraz Coonawarra	Parentage
Own roots†	Own roots	*V. vinifera*
	Petit Verdot 8092	*V. vinifera*
Ramsey†		*V. champini*
K51-32		*V. champini x V. riparia*
K51-40†		*V. champini x V. riparia*
Freedom		*V.champini x 1613 Couderc*
Schwarzmann†		*V. riparia x V. rupestris*
	101-14	*V. riparia x V. rupestris*
SO4 8341	SO4 8341	*V. berlandieri x V. riparia*
5C Teleki A6V18 FPMS 1966	5C Teleki A6V18 FPMS 1966	*V. berlandieri x V. riparia*
	5C Teleki 8344	*V. berlandieri x V. riparia*
	5C Teleki 8343	*V. berlandieri x V. riparia*
	420A	*V. berlandieri x V. riparia*
	34EM	*V. berlandieri x V. riparia*
Fercal		*(V. berlandier x V. vinifera) x 333EM*
	1616 Couderc	*V. longii x V. riparia*

†Chardonnay vines on these rootstock genotypes were also assessed in a Padthaway vineyard by Walker et al. (2010a).

Fruit growth was assessed at harvest by measurement of yield, bunch number and weight of a 100-berry sample. For these measurements the unit vine length was set as the within-row inter-vine distance with the midpoint set at the vine crown. At both sites, measurements were made in 2010 and 2011. The 100-berry sample was generated by sampling bunches on both sides of the vine and picking berries from the left, right, top, bottom, back and front of the bunch. The samples were transported from the field to the laboratory in chilled insulated containers.

After weighing the 100-berry sample, the fruit was crushed in a hand press and the extracted juice was clarified by centrifuging at 10397 x *g* for 10 minutes. In 2010 and 2011, the total soluble solids concentration was measured on clarified juice by digital refractometer and expressed as °Brix at 20°C. In 2011, pH and the concentration of titratable acid (TA) were measured on an auto-endpoint TA and pH meter (Metrohm, Ionenstrasse, Switzerland); the juice was titrated against 0.133 M NaOH. At the Shiraz trial, measurements of pH and TA were undertaken on five of the ten replicates. After measurement, samples were frozen for later measurement of Na^+ and Cl^- concentrations.

At the Coonawarra site, Shiraz yields were also measured in the four seasons from 1989 through to 1992 and reported in Nicholas (2006).

5.3 Results and discussion

5.3.1 Missing vines

The number of missing vines ranged from 0 to 3 (per 6 replicates) at Padthaway and 0 to 2 (per 10 replicates) at Coonawarra (Table 3). At both sites, rootstock genotype did not explain a significant amount of the variation in the number of missing vines.

Table 3. The number of missing vines by genotype at Padthaway (out of 6) and Coonawarra sites (out of 10).

Padthaway	Missing	Coonawarra	Missing
Own roots	0	Own roots	0
		Petit Verdot 8092	1
Ramsey	1		
K51-32	1		
K51-40	2		
Freedom	2		
Schwarzmann	1		
		101-14	1
SO4 8341	2	SO4 8341	0
5C Teleki A6V18 FPMS 1966	3	5C Teleki A6V18 FPMS 1966	0
		5C Teleki 8344	1
		5C Teleki 8343	2
		420A	0
		34EM	0
Fercal	1		
		1616 Couderc	0

5.3.2 Shiraz at Coonawarra

5.3.2.1 Shiraz pruning weights and yield

Rootstock genotype affected the pruning weights from Shiraz vines in both 2010 and 2011 (Table 4). In 2010, the weights from vines grafted to 1616 and Petit Verdot roots were less than those on own roots and grafted to 101-14, SO4 and all clones of 5C Teleki. In 2011, the weights from vines grafted to 1616, 420A and Petit Verdot were less than those on 101-14 and 5C Teleki A6V18. The weights from weakest vines, that is those on 1616 and Petit Verdot roots, increased in the wetter season, 2011.

The effect of rootstock genotype on the yield of Shiraz vines was modified by season (Table 5). In both seasons, the yields of vines grafted to Petit Verdot were less than those on the other rootstock genotypes. Considering these other genotypes, in the drier year of 2010, the yield of vines on own roots, SO4, 5C Teleki A6V18 & 8344, and 34 EM were higher than those on 1616. In the wetter year of 2011, the yields of vines on own roots and 5C Teleki A6V18 were higher than those on 420A.

At this site, Nicholas (2006) measured yields when vine the vines were between three to six years of age (1989-1992). Nicholas (2006) found that the yields from vines on all rootstock genotypes (including on own roots) were equivalent and greater than those from vines grafted to Petit Verdot (Figure 1).

Table 4. The effects of rootstock genotype and season on pruning weight (kg/vine) at Coonawarra.

Rootstock	2010	2011
Own roots	0.9^{ab}	0.9^{ab}
Petit Verdot	0.3^{c}	0.7^{b}
101-14	0.7^{ab}	1.0^{a}
SO4 8341	0.7^{ab}	0.7^{ab}
5C Teleki A6V18	0.8^{ab}	1.0^{a}
5C Teleki 8344	0.7^{b}	0.7^{ab}
5C Teleki 8343	0.6^{b}	0.9^{ab}
420A	0.5^{bc}	0.6^{b}
1616	0.4^{c}	0.6^{b}
34EM	0.5^{bc}	0.8^{ab}

Values followed by different letters are significantly different (P = 0.05).

Inclusion of measurements from Petit Verdot in the analysis of the data set comprising the mean yields 89-92 and 2010-11 produced an unacceptable decay in the sensitivity. It was removed and the resultant analysis is shown in Figure 1. Yield trends have changed over time. For vines at 24 and 25 years of age, the yields on 5C Teleki 8344, 101-14, 5C Teleki 8343, 420A, 1616 and Petit Verdot were less than those on own roots and 5C Teleki A6V18. These results show that the effect of rootstock genotype on the yield of Shiraz vines was not stable over 3 decades.

Table 5. The effects of rootstock genotype and season on yield (kg/vine) of Shiraz vines at Coonawarra.

Rootstock	2010†	2011†
Own roots	10.3^{ab}	10.6^{a}
Petit Verdot	0.7^{d}	0.3^{d}
101-14	6.9^{bc}	5.5^{bc}
SO4 8341	9.4^{ab}	6.7^{bc}
5C Teleki A6V18	10.3^{ab}	8.6^{ab}
5C Teleki 8344	8.2^{ab}	4.5^{bc}
5C Teleki 8343	6.3^{bc}	4.9^{bc}
420A	4.2^{bc}	4.1^{c}
1616	4.1^{c}	4.1^{bc}
34EM	8.6^{ab}	7.1^{abc}

†Analysis undertaken on data subject to square root transformation. Back transformed values are tabulated.

Values followed by different letters are significantly different (P = 0.05).

In 2010 and 2011, the effect of rootstock genotype on the number of bunches per vine was modified by season (Table 6). Bunch number accounted for 74% of the variation in vine yield overall and more than 70% in individual years. In 2010, Shiraz vines grafted to 5C Teleki 8344 produced the greatest number of bunches at 145 bunches per vine. This value was equivalent to those from vines on own roots and grafted to 5C Teleki A6V18, SO4 8341 and 101-14. In 2011, vines on own roots and those grafted to 5C Teleki A6V18 continued to produce high bunch numbers. Shiraz grafted to 5C Teleki 8344 and 1616 both produced significantly lower bunch numbers in 2011 compared to their 2010 counts. In both years, Shiraz grafted to Petit Verdot had the lowest number of bunches per vine.

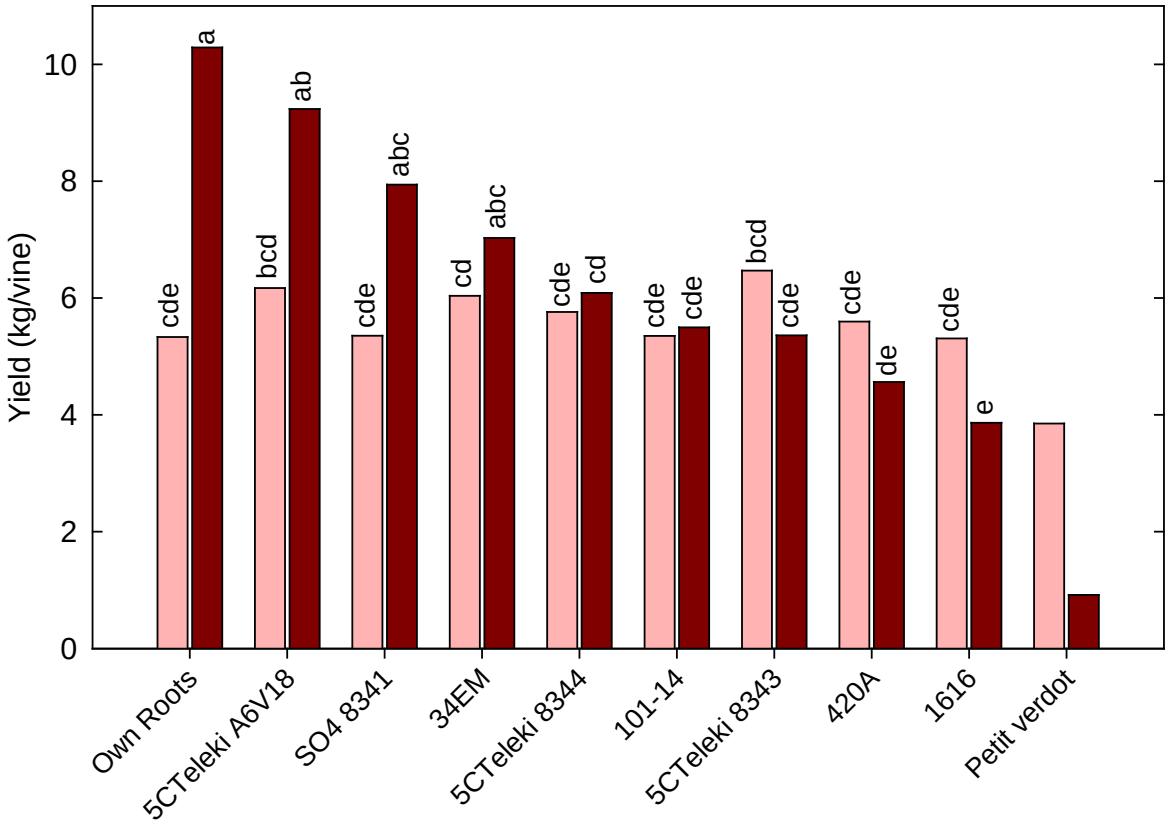


Figure 1. The effect of rootstock genotype on yield of Shiraz vines. Vine age, three-six years , 24-25 years . Bars with different letters are significantly different at *P* = 0.05. See text about absence of lettering above values for Petit Verdot.

The effect of rootstock genotype on average bunch weight was modified by season. The bunch weights on vines grafted to Petit Verdot decreased between 2010 and 2011 while those from vines on 1616 increased (Table 6). Bunch weight accounted for more than 50% of the variation in vine yield overall and more than 50% in individual years. Shiraz on 34EM produced the heaviest bunches in both 2010 and 2011. In both seasons, bunch weights from vines on 34 EM were equivalent to those from vines on own roots and grafted to 5C Teleki A6V18, 5C Teleki 8343 and SO4 8341. In 2011, bunch weights from vines grafted to 101-14 and 5C Teleki 8344 were also be equivalent to those from vines on 34EM. Vines grafted to Petit Verdot had low bunch weights in both seasons.

The effect of rootstock genotype on berry weight was modified by season (Table 6). The average berry weight of 1.31 g in the wetter season, 2011, was significantly higher than that

of 0.99 g in 2010. The berry weight increased in 2011 in vines on own roots and all grafted vines excluding those on Petit Verdot, 101-14 and 5C Teleki 8343.

Table 6. The effects of rootstock genotype and season on bunch number per vine and bunch and berry weights (g) from Shiraz vines.

	Bunch number †		Bunch weight‡		Berry weight	
Rootstock	2010	2011	2010	2011	2010	2011
Own roots	136.2^{ab}	137.6^{ab}	74.0^{ab}	75.3^{ab}	1.13^{b}	1.40^{a}
Petit Verdot	24.3^{d}	20.4^{d}	19.6^{d}	11.1^{e}	0.80^{c}	0.91^{c}
101-14	120.8^{ab}	76.7^{bc}	51.5^{bc}	69.8^{ab}	0.95^{bc}	1.31^{ab}
SO4 8341	135.0^{ab}	90.1^{bc}	66.5^{ab}	73.8^{ab}	0.98^{bc}	1.32^{a}
5C Teleki A6V18	136.2^{ab}	114.7^{ab}	74.2^{ab}	69.8^{ab}	1.11^{b}	1.33^{a}
5C Teleki 8344	145.2^{a}	73.3^{bc}	56.1^{b}	61.4^{ab}	0.96^{bc}	1.35^{a}
5C Teleki 8343	83.9^{bc}	74.5^{bc}	71.2^{ab}	64.5^{ab}	1.30^{ab}	1.35^{a}
420A	72.3^{c}	64.0^{c}	51.2^{bc}	56.9^{b}	0.82^{c}	1.33^{a}
1616	105.9^{b}	71.9^{c}	36.1^{c}	54.2^{b}	0.83^{c}	1.35^{a}
34EM	99.4^{bc}	76.4^{bc}	86.3^{a}	89.3^{a}	1.09^{b}	1.41^{a}

† Analysis undertaken on data subject to square root transformation. Back transformed values are tabulated.
‡ geometric mean.
Values followed by different letters are significantly different (P = 0.05).

5.3.2.2 Berry composition, Shiraz

The effect of rootstock genotype on the concentration of total soluble solids (TSS) in juice was modified by season (Figure 2). In 2010, the concentration of TSS in juice from vines grafted to Petit Verdot was higher than that from vines on own roots and the other grafted vines except for those on 1616. In 2010, the concentration of TSS in juice from vines on own roots was equivalent to that of grafted vines except those on Petit Verdot and 1616. In 2011, the concentrations of TSS in juice from vines on Petit Verdot and 1616 were again higher than those from vines on their own roots and other grafted vines except those on 5C Teleki 8344 and 5C Teleki 8343.

In 2011, the pH of 2.91 in Shiraz fruit from on own rooted vines was lower than that from all grafted vines except those on Petit Verdot (Figure 3). The concentrations of titratable acid in fruit from vines on own roots and grafted to 420A, 101-14, SO4 8341, 1616 and 5C Teleki 8344 were lower than in fruit from vines grafted to Petit Verdot (Figure 3).

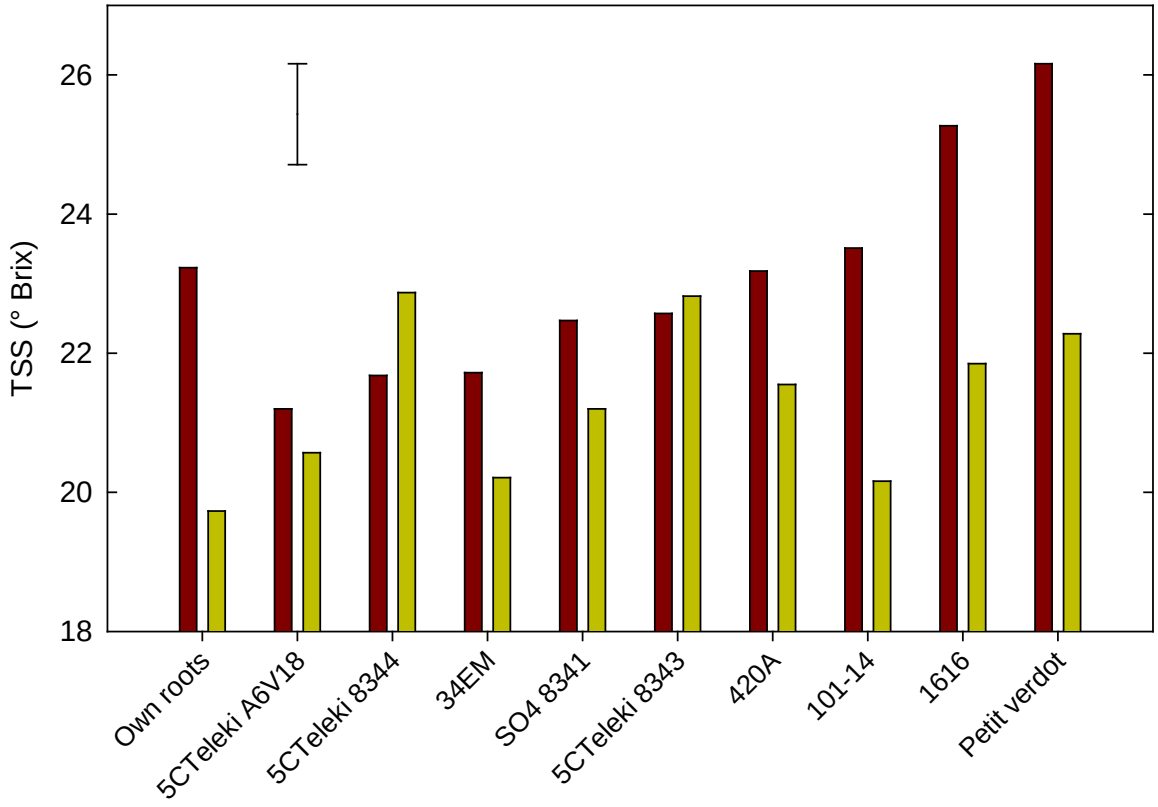


Figure 2. The effect of rootstock genotype and season on the concentration of TSS in grape juice from Shiraz vines. Season 2010 and 2011 . Error bar represents least significant difference between rootstocks across two years (*P*=0.05).

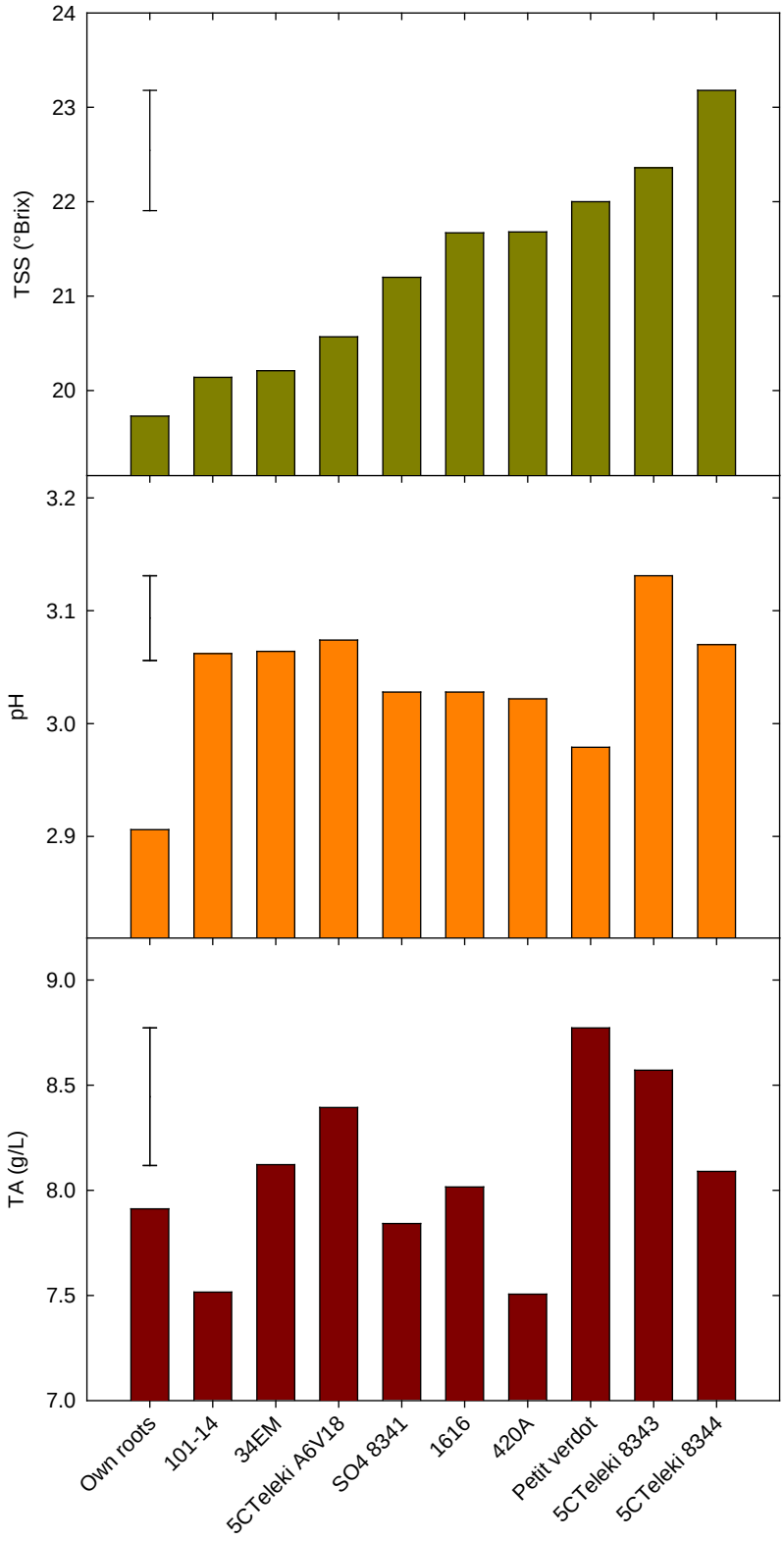


Figure 3. The effect of rootstock genotype on the concentration of TSS, pH and concentration of TA in grape juice from Shiraz vines in 2011. Error bars represent least significant difference between rootstock means (*P*=0.05).

5.3.3 Chardonnay at Padthaway

5.3.3.1 Chardonnay yield and pruning weights

The effect of rootstock genotype on yield was modified by season (Figure 4). The average yield of 8.9 kg/vine in 2011 was higher than the 6.4 kg/vine in 2010; 2011 was wetter than 2010.

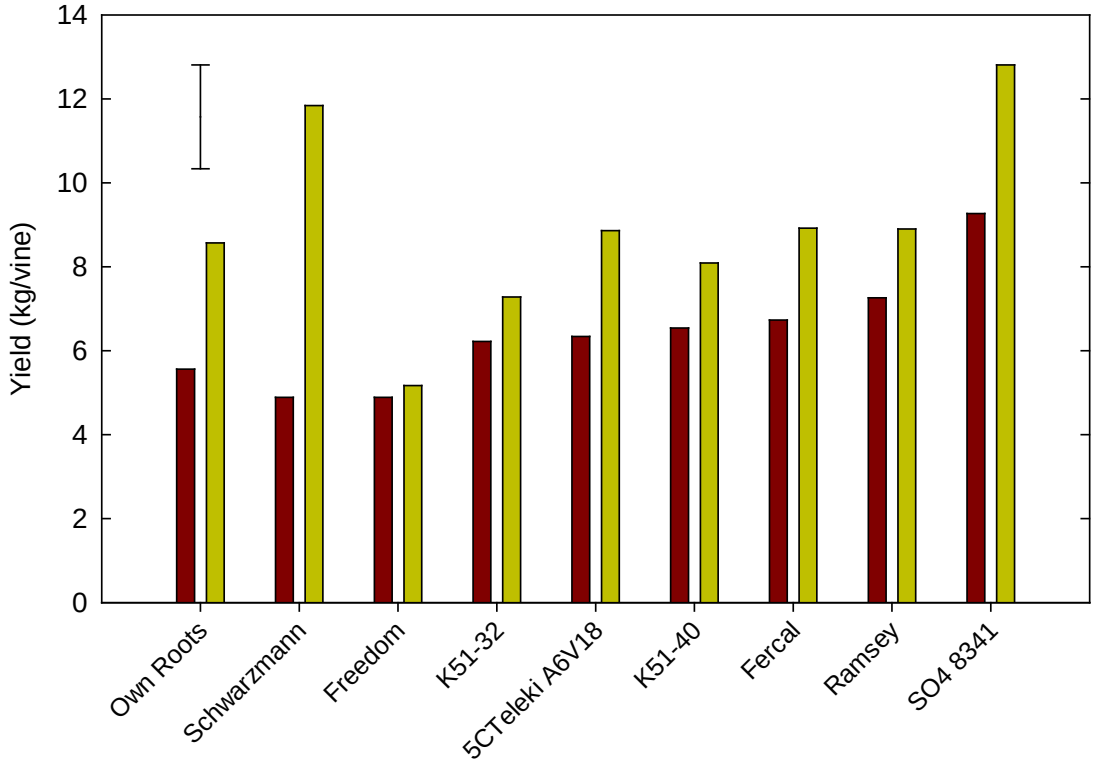


Figure 4. The effect of rootstock genotype and season on the yield of Chardonnay vines. Season 2010 and 2011 . Error bar represents least significant difference between rootstocks across years (*P* = 0.05).

In 2010, the yield from vines grafted to SO4 8341 was significantly higher than those from vines on their own roots and on the remaining rootstocks. In 2011, vines on SO4 8341 and Schwarzmann rootstocks produced greater yields than those on their own roots. Vines on SO4 8341 was again the heaviest bearer at 12.8 kg/vine. Yields from vines grafted to Freedom and K51-32 were lower than the yield from own rooted vines.

The average yields for Chardonnay vines growing at Padthaway on a suite of rootstocks consisting of own roots, Ramsey, K51-40 and Schwarzmann were 6.1 ±0.5 and 9.4 ±0.8 kg/vine (± standard error of mean) in 2010 and 2011, respectively. Walker et al. (2010a) also assessed Chardonnay vines on these rootstocks at a vineyard in Padthaway. Their average yield of 5.5 ±0.6 kg/vine is less than that found at the present site in 2011. They found that yield on Ramsey rootstock was superior to those on own roots and the other two rootstocks which were equivalent. In contrast, in the drier season of 2010 we found the yields of vines on all four genotypes were equivalent and in 2011, the yield of vines grafted to Schwarzmann was superior to vines on own roots and the other two rootstocks which were equivalent.

The effect of rootstock genotype on the number of bunches per vine was modified by season (Figure 5). The average of 80 bunches per vine in 2011, was just less than that of 86 per vine in 2010. Bunch number accounted for more than 50% of the variation in vine yield overall and more than 75% in individual years.

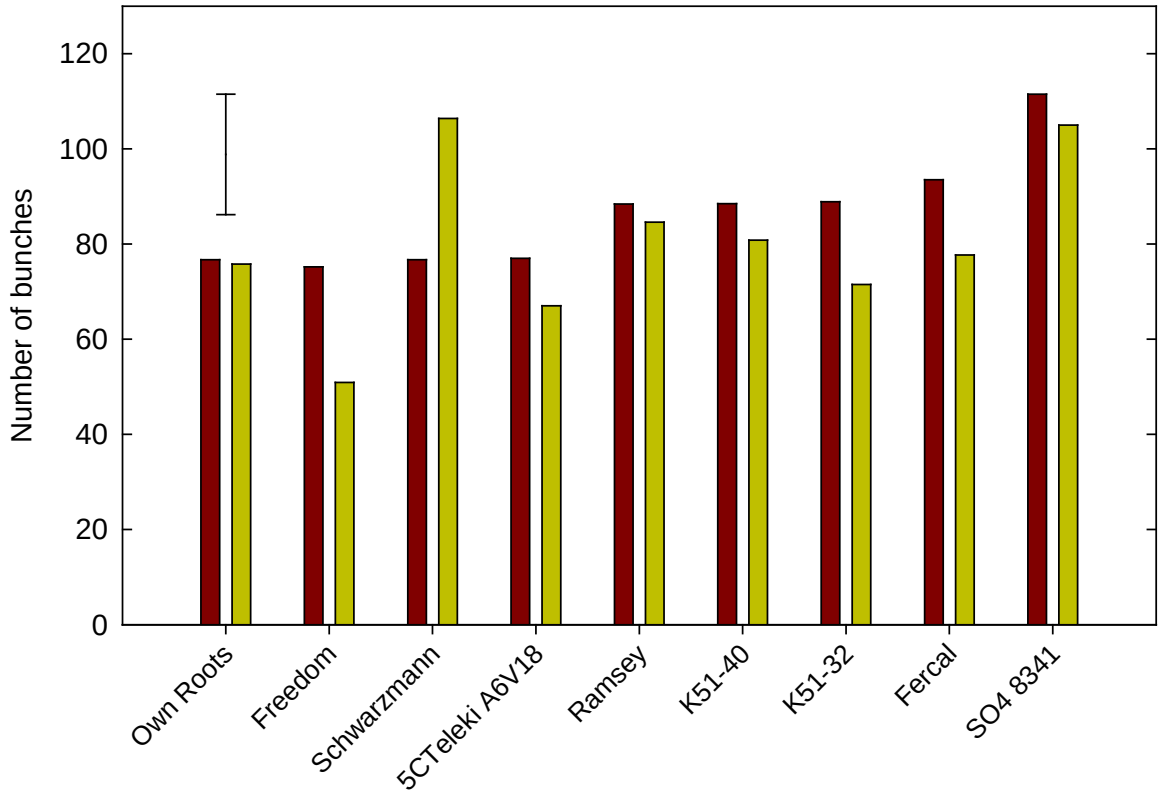


Figure 5. The effect of rootstock genotype and season on the number of bunches on Chardonnay vines. Season 2010 and 2011 . Error bar represents least significant difference between rootstocks across or within years (*P*=0.05).

In 2010, the number of bunches on vines grafted to SO4-8341 were higher than those on vines grafted to 5C Teleki A6V18, Schwarzmann, Freedom and vines on own roots. Again in 2011, vines grafted to SO4 8341 had more bunches than those grafted to K51-32, K51-40. Fercal, 5C Teleki A6V18, Freedom and vines on own roots. The number of bunches on vines grafted to Schwarzmann increased between 2010 and 2011.

The effect of rootstock genotype on the average bunch weight was also modified by season (Figure 6). In 2011, bunches weighed 50% more than in 2010, 112 g and 74 g respectively. Bunch weight accounted for more than 40% of the variation in vine yield overall; more than 40% in 2010, but only 11% in 2011. In 2010, the weight of bunches from grafted vines was equivalent to those from vines on their own roots. Vines grafted to SO4-8341, Ramsey and 5C Teleki A6V18 had heavier bunches than vines on Schwarzmann and Freedom. In 2011, bunches from vines on 5C Teleki A6V18 were heavier than those from vines on own roots and the other rootstocks, excepting SO4-8341. Vines on 5C Teleki A6V18 and SO4-8341 had heavier bunches than those on Ramsey, Freedom, K51-40 and K51-32.

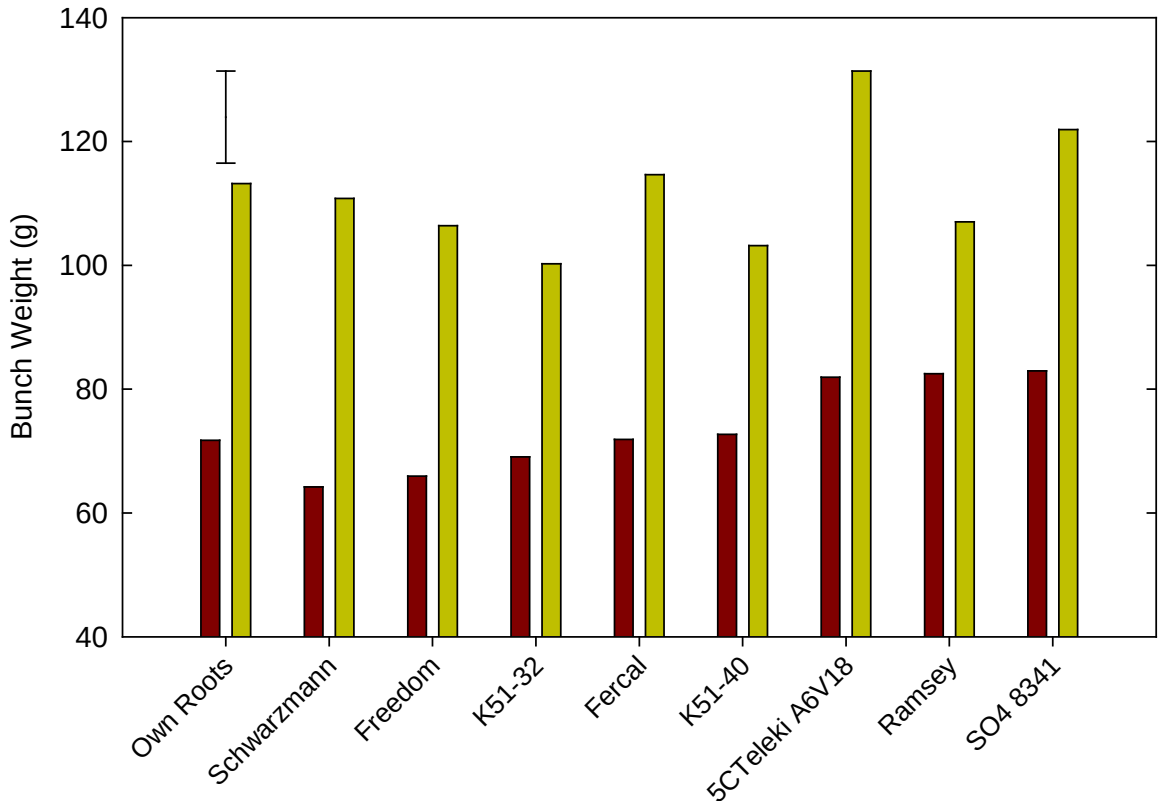


Figure 6. The effect of rootstock genotype and season on the average of weight of bunches from Chardonnay vines. Season 2010 and 2011 . Error bar represents least significant difference between rootstocks across or within years (*P*=0.05).

The effect of rootstock genotype on the average berry weight was modified by season (Figure 7). The average berry weight of 1.28 g in the wetter season, 2011, was significantly higher than that in 2010, 1.03 g. Comparing the individual rootstocks across the two seasons shows that the berry weight increased in vines on own roots and all rootstock except SO4-8341. Within season comparisons showed that in both seasons, the weight of berries from vines on own roots was equivalent to those from grafted vines.

Pruning weights from Chardonnay vines ranged from 0.6 to 1.1 kg/vine across rootstock genotypes (Table 7). Rootstock genotype did not significantly affect the weight.

5.3.3.2 Berry composition, Chardonnay

The concentration of TSS in juice was independently affected by season and rootstock genotype. The TSS concentration in 2011 of 21.7 °Brix was higher ($P < 0.001$) than that of 21.3 °Brix in 2010 (data not shown). Fruit from vines grafted to Schwarzmann and Freedom had the highest concentrations of TSS and that from those grafted to Ramsey the lowest (Figure 8). Fruit from vines grafted to Ramsey had a lower concentration of TSS than those from vines grafted to the remaining rootstock genotypes, excepts own roots and K51-40.

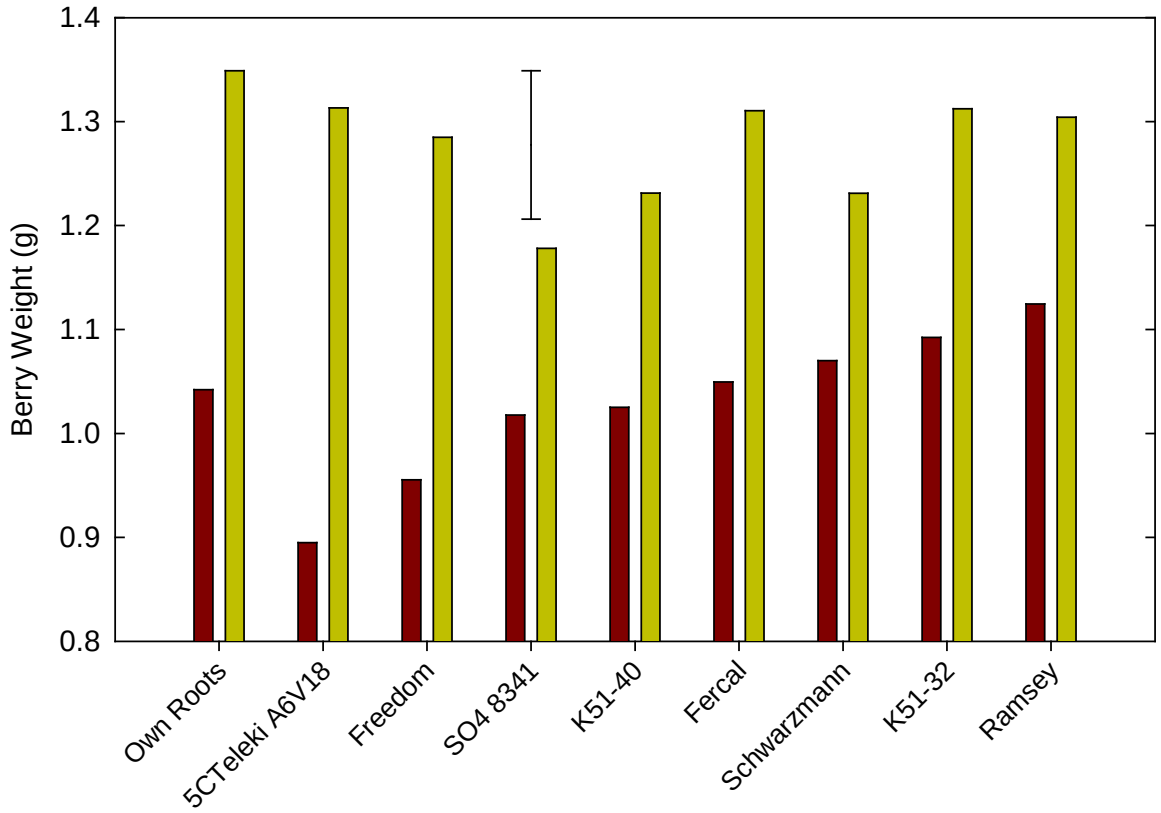


Figure 7. The effect of rootstock genotype and season on the average berry weight from Chardonnay vines. Season 2010 and 2011 . Error bar represents least significant difference between rootstocks across or within years (*P*=0.05).

Table 7. The effect of rootstock genotype on pruning weights at Padthaway in 2011.

[†]Rootstock	Pruning weight (kg/vine)
Own roots	0.65
Ramsey	1.04
K51-32	0.94
K51-40	1.09
Schwarzmann	0.77
SO4 8341	0.80
5C Teleki A6V18	0.80
Fercal	0.63
Freedom	0.62

[†]No significant difference (*P*=0.05)

In 2011, neither juice TSS concentration nor pH were affected by rootstock genotype with mean values of 21.7 °Brix and 2.9 pH (Table 8). Fruit from vines grafted to Ramsey and K51-32 had higher concentrations of TA than those from vines on own roots and grafted to Schwarzmann, Fercal, 5C Teleki A6V18 and SO4-8341 (Table 8).

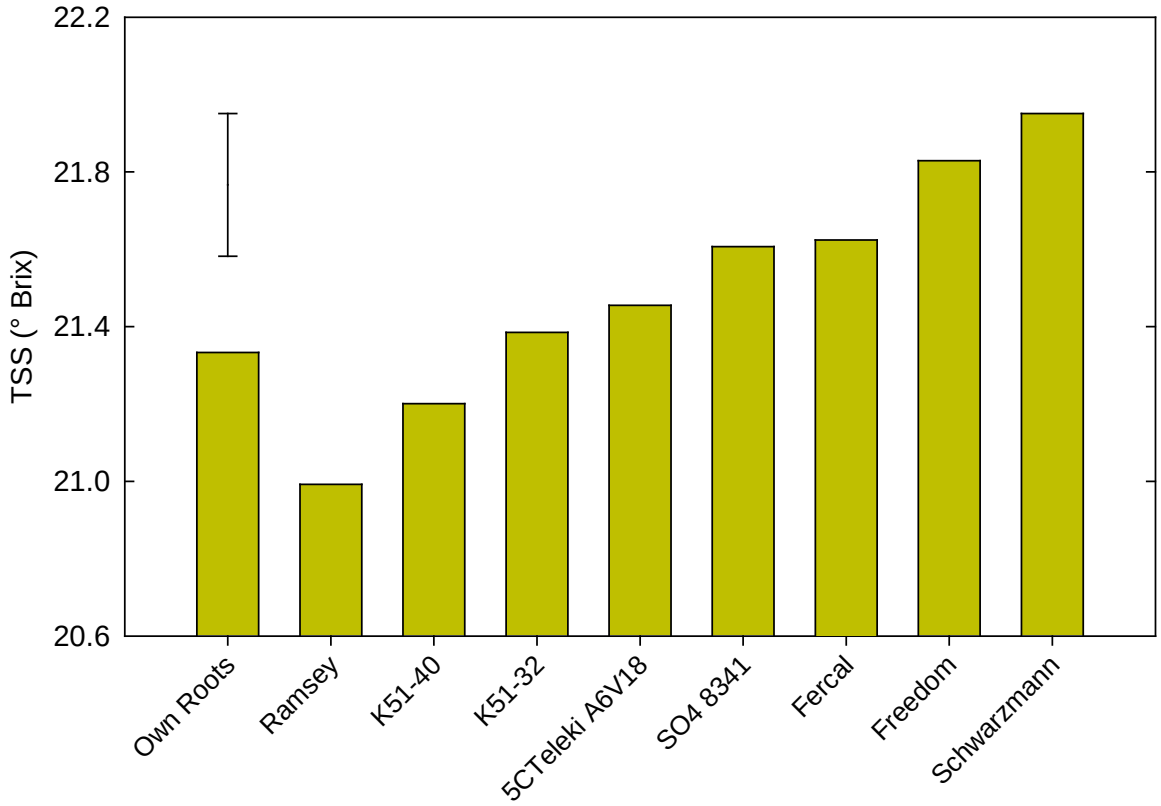


Figure 8. The effect of rootstock genotype on the concentration of TSS in grape juice from Chardonnay vines. Error bar represents least significant difference between rootstocks across two years (*P*=0.05).

Table 8. The effects of rootstock genotype on the concentration of total soluble solids, pH and concentration of TA in juice from Chardonnay vines in 2011.

Rootstock	Total soluble solids (°Brix)	Titratable acidity (g/L)	pH
Own roots	21.6[a]	7.78[b]	2.98[a]
Ramsey	21.2[a]	8.44[a]	2.98[a]
K51-32	21.6[a]	8.35[a]	2.93[a]
K51-40	21.7[a]	8.21[ab]	2.96[a]
Schwarzmann	22.1[a]	7.54[b]	2.98[a]
SO4 8341	21.9[a]	7.83[b]	2.93[a]
5C Teleki A6V18	21.6[a]	7.71[b]	2.93[a]
Fercal	21.8[a]	7.57[b]	2.97[a]
Freedom	21.9[a]	8.20[ab]	2.96[a]

Superscript letters indicate significant differences (*P*=0.05) between rootstocks.

6. SALT EXCLUSION BY GRAFTED VINES IN THE LIMESTONE COAST

6.1 Introduction

Over the last decade, salinity has been emerging as a concern for some vineyards in the South East of SA. Salt excluding rootstocks are seen as one strategy to manage the potential risk associated with excessive soil salinity.

The salt excluding properties of rootstocks suited to 'supplementary irrigation' districts, such as the South East of SA, are less well characterised than those suited to 'full irrigation' districts, such as the Riverland. SARDI established rootstock trials throughout the Limestone Coast in the early 1980's. The current project has revisited two of these sites, as described in Chapter 5.1, and the Na^+ and Cl^- concentrations of petiole and grape juice have been analysed to characterise the salt excluding properties of the rootstocks.

Rootstock performance, at the SARDI Chardonnay site, has also been compared to that of rootstocks in a CSIRO trial in the same district. Both the SARDI and CSIRO trials contain Chardonnay vines on eight rootstocks and on own roots. They share four rootstock genotypes in common.

Revisiting the SARDI Chardonnay rootstock trial not only expands the range of rootstocks being assessed in the district, but has the additional benefit of giving an indication of the exclusion properties in a mature, 25 year old, vine.

6.2 Materials and methods

Salt exclusion investigations were conducted at the same vineyards as those involved in the longevity studies. Vineyard descriptions, trial design and analysis are described in Chapter 5.2 of this report.

6.2.1 Meteorological, irrigation and soil measurements

Rainfall data were sourced from local Bureau of Meteorology automatic weather stations (station numbers 026100 for Padthaway South and 026091 for Coonawarra). Values of the long term average reference evapotranspiration (ETo) for Padthaway and Coonawarra were sourced in September 2011 from http://www.pir.sa.gov.au/pirsa/nrm/water_management/ires/icms. Long term average rainfall was calculated from data generated by running a data drill at http://www.nrm.qld.gov.au/silo/ for Padthaway in July 2006 and for Coonawarra in September 2011.

Data on irrigation depths were sourced from vineyard management records. Information on the salinity of irrigation water was sourced from vineyard management records and OBSWELL (Government of SA, 2010) .

Soils were sampled from each site at the beginning and end of the 2010 and 2011 irrigation seasons. At the Padthaway site, samples were collected at depths of 0.1 m, 0.3 m, 0.5 m, 0.7 m, 0.9 m and 1.1 m and at Coonawarra depths of 0.05 m, 0.15 m, 0.25 m, 0.35 m, 0.45 m. Salinity was measured as the electrical conductivity of 1:5 soil:water extracts ($EC_{1:5}$) following method of Rayment and Higginson (1992). The salinity was measured using a temperature compensated conductivity meter (model CON510, Eutech, Singapore) and reported at 25^{o}C. The measures of $EC_{1:5}$ were converted to those of EC_e using the "R" values in Cass et al. (1996).

6.2.2 Plant tissue sampling and analysis

Leaf petiole samples were collected opposite to basal inflorescences at flowering (E-L stage 23-25) in 2010 and 2011 seasons (year of harvest). Up to ten petioles were collected from either side of the canopy. If there was less than 10 basal inflorescences, then petioles were collected from opposite basal tendrils. Where the central vine in a plot was missing, petioles were collected from barrier vines. The petioles were dried at 70°C for at least 72 hours and ground using a Micro Hammer-Cutter Mill (Culatti AG, Zurich, Switzerland) to pass through a 0.5 mm mesh.

The Cl^- concentrations in petioles and juice were measured by silver ion titration with a Buchler chloridometer (Labconco, Kansas City, MO, USA). The Na^+ concentrations were measured by ICP (Spectro Analytical Instruments, Kleve, Germany).

6.3 Results and discussion

6.3.1 Irrigation, rainfall and soil salinity

The long term average annual rainfalls (1956-2006) for Padthaway and Coonawarra were 495 and 606 mm, respectively. Both 2010 and 2011 were wetter than average. In 2010, annual rainfall at both sites was about 80 mm above average and in 2011 about 200 mm above average (Table 9).

The depths of annual rain fall plus irrigation (received water) were in excess of 700 mm at both sites in both seasons (Table 9). Cleugh (2006) found the average annual rate of evapotranspiration by vineyards in Padthaway was 532mm (and the rate between Sept to February 375 mm). It is likely that the values for Coonawarra would be about 95% of those at Padthaway as the annual values of reference evapotranspiration at Coonawarra were about 95% of those at Padthaway. The annual depths of received water were at least 150 mm in excess of crop evapotranspiration.

Table 9. Irrigation and rainfall (mm) and irrigation water and soil salinity (dS/m) at Padthaway and Coonawarra sites in 2010 and 2011 seasons (year of harvest).

	Padthaway		Coonawarra	
	2010	2011	2010	2011
Irrigation	240	60	20	0
Rainfall, July – June	576	711	689	819
Rainfall, Oct. – Mar.	180	382	205	440
Irrigation water EC	1.9	1.9	1.4[†]	-[‡]
Pre irrigation, Sept., EC_e	0.3	0.3	1.0	1.1
Post irrigation, Mar-May, EC_e	1.3	0.4	1.9	0.6

[†] No data was available for the irrigation bore and this value was taken from nearest OBSWELL monitored bore at about 0.6 km from site. Records from this bore show that the single 2010 reading was below the average of 1.9 dS/m which had been recorded at the irrigation bore over the last 2 decades at this site.

[‡] no irrigation applied at this site in 2011

At both sites the salinities of irrigation water were high (Table 9) (Hart, 1974). In 2010, when in-season rainfall was less than about 200 mm, application of saline irrigation raised soil

salinity at both sites (Table 9). In 2011, when in-season rainfall was about 400 mm, the application of saline irrigation at Padthaway, albeit only 25% the depth added in 2010, did not cause a rise in soil salinity. In Coonawarra, where no irrigation was applied in 2011, rainfall was sufficient to flush soil salt during the season and soil salinity fell between September and March.

In 2010, saline irrigation at both sites caused a within season rise in soil salinity, however there was no build up in soil salinity between September 2009 and September 2010. The leaching fractions produced by the depth of received water in excess of crop evapotranspiration were sufficient to remove salts added in irrigation water.

6.3.2 Shiraz rootstock trial at Coonawarra

Soil salinities measured just prior to budburst in September 2009 and 2010 (Table 9), were below the 2.1 dS/m (EC_e) salinity threshold for vines on own roots (Zhang et al. 2002). Both seasons opened with non-saline soils. Although the irrigation water source was saline, 1.4 dS/m, the wetter than average conditions meant that there was little or no requirement for irrigation and only 20 mm was added in 2010 and 0 mm in 2011. The amount of salt added in 20 mm of irrigation is too small to explain the 0.9 dS/m rise in soil salinity in 2010. It is likely that most of this salt was added in previous seasons. It had been flushed into the sub-soil before bud-burst on 2009 and then migrated upward during the season. In 2011, within season rain, well above average, continued to flush salts added by irrigations in previous seasons. Levels of soil salinity in both assessment years were low. However despite the low levels, rootstock genotype affected salt levels with in the vines.

6.3.2.1 Leaf petiole Na^+ and Cl^- concentrations

The rootstock genotype effect on the leaf petiole concentration of Na^+ was modified by season, but values averaged over all genotypes were equivalent in both seasons (Table 10). In 2010, the Na^+ concentration of leaf petioles from Shiraz on own roots, 0.12%, was greater than that in grafted vines excepting those on 5C Teleki 8344, 1616 and 420A. This trend did not continue into 2011. The Na^+ concentration in own rooted vines dropped significantly to 0.07% and that in vines grafted to 34EM doubled from 0.06 to 0.12%.

The effect of rootstock genotype on leaf petiole Cl^- concentrations was not modified by season (Table 10). Leaf petiole Cl^- concentrations were equivalent in 2010 and 2011, 0.24% and 0.26%, respectively (data not tabulated).

The concentration of Cl^- in the leaf petioles from vines on their own roots and those grafted to another *V. vinifera* genotype, Petit Verdot, were higher than those in vines grafted to the other rootstocks (Table 10). The average leaf petiole Cl^- concentration of vines on *V. vinifera* roots was 0.53% compared to an average of 0.21% in vines on rootstocks with other Vitis genus in their pedigree. Vines grafted to 101-14 had the lowest concentration of Cl^- in the petiole.

6.3.2.2 Grape juice Na^+ and Cl^- concentrations

The Na^+ concentration in juice was affected by both season and rootstock genotype, but not by an interaction between these two parameters (Table 11). The average juice concentration of Na^+ decreased from 15.9 mg/L in 2010 to 9.0 mg/L in 2011. The Na^+ concentration of 20.2 mg/L in juice from vines their own roots was higher than that in grafted vines excepting those on 5C Teleki 8344. It was also higher than that from the other vines on *V. vinifera* roots, Petit Verdot.

Table 10: The effect of rootstock genotype and season (year of harvest) on leaf petiole Na^+ concentration (%) and the effect of rootstock genotype on leaf petiole Cl^- concentration (%) in Shiraz at flowering.

	Petiole Na^+ †		Petiole Cl^- †
	2010	2011	
Rootstock			
Own roots	0.12^{a}	0.07^{b}	0.51^{a}
Petit Verdot	0.06^{b}	0.07^{b}	0.54^{a}
101-14	0.04^{b}	0.06^{b}	0.13^{e}
SO4 8341	0.07^{b}	0.06^{b}	0.21^{cd}
5C Teleki A6V18	0.06^{b}	0.09^{ab}	0.19^{cd}
5C Teleki 8344	0.08^{ab}	0.07^{b}	0.22^{bc}
5C Teleki 8343	0.07^{b}	0.09^{ab}	0.21^{c}
420A	0.08^{ab}	0.11^{ab}	0.29^{bc}
1616	0.08^{ab}	0.10^{ab}	0.30^{b}
34EM	0.06^{b}	0.12^{a}	0.15^{d}
Season			
2010			0.24^{A}
2011			0.26^{A}

† Data is geometric mean.
Superscript letters indicate significant differences (*P*=0.05); uppercase letters for comparison between seasons; lowercase letters for comparison between rootstocks in the same and different seasons.

Rootstock genotype also affected the Cl^- concentration in juice, but values were not affected by season (Table 11). In common with findings in the petiole, the juice Cl^- concentration from vines on their own roots was greater than that from vines grafted to all other rootstock genotypes excluding the other *V. vinifera* cv Petit Verdot. Vines grafted to 34EM and 101-14 had the lowest concentrations of Cl^- in juice.

The juices from vines grafted to 34EM and 101-14 had the lowest Na^+ and Cl^- concentrations.

Whilst the Na^+ concentration in juice clearly responded to reducing salt loads in 2011 (less irrigation and more rain for leaching), the Cl^- concentration in juice did not respond to the reduction in seasonal salt load. This suggests that sources of Cl^- other than those in the soil solution are contributing to inter-seasonal variations in the Cl^- concentrations in juice.

6.3.3 Chardonnay rootstock trial at Padthaway

6.3.3.1 Irrigation, rainfall and soil salinity

Soil salinities measured just prior to budburst in September 2009 and 2010 (Table 9), were well below the 2.1 dS/m (EC_e) salinity threshold for vines on own roots (Zhang et al. 2002). Both seasons opened with non-saline soils. Although the irrigation water source was saline, 1.9 dS/m, the wetter than average conditions in 2011 reduced requirement for irrigation and only 60 mm was added in 2011. The salt added in irrigation water in 2010 caused a 1.0 dS/m rise in soil salinity. In 2011, within season rain, well in excess of average, prevented

saline irrigation during the season from causing a build up of salt in the soil. The levels of soil salinity in both assessment years were low. However despite the low levels, rootstock genotype affected salt levels within the vines.

Table 11: The effect of rootstock genotype and season (year of harvest) on the concentrations of Na^+ and Cl^- (mg/L) in juice from Shiraz vines.

	Juice Na^+ †	Juice Cl^- ‡
Rootstock genotype		
Own roots	20.2^{a}	34.9^{a}
Petit Verdot	9.6^{c}	30.6^{ab}
101-14	7.9^{c}	19.6^{cd}
SO4 8341	12.1^{bc}	22.4^{c}
5C Teleki A6V18	12.7^{bc}	25.3^{bc}
5C Teleki 8344	16.9^{ab}	28.1^{b}
5C Teleki 8343	11.1^{bc}	23.2^{c}
420A	14.3^{b}	28.1^{b}
1616	12.8^{bc}	28.5^{b}
34EM	7.4^{c}	18.2^{d}
Season		
2010	15.9^{A}	24.4^{A}
2011	9.0^{B}	26.4^{A}

† Data has been back transformed from square root transformation.
‡ Data is geometric mean.
Superscript letters indicate significant differences (*P*=0.05); uppercase letters for comparison between seasons; lowercase letters for comparison between rootstocks in the same and different seasons.

6.3.3.2 Leaf petiole Na^+ and Cl^- concentrations

The Na^+ concentration in leaf petioles was affected by season, but neither by rootstock genotype nor by the interaction between these two parameters. In 2010, the value of 0.14%, was double that found in 2011, 0.07% (data not tabulated). Values for the different rootstock genotypes are presented in Table 12.

The Cl^- concentration in leaf petioles was affected by both season and rootstock genotype, but not by the interaction between these two parameters. In 2010, the value in the drier season, 2010, of 0.37%, was higher than that of 0.26% in 2011 (data not tabulated). The likely cause for this result is the difference in rainfall and irrigation between the two seasons.

The concentration of Cl^- in petioles from vines on their own roots, 0.69%, was higher than those from grafted vines (Figure 9). Chardonnay grafted to K51-40 had higher Cl^- concentration than other grafted vines. Chardonnay grafted to Schwarzmann had the lowest Cl^- concentration in the petioles; less than those in un-grafted vines and vines on K51-40, K51-32 and Freedom.

6.3.3.3 Grape juice Na^+ and Cl^- concentrations

The effect of rootstock genotype on the concentrations of Na^+ in juice was modified by season (Figure 10). The Na^+ concentrations in juice from ungrafted vines and those grafted

to Freedom decreased in 2011, the wetter season. In contrast, the Na^+ concentrations in juice from vines grafted to Schwarzmann increased over the same period. The Na^+ concentrations in juice from all other rootstock genotypes were equivalent in both seasons.

Table 12. The effect of rootstock genotype on the Na^+ concentration (%) in leaf petioles from Chardonnay vines at flowering.

†Rootstock	Na^+
Own roots	0.11
Ramsey	0.10
K51-32	0.11
K51-40	0.09
Schwarzmann	0.11
SO4 8341	0.09
5C Teleki A6V18	0.10
Fercal	0.11
Freedom	0.10

†No significant difference (*P*=0.05).

The concentration Cl^- in the juice of Chardonnay vines was affected by season and rootstock genotype and the interaction between these two parameters.

In 2010, the Cl^- concentration in juice from vines grafted to K51-40 was higher than that on own roots and in other grafted vines (Table 13). The Cl^- concentration in juice from ungrafted Chardonnay vines was higher than those in juices from the other grafted vines. This result is similar to the effect that rootstock genotype had on petiole Cl^- concentrations where own roots and K51-40 had the highest leaf petiole Cl^- concentrations.

The reduced salt load in 2011 cause a fall in the juice Cl^- in vines on all rootstock genotypes. In Chardonnay on own roots and on K51-40, levels fell to such an extent that they were equivalent to those in other rootstock genotypes.

Whilst the Cl^- concentration in juice clearly responded to reducing salt loads in 2011 (less irrigation and more rain for leaching), the Na^+ concentration in juice from vines on most genotypes did not respond to the reduction in seasonal salt load. This suggests that sources of Na^+ other than those in the soil solution are contributing to inter-seasonal variations in the Na^+ concentrations in juice.

6.3.4 Comparison of SARDI and CSIRO Chardonnay trials

Both SARDI and CSIRO have planted Chardonnay rootstock trials at Padthaway. Both trials contain vines on eight rootstocks and on own roots. They share three rootstocks in common (Table 14). Supplementary irrigation at both sites used saline water (electrical conductivity greater than 1.6 dS/m). The concentrations of Na^+ and Cl^- in juice from own rooted vines in both trials were similar (Table 14). The yields of vines on this group of rootstocks at the SARDI site in 2010 (vine age 24 years) were equivalent to those at CSIRO site in 1996-97 (vine age, four and five years).

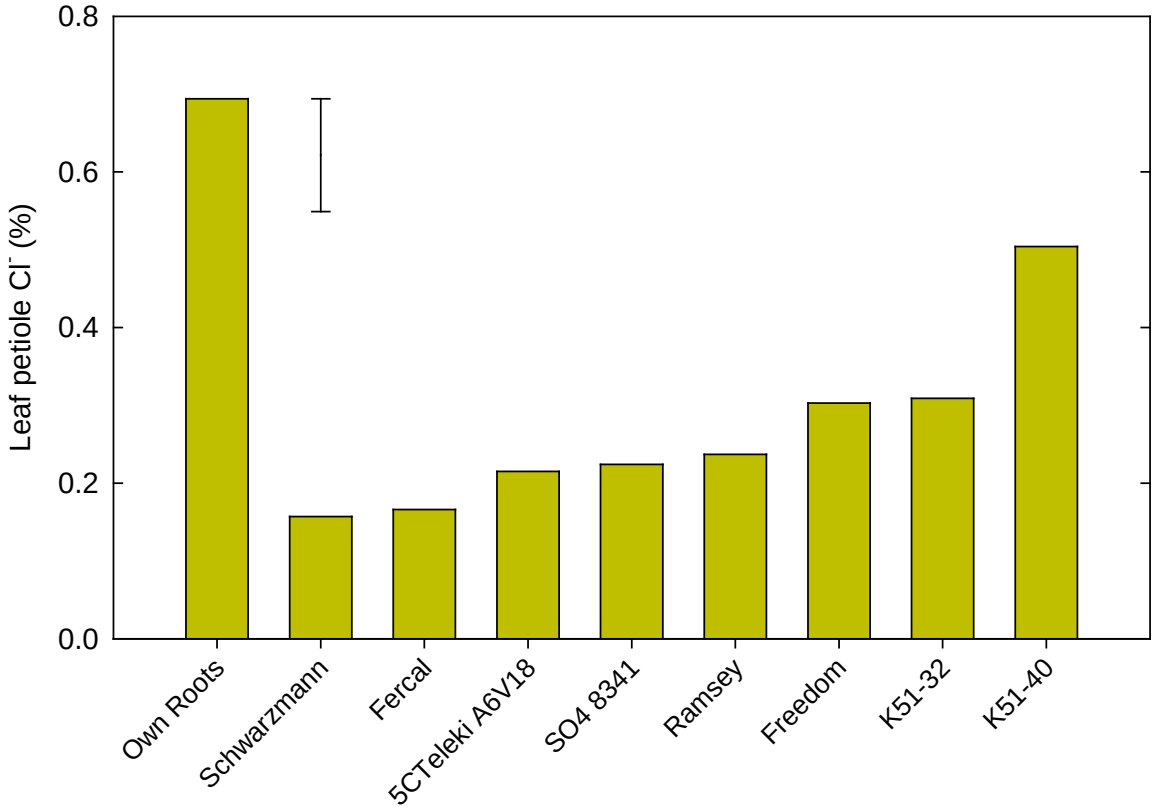


Figure 9. The effect of rootstock genotype on the Cl^- concentration in leaf petioles from Chardonnay vines at flowering. Error bar represents least significant difference between rootstocks across two years (*P*=0.05).

At both sites, the concentrations of Cl^- in juice (expressed as NaCl) were well below the maximum allowable in wine of 1 g/L (Table 14). However, it should be noted that some consumers can detect an effect of salt on taste at concentrations below 1 g/L.

At the SARDI site, vines grafted to Ramsey, K51-40 and Schwarzmann had lower juice Na^+ concentration than vines on own roots. In contrast, at the CSIRO site, the juice Na^+ concentrations were equivalent. Further at the SARDI site, the juice Na^+ concentrations on vines grafted to 7 of the 8 rootstocks were less than that in ungrafted vines (Table 14).

At both CSIRO and SARDI sites, the effects of the rootstocks Ramsey, K51-40 and Schwarzmann rootstocks on juice Cl^- concentrations relative to ungrafted vines were the same. Juice from vines on Ramsey and Schwarzmann had low concentrations of Cl^-. At the SARDI site, vines on Fercal and SO4 also had low concentrations of Cl^- in juice.

The low concentrations of Na^+ and Cl^- in the juice from Chardonnay vines on Fercal and SO4 indicates that their salt exclusion behaviours are the equal to those of the more well known salt excluding rootstocks such as Ramsey and Schwarzmann. At this site, the yields of vines on Fercal and SO4 were equivalent to or more than those of vines on Ramsey and Schwarzmann.

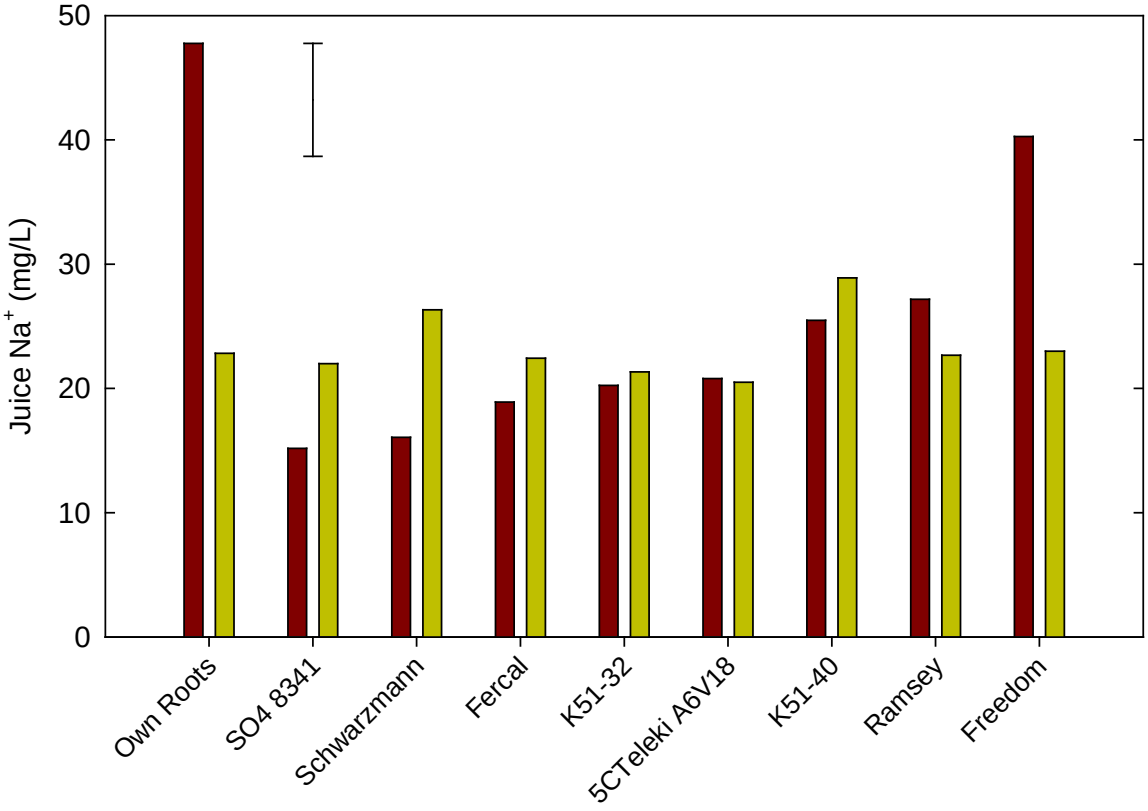


Figure 10. The effect of rootstock genotype and season on the concentration of Na^+ in juice from Chardonnay vines. Season 2010 and 2011. Error bar represents least significant difference between rootstocks across two years (*P*=0.05).

Table 13. The effect of rootstock genotype on the concentration of Cl^- (mg/L) in juice from Chardonnay vines.

Rootstock	2010	2011
Own roots	72.7[b]	10.2[f]
Ramsey	22.6[e]	9.5[f]
K51-32	37.9[c]	8.9[f]
K51-40	176.3[a]	12.5[f]
Schwarzmann	26.8[cde]	11.5[f]
SO4 8341	27.4[cde]	9.8[f]
5C Teleki A6V18	34.3[cd]	9.7[f]
Fercal	25.0[de]	9.3[f]
Freedom	39.0[c]	12.3[f]

† Data is geometric mean.
Superscript letters indicate significant differences (P=0.05) between means of rootstocks in the same and different seasons.

Table 14. The effect of rootstock on the concentrations of Na^+ and Cl^- in juice from fruit on grafted Chardonnay vines at two rootstock trial sites in Padthaway.

Rootstock	Juice Na^+ (mg/L)		Juice Cl^- expressed as NaCl (mg/L)	
	SARDI (2010)	CSIRO† (1996-97)	SARDI (2010)	CSIRO† (1996-97)
Own Roots	48[a]	46[ab]	120[b]	122[a]
Ramsey	27[b]	41[b]	36[e]	54[b]
K51-32	21[bc]		66[cd]	
K51-40	28[b]	41[b]	262[a]	163[a]
Schwarzmann	16[c]	48[a]	45[de]	48[b]
SO4 8341	12[c]		40[e]	
5C Teleki A6V18	23[bc]		61[cd]	
Fercal	19[bc]		41[e]	
Freedom	40[a]		58[cd]	

† Walker et al. 2010a.
Rootstock genotypes, in the same trial, followed by different superscript letters are significantly different (*P*=0.05).

7. EFFECT OF REDUCED IRRIGATION ON SALT EXCLUSION PROPERTIES OF GRAFTED SHIRAZ VINES IN THE RIVERLAND

7.1 Introduction

The role that rootstocks may play in managing salt stress in the fully irrigated in-land regions has been well characterised in studies conducted in the 1990's. Walker et al. (2002b, 2004, 2010a) reported on large field trials that characterised the effects of rootstocks on the response of both dried fruit and wine grape cultivars to saline irrigation. The studies showed that when irrigated at 100% of irrigation allocation, many of the common rootstocks were more tolerant of salinity than own rooted vines and that their use prevented the Na^+ and Cl^- concentrations in fruit rising to undesirable levels.

These studies were designed in a time when it was believed that the security of irrigation water supply was high enough to provide full irrigation allocations in 99 out of 100 years. In the following decade, drought so reduced the levels in water storages in the Murray River headwaters that irrigation allocation in the Riverland were at less than 60% for four consecutive seasons between 2006 and 2010. During this period, the salinity of the River Murray was not high with annual average values remaining below 0.5 dS/m. However, there were still reports of undesirably high levels of salt in fruit. It was envisaged that the source of this salt was a build up in soil salinity caused by an absence of leaching irrigations during the extended drought. For vineyards where the soils were saline, but the irrigation water non-saline, it was unclear whether the salt exclusion properties of many of the common rootstocks were affected by reductions in irrigation allocation.

In 2004, sampling of soils and irrigation at a SARDI Shiraz rootstock by irrigation trial at Kingston-on-Murray showed that the soils were saline (ECe 4.0 dS/m), but the irrigation water was non-saline (ECw 0.4 dS/m). Leaf and fruit samples were collected in this season and stored in either a dried or a frozen state. These samples were analysed in 2010 to determine whether reducing irrigation altered the ability of rootstocks to exclude salt from leaves and fruit.

7.2 Materials and methods

Stevens et al. (2010) gives detailed description of vines, vineyard layout, the soil texture and salinity, the depth and salinity of irrigation water, temporal variation in soil water content and soil salinity and the weather.

The SARDI irrigation by rootstock trial ran for four seasons from 2001 to 2004 (year of harvest). The average seasonal depth of irrigation and rain, and water and soil salinity are reported in Table 15. Over the four seasons, a 30% reduction in irrigation caused a 31% yield loss (Stevens et al. 2010). Irrigation water was non-saline (0.4 dS/m), however soils were saline (4.1 dS/m).

Table 15. The average seasonal irrigation and rain (mm) and salinity (dS/m) of received water (EC_w) and soil (EC_e) for seasons 2001-2004 (year of harvest).

Irrigation treatment		Rain	EC_w	EC_e
Full	30% Reduced			
743	517	213	0.4	4.1

7.2.1 Trial design

The trial was established in 1999 by imposing irrigation treatments on an established Shiraz rootstock trial which had been planted in 1996. The rootstock trial was a randomised block design incorporating 12 replicates and 8 rootstock. The rootstocks were: Ramsey, 140 Ruggeri, 1103 Paulsen, 110 Richter, Schwarzmann, 99 Richter, 101-14 and 5C Teleki. Each block contained 2 rows of 4 plots (8 rootstocks) with each plot consisting of 3 vines planted to the same rootstock. Measurements were made on samples from the middle vine. At least 2 barrier vines existed at both ends of the trial vine rows. A split-split plot design was imposed by pairing adjacent blocks and then randomly allocating the CONTROL and 30% REDUCED irrigation treatments within the pair. A 30% reduction in irrigation was achieved by using emitters with an output that was 70% of those in the CONTROL treatment. Irrigation treatments were also applied to a barrier row on either side of the trial vines.

7.2.2 Measurements of Na^+ and Cl^- concentrations in petioles and fruit

Na^+ and Cl^- concentrations were determined in petioles and berry samples which were collected in the 2003-04 season and processed in 2011. Petioles opposite the basal bunch were sampled at full bloom from all rootstocks and dried at 70^{o}C. Determination of Cl^- concentration and pre-digest sample preparation followed procedures described in Stevens et al. (2008). Na^+ concentration was determined on nitric acid and hydrogen peroxide digest with ICP (Spectro Analytical Instruments, Kleve, Germany). Fifty-berry samples were collected on 18 February 2004, about 1 month before harvest, from vines on the rootstocks Ramsey, 140 Ruggeri, 1103 Paulsen, 110 Richter, and Schwarzmann. Samples were frozen. The samples thawed during storage due to an electrical fault and were re-frozen before berries collapsed. In 2011, samples were thawed overnight at 4^{o}C, then homogenised with an Ultra-Tarrax T25 (IKA, Selangor, Malaysia) at 24,000 rpm for about 45 seconds and centrifuged at 10397 x *g* for 10 minutes. The Cl^- concentration was determined by silver ion titration with a Buchler chloridometer (Labconco, Kansas City, MO, USA) and determination of Na^+ concentration followed method used for leaf petiole tissue in Chapter 6.2.2.

We were uncertain as to whether thawing during storage had enhanced extraction of Na^+ and Cl^- from berries. Further, reported levels of Cl^- in Shiraz wine were about double that in juice which indicated that pressing of fruit was not extracting all the Cl^- extracted during vinification. In order to explore the effects that thawing and two different methods of preparing juice had on juice concentrations of Na^+ and Cl^- we collected three 100-berry samples of Shiraz fruit from 5 replicates of own rooted vines in the SARDI rootstock trial at Coonawarra. Samples were randomly allocated to three treatments consisting of different methods of juice preparation:

1. Hand press, centrifuge and freeze, thaw and measure
2. Freeze, thaw, homogenise, centrifuge, freeze, thaw and measure
3. Repeat freeze-thaw cycle three times causing collapse of berries, homogenise, centrifuge, freeze, thaw and measure

7.3 Results and discussion

7.3.1 Juice preparation method effects on Na^+ and Cl^- concentrations

The method of juice preparation did not affect the concentration of Na^+ in juice (Table 16). The Cl^- concentration in juice which had been prepared by homogenising the fruit was more than double that in juice prepared by hand pressing fruit. Subjecting fruit to multiple freeze-thaw cycles did not affect the concentrations Na^+ and Cl^- in the juice.

Walker et al. (2010b) found in Shiraz that the ratio of concentration of Cl^- in wine to that in juice was 2.2:1. Based on their finding that Cl^- concentration in the berry skin was about 7-fold that in the pulp, they suggested vinification released more Cl^- from the skin than juicing. They prepared juice by gently crushing grapes with mortar and pestle. It is likely that neither this technique nor hand pressing leads to a rupture of skin cells. Homogenisation ruptures skin, pulp and seed cells. The ratio of Cl^- concentration in the juice prepared by homogenisation to that prepared by pressing is 2.4:1. Given that the ratio of Cl^- concentration in wine to that in pressed juice is 2.2:1, it is likely that the Cl^- concentration in homogenised juice will be similar to that in red wine prepared from the same fruit.

Table 16. The effect of juice preparation method on the concentrations of Na^+ and Cl^- in the juice.

Ion (mg/L)	Juice preparation method			LSD (*P*=0.05)
	Hand press	Homogenise	Freeze-thaw cycle and homogenise	
Na^+	14	12	12	NS[†]
Cl^-	27	65	67	3

[†] NS not significant.

7.3.2 Effects of a 30% reduction in irrigation on Na^+ and Cl^- concentrations in petioles and juice

Rootstock genotype modified the effects of irrigation on Na^+ concentrations in the petioles (Table 17). Under full irrigation, vines on Ramsey, 1103 Paulsen, Schwarzmann and 5C Teleki had the highest concentration of Na^+. Under reduced irrigation vines on Ramsey, 1103 Paulsen, 5C Teleki and 99 Richter the highest concentration of Na^+. Under both full and reduced irrigation, vines on 140 Ruggeri and 101-14 had the lowest concentration of Na^+. Reducing irrigation increased the concentrations of Na^+ in the petiole of vines on Ramsey, 1103 Paulsen and 99 Richter.

The petiole Cl^- concentration was modified by irrigation and rootstock genotype, but not by the interaction between them. Reducing irrigation increased the Cl^- concentration in the petioles and this effect was not modified by rootstock genotype (Table 17). Vines on Ramsey and 5C Teleki had the highest concentration of Cl^- in petioles and those on 140 Ruggeri and 110 Richter the lowest.

In common with the petioles, rootstock genotype modified the effects of irrigation on Na^+ concentrations in the juice (Table 17). Vines on Ramsey had the highest concentration of Na^+ under both full and reduced irrigation. Under full irrigation, vines on 1103 Paulsen and 110 Richter the lowest concentrations. Reducing irrigation increased the concentrations of Na^+ in the juice of vines on 1103 Paulsen, and under reduced irrigation, vines on 110 Richter the lowest concentration of Na^+.

Reducing irrigation increased the Cl^- concentration in the juice, and these effects were not modified by rootstock genotype (Table 17). Vines on Ramsey had the highest concentration of Cl^- in juice.

Even though this site had saline soils, the concentrations of Cl^- (expressed as NaCl) in all juices were well below the maximum allowable in wine of 1 g/L (Table 17).

The average Cl^- concentrations in juice from vines on Ramsey was more than two-fold that from vines on 140 Ruggeri, 110 Richter and Schwarzmann (Table 17). Reducing irrigation increased the average Cl^- level by 24%. Reducing irrigation did not affect the Na^+ concentrations in vines on Ramsey, 140 Ruggeri, 110 Richter and Schwarzmann, but it doubled concentrations in juice from vines on 1103 Paulsen. Juice from vines on Ramsey had more than twice the Na^+ of that from vines 110 Richter.

On saline soils, reducing irrigation by 30% caused a 24% rise in Cl^- concentrations in juice from grafted vines, but did not affect Na^+ concentrations except in vines on 1103 Paulsen rootstock.

Table 17. The effects of irrigation and rootstock genotype on the concentrations of Na^+ and Cl^- in petioles (g/100g) sampled at full bloom and juice (mg/L).

Irrigation		Rootstock							
CONTROL		Ramsey	1103 Paulsen		Schwarzmann		101-14		
30% REDUCED		140 Ruggeri		110 Richter		5C Teleki		99 Richter	
Petiole									
Na^+									
CONTROL		0.15^{BC}	0.12^{CD}	0.14^{BC}	0.07^{E}	0.15^{BC}	0.14^{BC}	0.07^{E}	0.11^{CDE}
30% REDUCED		0.22^{A}	0.15^{BC}	0.22^{A}	0.09^{DE}	0.15^{BC}	0.18^{AB}	0.08^{E}	0.18^{AB}
Cl^-									
0.40^{b}	0.48^{a}	0.89^{A}	0.18^{D}	0.34^{B}	0.18^{D}	0.26^{C}	0.95^{A}	0.36^{B}	0.38^{B}
Juice									
Na^+									
CONTROL		52^{A}	28^{BC}	17^{CD}	13^{D}	30^{B}			
30% REDUCED		53^{A}	28^{BC}	36^{B}	17^{CD}	38^{B}			
$^{\dagger}Cl^-$									
67^{b}	83^{a}	140^{A}	54^{D}	80^{B}	60^{CD}	63^{C}			

Values followed by different letters are significantly different (P=0.05); lowercase letters for comparison between irrigation treatments; uppercase for comparison between rootstocks genotypes in the same and difference irrigation treatments, excepting petiole and juice Cl^- in which letters indicate difference between rootstock genotypes.

† Back transformed geometric means

8. THE EFFECT OF ROOTSTOCKS ON TOLERANCE OF GRAFTED CHARDONNAY VINES TO NEAR-ZERO IRRIGATION IN THE RIVERLAND

8.1 Introduction

The roles that rootstocks may play in managing water stress in the fully irrigated in-land regions had been well characterised in studies conducted between 1999 and 2004. Stevens et al. (2008, 2010) reported on large field trials undertaken in the CRC Viticulture that investigated whether rootstocks differed in their response to about 30% reduction in irrigation allocation. These studies showed that a set of the more common rootstocks were equally tolerant of up to a 35 % reduction in irrigation (65% of full irrigation allocation).

These studies were designed in a time when it was believed that the security of irrigation water supply was high enough to provide full irrigation allocations in 99 out of 100 years. Between 2007 and 2010 in the Riverland, South Australia, the irrigation allocations varied between 2% and 16 % of full allocation at the opening of the grape growing season and between 15% and 48% of full allocation during mid-season. It is unclear whether the more common rootstocks are equally tolerant of reduction in irrigation to near zero early in the season.

Data collected from a SARDI rootstock by irrigation trial at Barmera in 2003 and 2004 showed that at this site neither rootstock nor a 35% reduction in irrigation affected the number of inflorescences and bunches per vine and that a 35% reduction in irrigation did not affect pruning weights. The entire vineyard received irrigation at the level of full allocation between 2005 and 2008 (water was purchased in seasons when water restrictions were in place). There was no market for the fruit in 2009 and the irrigation was turned off in late October 2008. In the two years up to end of October 2010 this vineyard had received 2% of its full irrigation allocation (this equated to a single 30 mm irrigation applied in September 2010 to ease removal of trellis posts). In mid-October 2010, the owner informed SARDI that the vineyard would be bulldozed in early November. We visited the vineyard at the end of October 2010 and measured the number of inflorescences and weight of prunings. These measures were compared with those taken in 2003 and 2004 to determine whether rootstocks were equally tolerant of reduction in irrigation allocation to the extreme degree seen in the last drought.

8.2 Materials and methods

Stevens et al. (2008) gives detailed description of vines, vineyard layout, the soil texture and salinity, the depth and salinity of irrigation water, temporal variation in soil water content and soil salinity, weather and original and modified trial designs.

The SARDI irrigation by rootstock trial ran for four seasons from 2001 to 2004 (year of harvest). The average seasonal depth of irrigation and rain, and water salinity are reported in Table 18.

Table 18. The average seasonal irrigation and rain (mm) and salinity (dS/m) of received water (EC_w) for seasons 2001-2004 (year of harvest).

Irrigation treatment		Rain	EC_w
Full	35% Reduced		
795	519	213	0.3

8.2.1 Soil water content and salinity, water table depth

Soil water content and salinity were measured in late October 2010 at same sites where the variation in soil water content under fully irrigated vines was monitored between 2001 and 2003 (Stevens et al. 2008). Soils were sampled in 3 replicates of vines on 110 Richter within 0.3-0.45 m distance from the trunks at depths of 0.05, 0.25, 0.50, 0.75 and 1.0 m. Gravimetric water content was determined on these samples by weighing before and after drying at 100°C until they reached a constant weight. Gravimetric water content was converted to volumetric using the bulk densities determined at sample sites during calibration of the neutron moisture meter in 2001 and 2003.

The estimation of the soil water content at permanent wilting point was based on the work of Meissner (2004) who fitted the parameters of the Van Genuchten (1980) model of the relationship between volumetric water content and matric potential to a large data set generated from local soils following the procedure described in Cock (1984). Meissner (2004) characterised the parameters in terms of the soil properties: particle size analysis, field texture, bulk density, reaction to 1 N HCl and carbonate type. Soils at the site were matched to those in this data set based on measurements of field texture, bulk density, reaction to 1 N HCl and carbonate type which were obtained during installation of neutron moisture meter access tubes.

Soil salinity was quantified by measuring the EC of saturated soil paste extracts (EC_e) and was reported in dS/m at 25°C.

Watertable depth was measured with test well that had a 5.1 m casing depth (originally 5.6 m, but partially backfilled since installation in 2002).

8.2.2 Measurements of weights of vegetative growth and inflorescence number

The vineyard manager contacted SARDI in mid October 2010 to inform them that the vineyard was to be removed in early November. Measurements of vegetative and reproductive growth were undertaken in late October 2010.

The total weight of vine vegetative growth was estimated from photographs of the vine taken against a white backdrop in late October 2010. The backdrop consisted of 2.5 by 1.75 m plasticised white cloth which had been scored with a 4 by 5 grid with a cell size of 0.5 by 0.35 m. The backdrop was mounted on 2.4 m poles. All vines were photographed with the middle of the grid aligned with their trunk. After photographing, all green growth was pruned from the western half of the vines in all even numbered replicates and stored at 4°C until processing. Processing consisted of stripping and counting the inflorescences and then drying these and stem and leaves at 75°C. The percentage of the white backdrop which was covered by green foliage was estimated for each photo. A calibration was developed by regressing the percentage cover estimates from photos of the western half of the canopies of sampled vines against the dry weights of vegetative growth. This regression was used to convert percentage cover scores for all vines into estimates of total dry weight of vegetative growth.

Inflorescence numbers in vines planted in odd-replicates were measured following method of Stevens et al. (2008).

8.2.3 Analysis

In order to test whether rootstock genotype effects on inflorescence number and pruning weights were modified by moving from irrigation with full allocation to irrigation with 2% of allocation we compared data sets collected after 2 seasons of irrigation with 2% allocation with those collected during SARDI rootstock by irrigation trial between 2001 and 2004. In this trial, analyses of inflorescence number and pruning weights showed that neither irrigation treatment (full or 65% of allocation) nor the interaction between irrigation and rootstock had significant effect on either parameter. Thus for the purposes of conducting the comparisons we ignored the irrigation treatment structure in the data set for inflorescence numbers from 2003 and for pruning weights from 2004.

Data on vine growth and inflorescence number was analysed as a split plot with rootstock as the main plot and year of observation as the sub-plot using Statistix Version 7.1 (Analytical Software, Tallahassee, FL, USA).

8.3 Results and discussion

8.3.1 Soil water content and salinity, water table depth

The water content of soils beneath vines grafted to 110 Richter at the end of October in 2010 after 2 seasons irrigation at 2% and that under full allocation at the end of October 2002 are shown in Figure 11. At the end of October 2010 the profile held only 16 mm of plant available water (water held at a matric suction greater than 1.5 MPa) as opposed to 169 mm at this time of year under full irrigation allocation. In contrast to the large change in soil water content, reducing irrigation to 2% of allocation caused only a minor change in soil salinity (Figure 11). The average values for entire profile in August 2003 and October 2010 were 0.9 and 1.2 dS/m, respectively. Both values are well below the threshold value of 1.5

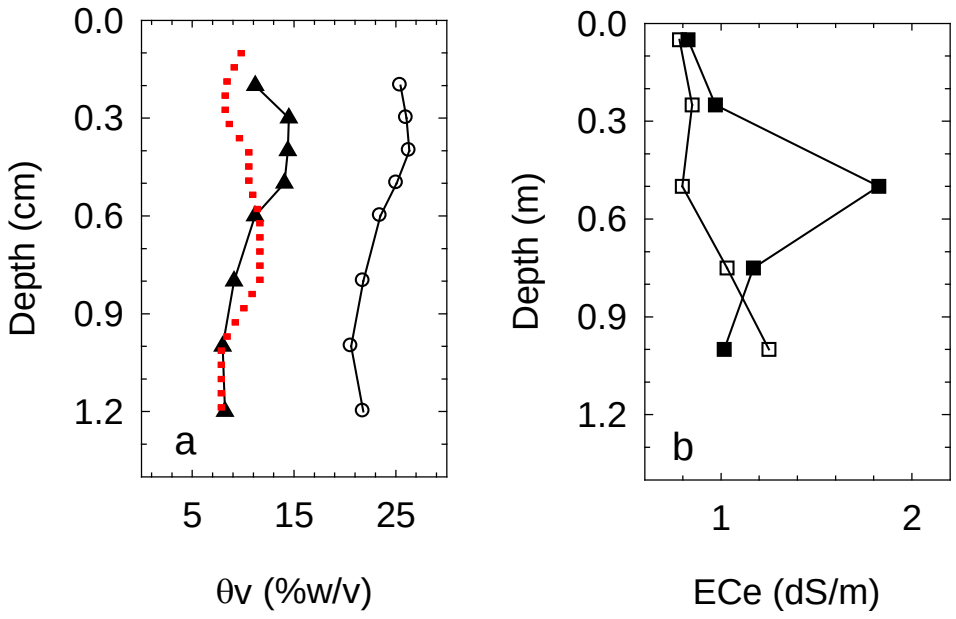


Figure 11. The variation in soil water content (a) and salinity (b) with depths. Red dashed line in (a) indicates soil water content at permanent wilting point (corresponding to soil matric potential of -1.5 MPa). Soil water content end of October 2010 ▲, end of October in full irrigated treatment 2003 ○, soil salinity end of October 2010 □, soil salinity end of August 2003 ■.

dS/m at above which soil salinity affects vine vegetative growth (Ayers and Westcot, 1985). The depth to the top of the water table had dropped from 3.8 m at its last October reading in 2003 to below the base of the test well casing at 5.1m at the end of October 2010.

8.3.2 Vegetative growth and inflorescence numbers

The relationship between dry weight of vegetative growth and percentage of the white backdrop which was covered by green vegetation is shown in Figure 12. It accounted for 95% of variation in the data set.

The effect of two seasons irrigation at 2% of allocation on canopy growth is illustrated in Table 19. These pictures are indicative of the average conditions. Some vines were dead. Vines were dead in 3 of the 10 plots of vines grafted onto K51-40 and in 2 of the 10 plots of vines grafted to 1103 Paulsen. Vines that had died after 2004 had vegetative growth and inflorescence scored as zeros.

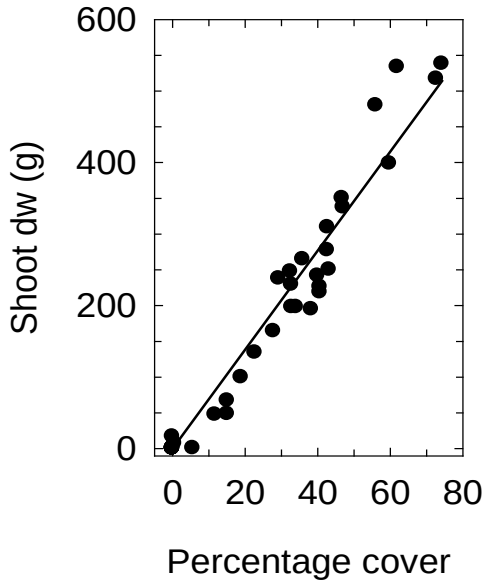


Figure 12. The relationship between dry weights of vegetative growth removed from the western half of vines and percentages of white backdrop which was covered green vegetation in a photos of the vines ($Y = 6.92*X$, $r^2 = 0.95$,n= 38).

The effect of rootstock genotype on dry weight of prunings from grafted vines was modified by irrigation allocation (Table 19). In 2004, the dry weight of prunings from vines grafted to Ramsey, 140 Ruggeri, 1103 Paulsen and K51-40 were equivalent and greater than those from vines grafted to 110 Richter. Reducing irrigation to near zero caused pruning weight to decline by 60% on average. In 2010, the pruning weight from vines grafted to Ramsey was equivalent to that from vines grafted to 140 Ruggeri and 110 Richter, and greater than those from vines grafted to 1103 Paulsen and K51-40. Comparing the ratios of weight in 2010 to 2004 across rootstocks shows that the relative decline in vines grafted to 110 Richter was much less than for those grafted to 140 Ruggeri, 1103 Paulsen and K51-40. The effect of rootstock genotype on inflorescence numbers from grafted vines was also modified by irrigation allocation (Table 19). In 2004, rootstock genotype did not effect the number of inflorescences per vine. Reducing irrigation to near zero caused inflorescence number to

decline by 90% on average. Based on inflorescence numbers, vines on Ramsey and 110 Richter were more tolerant of near-zero irrigation.

Based on the effect of near-zero irrigation on inflorescence numbers, we rate Ramsey and 110 Richter as having good tolerance to near-zero irrigation, 140 Ruggeri as having moderate tolerance and 1103 Paulsen and K51-40 as having poor tolerance (Table 19). Thus the rankings in this study for 140 Ruggeri and 1103 Paulsen are different (less tolerant) to those proposed for drought by Nicholas (1997).

Table 19. The effect of two seasons irrigation at 2% of allocation on canopy growth; the effect of rootstock genotype and irrigation allocation on the pruning dry weights (kg/vine) and number of inflorescences per vine; rankings for rootstock genotype tolerance to near zero irrigation.

Photo 10/2010					
Rootstock	Ramsey	140 Ruggeri	1103 Paulsen	110 Richter	K51-40
Pruning dry weight					
Full irrigation (2004)	1.11[a†]	1.14[a]	1.02[a]	0.69[b]	1.01[a]
2% irrigation (2010)	0.68[bc]	0.52[bcd]	0.31[de]	0.45[cd]	0.16[e]
Inflorescences per vine[‡]					
Full irrigation (2003)	511[a]	520[a]	418[a]	556[a]	454[a]
2% irrigation (2010)	123[b]	40[cd]	4[d]	81[bc]	0[d]
Drought / near zero irrigation tolerance					
Nicholas*	good	good	good	good	poor
This study	good	moderate	poor	good	poor

[†]Values followed by the same letter are not significantly different ($P = 0.05$).
[‡]Data subject to square root transformation for analysis, mean are back-transformed data.
*Nicholas. (1997).

9. OUTCOMES AND RECOMMENDATIONS

Output 1

Assess the long-term performance (> 20 years) of rootstocks at selected sites in the Limestone Coast Wine region, SA.

Performance Targets:

- Assess the effect of rootstock on vine yield and vegetative growth in long-established SARDI trials at Padthaway and Coonawarra.
- Evaluate the stability of yield response to rootstock by comparing current yields at 25 years of age with those recorded from the same vines between 3 and 6 years of age in a trial at Coonawarra.

Yield assessment of a Shiraz rootstock trial planted on terra rosa soils in Coonawarra in its 24^{th} and 25^{th} year showed that the higher yields were achieved in Shiraz vines on own roots and grafted to 5C Teleki A6V18 and 34EM.

Yield assessment of a Chardonnay rootstock trial planted on deep sands in Padthaway in its 24^{th} and 25^{th} year showed that vines grafted to SO4 and Fercal had yields which exceeded or equalled those from vines on own roots and Ramsey.

Most currently available information on rootstocks is based on assessment of vines in their first decade of life. These assessments give information about grafted vine performance in their third decade of life.

Comparison of yields from the Shiraz rootstock trial measured in 2010 and 2011 with those measured in 1989 through to 1992 showed that as the vines aged, the yield from vines on 5C Teleki A6V18 kept pace with those from own rooted vines, whereas yields from vines on 5C Teleki 8344, 101-14, 5C Teleki 8343, 420A, 1616 fell behind.

Growers selecting rootstock genotypes based on advantages identified in the first decade of field trials expect that these advantages will be there in the third decade. We found that aging affected the relative performance of rootstock genotypes. Was this a peculiarity of this site? **We recommend that this longitudinal assessment of performance be conducted in other rootstock trials for which SARDI has in-house historic data sets of yield.** Such a study would give Australian producers information about the useful life of grafted vineyards grown under commercial conditions.

Output 2

Extend the number of rootstocks that have had their salt exclusion properties assessed in the Limestone Coast Wine region, SA.

Performance Targets:

- Conduct these assessments at sites where the set of rootstocks and the soil types are different to those which have already been assessed by CSIRO.
- Assess the effect of rootstock on the exclusion of Na^+ and Cl^- from leaf petiole and fruit in long-established SARDI trials at Padthaway and Coonawarra.

CSIRO has assessed Shiraz and Chardonnay rootstock trials located on the Padthaway Flats on “uniform shallow brownish gravelly calcareous mottled clay” (Walker et al. 2010a) locally referred to as shallow loamy clay on calcrete soils. The SARDI Chardonnay rootstock trial, assessed at Padthaway, was on a deep sand and the Shiraz trial at Coonawarra was on terra rosa.

The two SARDI trials contained 16 genotypes in total. Twelve of these were different to those assessed by Walker et al. (2010a) at Padthaway.

At the Chardonnay site, in the drier of the two seasons, the concentrations of Na^+ and Cl^- in juice from own rooted vines were similar to that recorded from own rooted Chardonnay at Padthaway by Walker et al. (2010a). The yield on Ramsey rootstock was equivalent to that from own rooted vines, but Cl^- concentrations in juice from vines on Ramsey was less than half that in juice from own rooted vines. The yields of vines on Fercal and SO4 were equal to or better than those of vines on Ramsey, and Na^+ and Cl^- concentrations in juice were less than or equal to those on Ramsey.

In both years, juice Na^+ and Cl^- concentrations in the own rooted Shiraz vines at Coonawarra were about half or less the concentration found by Walker et al (2010a) at their Padthaway site. At the Coonawarra site the salinity pressure was low. Even so, the juice Na^+ and Cl^- concentrations in vines on all rootstocks were less than those on own rooted vines. Juice Na^+ and Cl^- concentrations in vines on 101-14 and 34EM were two-thirds or less those from own rooted vines.

SARDI did not have historic data sets of juice Na^+ and Cl^- concentrations in vines for either of these sites. Therefore it remains unclear whether rootstock salt exclusion behaviour drifts with vine age, as was found for yield performance. **We recommend that this longitudinal assessment of salt exclusion performance be conducted in other rootstock trials for which SARDI has in-house historic data sets of vine salt status.** Such a study would indicate the stability of rootstock salt exclusion over time and give Australian producers an insight into the long-term performance of grafted vines grown under commercial conditions.

Output 3

Assess the effect of reducing irrigation on salt exclusion from Shiraz vines grafted to a range of rootstocks receiving non-saline irrigation, but growing on saline soils in the Riverland Wine region, SA.

Performance Targets:

- Measure Na^+ and Cl^- concentrations in samples of fruit and leaf petioles, which have been stored since collection in 2004, from a SARDI rootstock by irrigation trial at Kingston-on-Murray.

In a SARDI Shiraz rootstock trial at Kingston-on-Murray which was growing on saline soils (4 dS/m), but receiving non-saline irrigation (0.4 dS/m), comparison between vines receiving 100% and 70% of irrigation allocations showed that a 30% reduction in irrigation raised juice Cl^- concentrations from 67 to 83 mg/L, but did not affect juice Na^+ concentrations except in vines on 1103 Paulsen where it doubled. On saline soils with 70% of full irrigation allocation, the use of four of the five rootstocks, 140 Ruggeri, Schwarzmann, 1103 Paulsen and 110 Richter, prevented juice Cl^- and Na^+ concentrations rising above 80 and 53 mg/L, respectively.

During the recent drought, irrigation waters in the middle reaches of the Murray River remained non-saline, but there were still reports of undesirable levels of salt in fruit. These results demonstrate that under reduced irrigation allocations, when soil salts build up because of reduced leaching, the use of rootstock vines can maintain juice Cl^- and Na^+ concentrations at acceptable levels.

Reducing irrigation allocations increases the concentration of Cl^- in fruit from vines grafted to salt excluding rootstocks. At this experimental site, the use of any of these rootstocks would probably maintain the Cl^- concentrations in red wine at less than 140 mg/L.

We have estimated the effects of irrigation and rootstock on wine Cl^- levels from measurements of Cl^- in juice. Ideally the measurements should be made on wine. Provisor made wines from these vines in 2003 and 2004, but SARDI did not retain them beyond 2008. However a recent audit of small-lot winemaking cellars at the CSIRO Merbein site has uncovered a set of wines for this project. **We recommend measurement of the Na^+ and Cl^- concentrations in these wines.**

Output 4

Assess the effect of near-zero irrigation on rootstock performance in a Chardonnay vineyard located in the Riverland Wine region, SA.

Performance Targets:

- Measure the soil water content, salinity and water table depth in a SARDI rootstock trial at Barmera which had been subjected to two years of near zero irrigation.
- Assess rootstock tolerance to extreme water stress by comparing measures of fruit and vegetative growth made after two years of near zero irrigation with those made under full irrigation at an earlier time when these vines were in a SARDI rootstock by irrigation trial.

After two seasons of irrigation at 2% of full allocation, soil water content had dropped from 169 mm of plant available water to 16 mm, soil salinity had remained relatively stable at about 1 dS/m and depth to water table had dropped from 3.8 m to below 5.1 m. Estimates of plant available water were developed without information on the particle size distribution of soils. This information would improve the accuracy of the estimate of plant available water. **We recommend undertaking particle size analysis of the soils at the site.**

Comparing measurements of vine vegetative growth and inflorescence number made when vineyard was in receipt of 100% irrigation allocation with those made when it was in receipt of 2% of allocation showed that vines on Ramsey and 110 Richter were more tolerant of the 98% reduction in irrigation than those on 1103 Paulsen and K51-40. Tolerance to such low levels may be relevant if vineyard “mothballing’ is used to sustain vineyards through future droughts.

Output 5

Pro-actively communicate outputs.

Performance Targets:

- Establish a steering committee comprising funders, industry representatives from the Limestone Coast and researchers involved in the field of salinity management of grapevines. Provide the committee with project updates and the opportunity for consultation on at least three occasions during the project.
- Use regional workshops and seminars to present project findings to Limestone Coast and Riverland grower groups.
- Use scientific and technical publications and presentations at national conferences to inform the national viticultural industry.

Over the life of the project, four meetings were held with a steering committee comprising: representatives of project funders; salinity, soil and water specialists from PIRSA and Flinders University; a rootstock and salinity specialist from CSIRO; and representatives from the Limestone Coast Wine Industry Technical Committee. See Appendix One for details.

Appendix One gives details of workshops and seminars, scientific and technical publications and conferences presentations.

10. APPENDICES

10.1 Appendix 1: Communication

10.1.1 Scientific publications

Stevens, R.M., Pech, J.M., Gibberd, M.R., Walker, R.R., and Nicholas, P.R. (2010). Reduced irrigation and rootstock effects on vegetative growth, yield and its components, and leaf physiological response of Shiraz. Australian Journal of Grape and Wine Research 16:413-425.

Stevens R.M., Harvey, G., and Partington, D.L. (2011). Irrigation of grapevines with saline water at different growth stages. Effects on leaf, wood and juice composition. Australian Journal of Grape and Wine Research 17:239-248.

Stevens R.M., Harvey, G., Norton, S., and Frahn, W. (2011). Over-canopy saline sprinkler irrigation of grapevines during different growth stages. Agricultural Water Management (DOI:10.1016/j.agwat.2011.09.003)

Stevens, R.M., Pech, J.M., Taylor, J., Clingeleffer, P., Walker, R.R., and Nicholas P.R. Irrigation and rootstock effects on berry shrinkage, and fruit and wine quality of Shiraz. Manuscript in preparation.

10.1.2 Conference papers/posters

Pitt, T.R., Stevens, R.M., Walker, R.R., Biswas, T.K. (2009). Managing Soil Salinity for Wine Quality in Groundwater Irrigated Vineyards (poster). 10th Irrigation Australia Ltd Conference, Swan Hill, Victoria, October 2009.

Pitt, T.R., Stevens, R.M., and Nicholas P. (2010). Sustaining perennial horticultural production under supplementary irrigation drawn from saline groundwater (poster). 11th Irrigation Australia Ltd Conference, Sydney, New South Wales, June 2010. pp 220-221

Sharpe, B., Marty, P., Pitt, T., and Stevens, R. (2011). The effects of low vigour rootstocks on vine capacity, vine water stress and grape quality of BVRC12 Shiraz (poster). In the Proceedings of the 14th Australian Wine Industry Technical Conference, Adelaide, 3-8 July, 2010; Blair, R.; Lee, T.; Pretorius, S., Eds. The Australian Wine Industry Technical Conference Inc.: Adelaide, South Australia, July 2010. pp 366-67.

Stevens R.M., Pitt, T.R., Pech J.M. and Skewes, M.(2011). Rootstock tolerance to cessation of irrigation (oral). CRUSH 2011, Adelaide South Australia, September 2011.

10.1.3 Steering committee meetings

Pitt, T.R. and Stevens, R.M. (2009). Salt tolerant rootstocks for long-term sustainability in the Limestone Coast (Oral). Naracoorte, South Australia, September 2009.

Minutes distributed October 2010

Pitt, T.R. and Stevens, R.M. (2009). Managing Soil Salinity for Wine Quality in Groundwater Irrigated Vineyards (Oral). Padthaway, South Australia, May 2010.

Minutes distributed August 2010

Pitt, T.R. and Stevens, R.M. (2009). Salt tolerant rootstocks for long-term sustainability in the Limestone Coast (Oral). Coonawarra, South Australia, December 2010.

Minutes distributed May 2011

Pitt, T.R. and Stevens, R.M. (2009). Managing Soil Salinity for Wine Quality in Groundwater Irrigated Vineyards (Oral). Adelaide, South Australia, May 2011.

Minutes distributed August 2011

10.1.4 Industry articles and fact sheets

Pitt, T.R. and Stevens, R.M., (2010). Sustaining perennial horticultural production under supplementary irrigation drawn from saline groundwater. National Program for Sustainable Irrigation Research Bulletin. NPSI, Narrabri NSW. 6 pp

Stevens R.M., Pitt, T.R., Dyson, C., Nicholas, P., Pech, J.M. and Skewes, M. Adding to our knowledge on rootstock effects. GWRDC Fact sheet.
http://www.gwrdc.com.au/site/page.cfm?U=19

10.1.5 Workshops and seminars

Pitt, T.R. (2009). Introducing SARDI's upcoming salinity research in the South East. Limestone Coast Wine Industry Technical Cub-Committee 'Composting Workshop', Struan House, South Australia, April 2009.

Pitt, T.R. (2010). Managing soil salinity for wine quality in groundwater irrigated vineyards. Limestone Coast Wine Industry Technical Sub-Committee 'Salinity Workshop', Stonehaven Cellar Door, Padthaway, South Australia, June 2010.

Pitt, T.R. (2010). Managing rootzone salinity in groundwater irrigated viticulture. About Science – Unlimited Research Discussion. Waite Campus, Urrbrae, South Australia, July 2010.

Pitt, T.R. (2010). Salt tolerant rootstocks for long-term sustainability in the Limestone Coast. Treasury Wines 'Technical Officers Meeting', Padthaway, South Australia, October 2010.

Pitt, T.R. (2010). Managing soil salinity for wine quality in groundwater irrigated vineyards. Barossa Grape and Wine Association - Viticulture Technical Group, 'Managing Saline Irrigation Water'. Yalumba Nursery, Nuriootpa, South Australia, November 2010.

Pitt, T.R. (2011). Managing soil salinity for wine quality in groundwater irrigated vineyards. Mudgee 'Future Leaders' SA Tour. Waite Campus, Urrbrae, South Australia, June 2011.

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Stevens, R.M., Pitt, T., Dyson, C., Pech, J., and Skewes, M. (2011). Rootstocks – longevity, salt exclusion and drought tolerance. Riverland Viticulture Technical Group. Loxton Research Centre, Loxton, South Australia, August 2011.

10.2 Appendix 2: Intellectual property

Outputs of this research are in the public domain.

10.3 Appendix 3: References

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10.4 Appendix 4: Staff

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10.5 Appendix 5: Budget Reconciliation