SOUTH AUSTRALIAN RESEARCH & DEVELOPMENT INSTITUTE
PIRSA

SARDI project IRSP-R1-008

Longevity and sustained performance of rootstocks in Lower Murray horticulture:

Viticulture and Citrus

Final report to:
The South Australian River Murray Sustainability Program
Industry-led Research Sub-Program

Tim Pitt, Mark Skewes, Jessica Tan and Jim Cox
31 January 2017

SARDI Project – SARMS IRSPR1-008: Longevity and sustained performance of rootstocks in Lower Murray horticulture; viticulture and citrus.

Authors: Pitt, T., Skewes, M., Tan. J and Cox, J.

Corresponding Author: Mr Timothy Pitt
South Australian Research and Development Institute
Waite Campus Adelaide
GPO Box 397 Adelaide SA 5001

Published by: South Australian Research and Development Institute
Sustainable Systems
January 2017

Authorised by: South Australian Government

Printed by: Sustainable Systems, SARDI, Urrbrae, South Australia

ISBN:

For more information about SARDI visit http://www.pir.sa.gov.au/research

Or contact SARDI Head Office on (08) 8303 9400

Cover page: (*clockwise from top left*) Yield assessment at Riverland viticulture rootstock trial; salt damaged Chardonnay leaf; Cabernet Sauvignon berry cluster; trunk of grafted Cabernet Sauvignon at 33 year old rootstock trial; cross section of bud-union from dead Navelina tree on C-35 citrange; bud-union crease in live Navelina tree on C-35 citrange; unhealthy and stunted Murcott tangor tree on Swingle citrumelo.

Acknowledgements

This trial was funded under the Industry-led Research Sub-program (IRSP), which is an initiative of the $265 million South Australian River Murray Sustainability (SARMS) Program. SARMS is funded by the Australian Government and delivered by the Government of South Australia through PIRSA.

Special thanks to the many private growers for provision of the trial site and ongoing assistance with vineyard management. Thanks also to current and former staff of the Department of Agriculture SA (PIRSA) who established these sites and collected historic datasets. In particular Phil Nicholas, Richard Cirami, Mike McCarthy and Peter Gallasch.

Past and current investigations were also made possible through support from various SA vine improvement committees, Vinehealth Australia (previously the Phylloxera and Grape Industry Board of SA), Wine Australia (previously the Grape and Wine Research and Development Corporation), Riverland Grape and Wine, Langhorne Creek Grape and Wine, Citrus Australia South Australian Region and Venus Citrus.

Sincere thanks to Consolidated Co-operative Wineries (CCW) and Accolade Wines who provided invaluable assistance with harvest logistics and fruit maturity assessments through both the 2015 and 2016 vintages. Thankyou.

Contents

Appendices

Glossary

Anthocyanin	A measure of grape juice colour density
BrimA	Similar to SAR, but takes account of absolute levels of sugar and acid, not just the ratio. Calculated as (°Brix – (4 x Acid concentration)) x 16.5
Cl^-	Chloride ion
Cordon	Arms of a vine, normally trained along a trellis wire
$EC_{1:5}$	The electrical conductivity of a 1:5 soil:water extract
EC_e	The electrical conductivity of the extract from a saturated soil paste
IRSP	Industry-Led Research Sub-Program
K^+	Potassium ion
LAI	Leaf Area Index
Lamina	The expanded portion or blade of a leaf
Na^+	Sodium ion
Petiole	The stalk that connects a leaf to the stem
pH	A numeric scale ranging from 0-14 to specify acidity (0) or alkalinity (14)
ppm	Parts Per Million
Rootstock	Hybrid planting material that provides the root portion of plant. Typically imparts a level of tolerance to production constraints
SAR	Sugar acid ratio of citrus fruit, calculated as °Brix / Acid concentration
SARDI	South Australian Research and Development Institute
SARMS	South Australian River Murray Sustainability Program
Scion	Fruiting part of plant grafted to a rootstock
TDS	Total Dissolved Solids
TSS	Total Soluble Solids (or °Brix)

Executive Summary

With over 25,000 ha of land currently planted to viticulture and citrus, the irrigation districts along South Australia's River Murray are unrivalled as the state's dominant producers of fruit for wine, fresh citrus and citrus juice products. In regions such as the Riverland, viticulture and citrus production face persistent pressure from a range of biological, climatic and soil constraints. One of the principal tools in negotiating these constraints is the use of rootstocks which not only impart a level of tolerance to difficult growing conditions but also influence plant vigour, cropping efficiency and fruit quality characteristics.

More than 90% of existing Riverland citrus plantings are grafted to rootstocks and all new orchards are now established with grafted trees. Similarly, more than 75% of the regions new vineyards incorporate rootstocks into their plantings. Rootstock selection decisions therefore have long reaching and important consequences for individual irrigators and the region as a whole.

SARDI and its predecessor, the SA Department of Agriculture, have been investigating the use of rootstocks to enhance the performance of both grapes and citrus since the 1970's. Through the 1980/90's there was significant industry investment in supplementing commercial experience with locally produced experimental data on rootstock performance. A range of viticulture and citrus rootstock comparison trials were planted across the state with many concentrated within River Murray irrigation districts. These rootstock comparison trials paired commonly grown or promising new varieties with new and familiar rootstocks. Generally, one or more commonly used rootstocks were included in each trial as a point of comparison. In the case of viticulture, own rooted vines were initially included but were ultimately omitted due to their susceptibility to various replant constraints. Other, less well understood rootstocks were frequently included so that their characteristics could be assessed and compared with the more well-known options. Own rooted trees were not included in any of the citrus rootstock trials.

Many of these trials were assessed within 10 years of planting after which the experimental vineyards/orchards were left to the host irrigators to manage as commercial plantings without further scientific evaluation. Consequently, most of the local knowledge on rootstock performance comes from young vineyards/orchards, supplemented by overseas research or observations of potted immature plants. Since that time, very little assessment has been conducted on mature plantings under Australian growing conditions and, as a result, two of South Australia's largest horticultural industries continue to make long-term rootstock decisions without knowing the longevity of their rootstock/scion selections.

This regionally focussed project sought to revisit historic viticulture and citrus rootstock plantings, most of which were now in their third decade of production and comprised multi-year agronomic data sets for longitudinal studies. The project sought to characterise the long-term capacity of various rootstock/scion combinations to overcome site limitations specific to SA Murray River growing systems and to test the impact of age on the stability of rootstock performance, initially characterised when the plants were young.

Viticulture results
Investigations through the life of this project have identified changes in the yield rankings of mature vines as compared to those measured when the vines were young. This occurred for multiple scions across different growing regions. At a Riverland Cabernet Sauvignon rootstock trial, yields measured at three to six years of age were compared with those measured at 22 and 23 years of age. Whilst yields were stable for many rootstock genotypes, vines grafted to Ramsey and K51-40 reduced by 16% and yield from vines grafted to Teleki 5C almost halved.

At a Riverland Shiraz rootstock trial, yields measured at four to six years of age were compared with those measured at 22 and 23 years of age. Whilst average yields across the whole trial changed little

over time, some grafted vines demonstrated a significant reduction in their yield potential, albeit at levels in excess of 28 kg/vine. Most notable yield reductions were Shiraz grafted to 140 Ruggeri and Ramsey, reducing by 18% and 12% respectively. Vines grafted to J17-69 and J17-48 displayed stable yields across the three decade assessment period.

At a 38 year old Colombard vineyard in the Riverland, the salt excluding properties of some rootstocks were maintained better than others. Vines grafted to Schwarzmann, K51-32, 101-14 and 140-Ruggeri showed little change at age 38 compared to measures collected when vines were first assessed at four to six years. Through the same period, the concentration of chloride in the juice from vines grafted to Teleki 5A, Teleki 5C (SO4) and K51-40 increased to two to five times that of other rootstock genotypes. Sodium concentrations reduced significantly across the four decade assessment period with only those vines grafted to Harmony expressing high juice concentrations.

At other Riverland sites, vines grafted to Teleki 5C and K51-40 were consistently amongst the most susceptible to expressing higher concentrations of both sodium and chloride in plant tissues and juice sampled at harvest.

At a Langhorne Creek Cabernet Sauvignon vineyard, vines were subjected to elevated levels of bunch stem necrosis (BSN). The incidence of BSN was modified by rootstock genotype with 40% of bunches on own rooted vines affected as compared to only 13% of bunches on vines grafted to Ramsey and 25% for those on 110 Richter. This resulted in more than 7 kg/vine of deliverable fruit from vines grafted to either Ramsey or 110 Richter as compared to only 3 kg/vine of deliverable fruit for own rooted vines.

Citrus results

At a suite of Riverland citrus rootstock assessment trials, the project identified significant age related changes to the performance of certain rootstocks. Navelina orange trees on C-35 citrange and F80-5 and F80-7 citrumelo rootstocks expressed incompatibility that led to tree death between the ages of 10 and 20 years. This is despite positive early performance of these rootstocks under Navelina.

Citrus incompatibility symptoms were also identified in a range of rootstocks when paired with Afourer, Murcott and Imperial mandarins, leading to varying degrees of reduction in tree health and yield, but no tree deaths as yet. Swingle citrumelo performed very poorly under Afourer and Murcott mandarins in this work, and the international literature highlights issues with this rootstock under mandarin types. C-32 citrange, on the other hand, showed promise as a potential rootstock for mandarins.

The citrus rootstock C-35 citrange performed poorly in all trials in which it was included, exhibiting incompatibility symptoms under Navelina orange and mandarin trees, and small tree size and reduced yield under Hockney and Summer Gold navel orange trees. Although known to be a dwarfing rootstock, yield per cross sectional area (a measure of yield efficiency) was mid-range to low in all trials, suggesting that high density plantings of trees on this rootstock may not reliably produce acceptable tonnages of fruit.

Extensions activities

The project conducted a range of industry engagement activities including workshops, factsheets and conference presentations. Engagement commenced with industry guidance on research priorities and has continued with the aim of extending outcomes to end users. The project also produced two irrigator focussed technical guides addressing long-term rootstock characteristics for both the viticulture and citrus industries. These summary technical guides will be made available at www.pir.sa.gov.au.

Background

Rootstocks are used in many South Australian orchards and vineyards to overcome a range of biological, climatic and soil limitations. They are particularly significant under replant conditions where nematodes, fungi and other soil based constraints are prevalent. Many rootstocks have been bred specifically for their tolerance to these constraints and can also impart favourable characteristics relating to vigour, yield and fruit quality. Decisions about which rootstock to use have historically been made using information sourced from overseas research and greenhouse trials, where conditions are very different to Australian vineyards; or from field trials that were evaluated when the trees and vines were relatively young, often less than 10 years in age. This reflects the short funding cycles into which researchers must fit their activities (trial establishment through to assessment) and means that Australian information about the performance of rootstock/scion selections beyond the first 10 years is scarce. Vineyard and orchard managers are consequently making long-term rootstock planting decisions without knowing the longevity of their rootstock/scion selections; while the vineyards and orchards they manage are expected to maintain their performance for 30+ years.

SARDI and its predecessor, the SA Department of Agriculture, have been investigating the use of rootstocks to enhance the performance of horticultural crops since the 1970's. It now has an extensive network of mature (23-38 years in age) statistically designed viticulture rootstock comparison trials distributed across seven South Australian wine regions and incorporating 10+ varieties and 30+ rootstocks, as well as a smaller number of citrus rootstock trials, predominantly planted on the Loxton Research Centre. Many of these rootstock trials were assessed within 10 years of planting. However, assessments of these young trials may not represent the performance of mature plantings. In addition, assessment of immature plantings provides little opportunity to identify incompatibility issues. This is particularly important for citrus crops where incompatibility can take years to express.

Since 2010, SARDI has been revisiting some of the mature vine rootstock trials to investigate the aging effect on sustained production, drought tolerance and long-term salt exclusion characteristics. This project enabled this work to be supplemented with additional data in 2015 and 2016 vintages. In addition, citrus rootstock trials were revisited also, providing valuable new information on performance of mature citrus rootstock/scion combinations that had not previously been collected.

Given the age of the trials evaluated in this project, investigations only cover the rootstock genotypes that were available at the time of planting (1970-1990's). As a result, the viticulture rootstock trials do not consider recent hybrids such as those produced by the CSIRO. Additionally, some of the citrus rootstocks evaluated were newly imported into Australia at the time of trial establishment and subsequently may not have been taken up by industry. They are included here for completeness.

Project Aims

The project sought to address SARMS IRSP research priorities specifically related to the adaption of established crop species to site specific production constraints. It aimed to do this by revisiting mature rootstock trials within the viticulture and citrus industries and characterising the long-term capacity of various rootstock/scion combinations to overcome site limitations specific to SA Murray River growing systems.

This regionally focussed project was consistent with outcomes listed within the IRSP guideline objectives, in that it was designed to:

- Contribute to regional development and sustained economic development by investigating and disseminating methods that improve sustained horticultural practices.
- Promote the use of rootstocks as a pest/disease management strategy enhancing the region's credentials as being 'clean and green' and maintaining export market accessibility.
- Identify the long-term productivity of pest/disease resistant rootstocks, ensuring the 'clean and green' reputation does not compromise on-farm profitability.

The project revisited historic SARDI viticulture and citrus rootstock trials with an aim to:

- Assess long-term yield and quality attributes of various scion by rootstock combinations, and determine if they are affected by age and whether such effects are dependent upon scion, location or management.
- Determine if longevity of various scions is affected by rootstock
- Use these findings to develop recommendations for vine and citrus rootstock longevity and sustained performance under SA Murray River conditions.

The project addressed these aims through the following key project activities:

- Collate information on historic trials and, in consultation with industry reference groups, select a subset of trials for assessment of longevity and sustained performance;
- Give priority to trials where information about performance was collected within the first 10 years of planting, allowing opportunity for longitudinal analysis of performance.
- Assess longevity by scoring for vine/tree presence;
- Assess sustained performance by measurement of vegetative and fruit growth, fruit composition and quality;
- In collaboration with regional industry bodies, summarise and extend findings via industry workshops, field days and publications. Wider distribution of findings to occur through future publication in scientific literature.

Outcomes and recommendations

An overarching and ongoing outcome from this project has been the opportunity to renew links between regional industry groups and the historic rootstock plantings which they helped to initiate 20-40 years ago. This extensive network of replicated rootstock comparison trials, and associated historical datasets, remains a valuable resource that offers a range of further research opportunities. These include characterising rootstock tolerance to production constraints such as biological (e.g. nematodes and trunk diseases), soil (e.g. salinity and sodicity) and climate (e.g. water availability/quality and temperature extremes). SARDI researchers are already negotiating opportunities to incorporate mature rootstock comparison trials (22+ years in age) into future agronomic and pathology investigations. In the meantime, results of this SARMS IRSP supported project have been summarised in two irrigator focussed technical guides which will be available online at www.pir.sa.gov.au. Key project outcomes and recommendations for both the viticulture and citrus industries are described below.

Viticulture

Viticulture rootstock comparison trials across multiple wine regions have shown changes to the yield rankings of mature vines as compared to those measured when the vines were young.

- Vines grafted to Teleki 5C showed significant age related yield decline at multiple sites.
- 140 Ruggeri and Ramsey showed similar trends but were more variable.
- It is recommended that similar longitudinal analysis occurs across other regions/sites to confirm that this trend is not unique to the sites assessed within this project

Vines grafted to Teleki 5C and K51-40 displayed an increase in juice chloride content in mature vines as compared to the same vines when young. All other rootstocks showed a decline across the same time period.

- These rootstocks were also the most prone to high sodium and chloride concentrations in leaf petiole samples collected at flowering and lamina sampled at harvest.
- Teleki 5C and K51-40 rootstocks should not be used in situations where high salinity (soil or irrigation water) is expected.

In 2015, at a 32 year old Cabernet Sauvignon rootstock trial in Langhorne Creek, bunch stem necrosis (BSN) affected 40% of bunches on own rooted vines as compared to 13 and 25% on vines grafted to Ramsey and 110 Richter respectively.

- It is recommended that an inventory of rootstock trials within Langhorne Creek Cabernet Sauvignon vineyards is collated in preparation for the next BSN event. Should BSN occur, the region's rootstock plantings could be surveyed visually and/or quantitatively to clarify the protective potential of rootstocks against bunch shrivel.

The incidence of unproductive cordon was modified by rootstock genotype at some trial sites.

- In Riverland vineyards, the incidence of unproductive cordon was typically focussed along the lower of two cordons and most likely due to shading.
- In Langhorne Creek vineyards, Eutypa dieback was the most likely cause. At these sites, own rooted vines tended to be less affected than vines grafted to 110 Richter and Teleki 5C.
- SARDI pathologists are soon to incorporate historic rootstock comparison trials into their pathology investigations to characterise the interaction between rootstock genotype and the incidence of trunk disease/dieback

Citrus

Navelina orange trees on C-35 citrange and F80-5 and F80-7 citrumelo rootstocks have expressed incompatibility, leading to tree death between the ages of 10 and 20 years. This is despite positive early performance of these rootstocks under Navelina.

- It is strongly recommended that C-35 citrange is not used with Navelina orange;
- F80-5 and F80-7 citrumelo are not currently used by industry, and no further development of these rootstocks is indicated.

Incompatibility symptoms were identified in a range of rootstocks when paired with Afourer, Murcott and Imperial mandarins, leading to varying degrees of reduction in tree health and yield, but no tree deaths as yet.

- Swingle citrumelo should not be used with mandarin varieties, due to incompatibility symptoms found in this project, and in other research trials across the world;
- Most citrange rootstocks (Carrizo, Troyer, Troyer 341, C-35) express bud-union symptoms of incompatibility with some mandarin varieties, and should be used with caution;
- C-32 citrange showed no bud-union symptoms with mandarins in these trials, and no reports were found in the literature, this rootstock is worthy of further study as a rootstock for mandarins in Australia.

The citrus rootstock C-35 citrange performed poorly in all trials in which it was included, exhibiting incompatibility symptoms under Navelina orange and mandarin trees, and small tree size and reduced yield under Hockney and Summer Gold navel orange trees. Although known to be a dwarfing rootstock, yield per cross sectional area (a measure of yield efficiency) was mid-range to low in all trials, suggesting that high density plantings of trees on this rootstock may not reliably produce acceptable tonnages of fruit.

- C-35 is not recommended as a rootstock for mandarins or navel oranges.

Section 1 Viticulture rootstock assessments: Revisiting historic trial sites

1.1 Introduction

Through the 1970's and 1980's, irrigation districts along South Australia's River Murray corridor saw vineyards go through major rehabilitation as plantings reached the end of their economic lives. Vineyards were replanted with more commercial varieties that were trellised to allow mechanisation. Many vines were grafted onto rootstocks in order to alleviate replant constraints such as nematodes. At that time, grape growers and wine makers were concerned about the impact of rootstocks upon fruit quality and a suite of rootstock comparison trials were established throughout South Australia's River Murray irrigation districts and ultimately into all SA wine production regions, Figure 1.

Many of these rootstock comparison trials were assessed within the first ten years from planting with results informing the South Australian River Murray region's rootstock selection decisions (Nicholas, 1991, 1997 and 2006). Information from these young vines supplemented that from overseas and potted trial research. Following assessment of the young rootstock trials, the vineyards were left to the host irrigators to manage as commercial plantings without further scientific evaluation.

Today, more than 50% of vineyards through the region are grafted to rootstocks (Vinehealth Australia, 2016). The proportion of rootstocks being incorporated into new plantings is considerably higher again. Rootstock selection decisions therefore have long reaching and important consequences for individual vineyards and the region as a whole. These decisions continue to be made based upon information from young vines or overseas research meaning that growers are making long-term rootstock decisions without knowing the longevity of their selections.

Recent work outside of SA's Murray irrigation districts suggest that the yield (Stevens et al., 2011) and salt exclusion properties (Tregeagle et al., 2006) of some rootstocks deteriorate as vines age beyond their first decade. Questions remained around how older rootstocks perform in mature River Murray vineyards.

With support from the SA River Murray Sustainability (SARMS) Program's Industry-Led Research Sub-Program (IRSP), SARDI re-established collaborations with host irrigators and revisited a suite of its mature rootstock comparison trials (now aged between 23-38 years) to assess performance against a number of yield and quality parameters and to determine if age had modified rootstock performance. These latest assessments occurred through the 2015 and 2016 vintages and are discussed herein.

1.2 Materials and methods

1.2.1 Site descriptions and trial analysis

The longevity, sustained performance and fruit quality of vines in 12 historic rootstock trials were assessed across the 2015 and 2016 vintages. In all, 21 rootstock genotypes (including *V.vinifera* vines on their own roots) were assessed across 12 rootstock assessment trial sites. All trial sites were located at commercial vineyards in South Australia's Riverland and Langhorne Creek irrigation districts.

Trials were established in three generations, with planting dates spanning 1979 through to 1996, and were laid out as randomised block designs. Experimental plots consisted of three adjacent vines in the same row with all measurements undertaken on the central vine. The exceptions were site rrco2, four vine plots, and rlcs2, single vine plots. Site details are shown in Table 1 and the distribution of rootstock genotypes across the trial sites is described in Table 2. Riverland vineyards were trained to a two wire vertical trellis and were mechanically pruned. Langhorne Creek vineyards were trained to a single wire vertical trellis and were spur pruned.

Six of the trial sites had previously been assessed by Nicholas (2006) and had associated datasets available for longitudinal comparisons of yield, maturity and various fruit quality parameters. Measurements reported in the current project were collected following the protocols described by Nicholas (2003).

Vine mortality and extent of unproductive cordon were analysed by Kruskal_Wallis one-way non-parametric ANOVA using Statistix Version 8 (Analytical Software, Tallahassee, FL). Longitudinal analysis of vine performance over time was assessed using the R software package (R Core Development Team, version 3.1.3, 2015). Analysis of variance (ANOVA) was used to statistically test for differences between rootstocks and time periods within sites. Pairwise-t-tests were then employed when there were significant main effects and interactions. Results from all statistical analyses were assessed against a significance level of 0.05 and deemed to be statistically significant if the p-value was < 0.05.

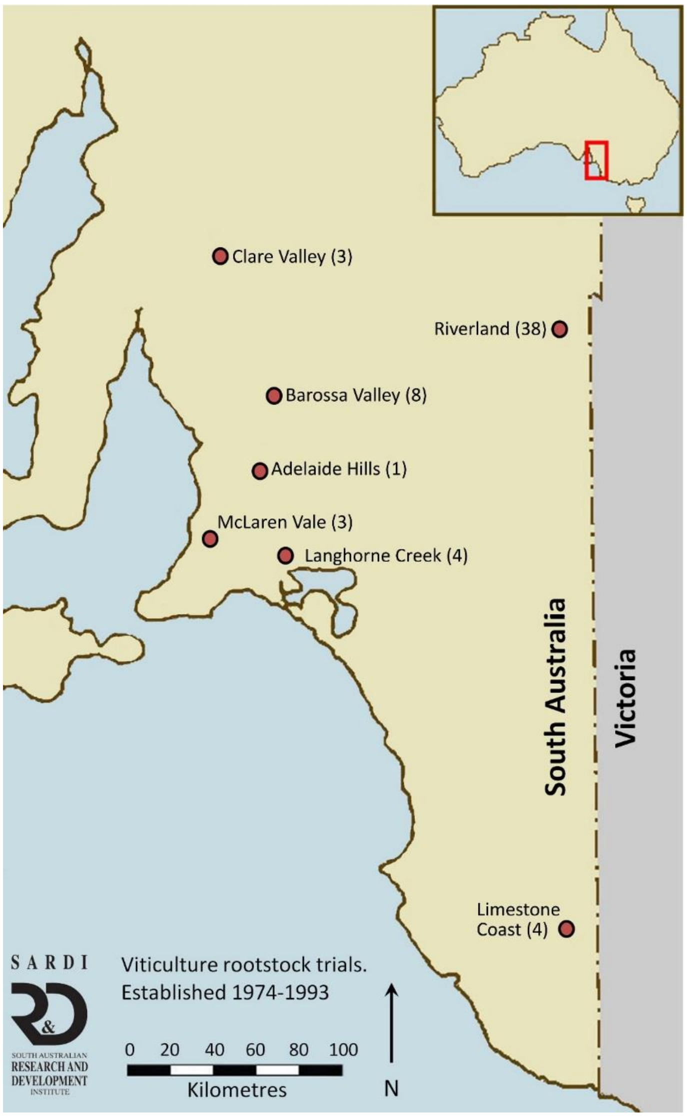

Figure 1. Distribution of SARDI's rootstock comparison trials across SA's principal wine production regions. Three generations of plantings established between 1974 and 1993

Table 1. Description of SARDI's rootstock trials located at commercial vineyards within South Australia's Riverland and Langhorne Creek irrigation districts.

	Trial ID.	Scion	Location	Planted	Replicates (n)	Historic data (years)	Row x vine (m)	Row orientation	Vertical Trellis	Wire heights (m)	Soil type *
Riverland	rrch4	Chardonnay (FVI10V5)	Loveday (34°17 S; 140°26 E)	1993	10	-	3.3 x 2.5	NW-SE	Double	1.2 & 1.5	Highly calcareous soft sandy loam
	rrch5	Chardonnay (FVI10V5)	Cobdogla (34°12 S; 140°25 E)	1993	10	-	3.6 x 1.8	N-S	Double	1.1 & 1.4	Fine sandy light clay over silty clay loam
	rrsh2	Shiraz (BVRC12)	Cobdogla (34°15 S; 140°25 E)	1993	10	1997-1999	3.6 x 2.4	N-S	Double	1.1 & 1.4	Calcareous fine sandy clay loam over clay
	rrsh3	Shiraz (BVRC12)	Barmera (34°16 S; 140°28 E)	1993	10	1996-1999	3.6 x 2.4	E-W	Double	1.4 & 1.7	Calcareous sandy clay loam
	rrsh6	Shiraz (BVRC 12)	Kingston O.M. (34°11 S; 140°19 E)	1996	6	2004	3 x 2	NW-SE	Double	1.2 & 1.5	Fine sandy clay loam over calcareous layer
	rrco2	Colombard (F13V8)	Loxton (34°26 S; 140°37 E)	1979	10	1982-1986	3.6 x 1.8	E-W	Double	1.2 & 1.5	Highly calcareous soft sandy loam
	rrcs1	Cab. Sauv. (FVG9V3)	Renmark (34°7 S; 140°43 E)	1992	12	-	3.3 x 2.4	NW-SE	Double	1.4 & 1.7	Massive sandy clay loam
	rrcs3	Cab. Sauv. (FVG9V3)	Berri (34°16 S; 140°35 E)	1993	10	1996-1999	3.3 x 2.5	E-W	Double	1.1 & 1.6	Loamy sand over sandy clay loam
	rrcs5	Cab. Sauv. (FVG9V3)	Kingston O.M. (34°11 S; 140°19 E)	1996	6	-	3 x 2	NW-SE	Double	1.2 & 1.5	Fine sandy clay loam over calcareous layer
Langhorne Creek	rlcs1	Cab. Sauv. (FVG9V3)	L.Creek (35°19 S; 139°2 E)	1983	7	1989-2001	3 x 2	N-S	Single	1.2	Sandy clay loam over light medium clay
	rlcs2	Cab. Sauv. (FVG9V3)	L.Creek (35°18 S; 139°2 E)	1993	8	-	3	E-W	Single	1.2	Silty clay loam over firm sandy light clay
	rlsh1	Shiraz (BVRC12)	L.Creek (35°17 S; 139°2 E)	1992	17	1997-2001	3.3 x 1.8	NW-SE	Single	1.4	Silty clay loam over firm medium clay

* more detailed soil descriptions available in section 1.3.1

Table 2. Rootstock genotypes available at SARDI's historic rootstock trials. Green squares represent availability of rootstock genotypes at each site

Rootstock Parentage	Rootstock Genotype	Riverland									Langhorne Creek		
		rrch4	rrch5	rrsh2	rrsh3	rrsh6	rrco2	rrcs1	rrcs3	rrcs5	rlsh1	rlcs1	rlcs2
V. vinifera	Own Roots						■				■	■	■
V. berlandieri x V. riparia	Teleki 5C					■		■	■	■		■	
	420A						■						
	Teleki 5A						■						
	5BB Kober						■						
	SO4						■						
V. berlandieri x V. rupestris	140 Ruggeri	■	■	■	■	■	■	■	■	■	■		
	99 Richter					■		■	■	■	■		
	110 Richter			■		■	■			■	■	■	
	1103 Paulsen			■		■				■			■
V. champinii	Ramsey	■	■	■	■	■	■	■	■	■		■	
V. champinii x V. riparia	K51-40	■	■	■	■		■	■	■				
	K51-32						■						
V. champinii x V. rupestris	J17-48			■				■	■				
	J17-69			■				■	■				
V. longii x V. riparia	1616						■						
V. riparia x V. rupestris	101-14	■	■	■	■	■	■	■	■	■			
	Schwarzmann					■	■			■		■	
	3309												■
V. rupestris	St George												■
Dogridge x 1613	Harmony						■						

1.2.2 Vine longevity and vigour assessments

The impact of rootstock genotype on vine longevity was assessed through a survey of survivability and vine health in Spring 2016. The survey was timed to ensure that healthy shoots were less than 60 cm long and unable to overgrow and mask dead or missing cordon. Survivability was assessed through a simple presence/absence/replant evaluation that resulted in a percent mortality for each rootstock by scion combination. Vine health was assessed by visual inspection of each vine where percentage of unproductive cordon was estimated using a disease severity rating scale, published by Wine Australia (2016), Figure 2.

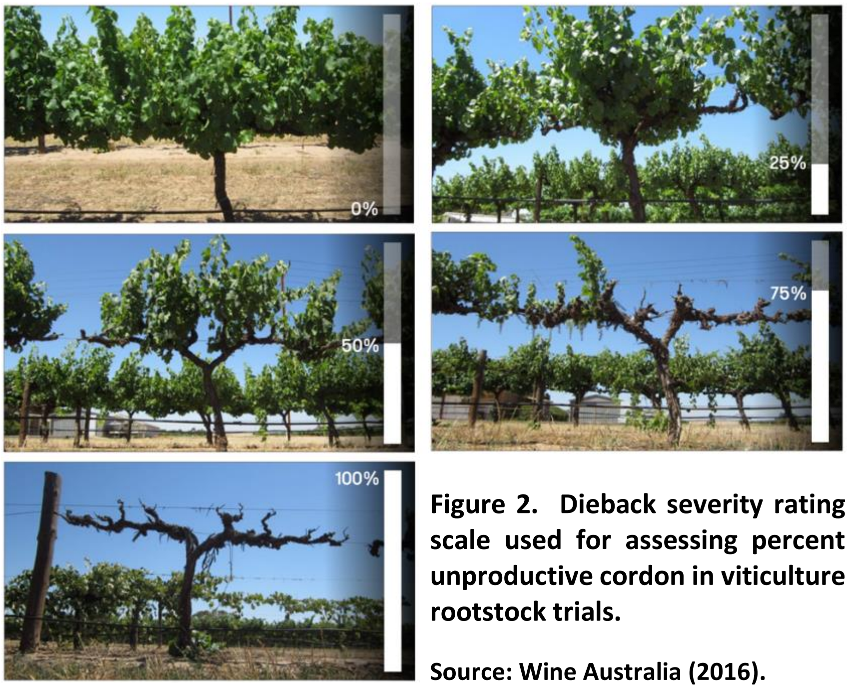

Figure 2. Dieback severity rating scale used for assessing percent unproductive cordon in viticulture rootstock trials.

Source: Wine Australia (2016).

Vigour was assessed by measurement of the leaf area index (LAI). The LAI was measured just prior to harvest in 2016 using an LAI-2000 Plant Canopy Analyser (LI-COR, Lincoln, NE, USA). Measurements were based on a modified version of a method described by Ollat et al. (1998). Measurements were collected around the central vine of each treatment plot with LAI calculated from three sets of 'one above canopy and five below canopy' readings. One of these sets was measured parallel to the vines and two sets were measured diagonal to the vines, Figure 3. Measurements were collected at dawn or dusk with lens facing away from sun. 'Below' canopy readings were measured along a 2m distance (every 0.5 m) at a height of 0.2 m above the original soil surface. This captured the entire canopy of the target vine as well as the edge of the border vines. 'Above' canopy readings were measured in the same orientation as the corresponding below readings at a height of 2.5 m. Above canopy readings were interpolated using the FV2000 software provided with the LAI-2000 instrument.

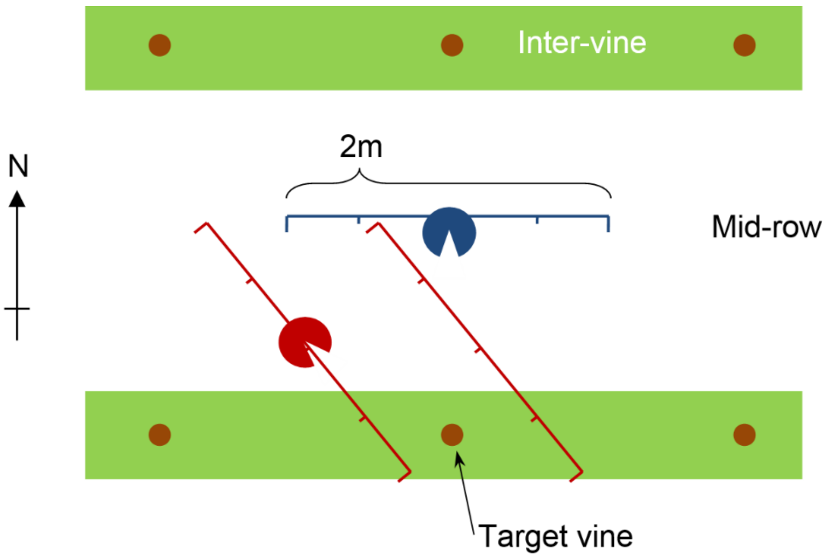

Figure 3. Above vine view of LAI-2000 data collection protocol, parallel and diagonal to the central target vine of each experimental plot. Lens masked with a 45° view cap which was aligned to face away from sun (typically south for parallel and south east for diagonal to vine measurements).

1.2.3 Yield, fruit maturity and juice phenolics

Fruit growth was assessed across all replicates at harvest by measurement of yield, bunch number and the 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. Measurements were made in vintages 2015 and 2016. 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. Total soluble solids concentration was measured on clarified juice by digital refractometer and expressed as °Brix 20°C. Juice pH and the concentration of titratable acid (TA) were measured using an auto-endpoint pH and TA meter (Metrohm, Ionenstrasse, Switzerland); the juice was titrated against 0.333 M NaOH to an endpoint of pH 8.2. Sub-samples from selected sites were frozen for later measurement of Sodium (Na^+), Chloride (Cl^-) and Potassium (K^+) concentrations. For red varieties, a second 100-berry sample was collected from each treatment plot and frozen at -18°C. Within six months of sampling, berries were thawed, macerated and the concentration of anthocyanins (mg malvidin-3-glucoside equivalents/g fresh berry weights) and tannins (mg catachin equivalents/g fresh berry weight) were determined by spectrophotometry following the methods of Iland et al. (2013).

At trial site rlcs1, a Langhorne Creek Cabernet Sauvignon, the incidence of Bunch Stem Necrosis (BSN) was assessed by determining the ratio of shrivelled to good quality bunches within each plot.

1.2.4 Ionic composition of leaf tissue and juice

Leaf petiole and lamina samples were collected opposite to basal inflorescences at flowering (E-L stage 23-25) and at harvest (E-L stage 38) respectively. Up to ten leaf tissue samples were collected from either side of the canopy. If there was less than 10 basal inflorescences, then leaf tissue samples were collected from opposite basal tendrils. Where the central vine in a plot was missing, samples were collected from barrier vines.

Leaf tissue samples 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. Berry samples were collected at harvest (E-L stage 38) in the 2015 and 2016 vintages and processed as described in section 1.2.3.

Cl^- concentration was measured by silver ion titration with a Buchler chloridometer (Labconco, Kansas City, MO, USA). Duplicate juice extracts were prepared by adding 1 mL aliquot of juice to 3 mL of an acid solution containing 10% (v/v) glacial acetic acid, 0.1 M nitric acid and 4 drops of gelatine reagent. Duplicate leaf tissue extracts were prepared by adding 20-100 mg dry samples to 4 mL of an acid solution containing 10% (v/v) glacial acetic acid, 0.1 M nitric acid and 4 drops of gelatine reagent.

Na^+ and K^+ concentrations were measured by ICP (Spectro Analytical Instruments, Kleve, Germany). Leaf sample extracts were prepared using 100-300 mg of dried, ground sample in a nitric acid and hydrogen peroxide digestion. Samples were diluted to 25 mL and cold digested overnight. Following this, the temperature of samples was increased over a 2.5 hour time period to a maximum not exceeding 125°C. Juice samples were analysed as per Wheal et al. (2011).

1.2.5 Irrigation water quality and soil measurements

Irrigation for trial sites was drawn from different points along the River Murray, spanning from Renmark down to Lake Alexandrina. Information on the salinity of irrigation water was sourced from the South Australian Department of Environment, Water and Natural Resources (DEWNR) via WaterConnect (2016), Figure 4 and Figure 5.

Soils were sampled at the beginning and end of the 2016 irrigation season. A hand auger (0.1 m diameter head) was used to collect samples in 0.2 m depth intervals to a depth of 1 m. Samples were taken from under-vine (between two drippers) and in the mid-row, Figure 6. Soil salinity was measured as the electrical conductivity of the extract from a saturated paste (EC_e) following the method of Rayment and Higginson (1992). Electrical conductivity was reported in dS/m at 25°C.

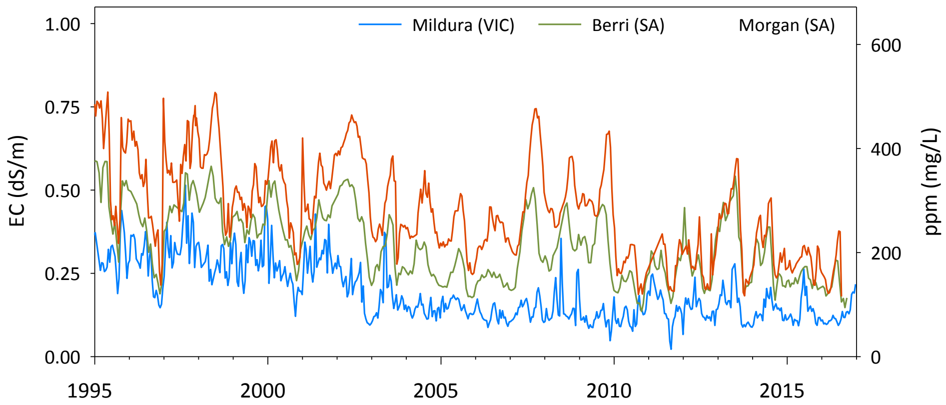

Figure 4. River Murray salinity concentrations (reported as Electrical Conductivity and Parts Per Million) at each of three sampling points along the river (1995-2017).

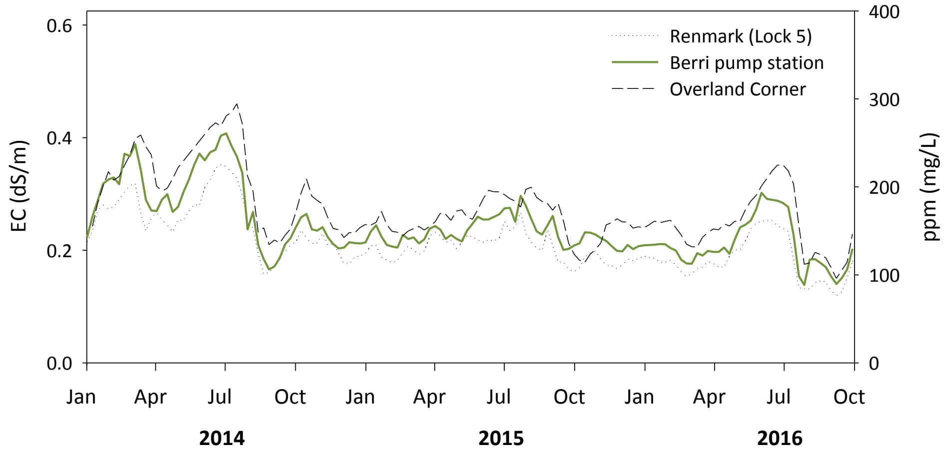

Figure 5. River Murray salinity concentrations (reported as Electrical Conductivity and Part Per Million) at each of three Riverland SA sampling points between January 2014 and October 2016

Figure 6. Salt affected Chardonnay leaf (a) and soil sampling in Riverland vineyard (b)..

1.3 Results and discussion

1.3.1 Findings from individual rootstock comparison trials at 20+ years

Riverland Chardonnay – ID No. rrch4

Location: Loveday

Scion variety/clone: Chardonnay FVI10V5

Trial design: Four rootstocks X 10 replicates

Planted: 1993

Previous assessment: None

Soil:

0-20	Highly calcareous soft light sandy loam	(5YR3/4)	Clear to:
20-40	Highly calcareous soft sandy loam	(5YR4/6)	Clear to:
40-80	Very highly calcareous massive clayey sand (mainly soft carbonate with 10-20% hard nodules)	(5YR6/8)	Gradual to:
80-100	Very highly calcareous massive clayey sand	(5YR6/8)	

Soil salinity not assessed

Vine longevity: No missing vines at age 23 years.

Vigour: Cordon dieback was minor with no notable trunk or foliar symptoms, Figure 7. Dieback was equivalent across all rootstock genotypes and tended to be concentrated along the lower cordon, most likely due to shading. LAI was not assessed at this site.

Yield: Average yields in 2016 were 7 kg/vine greater than those in 2015, attributable largely to a significant increase in the number of bunches per vine.

Rootstock effects on yield components were modified by season. In 2016, the yields of vines grafted to 101-14 and Ramsey were greater than those from vines grafted to 140-Ruggeri. This was associated with fewer bunches and smaller berries from vines grafted to 140-Ruggeri. In 2015, 101-14 produced greater yields than 140-Ruggeri, but Ramsey and 140-Ruggeri were equivalent. Across the two year assessment period, vines grafted to 140 Ruggeri produced significantly lower yields than other vines, Table 3.

Fruit maturity: The 2015 crop was scheduled for commercial harvest one week earlier than that of 2016. This difference in fruit maturity was reflected in average TSS values of 22.6 and 21.5 °Brix for 2015 and 2016 respectively.

Vines grafted to 101-14 had the lowest TSS whilst fruit from vines grafted to Ramsey was the highest. The TA concentration in fruit from vines grafted to 101-14 and 140-Ruggeri were lower than in fruit from vines grafted to K51-40 and Ramsey. Across the two year assessment period, there was no significant rootstock effect on either TSS or pH. However, vines grafted to K51-40 produced fruit with greater TA, Table 4.

Juice phenolics: Not assessed

Potassium: Not assessed

Sodium: Not assessed

Chloride: Not assessed

Table 3. The effect of rootstock genotype on yield components at a Riverland Chardonnay rootstock comparison trial (rrch4) aged 22-23years

	Yield (kg/vine)	Bunches (n/vine)	Bunch Wt. (g)	Berry Wt (g)	Berries/bunch
AGE (yrs)	22-23	22-23	22-23	22-23	22-23
101-14	32.8[a]	421.8[a]	78.6[a]	1.28[b]	62.0[a]
Ramsey	30.7[a]	393.1[ab]	79.1[a]	1.26[bc]	63.1[a]
K51-40	29.8[ab]	378.0[ab]	78.9[a]	1.39[a]	57.0[b]
140 Ruggeri	26.9[b]	365.0[b]	74.5[a]	1.19[c]	62.6[a]

Values followed by the same letter are not significantly different (*P*=0.05)

Table 4. The effect of rootstock genotype on maturity components (TSS, TA, pH) at a Riverland Chardonnay rootstock comparison trial (rrch4) aged 22-23 years.

	Total soluble solids (°Brix)	Titratable acidity (g/L)	pH
AGE (yrs)	22-23	22-23	22-23
101-14	21.7[a]	6.58[bc]	3.25[a]
Ramsey	22.2[a]	6.96[ab]	3.28[a]
K51-40	22.2[a]	7.25[a]	3.28[a]
140 Ruggeri	22.1[a]	6.44[c]	3.27[a]

Values followed by the same letter are not significantly different (*P*=0.05)

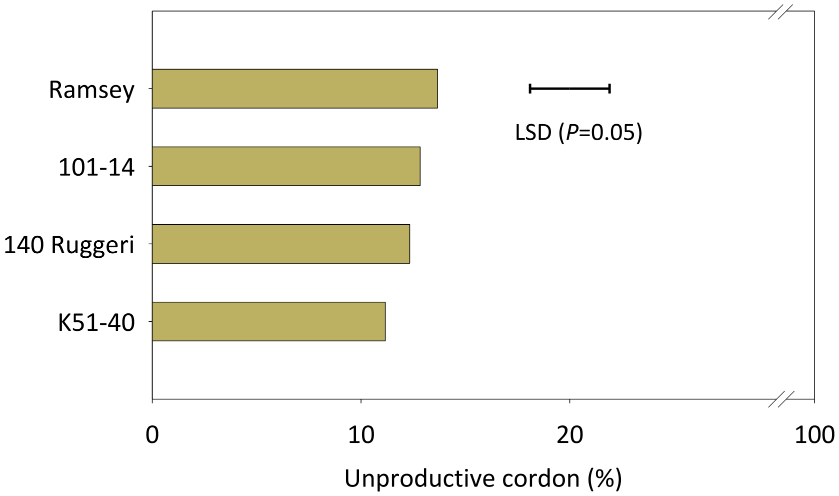

Figure 7. The effect of rootstock genotype on the percent of unproductive cordon at a 23 year old Riverland Chardonnay rootstock trial (rrch4).

Riverland Chardonnay – ID No. rrch5

Location: Cobdogla

Scion variety/clone: Chardonnay FVI10V5

Trial design: Four rootstocks X 10 replicates

Planted: 1993

Previous assessment: None

Soil:

0-10	Firm massive sandy clay loam	(7.5YR4/3)	Clear to:
10-25	Highly calcareous massive fine sandy light clay mottled	(10YR5/3) (7.5YR4/4)	Clear to:
25-75	Firm very highly calcareous medium clay with 10-20% soft carbonate segregations and weak blocky structure	(10YR5/4)	Gradual to:
75-100	Soft massive moderately calc. silty clay loam mottled	(10YR5/4) (10YR6/6)	

Prior to the 2016 irrigation season, average soil salinity was below 0.8 dS/m under-vine and below 1.1 in the mid-row. Following the 2016 irrigation season, average soil salinity had increased to more than 1.2 dS/m under-vine and 2.6 dS/m in the mid-row Figure 8. Irrigation water quality through the same period was good, Figure 5. Whilst mid-row salinity did escalate through the irrigation season, it was not at levels that would cause concern providing winter rains and/or late season leaching irrigations were available to leach the soil of salts.

Vine longevity: Two of the 30 vines grafted to 140 Ruggeri had been replanted within the vineyards first 10 years. These vines were planted as border vines within different experimental plots and were not enough to suggest longevity or potential incompatibility issues associated with rootstock genotype.

Vigour: Cordon dieback was minor with no notable trunk or foliar symptoms. Dieback was equivalent across all rootstock genotypes, Figure 9. LAI was not assessed at this site.

Yield: Average yields were equivalent across both the 2015 and 2016 vintages with season not impacting the effect of rootstock genotype upon yield. In both seasons, yield from vines grafted to K51-40 was significantly lower than that from vines grafted to 101-14, Ramsey and 140-Ruggeri, Table 5. The reduced yield was driven by a significantly lower bunch count per vine. Berry weights from K51-40 vines were greater than those from Ramsey and 140-Ruggeri.

Fruit maturity: Neither pH, TA nor measures of TSS were affected by rootstock genotype during the period of investigation, Table 6. However, there was significant difference between the average values of the 2015 and 2016 vintages, with 2015 being significantly more advanced.

Juice phenolics: Not assessed

Potassium (K): Vines grafted to Ramsey and 140 Ruggeri produced fruit with significantly lower concentrations of potassium than vines on 101-14 and K51-40, Table 7.

Sodium (Na^+): Whiles below concentrations that would cause concern for local or export markets, vines grafted to Ramsey expressed the highest concentration of Na^+

in leaf tissue and berries sampled at harvest. Vines grafted to 101-14 were the lowest, Table 7.

Chloride (Cl^-): Vines grafted to K51-40 had the highest concentrations of Cl^- in the juice and also had high leaf tissue concentrations, equivalent only to vines grafted to Ramsey, Table 7.

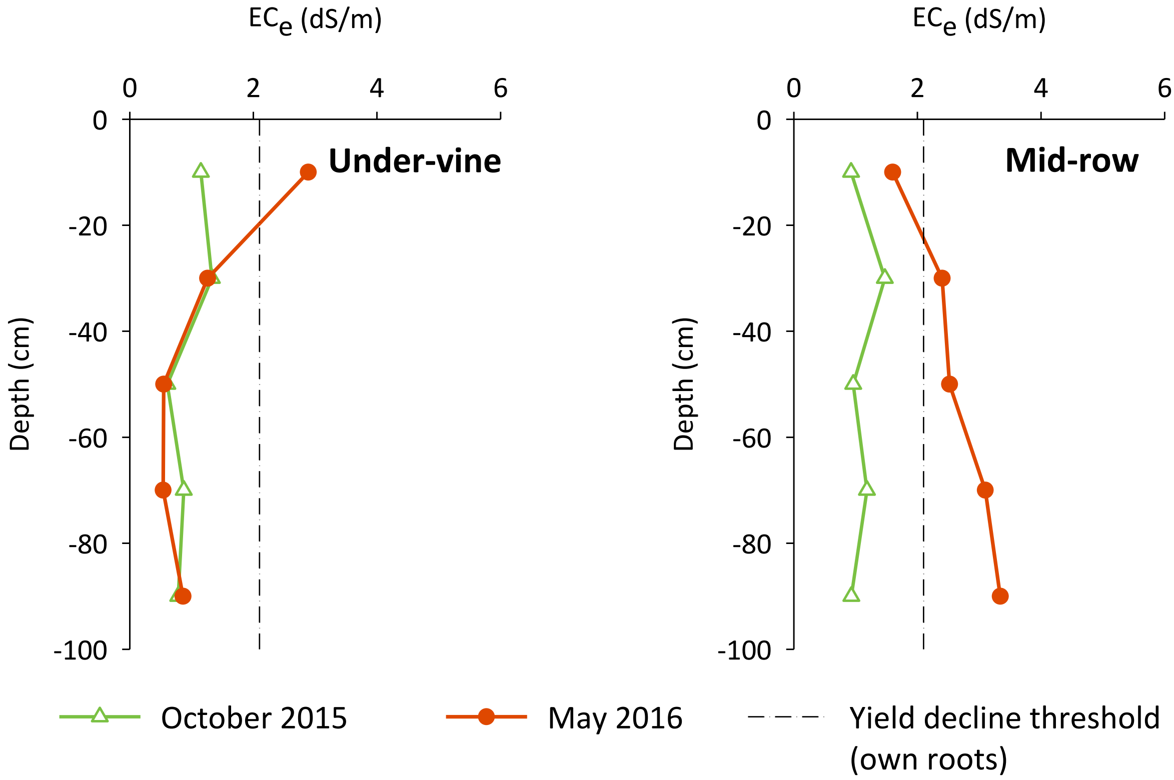

Figure 8. Variation in soil salinity (EC_e dS/m) with depth at a Riverland Chardonnay rootstock trial (rrch5). Samples collected before and after the 2015/16 irrigation season from under-vine and mid-row soils.

Table 5. The effect of rootstock genotype on yield components at a Riverland Chardonnay rootstock comparison trial (rrch5) aged 22-23years

AGE (yrs)	Yield (kg/vine) 22-23	Bunches (n/vine) 22-23	Bunch Wt. (g) 22-23	Berry Wt (g) 22-23	Berries/bunch 22-23
101-14	24.5^{ab}	385.5^{a}	64.6^{b}	1.07^{ab}	61.2^{b}
Ramsey	25.4^{a}	362.2^{a}	71.7^{a}	1.00^{c}	72.5^{a}
K51-40	20.8^{c}	319.5^{b}	66.0^{ab}	1.09^{a}	60.1^{b}
140 Ruggeri	23.3^{b}	358.4^{ab}	66.2^{ab}	1.01^{bc}	65.7^{ab}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 6. The effect of rootstock genotype on maturity components (TSS, TA, pH) at a Riverland Chardonnay rootstock comparison trial (rrch5) aged 22-23 years.

	Total soluble solids (°Brix)	Titratable acidity (g/L)	pH
AGE (yrs)	22-23	22-23	22-23
101-14	21.6[a]	6.17[a]	3.53[a]
Ramsey	22.2[a]	6.18[a]	3.54[a]
K51-40	22.1[a]	6.39[a]	3.54[a]
140 Ruggeri	22.5[a]	6.29[a]	3.50[a]

Values followed by the same letter are not significantly different (*P*=0.05)

Table 7. The effect of rootstock genotype on ionic composition of leaf and juice samples collected at harvest at a Riverland Chardonnay rootstock comparison trial (rrch5) aged 22-23years

	Lamina Na^+ (%)	Lamina Cl^- (%)	Juice Na^+ (mg/L)	Juice Cl^- (mg/L)	Juice K^+ (mg/L)
AGE (yrs)	22-23	22-23	22-23	22-23	22-23
101-14	0.02[b]	0.13[b]	19.7[b]	8.6[b]	1345[a]
Ramsey	0.07[a]	0.37[a]	62.1[a]	41.2[b]	859[b]
K51-40	0.04[b]	0.40[a]	37.5[ab]	92.9[a]	1289[a]
140 Ruggeri	0.04[b]	0.11[b]	46.0[ab]	19.4[b]	962[b]

Values followed by the same letter are not significantly different (*P*=0.05)

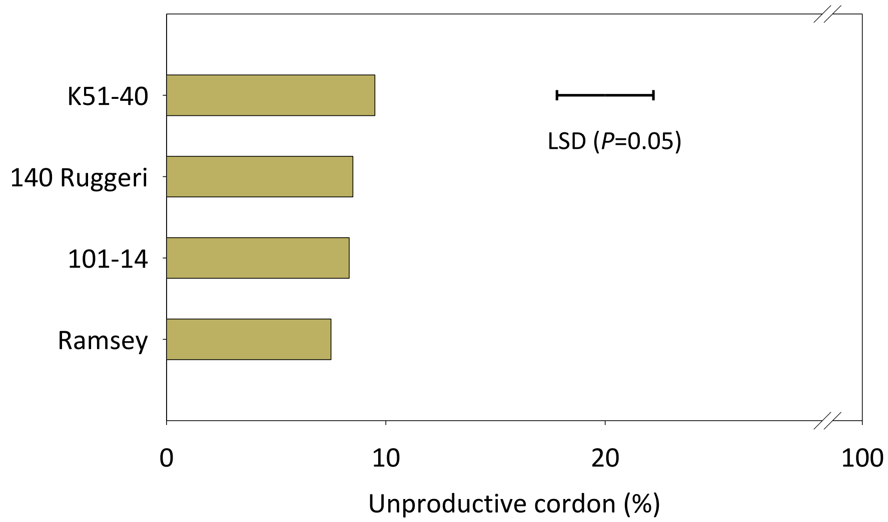

Figure 9. The effect of rootstock genotype on the percent of unproductive cordon at a 23 year old Riverland Chardonnay rootstock trial (rrch5).

Riverland Shiraz – ID No. rrsh2

Location: Cobdogla

Scion variety/clone: Shiraz BVRC12

Trial design: Eight rootstocks X 10 replicates

Planted: 1993

Previous assessment: Three seasons; 1997 – 1999 (Nicholas, 2006)

Soil:

0-20	Moderately calcareous fine sandy clay loam	(7.5YR4/3)	Clear to:
20-35	Highly calcareous weakly blocky fine sandy light clay	(7.5YR4/6)	Clear to:
35-70	Very highly calcareous light clay and 20-50% soft carbonate segregations	(10YR5/4) (7.5YR4/6)	Gradual to:
70-100	Highly calcareous firm heavy clay with mottles and block structure	(5YR5/8) (10YR5/6)	

Prior to the 2016 irrigation season, average soil salinity was below 1 dS/m in both the under-vine and mid-row soils. Following the 2016 irrigation season, the under-vine soils remained non-saline but the mid-row soils had increased to more than 4dS/m, Figure 10. Irrigation water quality through the same period was good, Figure 5. Results show a more rapid accumulation of salts at the outer edge of the wetted area than observed at other trial sites that is likely associated with the heavier textured soils at depth. While the 2015/16 season commenced with low salinity soils, the rapid accumulation of salts through a single season suggests considerable risk of salt uptake by the vine in years where rain and/or irrigation allocations are not sufficient to meet soil leaching requirements.

Vine longevity: No missing vines at age 23 years.

Vigour: Where present, areas of unproductive cordon were largely located along the lower cordon of the double wire trellis and most likely due to shading rather than trunk disease. Vines grafted to 101-14 had the greatest areas of dead cordon, Figure 12. Vines grafted to J17-69, K51-40 and Ramsey showed the greatest vigour and those on 110-Richter, 140 Ruggeri and J17-48 the lowest, Figure 13.

Yield: Yields from grafted vines in their third decade of life were compared to those collected from the same vines in their first decade of life. Average yields exceeded 30 kg/vine in the first decade of production and vines continued to produce close to this amount at age 23. However, some grafted vines demonstrated a significant reduction in their yield potential, albeit at yields in excess of 28 kg/vine for all treatments. Most notable yield reductions were Shiraz grafted to 140 Ruggeri and Ramsey, reducing by 18% and 12% respectively. Vines grafted to J17-69 or J17-48 displayed stable yields across the three decade assessment period, Figure 11 and Table 8

Bunch number and weight did not differentiate between rootstock genotype nor was there significant change in average values measured at age four to six years against those collected at age 22-23 years. A notable outlier to this consistency was the vineyards sixth year when average bunch count exceeded 600 bunches per vine. This was much higher than other assessment years and resulted in correspondingly smaller bunches and berry weights in that year compared to other seasons (data not shown).

The effect of rootstock genotype on berry weight was modified by vine age, Table 8. Through the vineyards first decade, average berry weight was 1.12 g and there was little difference between rootstocks with only vines grafted to 110 Richter and J17-48 having smaller berries. In the third decade, average berry weights were significantly higher, 1.49 g and J17-48 was now equivalent to the heaviest berries. Vines grafted to 110 Richter remained the smallest berries across both time periods.

Fruit maturity: Measures of fruit maturity changed between the vineyards first and third decade with TSS and TA suggesting yield assessments were conducted on riper fruit at age 22-23. In general, rootstock genotype did not affect change in fruit maturity although fruit from vines grafted to 1103 Paulsen had significantly lower TSS than that from vines grafted to K51-40, Table 10.

Juice phenolics: Colour density, reported as anthocyanin concentration, was measured in both the first and third decades of the vineyards life. There was no significant change over this period apart from vines grafted to J17-48 and J17-69 both of which decreased over time. This is despite their consistent yields over the same period. The concentration of tannins was only measured in the third decade. Tannin concentrations were greatest in fruit from vines grafted to J17-48 (3.47) and significantly higher than that from vines grafted to Ramsey, K51-40, 101-14, J17-69 and 1103 Paulsen, Table 11. There was a significant negative relationship between yield and juice phenolics with the higher yielding vines having a lower colour density and a lower tannin concentration.

Potassium (K^+): Concentrations of K^+ in the juice were equivalent across all rootstock genotypes, Table 11.

Sodium (Na^+): Vines grafted to Ramsey, K51-40 and 140 Ruggeri had the highest concentrations of Na^+ in leaf petioles sampled at flowering as well as in leaf lamina and juice sampled at harvest, Table 9. Whilst rootstock genotype did elicit a significant difference in the uptake and expression of Na^+, concentrations were not at a level known to cause leaf damage or compromise wine quality.

Chloride (Cl^-): Vines grafted to K51-40 also presented the highest concentrations of Cl^- in their leaf petiole and lamina samples and in juice sampled at harvest, Table 9. Vines grafted to J17-69 also had elevated concentrations of Cl^- but without the corresponding Na^+. Vines grafted to Ramsey showed elevated leaf tissue concentrations but this did not translate to high juice concentrations.

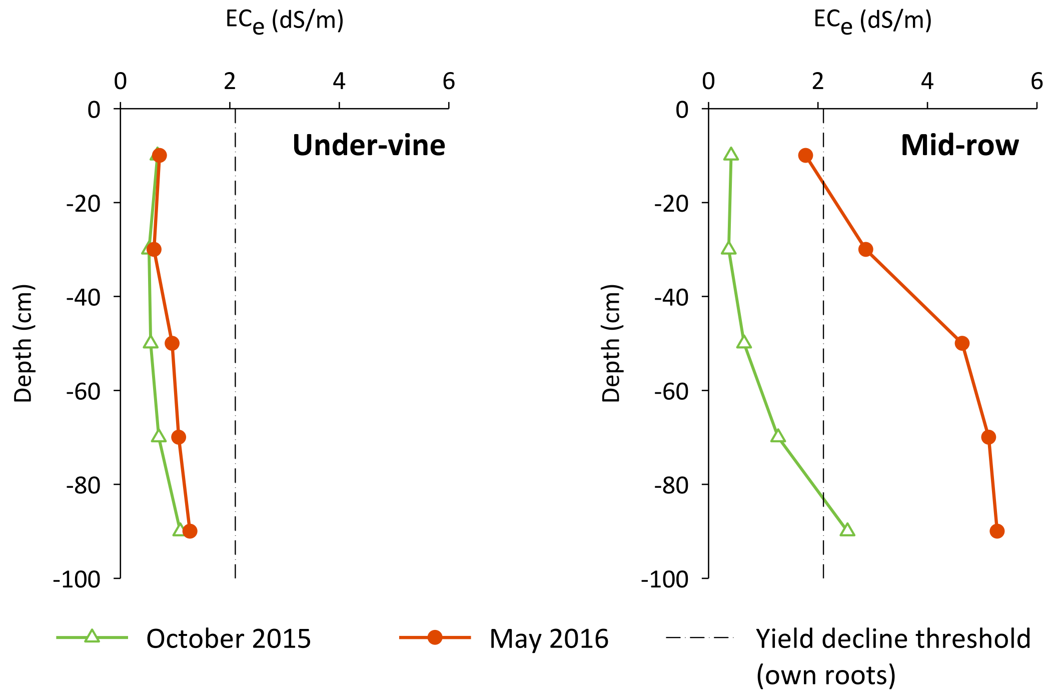

Figure 10. Variation in soil salinity (EC_e dS/m) with depth at a Riverland Shiraz rootstock trial (rrsh2). Samples collected before and after the 2015/16 irrigation season from under-vine and mid-row soils.

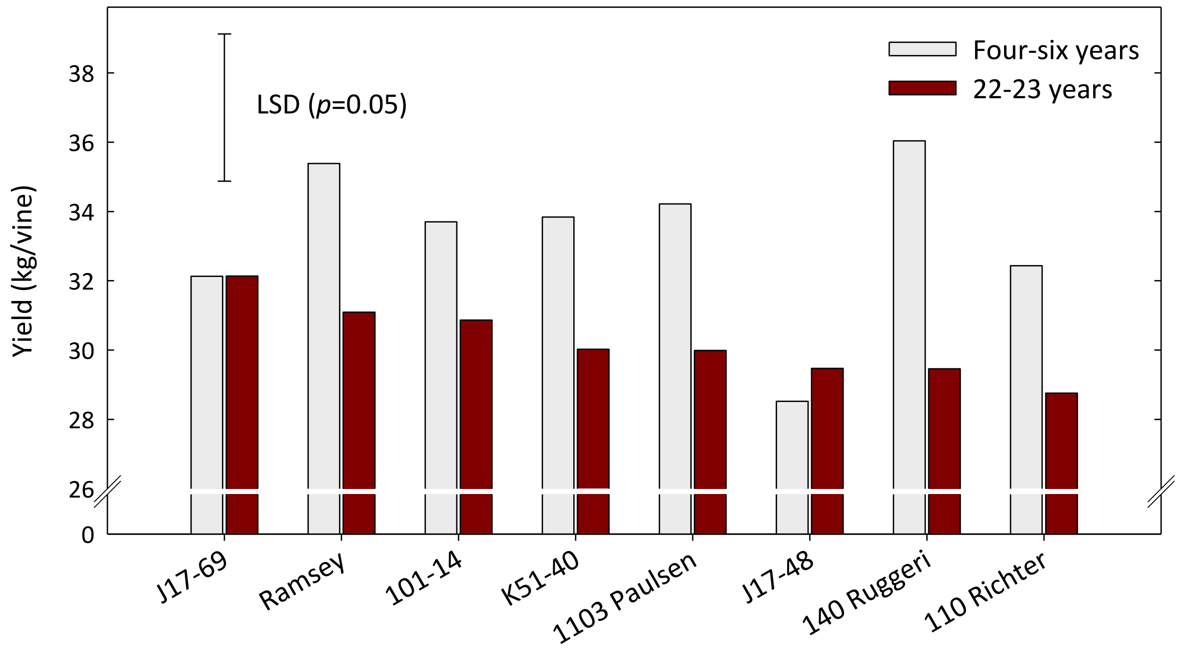

Figure 11. The effect of rootstock genotype on the yield of Riverland Shiraz at a rootstock comparison trial (rrsh2) aged 4-6 and 22-23 years.

Table 8. The effect of rootstock genotype on yield components at a Riverland Shiraz rootstock comparison trial (rrsh2) aged 4-6 and 22-23 years

	Yield (kg/vine)		Bunches (n/vine)		Bunch Wt. (g)		Berry Wt. (g)		Berries/bunch	
AGE (yrs)	4-6	22-23	4-6	22-23	4-6	22-23	4-6	22-23	4-6	22-23
140 Ruggeri	36.0^{a}	29.5^{efg}	504.1^{ab}	356.5^{e}	75.7^{def}	83.3^{abcd}	1.15^{e}	1.43^{cd}	66.4^{bcd}	59.7^{def}
Ramsey	35.5^{a}	31.1^{cdef}	518.1^{ab}	348.8^{e}	73.2^{efg}	89.9^{a}	1.18^{e}	1.52^{ab}	62.5^{bcdef}	60.1^{cdef}
1103 Paulsen	34.2^{ab}	30.0^{defg}	472.3^{bc}	359.6^{e}	76.1^{def}	85.2^{abc}	1.12^{e}	1.48^{bc}	67.9^{abc}	58.8^{def}
K51-40	33.8^{ab}	30.0^{defg}	483.7^{bc}	357.2^{e}	73.8^{ef}	84.1^{abcd}	1.15^{e}	1.55^{ab}	63.9^{bcde}	55.4^{f}
101-14	33.7^{abc}	30.9^{defg}	552.8^{a}	365.2^{de}	65.4^{g}	85.3^{abc}	1.17^{e}	1.57^{a}	55.8^{f}	55.1^{f}
110 Richter	32.4^{bcd}	28.8^{fg}	454.0^{bc}	367.6^{de}	76.9^{cde}	78.6^{bcde}	1.05^{f}	1.36^{d}	73.8^{a}	58.8^{def}
J17-69	32.1^{bcde}	32.1^{bcde}	504.9^{ab}	379.1^{de}	68.6^{fg}	85.7^{ab}	1.12^{e}	1.50^{abc}	61.2^{cdef}	58.2^{ef}
J17-48	28.2^{g}	29.5^{efg}	435.7^{cd}	337.6^{e}	71.5^{efg}	88.4^{a}	1.03^{f}	1.50^{abc}	69.6^{ab}	59.7^{def}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 9. The effect of rootstock genotype on ionic composition of leaf petioles collected at flowering and leaf lamina and juice samples collected at harvest at a Riverland Shiraz rootstock comparison trial (rrsh2) aged 22-23years

	Petiole Na^{+} (%)	Petiole Cl^{-} (%)	Lamina Na^{+} (%)	Lamina Cl^{-} (%)	Juice Na^{+} (mg/L)	Juice Cl^{-} (mg/L)	Juice K^{+} (mg/L)
140 Ruggeri	0.08^{c}	0.06^{f}	0.05^{a}	0.10^{c}	24.8^{b}	34.4^{c}	1077^{a}
Ramsey	0.09^{bc}	0.46^{c}	0.05^{a}	0.21^{b}	25.2^{b}	60.5^{bc}	880^{a}
1103 Paulsen	0.12^{a}	0.09^{ef}	0.03^{b}	0.07^{c}	14.3^{cd}	29.9^{c}	997^{a}
K51-40	0.10^{ab}	0.71^{a}	0.05^{a}	0.39^{a}	35.2^{a}	160.3^{a}	1147^{a}
101-14	0.04^{d}	0.20^{d}	0.03^{bc}	0.09^{c}	21.1^{bc}	64.2^{bc}	1040^{a}
110 Richter	0.09^{bc}	0.06^{f}	0.04^{b}	0.08^{c}	14.3^{cd}	34.2^{c}	815^{a}
J17-69	0.03^{d}	0.59^{b}	0.02^{c}	0.22^{b}	10.6^{d}	92.9^{b}	993^{a}
J17-48	0.03^{d}	0.16^{de}	0.02^{c}	0.10^{c}	11.3^{d}	42.3^{c}	964^{a}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 10. The effect of rootstock genotype on fruit maturity components (TSS, TA and pH) at a Riverland Shiraz rootstock comparison trial (rrsh2) aged 4-6 and 22-23 years

	Total soluble solids (°Brix)		Titratable acidity (g/L)		pH	
AGE (yrs)	4-6	22-23	4-6	22-23	4-6	22-23
140 Ruggeri	21.7[efg]	22.9[abc]	5.90[a]	5.19[cde]	4.20[ab]	3.37[fgh]
Ramsey	21.4[fg]	22.8[abcd]	5.73[ab]	5.01[e]	4.18[abc]	3.43[fg]
1103 Paulsen	20.9[g]	22.4[bcde]	5.97[a]	5.37[cd]	4.09[de]	3.37[fgh]
K51-40	22.5[abcde]	23.5[a]	6.03[a]	5.09[de]	4.22[a]	3.44[f]
101-14	21.7[efg]	23.0[ab]	5.84[a]	5.22[cde]	4.14[bcd]	3.38[fgh]
110 Richter	21.7[efg]	22.4[bcde]	5.99[a]	5.25[cde]	4.05[e]	3.33[h]
J17-69	22.0[cdef]	22.6[abcde]	5.89[a]	5.46[bc]	4.12[cd]	3.36[gh]
J17-48	21.8[def]	22.8[abcd]	5.97[a]	5.32[cde]	4.17[abc]	3.36[h]

Values followed by the same letter are not significantly different (*P*=0.05)

Table 11. The effect of rootstock genotype on juice phenolics (anthocyanin and tannins) at a Riverland Shiraz rootstock comparison trial (rrsh2) aged 4-6 and 22-23 years.

	Anthocyanin (mg/g)		Tannin (mg/g)	
AGE (yrs)	4-6	22-23	4-6	22-23
140 Ruggeri	0.66[cd]	0.70[bcd]	-	3.27[abc]
Ramsey	0.68[cd]	0.67[cd]	-	2.92[d]
1103 Paulsen	0.66[cd]	0.63[d]	-	3.06[bcd]
K51-40	0.68[cd]	0.68[cd]	-	2.98[d]
101-14	0.74[bc]	0.68[cd]	-	3.02[d]
110 Richter	0.80[ab]	0.72[bcd]	-	3.29[ab]
J17-69	0.74[bc]	0.64[d]	-	3.05[cd]
J17-48	0.84[a]	0.73[bcd]	-	3.47[a]

Values followed by the same letter are not significantly different (*P*=0.05)

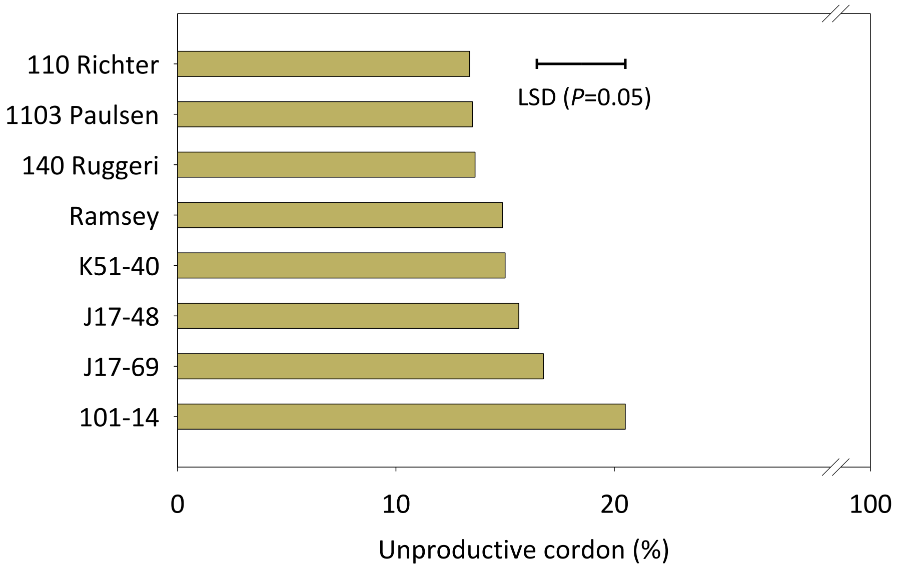

Figure 12. The effect of rootstock genotype on the percent of unproductive cordon at a 23 year old Riverland Shiraz rootstock trial (rrsh2).

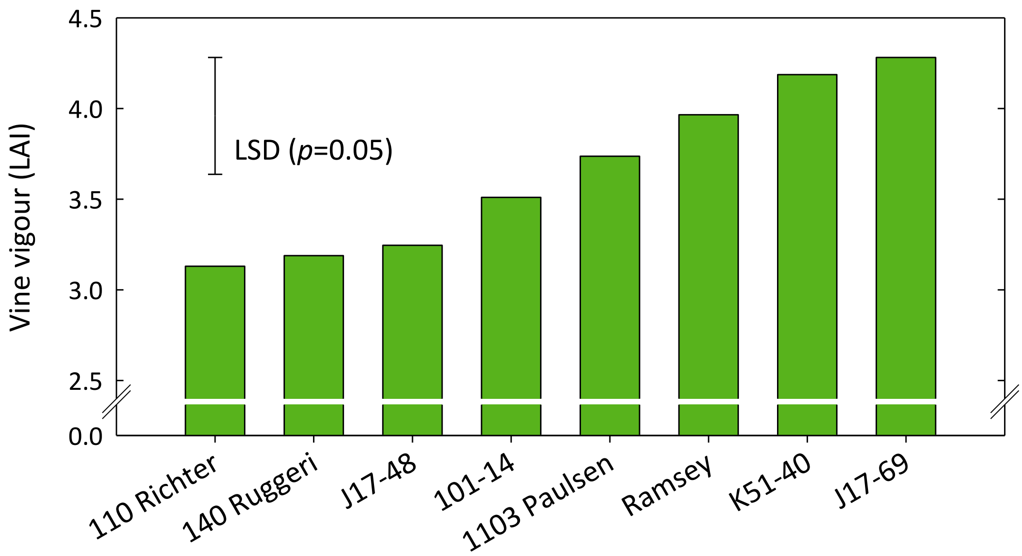

Figure 13. The effect of rootstock genotype on vine vigour as measured by LAI in a 23 year old Riverland Shiraz vineyard (rrsh2).

Riverland Shiraz – ID No. rrsh3

Location: Barmera

Scion variety/clone: Shiraz BVRC12

Trial design: Eight rootstocks X 10 replicates

Planted: 1993

Previous assessment: Three seasons; 1997 – 1999 (Nicholas, 2006)

Soil:

0-10	Moderately calcareous light sandy clay loam	(5YR3/3)	Clear to:
10-35	Moderately calcareous sandy clay loam	(2.5YR3/6)	Gradual to:
35-50	Highly calcareous light sandy clay loam	(5YR4/6)	Gradual to:
50-75	Very highly calcareous light sandy clay loam	(5YR5/8)	Diffuse to:
75-100	Very highly calcareous sandy clay loam	(5YR5/8)	

Soil salinity was not assessed at this site

Vine longevity: No missing vines at age 23 years.

Vigour: Cordon dieback was minor and equivalent across rootstock genotypes, Figure 14. Measures of LAI ahead of the 2016 harvest showed no discernible difference in vine vigour with an average LAI of 3, data not shown. There was a significant positive linear relationship between LAI and yield in 2016, where the larger canopies produced the greatest weight of fruit. This was particularly evident for vines grafted to 101-14.

Yield: In 2015, the vineyard was commercially harvested before the project could collect experimental measures. Yield components from the 2016 vintage are presented against first decade data in Table 13.

Similar trends were observed as at rrsh3. Viz., despite significant yield reductions over time, vines grafted to Ramsey remained the highest yielding, Table 13. Unlike the rrsh2 vines, the ranking of yield at rrsh3 did not significantly change.

Bunch number and weight did not differentiate between rootstocks and there was no significant change between the first and third decades. Berry weights were also stable with vine age and rootstock genotype, although there was a tendency for berry size to be larger earlier in the vineyard's life, largely driven by unusually large berries in the vineyards fourth year.

Fruit maturity: The traditional indicators of fruit maturity did not alter between the vineyard's first and third decades with TSS, pH and TA all showing similar trends. Rootstock genotype did not affect change in fruit maturity although fruit from vines grafted to K51-40 was trending towards more advanced maturity than that harvested from vines grafted to Ramsey, 140 Ruggeri and 101-14, Table 14. This aligns with results from rrsh2.

Juice phenolics: Colour density was lower in the vineyard's 23rd year as compared to that measured in its first decade. At both times, anthocyanin concentrations were equivalent regardless of rootstock genotype, Table 12. Average tannin content was 2.9 mg/L in the 2016 vintage. While the concentration of tannins was not affected by rootstock, vines grafted to Ramsey were trending lowest. There was a significant negative relationship between yield and juice phenolics with the higher yielding vines having both a lower colour density and a lower tannin concentration.

Potassium (K^+): Not assessed

Sodium (Na^+): Not assessed

Chloride (Cl^-): Not assessed

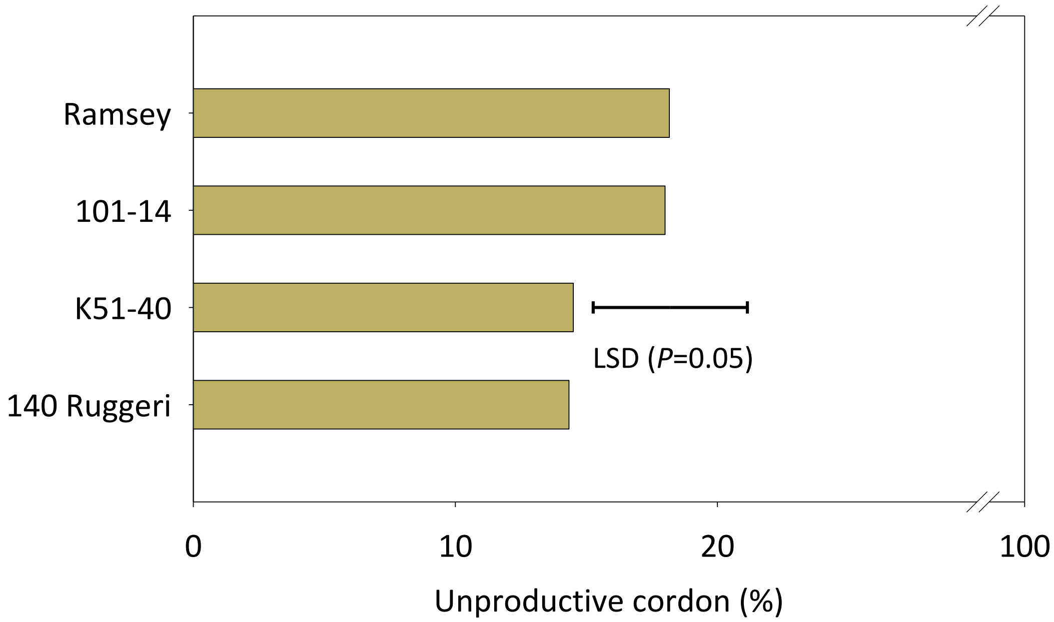

Figure 14. The effect of rootstock genotype on the percent of unproductive cordon at a 23 year old Riverland Shiraz rootstock trial (rrsh3).

Table 12. The effect of rootstock genotype on juice phenolics (anthocyanin and tannins) at a Riverland Shiraz rootstock comparison trial (rrsh3) aged 4-6 and 23 years.

	Anthocyanin (mg/g)		Tannin (mg/g)
AGE (yrs)	4-6	23	23
Ramsey	0.84[ab]	0.67[c]	2.69[a]
101-14	0.89[a]	0.73[bc]	2.89[a]
K51-40	0.89[a]	0.68[c]	2.87[a]
140 Ruggeri	0.86[a]	0.72[bc]	2.96[a]

Values followed by the same letter are not significantly different (*P*=0.05)

Table 13. The effect of rootstock genotype on yield components at a Riverland Shiraz rootstock comparison trial (rrsh3) aged 4-6 and 23 years

	Yield (kg/vine)		Bunches (n/vine)		Bunch Wt. (g)		Berry Wt. (g)		Berries/bunch	
AGE (yrs)	4-6	23	4-6	23	4-6	23	4-6	23	4-6	23
Ramsey	31.7^{a}	28.1^{bcd}	508.4^{ab}	419.9^{bcd}	67.3^{a}	67.8^{a}	1.17^{a}	1.02^{cd}	56.3^{bc}	66.5^{a}
101-14	29.5^{b}	26.1^{d}	525.7^{a}	393.7^{cd}	62.5^{a}	66.6^{a}	1.15^{ab}	1.08^{abcd}	53.0^{c}	61.6^{ab}
K51-40	29.1^{b}	25.9^{d}	473.4^{abc}	372.3^{d}	66.8^{a}	69.9^{a}	1.15^{ab}	1.05^{bcd}	56.9^{bc}	66.8^{a}
140 Ruggeri	28.8^{bc}	26.6^{cd}	505.8^{ab}	436.7^{abcd}	63.2^{a}	61.5^{a}	1.12^{abc}	1.00^{d}	55.3^{bc}	61.8^{ab}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 14. The effect of rootstock genotype on fruit maturity components (TSS, TA and pH) at a Riverland Shiraz rootstock comparison trial (rrsh3) aged 4-6 and 23 years

	Total soluble solids (°Brix)		Titratable acidity (g/L)		pH	
AGE (yrs)	4-6	23	4-6	23	4-6	23
Ramsey	23.5^{b}	23.5^{b}	5.60^{a}	3.65^{b}	3.93^{ab}	3.76^{d}
101-14	23.4^{b}	23.5^{b}	5.54^{a}	3.66^{b}	3.87^{bcd}	3.75^{d}
K51-40	24.6^{a}	24.3^{ab}	5.66^{a}	3.66^{b}	4.00^{a}	3.79^{cd}
140 Ruggeri	24.2^{ab}	23.9^{ab}	5.65^{a}	3.61^{b}	3.90^{abc}	3.76^{d}

Values followed by the same letter are not significantly different (*P*=0.05)

Riverland Shiraz – ID No. rrsh6

Location: Kingston on Murray

Scion variety/clone: Shiraz BVRC12

Trial design: Eight rootstocks X six replicates

Planted: 1996

Previous assessment: One season, 2004 (Stevens et al., 2010, Stevens et al., 2011)

Soil:

0-10	Light sandy clay loam	(7.5YR4/3)	Clear to:
10-40	Highly calcareous light sandy clay loam	(7.5YR5/4)	Gradual to:
40-70	Highly calcareous sandy clay loam	(7.5YR7/4)	Gradual to:
70-90	Moderately calcareous clay loam, sandy	(7.5YR6/4)	Gradual to:
90-110	Carbonate layer	Nil	

The skeletal, calcareous soils of this trial site are not typical of most Riverland vineyards. Industry feedback suggested greater value in investing project resources towards other trial sites. As such, yield and vigour assessments were omitted from this site. However, the sites history of above average soil salinity did present an opportunity to assess rootstock salt exclusion characteristics. These measures were complemented by fruit maturity and other fruit quality parameters.

In 2004, soil sampling showed that under-vine soils were saline, 4 dS/m, and exceeded the yield decline threshold for own rooted vines, Figure 15a. Through the same period, the irrigation water was non-saline at approximately 0.4 dS/m. These measures were repeated through 2015/16 and showed that irrigation quality remained good and that the under-vine salinity had dropped below the yield decline threshold of 2.1 dS/m, Figure 15b. Mid-row sampling in 2015/16 suggested that salts were now sitting at the edge of the irrigated rootzone, within the mid-row soils, Figure 15c. If mobilised back towards the under-vine soils during the growing season, these mid-row salts would represent a risk to vine health and fruit quality.

Vine longevity: No missing vines at age 20 years and no signs of rootstock incompatibility.

Vigour: Not assessed

Yield: Not assessed

Fruit maturity: 2015 berry samples were collected at a more advanced maturity than would normally be accepted by the winery and average TSS across the two seasons was therefore higher than typical at 27°Brix. Rootstock genotype did not modify TSS in either year, nor did it impact upon juice pH or TA, Table 15.

Juice phenolics: Neither juice anthocyanins nor tannins were modified by rootstock genotype with average values of 0.9 and 4.2 mg/g respectively, Table 15.

NB: Fruit from vines grafted to 99 Richter, 101-14 and Teleki 5C were not assessed for ionic composition in 2004 and were therefore not available for longitudinal analysis

Potassium (K^+): Average concentrations of K^+ in the juice decreased between the first and third decades. In the first decade, fruit from vines grafted to Ramsey and Schwarzmann expressed the highest concentrations of K^+, whereas in the third decade these vines were trending lower and fruit from vines grafted to Teleki 5C had the highest K^+ content, Table 16 and .

Sodium (Na^+): Na^+ content of leaf petioles sampled at flowering was modified by rootstock genotype at each time step, Figure 16. When the vines were young, and had greater exposure to soil salinity, vines grafted to 101-14 and 110 Richter expressed the lowest concentration of Na^+ in their leaf petioles. Twelve years later, sodium concentrations significantly dropped in all vines apart from those grafted to 110 Richter and Teleki 5C which both increased. Leaf lamina and berries sampled at harvest showed higher concentrations of Na^+ in vines grafted to Teleki 5C and, to a lesser extent, Ramsey, Table 16.

Chloride (Cl^-): Trends in the expression of Cl^- were stable over time with vines grafted to Teleki 5C, and to a lesser extent Ramsey, having higher concentrations of Cl^- in their leaf petioles sampled at flowering and their leaf lamina and juice sampled at harvest, Figure 16 and Table 16. A noteworthy trend was that Cl^- concentrations in petioles sampled from vines grafted to Teleki 5C increased by more than 50% between the first and third decades whereas other rootstocks remained stable. Cl- concentrations in lamina and juice at harvest decreased between the first and third decades but those from Teleki 5C remained high, Table 16.

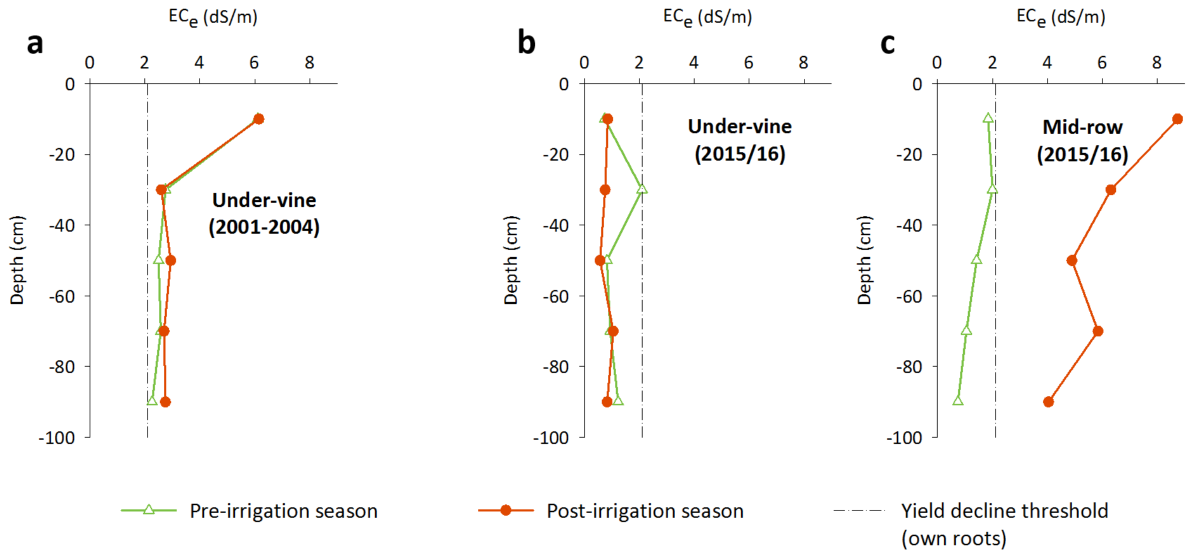

Figure 15. Variation in soil salinity (EC_e dS/m) with depth at a Riverland Shiraz rootstock trial (rrsh6). Change in under-vine salinity pre- and post-irrigation season between 2001-2004 (a) and 2015/16 (b) plus mid-row salinities sampled in 2015/16 (c).

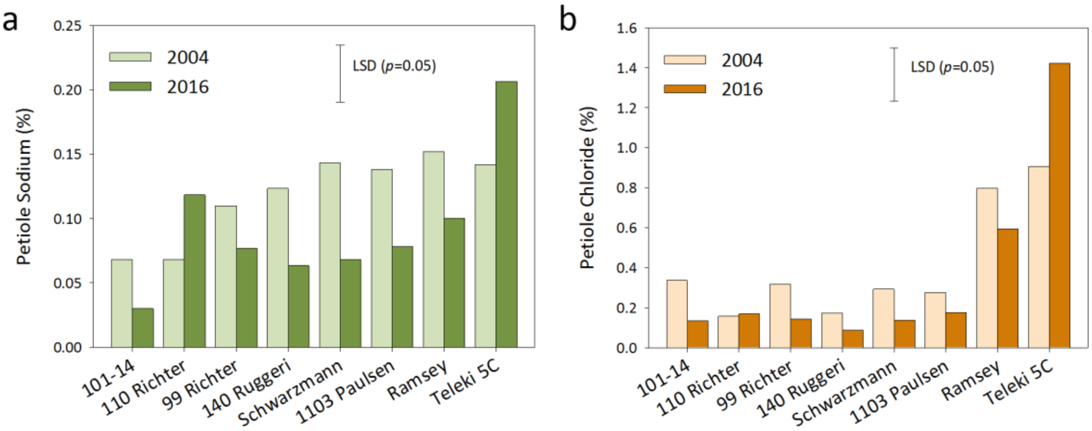

Figure 16. Effect of rootstock genotype and vine age on the concentration of sodium (a) and chloride (b) in leaf petioles collected at flowering from Riverland Shiraz vines at age 8 and 20 years. Least Significant Difference (LSD) bars reflect differences between rootstocks across two decades (*P*=0.05)

Table 15. The effect of rootstock genotype on fruit maturity components (TSS, TA and pH) and juice phenolics at a Riverland Shiraz rootstock comparison trial (rrsh6) aged 20-21 years

	Total soluble solids (°Brix)	Titratable acidity (g/L)	pH	Anthocyanin (mg/g)	Tannin (mg/g)
AGE (yrs)	20-21	20-21	20-21	20-21	20-21
Ramsey	26.0^{a}	4.36^{ab}	3.74^{ab}	0.81^{a}	3.90^{a}
101-14	26.3^{a}	4.60^{a}	3.68^{b}	0.86^{a}	4.00^{a}
1103 Paulsen	26.6^{a}	4.38^{ab}	3.73^{ab}	0.85^{a}	4.11^{a}
Schwarzman	27.6^{a}	4.24^{b}	3.75^{ab}	0.91^{a}	4.34^{a}
99 Richter	26.6^{a}	4.09^{b}	3.82^{a}	0.88^{a}	4.26^{a}
110 Richter	27.1^{a}	4.30^{ab}	3.76^{ab}	0.86^{a}	4.26^{a}
Teleki 5C	27.7^{a}	4.09^{b}	3.81^{a}	0.91^{a}	4.42^{a}
140 Ruggeri	27.0^{a}	4.31^{ab}	3.73^{ab}	0.91^{a}	4.32^{a}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 16. The effect of rootstock genotype on ionic composition of leaf petioles collected at flowering and leaf lamina and juice samples collected at harvest at a Riverland Shiraz rootstock comparison trial (rrsh6) aged 9 and 20-21 years

	Petiole Na^{+} (%)		Petiole Cl^{-} (%)		Lamina Na^{+} (%)	Lamina Cl^{-} (%)	Juice Na^{+} (mg/L)		Juice Cl^{-} (mg/L)		Juice K^{+} (mg/L)	
AGE (yrs)	9	20-21	9	20-21	20-21	20-21	9	20-21	9	20-21	9	20-21
Ramsey	0.15^{b}	0.10^{cdefg}	0.80^{bc}	0.60^{cd}	0.09^{b}	0.21^{b}	52.0^{a}	26.0^{c}	135.0^{a}	55.3^{bcd}	3400^{a}	1220^{c}
101-14	0.07^{fgh}	0.03^{h}	0.34^{de}	0.14^{e}	0.03^{d}	0.09^{c}	-	13.8^{e}	-	37.7^{cde}	-	1163^{c}
1103 Paulsen	0.14^{bc}	0.08^{defg}	0.28^{e}	0.18^{e}	0.06^{cd}	0.08^{c}	16.7^{e}	15.7^{e}	66.5^{bc}	31.1^{e}	3083^{a}	1457^{bc}
Schwarzman	0.14^{b}	0.07^{fgh}	0.29^{e}	0.14^{e}	0.06^{cd}	0.10^{c}	31.9^{c}	17.4^{e}	70.2^{b}	34.3^{de}	3233^{a}	1278^{bc}
99 Richter	0.11^{bcdef}	0.08^{efg}	0.32^{e}	0.14^{e}	0.05^{cd}	0.08^{c}	-	17.1^{e}	-	32.4^{de}	-	1379^{bc}
110 Richter	0.07^{fgh}	0.12^{bcde}	0.16^{e}	0.17^{e}	0.05^{cd}	0.09^{c}	12.9^{e}	18.6^{de}	54.0^{bcde}	33.9^{de}	2950^{a}	1305^{bc}
Teleki 5C	0.14^{bc}	0.21^{a}	0.91^{b}	1.43^{a}	0.16^{a}	0.48^{a}	-	42.1^{b}	-	155.3^{a}	-	1564^{b}
140 Ruggeri	0.12^{bcd}	0.06^{gh}	0.17^{e}	0.09^{e}	0.07^{bc}	0.08^{c}	28.2^{c}	24.8^{cd}	50.0^{bcde}	36.4^{de}	3017^{a}	1411^{bc}

Values followed by the same letter are not significantly different (*P*=0.05)

Riverland Colombard – ID No. rrco2

Location: Loxton

Scion variety/clone: Colombard F13V8

Trial design: 14 rootstocks X 10 replicates

Planted: 1979

Previous assessment: Five seasons; 1982 – 1986 (Nicholas, 2006)

Soil:

0-20	Highly calcareous soft sandy	(5YR3/3)	Clear to:
20-35	Highly calcareous soft light sandy clay loam	(2.5YR4/4)	Gradual to:
35-60	Very highly calcareous sandy clay loam	(5YR4/6)	Gradual to:
60-80	Very highly calcareous light sandy clay loam with 10-20% semi hard carbonate fragments.	(5YR5/8)	Clear to:
80-100	Very highly calcareous light sandy clay loam with more than 50% semi hard carbonate fragments (softened pan).	(2.5YR4/6)	

This vineyard changed ownership in the period between first and fourth decade assessments. Identifying the new owners and locating the historic trial site proved difficult and it wasn't until the 2015/16 vintage that the planting was confidently identified. As a consequence, a number of measures were missed from this site. These included year one harvest assessments and the characterisation of pre-irrigation season soil salinities. Feedback from the current manager suggested that the site once faced pressure from saline soils and that a network of drainage pipes had been installed deliberately to manage saline drainage water. Post-irrigation season soil salinities, following the 2016 vintage, suggest that the current irrigation schedule is sufficient to maintain hospitable soils under-vine but that salts can accumulate at the outer edge of the wetting pattern, in the mid-row soils, Figure 17. It is likely that without adequate leaching, vines would be susceptible to salt uptake through the growing season.

Vine longevity: There were a total of seven dead vines from the 392 assessed. Whilst there were no obvious signs of rootstock incompatibility, more than 70% of the dead vines at this trial site were Colombard vines grafted to Teleki 5C (SO4).

Vigour: Figure 18 suggests that vines grafted to Teleki 5C (SO4) had significantly greater proportions of cordon dieback against own rooted vines and those grafted to all other rootstocks. Some of the better performing vines in terms of retaining productive cordon were those grafted to Ramsey and K51-32. Interestingly at this site, own rooted vines showed relatively low levels of dead cordon.

Yield: On average, yields almost halved over the four decade assessment period. Early in the vineyards life, vines grafted to Ramsey were the most precocious yielders followed by those grafted to K51-40 and 140 Ruggeri. Despite yields reducing with time, Ramsey, K51-40 and 140 Ruggeri remained the highest yielders at age 38 years, Table 17. Much of this was driven by greater bunch counts and the tendency for Ramsey and K51-40 in particular to continue producing larger berries whereas all other rootstocks saw berry size decrease. Across the four decade assessment period, yield from vines grafted to Harmony, Teleki 5C (SO4), Teleki 5A and 5BB Kober declined by more than 65%, a much greater decline than that for other grafted vines.

Fruit maturity: At ages 4-8 years, the heavier yielding vines tended to ripen the slowest. Fruit from vines grafted to Ramsey, and to a lesser extent K51-40 and 140 Ruggeri, had both the lowest TSS and the lowest pH. At age 38, the fruit maturity parameters of TSS, TA and pH were equivalent across all rootstock genotypes excepting Harmony that had a higher juice pH than that from 140 Ruggeri and 420-A, Table 18.

Juice phenolics: Not assessed

Potassium (K^+): Concentrations of K^+ in the juice decreased significantly over the four decade assessment period irrespective of rootstock genotype. Early in the vineyard's life, K^+ in juice was lowest in fruit from vines grafted to 420-A with all other rootstocks being equivalent. At age 38 years, 420-A continued to exclude K^+ from the juice, but so too did 1616 and 110 Richter, Table 19.

Sodium (Na^+): Juice Na^+ concentrations reduced significantly over the four decades across all rootstock genotypes with only those vines grafted to Harmony rootstocks continuing to express elevated levels, Figure 19a. Na^+ in leaf lamina sampled at harvest were low in all vines excepting those grafted to Harmony and Teleki 5C (SO4), Table 19.

Chloride (Cl^-): Over the four decade assessment period, the Cl^- excluding properties of some rootstocks were maintained better than others. Vines grafted to Schwarzmann, 140 Ruggeri, 110 Richter and others had lower Cl^- concentrations at age 38 compared to their first assessment at four to six years of age. Through the same period, vines grafted to K51-40 and Teleki type rootstocks increased their Cl^- uptake. Cl^- presented in juice and leaf lamina at concentrations of two to five times those measured in other grafted vines, Figure 19b and Table 19. Own rooted vines sat between the best and worst salt excluding rootstocks, Figure 19b.

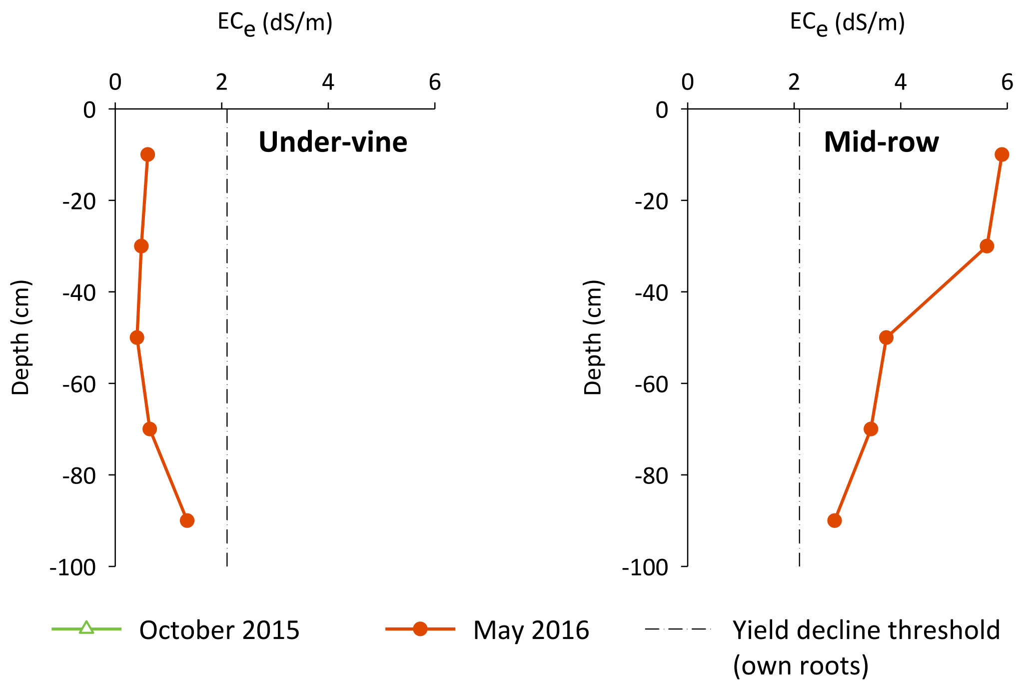

Figure 17. Variation in soil salinity (EC_e dS/m) with depth at a 38 year old Riverland Colombard rootstock trial (rrco2). Samples collected before and after the 2015/16 irrigation season from under-vine and mid-row soils. (October 2015 data not collected)

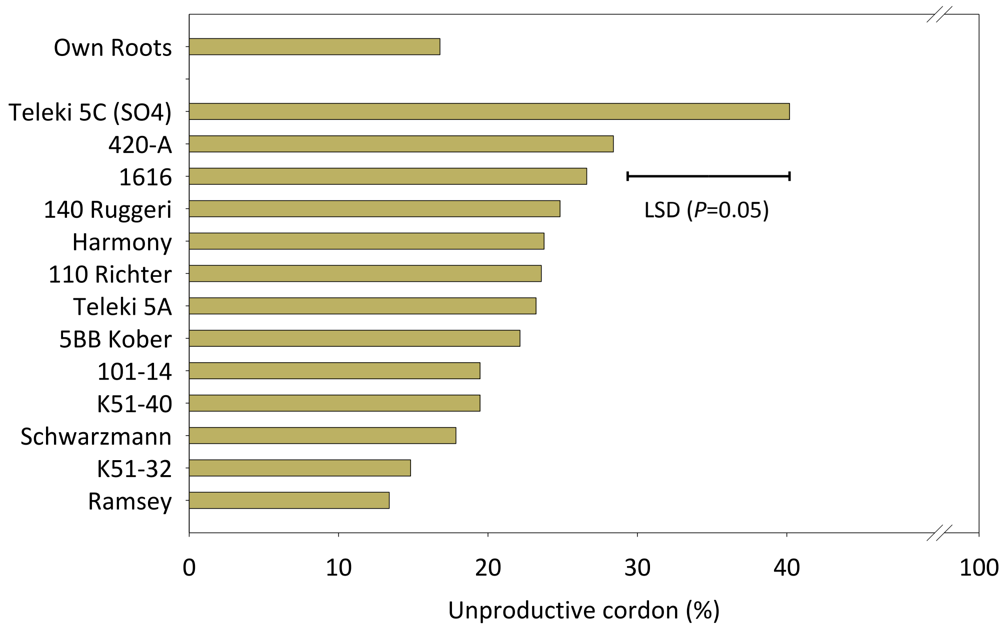

Figure 18. The effect of rootstock genotype on the percent of unproductive cordon at a 38 year old Riverland Colombard rootstock trial (rrco2).

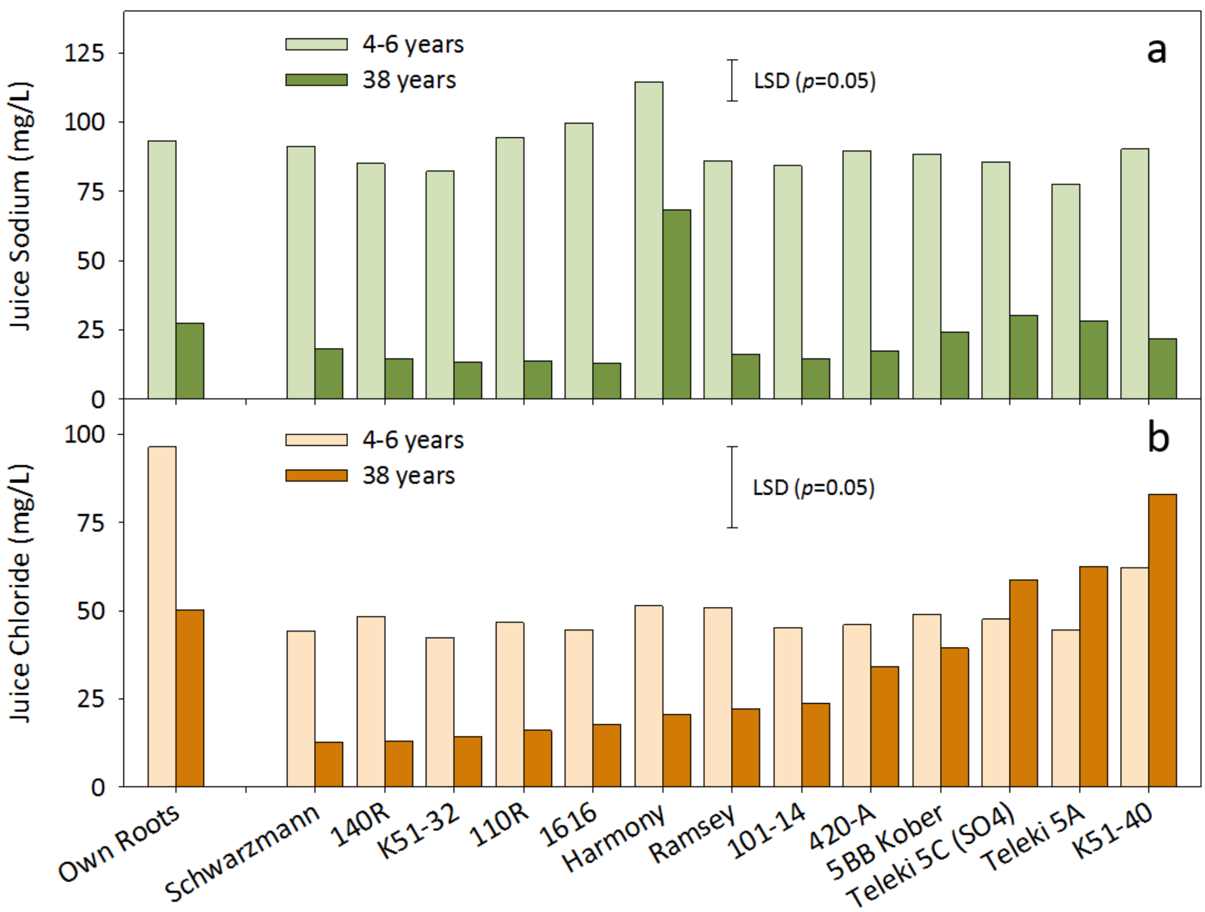

Figure 19. Effect of rootstock genotype and vine age on the concentration of sodium (a) and chloride (b) in juice from Riverland Colombard vines at ages 4-6 and 38 years. Least Significant Difference (LSD) bars reflect differences between rootstocks across four decades (*P*=0.05)

Table 17. The effect of rootstock genotype on yield components at a Riverland Colombard rootstock comparison trial (rrco2) aged 4-8 and 38 years

	Yield (kg/vine)		Bunches (n/vine)		Bunch Wt. (g)		Berry Wt. (g)		Berries/bunch	
AGE (yrs)	4-8	38	4-8	38	4-8	38	4-8	38	4-8	38
Ramsey	25.6^{a}	16.4^{def}	183.0^{def}	251.6^{a}	158.8^{a}	65.7^{f}	1.78^{a}	1.59^{cde}	90.0^{ab}	41.2^{gh}
K51-40	21.2^{b}	12.4^{fghi}	169.6^{efg}	201.3^{bcd}	140.4^{bcd}	62.0^{fg}	1.66^{bcd}	1.37^{ef}	85.0^{bcde}	45.7^{gh}
Schwarz	20.6^{bc}	10.1^{fghij}	155.9^{ghij}	184.0^{cdef}	153.1^{ab}	54.5^{fg}	1.64^{bcd}	1.18^{fghij}	93.0^{a}	46.7^{g}
101-14	20.6^{bc}	10.3^{fghij}	168.2^{fg}	195.7^{bcde}	140.3^{bcd}	54.4^{fg}	1.70^{abc}	1.19^{fghij}	82.4^{cdef}	44.7^{gh}
Harmony	18.4^{bcde}	5.5^{ij}	150.1^{hijk}	152.6^{ghijk}	145.2^{abc}	33.7^{g}	1.63^{bcd}	1.00^{ijk}	89.2^{abc}	33.0^{h}
K51-32	18.8^{bcde}	12.8^{fgh}	144.6^{ijk}	214.7^{bc}	146.8^{abc}	59.5^{fg}	1.60^{cd}	1.29^{fg}	90.7^{ab}	46.9^{g}
140 Ruggeri	21.2^{b}	13.3^{fg}	165.6^{fgh}	227.8^{ab}	157.8^{a}	58.8^{fg}	1.68^{abc}	1.24^{fgh}	92.9^{a}	46.9^{g}
110 Richter	19.3^{bcd}	11.6^{fghij}	169.9^{efg}	216.9^{bc}	139.0^{bcd}	53.0^{fg}	1.62^{bcd}	1.12^{ghijk}	85.8^{bcde}	46.9^{g}
1616	17.7^{cde}	7.0^{ghij}	151.1^{hijk}	129.4^{jkl}	136.8^{cd}	51.7^{fg}	1.73^{ab}	1.19^{fghi}	79.4^{ef}	43.0^{gh}
Teleki 5A	17.2^{de}	6.3^{hij}	148.1^{ijk}	165.2^{fghi}	138.0^{cd}	37.5^{fg}	1.66^{bcd}	0.96^{jk}	83.1^{cdef}	38.4^{gh}
5BB Kober	16.1^{ef}	6.5^{ghij}	143.1^{ijk}	160.6^{fghij}	136.1^{cd}	37.9^{fg}	1.68^{abc}	1.04^{hijk}	81.4^{def}	35.6^{gh}
Teleki 5C (SO4)	16.0^{ef}	5.1^{j}	141.6^{ijk}	148.7^{hijk}	140.1^{bcd}	34.1^{g}	1.64^{bcd}	0.90^{k}	85.2^{bcde}	38.5^{gh}
Own	13.4^{f}	9.5^{fghij}	134.5^{jk}	208.5^{bcd}	120.9^{e}	45.7^{fg}	1.55^{de}	0.97^{ijk}	77.8^{f}	47.7^{g}
420-A	11.6^{fghi}	5.6^{ij}	108.5^{l}	125.6^{kl}	129.4^{de}	43.8^{fg}	1.48^{e}	1.04^{hijk}	87.6^{abcd}	41.3^{gh}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 18. The effect of rootstock genotype on fruit maturity components (TSS, TA and pH) at a Riverland Colombard rootstock comparison trial (rrco2) aged 4-8 and 38 years

	Total soluble solids (°Brix)		Titratable acidity (g/L)		pH	
AGE (yrs)	4-8	38	4-8	38	4-8	38
Ramsey	18.1[e]	22.6[a]	11.84[a]	7.30[g]	3.18[bc]	3.21[abc]
K51-40	19.1[cd]	22.7[a]	11.77[a]	7.18[g]	3.22[ab]	3.20[abc]
Schwarz	19.1[cd]	22.4[a]	11.13[cd]	7.20[g]	3.21[abc]	3.21[abc]
101-14	19.8[bc]	22.1[a]	11.01[def]	7.04[g]	3.19[abc]	3.20[abc]
Harmony	19.5[bcd]	22.6[a]	11.03[de]	7.16[g]	3.23[a]	3.25[a]
K51-32	19.5[bc]	22.8[a]	11.61[ab]	7.20[g]	3.21[abc]	3.18[abc]
140 Ruggeri	18.6[de]	22.2[a]	11.49[abc]	6.98[g]	3.19[abc]	3.17[bc]
110 Richter	19.6[bc]	22.0[a]	11.26[bcd]	7.30[g]	3.17[c]	3.18[abc]
1616	20.1[b]	22.7[a]	11.17[cd]	7.23[g]	3.21[abc]	3.19[abc]
Teleki 5A	19.6[bc]	22.4[a]	11.06[d]	6.96[g]	3.20[abc]	3.18[abc]
5BB Kober	19.4[bcd]	22.2[a]	11.16[cd]	7.06[g]	3.22[a]	3.21[abc]
Teleki 5C (SO4)	19.4[bcd]	22.5[a]	11.03[de]	6.94[g]	3.19[abc]	3.20[abc]
Own	20.0[b]	21.8[a]	10.62[f]	7.17[g]	3.19[abc]	3.18[abc]
420-A	19.5[bc]	22.2[a]	10.65[ef]	7.33[g]	3.16[c]	3.17[bc]

Values followed by the same letter are not significantly different (*P*=0.05)

Table 19. The effect of rootstock genotype on ionic composition of leaf petioles collected at flowering and leaf lamina and juice samples collected at harvest at a Riverland Colombard rootstock comparison trial (rrco2) aged 4-8 and 38 years

	Petiole Cl^- (%)	Lamina Na^+ (%)	Lamina Cl^- (%)	Juice K^+ (mg/L)	
AGE (yrs)	38	38	38	4-8	34
Ramsey	0.3[d]	0.03[c]	0.24[e]	1661[a]	922[cde]
K51-40	0.7[b]	0.02[c]	0.77[ab]	1686[a]	1021[cd]
Schwarz	0.1[d]	0.02[c]	0.12[e]	1683[a]	901[cde]
101-14	0.2[d]	0.02[c]	0.15[e]	1649[ab]	859[cde]
Harmony	0.2[d]	0.09[a]	0.21[e]	1698[a]	1042[c]
K51-32	0.2[d]	0.02[c]	0.18[e]	1663[a]	836[cdef]
140 Ruggeri	0.1[d]	0.02[c]	0.12[e]	1634[ab]	796[ef]
110 Richter	0.2[d]	0.02[c]	0.13[e]	1645[ab]	635[f]
1616	0.3[cd]	0.02[c]	0.29[de]	1672[a]	741[ef]
Teleki 5A	1.0[a]	0.03[c]	0.78[ab]	1630[ab]	890[cde]
5BB Kober	0.8[ab]	0.03[c]	0.59[bc]	1665[a]	900[cde]
Teleki 5C (SO4)	1.0[a]	0.06[b]	0.81[a]	1621[ab]	842[cdef]
Own	0.7[b]	0.02[c]	0.62[abc]	1625[ab]	809[def]
420-A	0.5[bc]	0.03[c]	0.46[cd]	1549[b]	789[ef]

Values followed by the same letter are not significantly different (*P*=0.05)

Riverland Cabernet Sauvignon – ID No. rrcs1

Location: Renmark

Scion variety/clone: Cabernet Sauvignon FVG9V3

Trial design: Eight rootstocks X 10 replicates

Planted: 1992

Previous assessment: None

Soil:

0-10	Firm massive sandy clay loam	(7.5YR3/2)	Clear to:
10-25	Firm massive fine sandy light clay	(5YR3/4)	Clear to:
25-40	Firm weakly blocky light clay	(7.5YR4/6)	Clear to:
40-60	Firm weakly blocky highly calcareous medium clay with 2-10% soft carbonate segregations	(7.5YR5/6)	Gradual to:
60-80	Highly calcareous fine sandy light clay with mottles	(10YR6/4) (7.5YR5/6)	Gradual to:
80-100	Moderately calcareous fine sandy clay loam with mottles	(2.5Y6/2) (10YR6/4)	

Under-vine soil salinity remained below 1 dS/m through the 2015/16 irrigation season, Figure 20. However, the deeper mid-row soils commenced the 2015/16 irrigation season above the 2.1 dS/m yield decline threshold for vines and this concentration of salts in the mid-row escalated through the season, ultimately exceeding 6 dS/m at depth in the mid-row by seasons end. This suggests that irrigations are doing a good job of retaining a non-saline wetted area under-vine but that salts are accumulating at the outer edge of that wetted area in the mid-row. Insufficient leaching could see these salts migrate toward the under-vine soils and present a risk to vine health, particularly if drought conditions present and irrigation allocations are not sufficient to wash salts out of the rootzone.

Vine longevity: No missing vines at age 24 years and no signs of rootstock incompatibility.

Vigour: Cordon dieback was insignificant and equivalent across all rootstock genotypes, Figure 21. There were no notable trunk or foliar symptoms. LAI was not assessed at this site.

Yield: Average yields across the 2015 and 2016 vintages was 18 kg/vine with 2015 yields being approximately 2 kg/vine heavier on average. This corresponded to a significantly lower bunch count in 2016. Across the two year assessment period, vines grafted to K51-40 produced significantly lower volumes of fruit than all other rootstock genotypes excepting J17-69, Table 20.

Rootstock effects on the weight of bunches was modified by season with vines grafted to 140-Ruggeri showing smaller bunches from one year to the next whilst those grafted to J17-48 and K51-40 produced significantly larger bunches from one year to the next. On average K51-40 produced the least number of bunches and these bunches were also trending to be the smallest.

Berries from vines grafted to Ramsey were significantly larger than those from most other rootstocks but particularly vines grafted to 140 Ruggeri and Teleki 5C, Table 20. Fruit from vines grafted to other rootstocks were equivalent and average berry size from all rootstock combinations did not change across the two year assessment period.

Fruit maturity: Commercial harvest occurred one month later in 2015 than it did in 2016, largely driven by intake scheduling issues at the winery during that vintage. As such, fruit was more mature on average in 2015 than in 2016. This difference in fruit maturity was reflected in average TSS values of 24.6 and 22.4 °Brix for 2015 and 2016 respectively and average TA concentrations of 5.97 and 6.54 mg/L for 2015 and 2016 respectively. Average differences between rootstocks across the two vintages were marginal although fruit from vines grafted to K51-40 presented higher TSS than those from higher yielding vines such as those grafted to Ramsey, 99 Richter and 140 Ruggeri, Table 21.

Juice phenolics: The later harvest in 2015 also influenced juice phenolics with 2015 having significantly higher colour density and tannin concentrations. However, tannin concentration was not modified by rootstock genotype. Vines grafted to Ramsey and 140 Ruggeri produced fruit with a lower colour density than the lower yielding vines such as those grafted to K51-40, Table 21.

Potassium (K^+): Juice K^+ concentrations were variable across the assessment period with no real rootstock effect, Table 22.

Sodium (Na^+): Na^+ concentrations in leaf lamina and berries sampled at harvest were low, averaging 0.016% and 12.8 mg/L respectively over the 2015 and 2016 vintages. Vines grafted to K51-40 expressed the highest Na^+ concentration in juice sampled at harvest at 26.1 mg/L, Table 22.

Chloride (Cl^-): Leaf tissue and juice concentrations of Cl^- followed a similar trend with vines grafted to K51-40 expressing more than double the Cl^- concentrations of other rootstock combinations, Table 22.

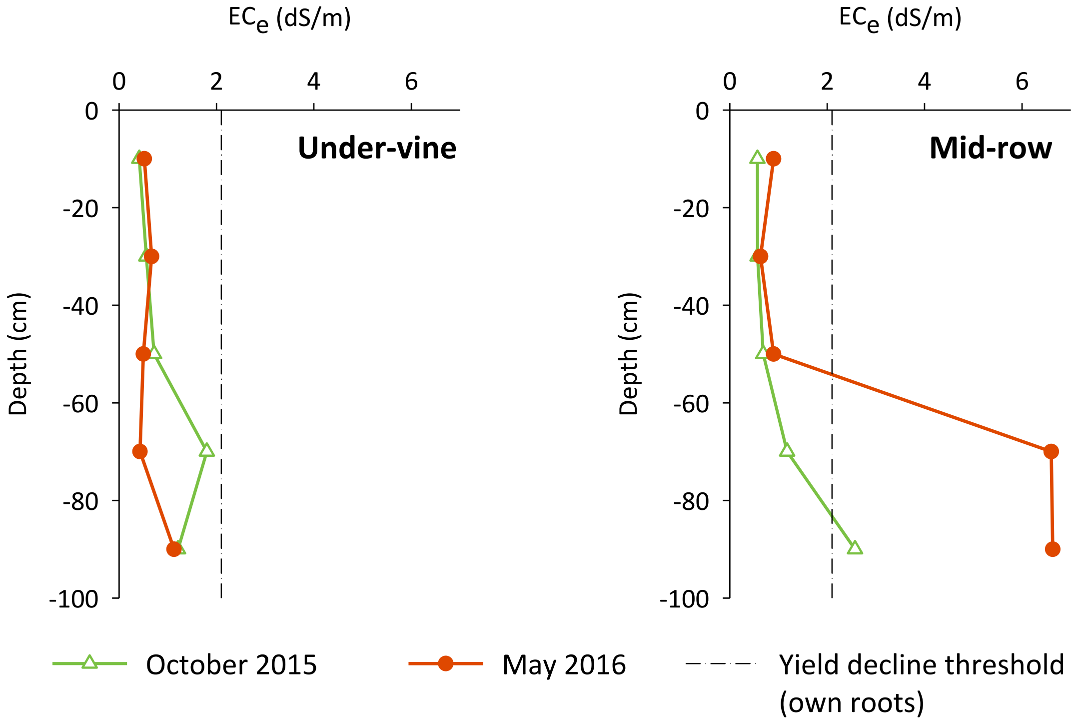

Figure 20. Variation in soil salinity (EC_e dS/m) with depth at a Riverland Cabernet Sauvignon rootstock trial (rrcs1). Samples collected before and after the 2015/16 irrigation season from under-vine and mid-row soils.

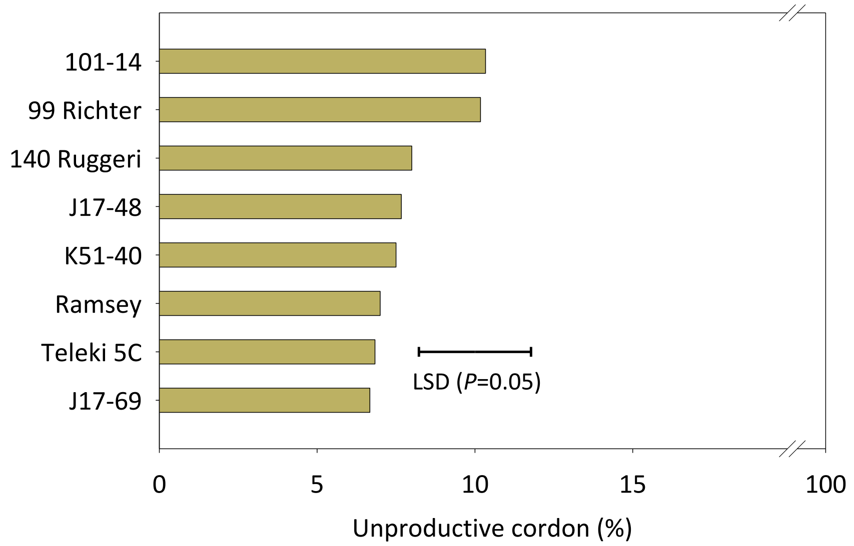

Figure 21. The effect of rootstock genotype on the percent of unproductive cordon at a 24 year old Riverland Cabernet Sauvignon rootstock trial (rrcs1).

Table 20. The effect of rootstock genotype on yield components at a Riverland Cabernet Sauvignon rootstock comparison trial (rrcs1) aged 23-24 years

	Yield (kg/vine)	Bunches (n/vine)	Bunch Wt. (g)	Berry Wt. (g)	Berries/bunch
AGE (yrs)	23-24	23-24	23-24	23-24	23-24
140 Ruggeri	19.0[ab]	352.9[abc]	54.4[abc]	0.96[c]	56.6[ab]
101-14	20.1[ab]	367.2[a]	54.8[ab]	1.02[ab]	53.9[abc]
99 Richter	19.1[ab]	349.5[abc]	54.6[abc]	1.00[bc]	55.0[ab]
Ramsey	19.8[ab]	362.6[ab]	54.5[abc]	1.05[a]	52.0[bc]
J17-48	18.3[ab]	321.9[bc]	58.4[a]	1.01[bc]	58.1[a]
J17-69	17.6[bc]	332.2[abc]	53.4[bc]	0.98[bc]	54.6[ab]
Teleki 5C	18.0[ab]	359.6[ab]	50.8[bc]	0.96[c]	53.1[bc]
K51-40	15.4[c]	312.9[c]	49.9[c]	1.01[abc]	49.4[c]

Values followed by the same letter are not significantly different (*P*=0.05)

Table 21. The effect of rootstock genotype on fruit maturity components (TSS, TA and pH) and juice phenolics at a Riverland Cabernet Sauvignon rootstock comparison trial (rrcs1) aged 23-24 years

AGE (yrs)	Total soluble solids (°Brix) 23-24	Titratable acidity (g/L) 23-24	pH 23-24	Anthocyanin (mg/g) 23-24	Tannin (mg/g) 20-21
140 Ruggeri	23.2[bc]	6.39[ab]	3.52[ab]	0.67[c]	4.82[a]
101-14	23.3[bc]	6.18[ab]	3.48[c]	0.78[ab]	5.16[a]
99 Richter	23.0[c]	6.45[a]	3.48[c]	0.70[bc]	4.78[a]
Ramsey	23.1[bc]	6.33[ab]	3.53[a]	0.68[c]	4.81[a]
J17-48	23.6[abc]	6.16[ab]	3.49[bc]	0.78[a]	5.21[a]
J17-69	23.8[ab]	6.11[b]	3.50[abc]	0.74[abc]	5.20[a]
Teleki 5C	23.8[ab]	6.20[ab]	3.49[bc]	0.76[ab]	5.17[a]
K51-40	24.2[a]	6.24[ab]	3.50[abc]	0.76[ab]	5.22[a]

Values followed by the same letter are not significantly different (*P*=0.05)

Table 22. The effect of rootstock genotype on ionic composition of leaf and juice samples collected at harvest at a Riverland Cabernet Sauvignon rootstock comparison trial (rrcs1) aged 22-23years

AGE (yrs)	Lamina Na^+ (%) 22-23	Lamina Cl^- (%) 22-23	Juice Na^+ (mg/L) 22-23	Juice Cl^- (mg/L) 22-23	Juice K^+ (mg/L) 22-23
140 Ruggeri	0.026[a]	0.07[e]	14.1[b]	35.0[c]	1119[a]
101-14	0.015[a]	0.10[de]	8.7[c]	21.6[c]	984[a]
99 Richter	0.017[a]	0.08[de]	11.4[bc]	21.4[c]	947[a]
Ramsey	0.017[a]	0.12[cd]	15.3[b]	26.5[c]	1131[a]
J17-48	0.016[a]	0.09[de]	8.3[c]	20.4[c]	949[a]
J17-69	0.015[a]	0.20[b]	7.4[c]	30.6[c]	964[a]
Teleki 5C	0.016[a]	0.16[bc]	11.4[bc]	56.3[b]	971[a]
K51-40	0.015[a]	0.45[a]	26.1[a]	111.0[a]	1069[a]

Values followed by the same letter are not significantly different (*P*=0.05)

Riverland Cabernet Sauvignon – ID No. rrcs3

Location: Berri

Scion variety/clone: Cabernet Sauvignon FVG9V3

Trial design: Eight rootstocks X 10 replicates

Planted: 1993

Previous assessment: Four seasons; 1996 – 1999 (Nicholas, 2006)

Soil:

0-15	Slightly calcareous loamy sand	(5YR3/4)	Gradual to:
15-40	Slightly calcareous loamy sand	(5YR4/6)	Gradual to:
40-55	Highly calcareous light sandy clay loam	(5YR4/6)	Gradual to:
55-100	Very highly calcareous sandy clay loam	(5YR6/8)	

There was very little salt pressure at this site with average under-vine and mid-row soil salinities remaining below 1 dS/m throughout the 2015/16 irrigation season, Figure 22.

Vine longevity: At age 23 years, only one of the 240 vines in the rootstock comparison trial had died. That vine was grafted to J17-69. For other vines there was no sign of rootstock incompatibility.

Vigour: Cordon dieback was equivalent across all rootstock combinations at 25 % on average. Much of this was located on the lower cordon and likely shade related. Vine vigour was equivalent across rootstocks (3.5 LAI) excepting that from vines grafted to Teleki 5C (2.9 LAI). The smaller canopies of Teleki 5C vines translated into lower yields relative to other rootstock combinations.

Yield: Yields measured at three to six years of age were compared with those measured at 22 and 23 years of age, Table 23 and Figure 24. Vines grafted to 99 Richter showed no significant change in yield performance with age, maintaining an average yield of 26.3 kg/vine. By comparison, the yield capacity of Cabernet Sauvignon vines grafted to Teleki 5C almost halved over the same time period. Vines grafted to Ramsey, J17-48 and K51-40 also exhibited reduced yield with age, but were still producing in excess of 22 kg/vine in their third decade.

Fruit maturity: Fruit TSS was equivalent across both time periods and was not modified by rootstock genotype, Table 24. Fruit pH was modified by vine age with average pH in the first decade at 4.16 and in the third decade at 3.53. Rootstock differences were marginal in the first decade and not apparent by the third.

Juice phenolics: Colour density tended to decrease with time at this site, averaging 0.9 mg/g anthocyanin aged three to six years and 0.7 mg/g aged 22-23 years. Colour density was lowest for the higher yielding vines such as Ramsey and 101-14. The lower yielding Teleki vines presented fruit with the highest anthocyanin concentrations. Similar trends occurred with tannin concentrations with fruit from the lower yielding Teleki 5C the greatest, 4.8 mg/g and tannin from the high yielding Ramsey vines the lowest, 4.3 mg/g, Table 24.

Potassium (K^+): Juice K^+ averaged 1311 mg/L with no significant rootstock response. In general, there was a predominantly positive relationship between juice pH and K^+ concentrations when considering all rootstocks, Table 25.

Sodium (Na^+): Low Na^+ concentrations in leaf tissue and juice samples reflected the non-saline soil condition. Leaf lamina samples from vines grafted to Teleki 5C and

140 Ruggeri were higher than that of other grafted vines and this carried through to the juice samples from Teleki 5C. All levels, even those from Teleki 5C were below levels that would normally cause concern, Table 25.

Chloride (Cl^-): Whilst salinity pressure was low, Cl^- concentrations in both leaf lamina and juice sampled at harvest was affected by rootstock genotype. Vines grafted to K51-40, J17-69 and, to a lesser extent Teleki 5C, were higher than other rootstock combinations, Table 25.

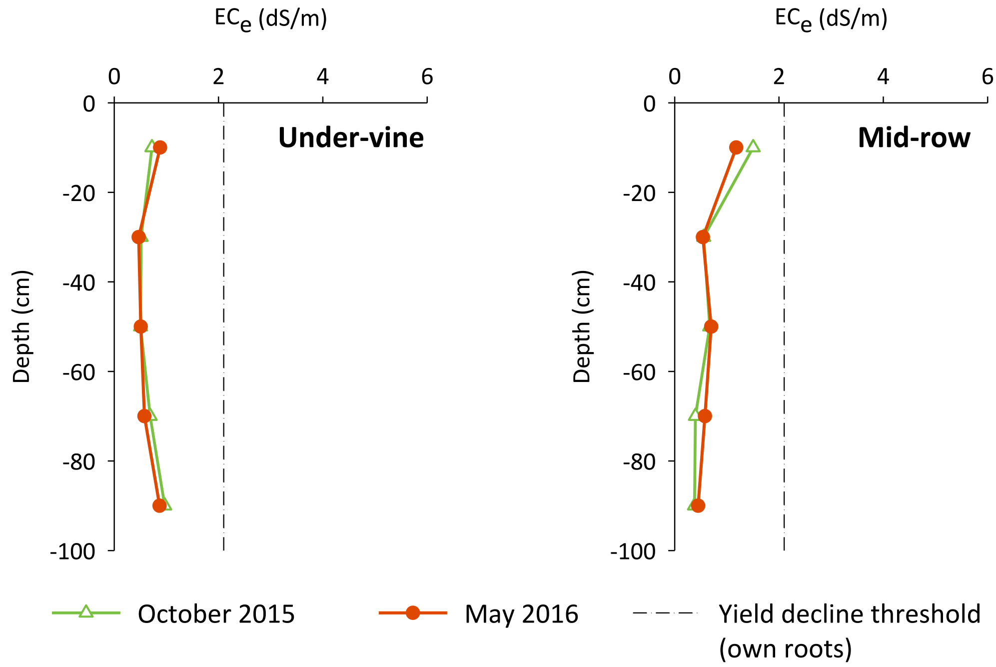

Figure 22. Variation in soil salinity (EC_e dS/m) with depth at a Riverland Cabernet Sauvignon rootstock trial (rrcs3). Samples collected before and after the 2015/16 irrigation season from under-vine and mid-row soils.

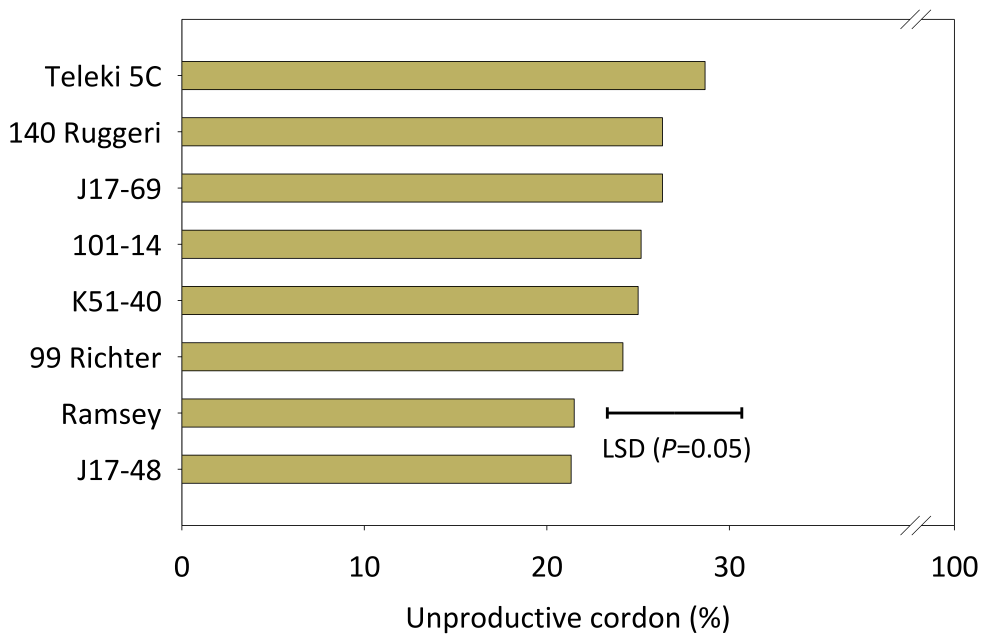

Figure 23. The effect of rootstock genotype on the percent of unproductive cordon at a 23 year old Riverland Cabernet Sauvignon rootstock trial (rrcs3).

Table 23. The effect of rootstock genotype on yield components at a Riverland Cabernet Sauvignon rootstock comparison trial aged 4-7 and 22-23 years

	Yield (kg/vine)		Bunches (n/vine)		Bunch Wt. (g)		Berry Wt. (g)		Berries/bunch	
AGE (yrs)	4-7	22-23	4-7	22-23	4-7	22-23	4-7	22-23	4-7	22-23
140 Ruggeri	27.3c^{def}	24.4^{fgh}	528.6^{ab}	373.5^{cd}	52.8^{e}	65.4^{abc}	0.92^{h}	1.08^{c}	44.2^{b}	60.8^{a}
101-14	30.0^{ab}	28.9^{bcde}	520.2^{ab}	413.6^{c}	57.4^{de}	70.1^{a}	0.98^{def}	1.16^{b}	45.9^{b}	60.8^{a}
99 Richter	26.3^{efg}	26.3^{efg}	510.3^{ab}	399.1^{c}	54.0^{e}	65.7^{ab}	0.94^{fgh}	1.07^{c}	45.1^{b}	61.4^{a}
Ramsey	32.2^{a}	27.1^{cdefg}	541.2^{a}	378.1^{cd}	57.7^{cde}	72.2^{a}	1.01^{d}	1.21^{a}	44.4^{b}	59.8^{a}
J17-48	29.4^{bc}	26.4^{defg}	479.1^{b}	364.4^{cd}	61.0^{bcd}	72.7^{a}	0.99^{de}	1.23^{a}	48.0^{b}	59.1^{a}
J17-69	25.5^{fg}	23.7^{gh}	511.1^{ab}	355.5^{cd}	51.4^{e}	66.9^{ab}	0.87^{i}	1.10^{c}	47.3^{b}	60.9^{a}
Teleki 5C	28.9^{bcd}	19.2^{i}	514.6^{ab}	329.8^{d}	55.5^{de}	57.1^{de}	0.93^{gh}	1.02^{d}	45.9^{b}	56.5^{a}
K51-40	26.5^{defg}	22.1^{hi}	479.4^{b}	334.6^{d}	54.9^{de}	66.2^{ab}	0.96^{efg}	1.16^{b}	44.7^{b}	57.2^{a}

Values followed by the same letter are not significantly different (P=0.05)

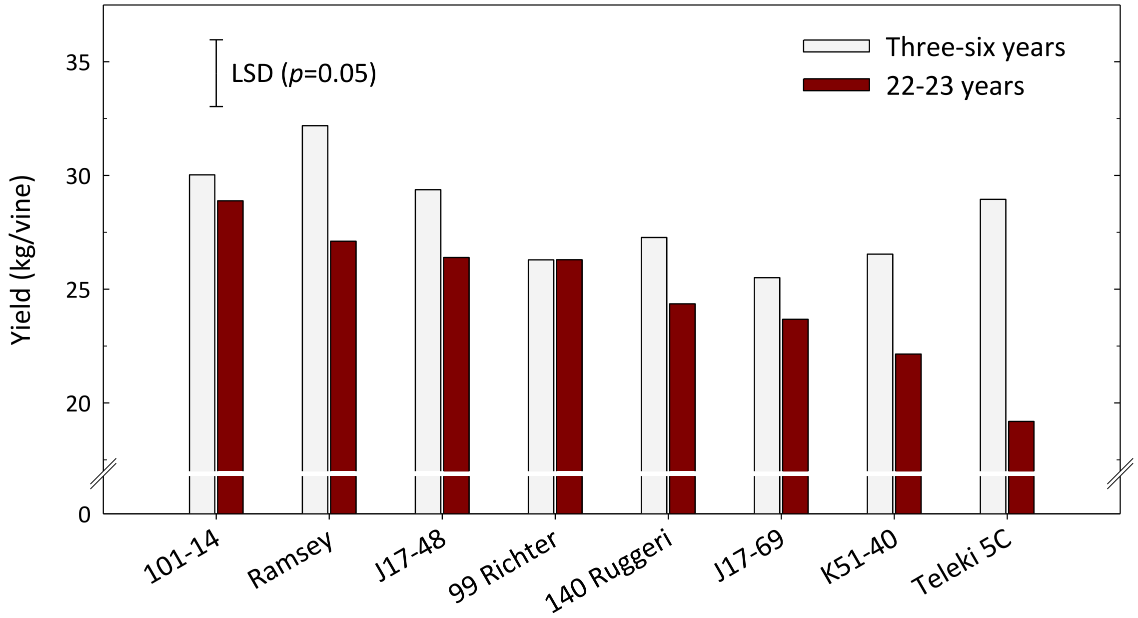

Figure 24. The effect of rootstock genotype on the yield of Riverland Cabernet Sauvignon at a rootstock comparison trial (rrcs3) aged 3-6 and 22-23 years.

Table 24. The effect of rootstock genotype on fruit maturity components (TSS, TA and pH) and on juice phenolics (anthocyanin and tannins) at a Riverland Cabernet Sauvignon rootstock comparison trial (rrcs3) aged 4-7 and 22-23 years

	Total soluble solids (°Brix)		Titratable acidity (g/L)		pH		Anthocyanin (mg/g)		Tannin (mg/g)
AGE (yrs)	4-7	22-23	4-7	22-23	22-23	22-23	4-7	22-23	22-23
140 Ruggeri	24.1^{a}	23.5^{ab}	6.62^{ab}	6.27^{cd}	4.13^{b}	3.53^{d}	0.93^{ab}	0.70^{fg}	4.65^{ab}
101-14	23.9^{ab}	23.1^{b}	6.33^{bcd}	6.09^{def}	4.17^{ab}	3.52^{d}	0.90^{abc}	0.68^{fg}	4.63^{ab}
99 Richter	23.8^{ab}	23.7^{ab}	6.70^{a}	5.90^{ef}	4.18^{ab}	3.53^{d}	0.89^{abc}	0.77^{def}	4.71^{a}
Ramsey	23.2^{b}	23.1^{b}	6.70^{a}	6.32^{bcd}	4.19^{a}	3.55^{d}	0.82^{cde}	0.63^{g}	4.29^{b}
J17-48	23.6^{ab}	23.9^{ab}	6.56^{abc}	5.99^{def}	4.20^{a}	3.56^{d}	0.87^{bcd}	0.71^{fg}	4.70^{a}
J17-69	24.2^{a}	23.6^{ab}	6.67^{a}	6.17^{de}	4.08^{c}	3.52^{d}	0.97^{a}	0.72^{efg}	4.74^{a}
Teleki 5C	23.7^{ab}	23.6^{ab}	6.70^{a}	5.82^{f}	4.16^{ab}	3.52^{d}	0.93^{ab}	0.78^{def}	4.80^{a}
K51-40	23.6^{ab}	24.0^{ab}	6.82^{a}	6.06^{def}	4.15^{ab}	3.53^{d}	0.86^{bcd}	0.75^{ef}	4.73^{a}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 25. The effect of rootstock genotype on ionic composition of leaf and juice samples collected at harvest at a Riverland Cabernet Sauvignon rootstock comparison trial (rrcs3) aged 22-23years

	Lamina Na^{+} (%)	Lamina Cl^{-} (%)	Juice Na^{+} (mg/L)	Juice Cl^{-} (mg/L)	Juice K^{+} (mg/L)
AGE (yrs)	22-23	22-23	22-23	22-23	22-23
140 Ruggeri	0.03^{a}	0.07^{c}	18.3^{b}	24.9^{bc}	1318^{a}
101-14	0.02^{bc}	0.12^{c}	11.5^{b}	19.8^{c}	1318^{a}
99 Richter	0.03^{abc}	0.07^{c}	13.3^{b}	18.8^{c}	1269^{a}
Ramsey	0.02^{bc}	0.12^{c}	12.0^{b}	24.3^{bc}	1177^{a}
J17-48	0.02^{abc}	0.11^{c}	12.0^{b}	17.8^{c}	1454^{a}
J17-69	0.02^{c}	0.43^{b}	11.8^{b}	59.6^{a}	1314^{a}
Teleki 5C	0.03^{a}	0.33^{b}	23.7^{a}	44.7^{ab}	1338^{a}
K51-40	0.03^{ab}	0.70^{a}	16.8^{b}	65.9^{a}	1304^{a}

Values followed by the same letter are not significantly different (*P*=0.05)

Riverland Cabernet Sauvignon – ID No. rrcs5

Location: Kingston on Murray

Scion variety/clone: Cabernet Sauvignon FVG9V3

Trial design: Eight rootstocks X six replicates

Planted: 1996

Previous assessment: None

Soil:

0-10	Light sandy clay loam	(7.5YR4/3)	Clear to:
10-40	Highly calcareous light sandy clay loam	(7.5YR5/4)	Gradual to:
40-70	Highly calcareous sandy clay loam	(7.5YR7/4)	Gradual to:
70-90	Moderately calcareous clay loam, sandy	(7.5YR6/4)	Gradual to:
90-110	Carbonate layer	Nil	

This site was situated directly adjacent to site rrsh6 and comprised similarly skeletal, calcareous soils that are not generally typical of most Riverland vineyards. Yield and vigour assessments were omitted from this site. However, the site's history of above average soil salinity did present an opportunity to assess rootstock salt exclusion characteristics. These measures were complemented by fruit maturity and other fruit quality parameters.

Vine longevity: No missing vines at age 20 years and no signs of rootstock incompatibility.

Vigour: Not assessed

Yield: Not assessed

Fruit maturity: 2015 berry samples were collected at a more advanced maturity than would normally be accepted by the winery and average TSS across the two seasons was therefore higher than typical at 26°Brix. TSS was equivalent across all rootstock genotypes excepting Teleki 5C which was greater than 110 Richter. Vines grafted to 140 Ruggeri had higher pH than those grafted to 101-14, Schwarzmann, 99 Richter and Teleki 5C, Table 26.

Juice phenolics: Juice colour density was greatest in fruit from vines grafted to 99 Richter and 110 Richter and lowest from those grafted to Ramsey. This trend repeated for tannin concentration in juice sampled at harvest, Table 26.

Potassium (K^+): Juice concentrations of K^+ (1312 mg/L) were equivalent across all rootstocks, Table 27.

Sodium (Na^+): Vines grafted to 101-14 expressed significantly lower leaf petiole concentrations of Na^+ than vines grafted to Teleki 5C and Ramsey. This did not translate to differences in leaf lamina sampled at harvest, Table 27. Juice from vines grafted to 101-14 and 140 Ruggeri had significantly lower concentrations of Na^+ compared to vines grafted to Ramsey and, to a lesser extent, Teleki 5C.

Chloride (Cl^-): Cl^- concentrations were greatest in leaf tissue and juice samples collected from vines grafted to Teleki 5C and Ramsey, Table 27. Juice samples from vines grafted to Teleki 5C had three times the Cl^- concentration of fruit from vines grafted to other rootstocks.

Table 26. The effect of rootstock genotype on fruit maturity components (TSS, TA and pH) and juice phenolics at a Riverland Cabernet Sauvignon rootstock comparison trial (rrcs5) aged 20-21 years

	Total soluble solids (°Brix)	Titratable acidity (g/L)	pH	Anthocyanin (mg/g)	Tannin (mg/g)
1103 Paulsen	27.0^{ab}	4.50^{abc}	3.66^{ab}	0.82^{ab}	5.52^{ab}
Ramsey	26.1^{ab}	4.45^{abc}	3.66^{ab}	0.79^{b}	5.35^{b}
101-14	26.6^{ab}	4.66^{ab}	3.61^{b}	0.85^{ab}	5.61^{ab}
140 Ruggeri	26.5^{ab}	4.30^{c}	3.71^{a}	0.84^{ab}	5.91^{ab}
Schwarzman	26.4^{ab}	4.62^{abc}	3.61^{b}	0.86^{ab}	5.82^{ab}
99 Richter	26.4^{ab}	4.71^{a}	3.61^{b}	0.90^{a}	5.76^{ab}
Teleki 5C	27.3^{a}	4.51^{abc}	3.61^{b}	0.85^{ab}	5.81^{ab}
110 Richter	25.8^{b}	4.38^{bc}	3.65^{ab}	0.89^{a}	6.03^{a}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 27. The effect of rootstock genotype on ionic composition of leaf petioles collected at flowering and leaf lamina and juice samples collected at harvest at a Riverland Cabernet Sauvignon rootstock comparison trial (rrcs5) aged 9 and 20-21 years

	Petiole Na^+ (%)	Petiole Cl^- (%)	Lamina Na^+ (%)	Lamina Cl^- (%)	Juice Na^+ (mg/L)	Juice Cl^- (mg/L)	Juice K^+ (mg/L)
1103 Paulsen	0.02^{a}	0.05^{b}	0.02^{a}	0.08^{c}	17.0^{abc}	22.9^{b}	1489^{a}
Ramsey	0.02^{a}	0.39^{a}	0.03^{a}	0.21^{b}	22.1^{a}	42.4^{ab}	1282^{a}
101-14	0.01^{b}	0.09^{b}	0.02^{a}	0.10^{c}	15.0^{c}	22.0^{b}	1211^{a}
140 Ruggeri	0.02^{a}	0.05^{b}	0.02^{a}	0.06^{c}	13.2^{c}	20.9^{b}	1294^{a}
Schwarzman	0.02^{a}	0.08^{b}	0.03^{a}	0.09^{c}	16.3^{abc}	23.0^{b}	1260^{a}
99 Richter	0.02^{a}	0.08^{b}	0.03^{a}	0.07^{c}	15.9^{bc}	24.3^{b}	1361^{a}
Teleki 5C	0.02^{a}	0.56^{a}	0.02^{a}	0.29^{a}	20.9^{ab}	60.7^{a}	1335^{a}
110 Richter	0.02^{a}	0.07^{b}	0.02^{a}	0.08^{c}	16.9^{abc}	24.8^{b}	1269^{a}

Values followed by the same letter are not significantly different (*P*=0.05)

Langhorne Creek Cabernet Sauvignon – ID No. rlcs1

Location: Langhorne Creek

Scion variety/clone: Cabernet Sauvignon FVG9V3

Trial design: Five rootstocks X seven replicates

Planted: 1983

Previous assessment: Five seasons; 1989 – 2001 (Nicholas, 2006)

Soil:

0-15	Hard fine sandy clay loam	(7.5YR3/2)	Clear to:
15-30	Soft massive sandy clay loam	(7.5YR3/1)	Gradual to:
30-75	Very soft sand	(5YR5/8)	Gradual to:
75-100	Firm light medium clay with moderate sub-angular blocky structure	(10YR5/3)	

The site was located on a low lying flood plain and historically prone to periodic flooding from the neighbouring Bremer River. Flows were not sufficient for the River to burst its banks during the period of this investigation and soil salinity was not assessed at this site.

Vine longevity: There were no missing vines at age 33 and no signs of rootstock incompatibility. However, there was widespread evidence of trunk disease through the block, see below.

Vigour: Across the 105 vines within the trial site, 40% of the cordon was assessed as being unproductive, Figure 26. Trunk and foliar symptoms pointed to trunk disease (most likely Eutypa dieback) as being the primary cause. Vines grafted to Teleki 5C (30%), and to a lesser extent Schwarzmann (37%), appeared to withstand the disease pressure better than other rootstock combinations. Despite the reduced incidence of dead wood with Teleki 5C vines, this rootstock trended lower in total yield than those grafted to 110 Richter and Ramsey, both of which had a greater proportion of dead wood.

Yield: Yield components were assessed in the first, second and fourth decades of the vineyard's life. At 32-33 years of age, own rooted vines produced 26% lower yield than vines grafted to Schwarzmann and almost 50% that of vines grafted to 110-Richter, Teleki-5C and Ramsey. This maintained the trend from the early years of the trial, Figure 27 and Table 30.

During the 2015 vintage, Cabernet Sauvignon vines across Langhorne Creek were subjected to elevated levels of bunch stem necrosis (BSN). Yield assessment protocols were modified to account for shrivelled bunches and investigate the influence of rootstock on the incidence and severity of BSN. BSN was found to affect 38% of bunches on

Figure 25. Healthy bunch (L) and BSN affected bunch (R) at a Cabernet Sauvignon rootstock trial in Langhorne Creek (2015)

own rooted vines as compared to 12.5% of bunches on vines grafted to Ramsey, Table 28. Whilst high vigour vines, such as those grown on Ramsey, are reported to be more susceptible to BSN than low vigour vines, this was not the case at this trial. Assessments were repeated in 2016 but the incidence of BSN was much lower than the previous vintage and too low for the rootstock effect to differentiate.

Fruit maturity: In both the second and fourth decades, berries harvested from vines grafted to Ramsey were less mature than those from own rooted vines and those grafted to other rootstocks, Table 31.

Juice phenolics: Fruit from vines grafted to Ramsey also had lower anthocyanin in the second decade. However, anthocyanin and tannin concentrations were equivalent across all rootstock genotypes, Table 31.

Potassium (K^+): Juice K^+ averaged 798 mg/L with no significant rootstock response, Table 29.

Sodium (Na^+): Vines grafted to Ramsey had the highest concentrations of Na^+ in leaf lamina and juice although levels were well below those that would cause concern to the winery, Table 29.

Chloride (Cl^-): Own rooted vines had significantly higher concentrations of Cl^- in leaf lamina and berries sampled at harvest as compared to vines grafted to rootstocks. Again, concentrations were low, Table 29.

Table 28. The effect of rootstock genotype on bunch count, the incidence of bunch stem necrosis and deliverable yields of 32 year old Cabernet Sauvignon vines in a Langhorne Creek rootstock comparison trial (2015)

Rootstock	Total bunch count (n/vine)	BSN incidence (%)	Deliverable fruit (kg/vine)
Own roots	88.0 ^{a}	38.1 ^{a}	2.8 ^{a}
Schwarzmann	98.1 ^{ab}	37.4 ^{a}	3.8 ^{ab}
Teleki 5C	107.4 ^{abc}	35.6 ^{a}	5.0 ^{b}
110 Richter	122.9 ^{c}	25.1 ^{ab}	7.3 ^{c}
Ramsey	109.4 ^{bc}	12.5 ^{b}	7.4 ^{c}
LSD (P=0.05)	*20.2*	*17.6*	*1.9*

Values followed by the same letter are not significantly different (P=0.05)

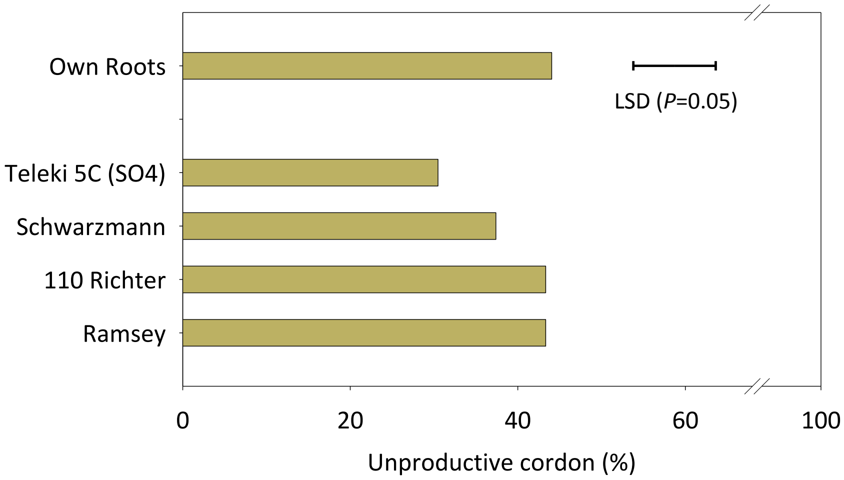

Figure 26. The effect of rootstock genotype on the percent of unproductive cordon at a 33 year old Langhorne Creek Cabernet Sauvignon rootstock trial (rlcs1).

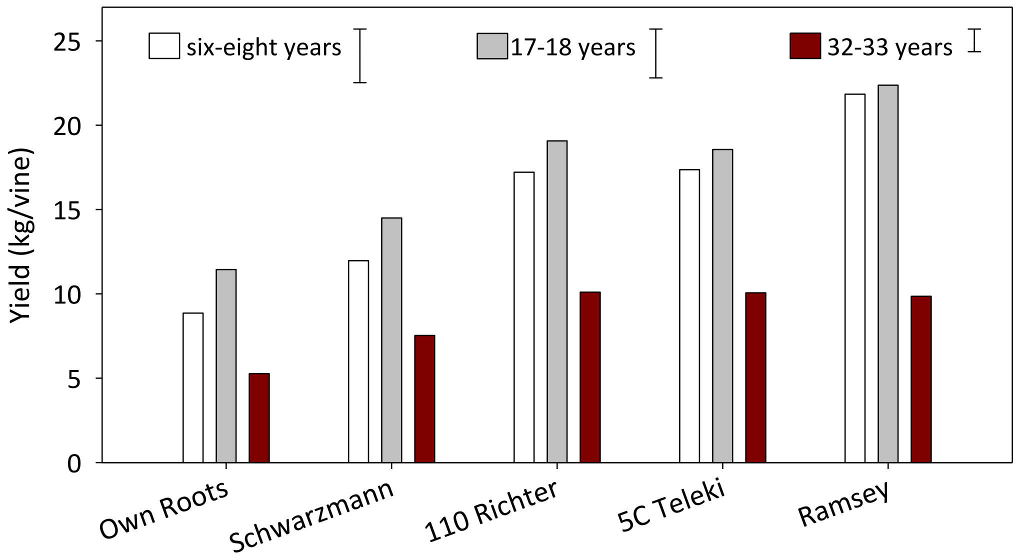

Figure 27. The effect of rootstock genotype on yield of Cabernet Sauvignon vines aged six-eight, 17-18 and 32-33 years. LSD bars (*P*=0.05) represent differences between rootstocks at each age.

Table 29. The effect of rootstock genotype on ionic composition of leaf and juice samples collected at harvest from a Langhorne Creek Cabernet Sauvignon rootstock comparison trial (rlcs1) aged 32-33 years

	Lamina Na^+ (%)	Lamina Cl^- (%)	Juice Na^+ (mg/L)	Juice Cl^- (mg/L)	Juice K^+ (mg/L)
Own roots	0.05^{c}	0.35^{a}	22.9^{b}	21.4^{a}	638^{a}
Schwarzmann	0.05^{bc}	0.08^{c}	28.0^{b}	15.9^{b}	772^{a}
Teleki 5C	0.05^{bc}	0.09^{c}	27.0^{b}	11.3^{b}	818^{a}
110 Richter	0.06^{ab}	0.08^{c}	24.6^{b}	11.6^{b}	831^{a}
Ramsey	0.06^{a}	0.16^{b}	36.0^{a}	11.7^{b}	934^{a}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 30. The effect of rootstock genotype on yield components at a Langhorne Creek Cabernet Sauvignon rootstock comparison trial aged 7-9, 17-18 and 32-33 years

	Yield (kg/vine)			Bunches (n/vine)		Bunch Wt. (g)		Berry Wt. (g)		Berries/bunch	
AGE (yrs)	7-9	17-18	32-33	17-18	32-33	17-18	32-33	17-18	32-33	17-18	32-33
Ramsey	21.8^{a}	22.4^{a}	8.6^{efg}	214.6^{a}	90.5^{d}	106.0^{a}	95.7^{ab}	1.34^{a}	1.13^{abc}	76.8^{bcd}	84.4^{abc}
110 Richter	17.2^{bc}	19.1^{ab}	8.7^{efg}	192.8^{a}	87.7^{de}	96.1^{ab}	100.0^{a}	1.20^{abc}	1.04^{bc}	76.3^{bcd}	98.7^{a}
Teleki 5C	17.4^{bc}	18.6^{abc}	7.5^{fgh}	198.0^{a}	75.0^{def}	95.0^{ab}	98.1^{a}	1.21^{abc}	1.07^{abc}	74.8^{cd}	93.9^{ab}
Schwarzmann	12.0^{de}	14.5^{cd}	5.6^{gh}	167.7^{b}	66.5^{ef}	85.1^{ab}	82.3^{ab}	1.14^{abc}	0.94^{c}	70.6^{cd}	88.0^{abc}
Own Roots	8.9^{efg}	11.4^{def}	4.0^{h}	142.6^{c}	58.1^{f}	81.2^{ab}	68.3^{b}	1.26^{ab}	0.96^{bc}	63.2^{d}	72.1^{cd}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 31. The effect of rootstock genotype on fruit maturity components (TSS, TA and pH) and juice phenolics (anthocyanin and tannins) at a Langhorne Creek Cabernet Sauvignon rootstock comparison trial (rlcs1) aged 17-18 and 32-33 years

	Total soluble solids (°Brix)		Titratable acidity (g/L)		pH		Anthocyanin (mg/g)		Tannin (mg/g)
AGE (yrs)	17-18	32-33	17-18	32-33	17-18	32-33	17-18	32-33	32-33
Ramsey	23.9^{e}	25.2^{d}	4.79^{c}	6.79^{a}	4.07^{c}	3.64^{e}	1.01^{b}	1.17^{ab}	5.45^{a}
110 Richter	24.7^{de}	26.3^{ab}	5.56^{bc}	6.30^{ab}	4.06^{c}	3.56^{f}	1.22^{ab}	1.37^{a}	5.85^{a}
Teleki 5C	25.1^{d}	25.9^{bc}	6.34^{ab}	5.85^{b}	4.10^{bc}	3.62^{ef}	1.36^{a}	1.38^{a}	6.10^{a}
Schwarzmann	25.1^{d}	26.9^{a}	5.84^{b}	5.89^{b}	4.21^{a}	3.71^{d}	1.34^{a}	1.38^{a}	5.97^{a}
Own Roots	25.4^{cd}	26.0^{bc}	5.81^{b}	5.67^{b}	4.17^{ab}	3.59^{ef}	1.34^{a}	1.30^{a}	6.08^{a}

Values followed by the same letter are not significantly different (*P*=0.05)

Langhorne Creek Cabernet Sauvignon – ID No. rlcs2

Location: Langhorne Creek

Scion variety/clone: Cabernet Sauvignon FVG9V3

Trial design: Eight rootstocks X six replicates

Planted: 1993

Previous assessment: None

Soil:

0-10	Hard silty clay loam	(7.5YR3/1)	Clear to:
10-35	Firm silty light medium clay with strong polyhedral structure	(7.5YR4/6)	Clear to:
35-60	Firm silty light clay with strong polyhedral structure	(7.5YR3/2)	Clear to:
60-90	Friable massive light sandy loam	(5YR4/3)	Gradual to:
90-100	Firm sandy light clay with weak sub-angular block structure	(7.5YR4/4)	

Vine longevity: Whilst the commercial vineyard surrounding this trial site was affected by trunk disease, the proportion of dead or dying vines in the vineyard was significantly lower than that observed within the rootstock comparison trial. Within the rootstock comparison trial, half of the vines grafted to 3309 were dead, with the surviving vines presenting a high proportion of unproductive cordon, Figure 28. This extreme mortality is suggestive of incompatibility issues and or a strong susceptibility to trunk disease. Those grafted to Rupestris St. George showed similarly high levels of unproductive cordon, but without the entire collapse of the vine. Vines grafted to 1103 Paulsen or on own roots also presented greater than 40% unproductive cordon, but were significantly more healthy than those on 3309 or St. George.

Vigour: Vine vigour, as assessed by leaf area indexing, reflected the high incidence of dead or unproductive cordon. Average LAI for surviving vines was below 2.0 and significantly lower for surviving vines grafted to 3309 at 0.8.

Yield: Too low to warrant investigation

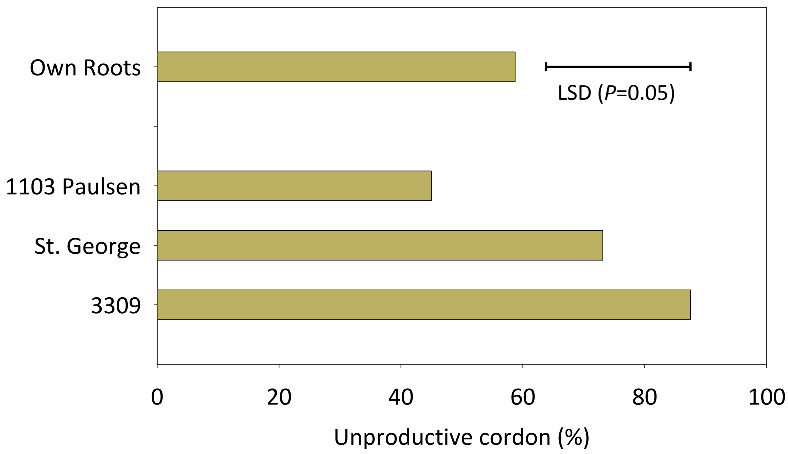

Figure 28. The effect of rootstock genotype on the percent of unproductive cordon at a 23 year old Langhorne Creek Cabernet Sauvignon rootstock trial (rlcs2).

Langhorne Creek Shiraz – ID No. rlsh1

Location: Langhorne Creek

Scion variety/clone: Shiraz BVRC12

Trial design: Four rootstocks X 17 replicates

Planted: 1992

Previous assessment: Four seasons; 1997 – 2001 (Nicholas, 2006)

Soil:

0-15	Firm weakly granular silty loam	(7.5YR3/2)	Clear to:
15-50	Soft silty clay loam with moderate sub-angular blocky structure	(7.5YR3/2)	Clear to:
50-75	Soft silty light clay with moderate sub-angular blocky structure	(7.5YR3/1)	Gradual to:
75-100	Firm medium clay with strong angular blocky structure	(7.5YR3/1)	

This vineyard was situated on silty loam over soft silty light clays, typical of Langhorne Creek flood plain soils. The site had not previously grown vines. Soil salinity was not assessed at this site.

Vine longevity: At age 24 years, there were no signs of rootstock incompatibility. Also, while there was widespread evidence of trunk disease through the block, only one of the 204 vines assessed at this site was reported as dead. That vine was a border vine grafted to 140 Ruggeri.

Vigour: The incidence of cordon dieback was most significant in vines grafted to 110 Richter and those on own roots, Figure 29. Vines grafted to 140 Ruggeri and 99 Richter had significantly lower incidence of dieback. Average vine vigour across the trial was greater than 2.1 LAI. Vines grafted to 110 Richter had significantly smaller canopies with an average LAI of 1.65, data not shown. As expected, vines presenting with the lowest incidence of cordon dieback, and having the highest vigour, were also those that produced the greatest yields.

Yield: Figure 29 and Table 33 show a downward trend in yield performance with age and that the downward trend is consistent across rootstocks. The most likely cause of this reduction is the high incidence of dieback. Early in the vineyards life, own rooted vines were out-yielded by grafted vines by more than 30%, regardless of rootstock. As the vineyard has aged, this margin has contracted to be less than 10% with yields in the third decade effectively being equivalent.

Fruit maturity: In general, fruit from grafted vines were equivalent in TSS, pH and TA at each time step. This is despite sugar contents in the third decade suggesting that sampling occurred at a more advanced maturity than in the first. Fruit from young own rooted vines had higher TSS than that from 99 Richter. This difference was less pronounced when the vines were older and differences instead appeared in the acid content. In the third decade, fruit from own rooted vines had lower pH and higher TA than 99 Richter, Table 34.

Juice phenolics: Early in the vineyards life, the influence of rootstock genotype upon Juice colour density was minimal. As the vineyard has aged, fruit from own rooted vines and, to a lesser extent, 110 Richter expressed higher concentrations of anthocyanin in the juice, Table 34. Tannin concentrations measured in the third decade followed the same trend and shows a correlation between the lower yielding vines producing the better quality fruit.

Potassium (K^+): Average concentrations of K^+ in the juice was not influenced by rootstock genotype at this site, Table 32.

Sodium (Na^+): All grafted vines had significantly lower concentrations of Na^+ in the leaf tissue and juice as compared to own rooted vines, Table 32.

Chloride (Cl^-): Grafted vines also had significantly lower concentrations of Cl^- in leaf tissue and juice samples collected just prior to harvest, Table 32.

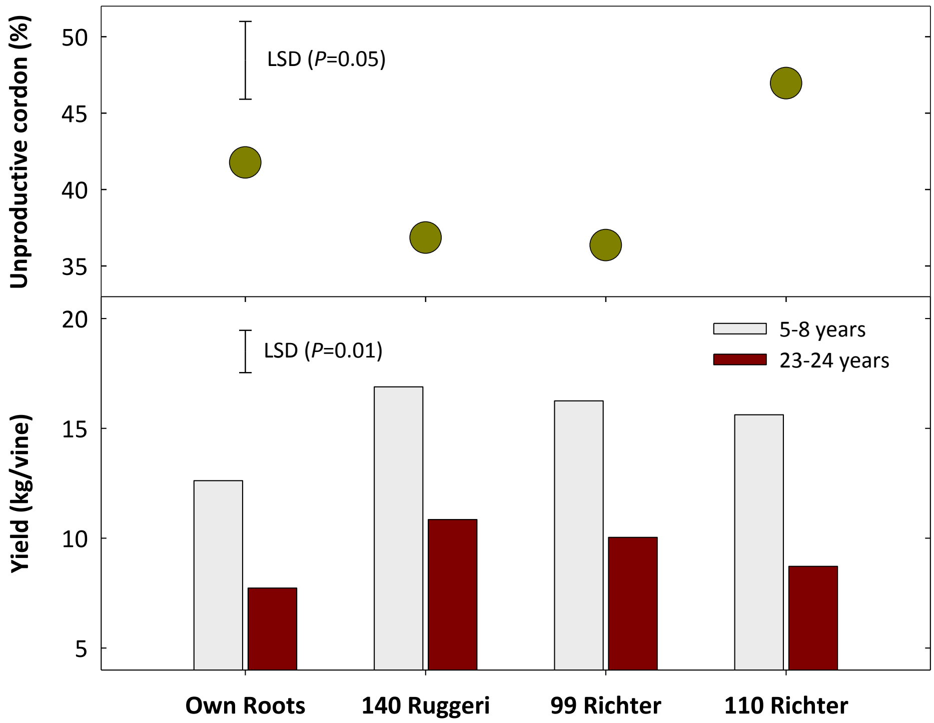

Figure 29. The effect of rootstock genotype on the incidence of cordon dieback (at age 24 years) and yield performance across three decades at a Langhorne Creek Shiraz rootstock comparison trial.

Table 32. The effect of rootstock genotype on ionic composition of leaf and juice samples collected at harvest from a Langhorne Creek Shiraz rootstock comparison trial (rlsh1) aged 23-24 years

	Lamina Na^+ (%)	Lamina Cl^- (%)	Juice Na^+ (mg/L)	Juice Cl^- (mg/L)	Juice K^+ (mg/L)
140 Ruggeri	0.183^b	0.165^b	40.5^b	67.5^b	1653^a
99 Richter	0.191^b	0.175^b	46.7^b	84.2^b	1637^a
110 Richter	0.169^b	0.200^b	39.2^b	111.3^{ab}	1491^a
Own Roots	0.266^a	0.488^a	72.5^a	184.4^a	1469^a

Values followed by the same letter are not significantly different (*P*=0.05)

Table 33. The effect of rootstock genotype on yield components at a Langhorne Creek Shiraz rootstock comparison trial aged 6-7, 9-10 and 23-24 years

	Yield (kg/vine)			Bunches (n/vine)			Bunch Wt. (g)			Berry Wt. (g)			Berries/bunch		
AGE (yrs)	6-7	9-10	23-24	6-7	9-10	23-24	6-7	9-10	23-24	6-7	9-10	23-24	6-7	9-10	23-24
140 Ruggeri	17.4^{a}	14.9^{bcd}	11.2^{fgh}	158.5^{c}	313.9^{a}	143.8^{c}	111.4^{a}	48.6^{f}	79.9^{c}	1.32^{a}	1.00^{e}	1.24^{bcd}	83.9^{a}	49.0^{e}	64.3^{c}
99 Richter	17.1^{ab}	14.4^{cd}	10.3^{gh}	162.1^{c}	277.6^{b}	143.0^{c}	109.3^{ab}	53.3^{ef}	72.7^{cd}	1.30^{abc}	1.00^{e}	1.23^{cd}	83.4^{ab}	52.5^{de}	59.2^{cd}
110 Richter	15.8^{abc}	14.2^{cde}	9.1^{h}	156.3^{c}	249.8^{b}	141.6^{c}	105.6^{ab}	57.7^{ef}	64.6^{de}	1.31^{ab}	1.04^{e}	1.19^{d}	80.0^{ab}	55.9^{de}	54.5d^{e}
Own Roots	12.8^{def}	11.7^{efg}	9.3^{h}	134.0^{c}	263.6^{b}	149.6^{c}	99.9^{b}	46.1^{f}	62.6^{de}	1.29^{abc}	0.90^{f}	1.24^{cd}	76.4^{b}	50.1^{e}	50.5^{e}

Values followed by the same letter are not significantly different (*P*=0.05)

Table 34. The effect of rootstock genotype on maturity (TSS, TA, pH) and juice phenolics (Anthocyanins and Tannins) at a Langhorne Creek Shiraz rootstock comparison trial aged 6-7, 9-10 and 23-24 years

	Total soluble solids (°Brix)			Titratable acidity (g/L)			pH			Anthocyanin (mg/g)			Tannin (mg/g)
AGE (yrs)	6-7	9-10	23-24	6-7	9-10	23-24	6-7	9-10	23-24	6-7	9-10	23-24	23-24
140 Ruggeri	22.4^{cd}	19.3^{ef}	25.2^{a}	4.56^{c}	6.56^{a}	6.22^{b}	3.58^{cd}	3.80^{ab}	3.52^{def}	1.95^{a}	1.12^{e}	1.38^{d}	3.88^{a}
99 Richter	22.2^{d}	18.2^{f}	24.6^{ab}	4.50^{c}	6.61^{a}	6.20^{b}	3.58^{cde}	3.85^{a}	3.51^{ef}	1.95^{a}	1.07^{e}	1.42^{d}	3.89^{a}
110 Richter	22.4^{cd}	18.8^{f}	25.5^{a}	4.39^{c}	6.70^{a}	6.22^{b}	3.57^{cde}	3.74^{b}	3.48^{f}	1.98^{a}	1.13^{e}	1.52^{c}	4.11^{a}
Own Roots	23.7^{bc}	20.6^{e}	25.6^{a}	4.41^{c}	6.77^{a}	6.69^{a}	3.60^{c}	3.80^{ab}	3.40^{g}	1.96^{a}	1.44^{cd}	1.62^{b}	4.14^{a}

Values followed by the same letter are not significantly different (*P*=0.05)

1.3.2 Viticulture rootstock characteristics: Summary of current and new knowledge

There are multiple publications that detail the general characteristics of viticulture rootstocks. These include:

DRY, N. 2007. *Grapevine Rootstocks – Selection and management for South Australian vineyards*. Phylloxera and Grape Industry Board of SA. Lythrum Press, Adelaide.

NICHOLAS, P. R. 1997. *Rootstock characteristics*. The Australian Grapegrower and Winemaker, 400, 30

NICHOLAS, P. R. 2006. *Grapevine rootstock trials in South Australia*. Adelaide, Australia: South Australian Research and Development Institute.

STEVENS, R. M., PITT, T. R., DYSON, C., PECH, J. M. & SKEWES, M. 2011. *Salt tolerant rootstocks for long-term sustainability in the Limestone Coast*. Final report to the GWRDC. Project number: SAR 09/03.

STEVENS, R. M., PITT, T. R., SKEWES, M., PECH, J. M. & NICHOLAS, P. R. 2013. *Variation amongst rootstocks in the tolerance of grafted Chardonnay vines to lethal water-stress*. Wine and Viticulture Journal, 28, 45-49.

VINEHEALTH AUSTRALIA. 2017. *Rootstocks: protection against phylloxera*. www.vinehealth.com.au

WINE AUSTRALIA. 2016. *Grapevine rootstock selector*. www.grapevinerootstock.com

The following section summarises the characteristics of those rootstocks included in SARDI's historic rootstock comparison trials. Each of these rootstocks is Phylloxera resistant and most of them remain widely accepted by industry. Current knowledge is also supplemented with learnings from SARDI's investigations of older rootstock comparison trials. Most of the findings from this and previous SARDI investigations support published rootstock recommendations. However, there are occasional disconnects that should encourage vineyard managers to take caution when making long-term planting decisions. For example, poor drought tolerance in 1103 Paulsen and 140 Ruggeri, the tendency for some grafted vines to declining yields with age and the consistently higher sodium and chloride content in leaf tissue and juice from vines grafted to K51-40 and Teleki 5C.

Rootstock	Published characteristics	SARDI observations at mature trials
Teleki 5C (SO4)	– Moderate to high root knot nematode resistance – Moderate vigour – Moderate/poor drought tolerance – Poor waterlogging tolerance – Moderate/poor salinity tolerance	– Consistently expressed highest salt concentrations in juice and leaf tissues – High rates of mortality and unproductive cordon at 38 yr old Colombard trial – Declining yields with age relative to other rootstocks
420A	– Moderate/high root knot nematode resistance, poor resistance to dagger and root lesion nematodes, low resistance to *Phytophthora spp*. – Moderate/low vigour – Moderate/poor drought tolerance – Moderate/poor waterlogging tolerance – Poor tolerance of soil salinity	– Lowest yields from Colombard grafted to this rootstock

Rootstock	Published characteristics	SARDI observations at mature trials
Teleki 5A (5BB Kober)	– Moderate resistance to root-knot nematode, low resistance to citrus, dagger and root-lesion nematodes – High/moderate vigour and yield – Sensitive to prolonged drought – Moderately sensitive to salt – Sensitive to waterlogging	– High concentrations of Cl^- in juice – Moderate yields
140 Ruggeri	– Variable reports of root knot nematode resistance, low resistance to dagger nematode and crown gall – Moderate/high vigour – High to very high drought tolerance – Moderate/low waterlogging tolerance – Moderate/high salinity tolerance	– Retained good vigour under severe drought stress but yield potential (inflorescence counts) collapsed – Moderate/high yields under full irrigation allocations but subject to decline over time – Good salt exclusion
99 Richter	– Variable reports of nematode resistance and high resistance to various root rots and crown gall – Moderate/high vigour – Moderate/high drought tolerance – Low tolerance to waterlogging – Moderate/low salinity tolerance	– Moderate vigour – Moderate yields stable over time
110 Richter	– Moderate/low resistance to nematodes, root rots and crown gall – Vigour variable, even from the same author – High to very high drought tolerance – Variable waterlogging tolerance – Moderate salinity tolerance	– Retained good vigour and yield potential under severe drought stress – Moderate yields – Moderate/high colour density and tannins in red varieties – Variable salt exclusion
1103 Paulsen	– Moderate to high resistance to nematode, poor resistance to *Phytophthora spp.* – Moderate/high vigour – Moderate/very high drought tolerance – Variable reports of drought tolerance – Moderate to high salinity tolerance	– Anecdotal suggestion of susceptibility to *Cylindrocarpon* root rot in highly irrigated Riverland vineyards, not observed at SARDI sites. – Low incidence of unproductive cordon in a vineyard highly affected by *Eutypa* – Moderate yield – Sensitive to drought stress
K51-40	– High to very high root knot nematode resistance, high citrus nematode resistance, low resistance to root rots and crown gall – Poor drought tolerance; – Low/moderate salinity tolerance	– Consistently expressed high salt concentrations in juice and leaf tissues – Moderate yields – Lower yields under Cabernet Sauvignon – Slightly advanced maturity relative to other rootstocks – Sensitive to drought stress

Rootstock	Published characteristics	SARDI observations at mature trials
Ramsey	– High to very high root knot and citrus nematode resistance, high root lesion nematode resistance, low resistance to dagger nematode, high resistance to *Phytophthora spp.* Low resistance to *Rhizoctonia*, *Fusarium*, *Cylindrocarpon* and *Pythium spp.* and crown gall – Moderate/very high vigour – Moderate/high drought tolerance – Variable waterlogging tolerance – High/very high salinity tolerance	– Retained good vigour and yield potential under severe drought stress – High vigour – High yields (declining more rapidly than other rootstocks at some sites) – More tolerant to BSN than own roots and other rootstocks (Langhorne Creek Cabernet Sauvignon, 2015) – Lower colour density and tannins – Moderate/Low salt exclusion
K51-32	– Moderate/high resistance to root knot nematode, moderate to low resistance to dagger nematode, low resistance to citrus nematode, poor resistance to crown gall – Moderate vigour – Variable drought tolerance – Moderate/low salinity tolerance	– Moderate yield – Low salt uptake – Low incidence of unproductive cordon
J17-48	– NA	– Moderate yields stable over time – Sensitive to drought stress
J17-69	– NA	– Moderate yields stable over time – Sensitive to drought stress
1616	– High resistance to root knot nematode, poor resistance to dagger nematode; – Very high salinity tolerance	– Low/moderate yield – Low/moderate salt uptake
101-14	– Moderate to high resistance to root knot nematode, moderate resistance to dagger and citrus nematodes, low to moderate resistance to *Phytophthora spp.*, high resistance to crown gall – Moderate/low vigour – Moderate/low drought tolerance – Variable waterlogging tolerance – Moderate/high salinity tolerance	– Moderate/high yields stable over time – Moderate vigour – Moderate/low salt uptake – Sensitive to drought stress
Schwarzmann	– Moderate to high resistance to root knot nematode, high resistance to dagger and citrus nematodes, high resistance to *Rhizoctonia* and *Cylindrocarpon spp.*, low resistance to *Fusarium* and *Pythium spp.* – Moderate vigour – Moderate/low drought tolerance – Moderate waterlogging tolerance – Moderate/high salinity tolerance	– Moderate/low yields – Low salt uptake

Rootstock	Published characteristics	SARDI observations at mature trials
3309	– Moderate to low resistance to root knot nematode, high resistance to dagger and root lesion nematodes, low resistance to *Phytophthora spp.* – Variable vigour – Moderate/low tolerance of drought – Variable waterlogging tolerance – Low salinity tolerance	– High mortality – High incidence of unproductive cordon likely due to Eutypa dieback
St George	– High resistance to root knot nematode, low resistance to *Phytophthora spp.* – Moderate/high vigour – Variable drought tolerance – Low tolerance to waterlogging – Moderate/high salinity tolerance	– High mortality – High incidence of unproductive cordon likely due to Eutypa dieback – Persistent suckering
Harmony	– Moderate to high resistance to root knot nematode, high resistance to dagger and citrus nematodes, low resistance to root lesion nematode, high resistance to crown gall – Moderate/high vigour – Low drought tolerance	– Highly susceptible to Na^+ uptake – Low/moderate yield

The following tables provide simple graphical representations of rootstock performance trends as influenced by scion material and irrigation district across the whole life of each vineyard (aged 23-38 years).

Table 35 highlights the tendency for Riverland growers to produce higher yields. Table 40 and Table 41 show the impact that these higher yields have upon colour density and, to a lesser extent, tannin concentrations of juice sampled at harvest. Table 35 also shows the precocious yielding of vines grafted to Ramsey relative to other rootstocks, regardless of vineyard location. The Colombard trial is conspicuous for the elevated concentrations of Na^+ in juice across all rootstocks relative to other sites.

Previously discussed trends for Teleki 5C, K51-40 and, to a lesser extent Ramsey, to present higher concentrations of Na^+ and Cl^- in juice sampled at harvest is masked by the averaging effect of incorporating data from throughout the vineyard's life, Table 38 and Table 39. When considering the 2015 and 2016 vintages alone, Teleki 5C and K51-40 are notable in retaining elevated concentrations whilst those from other rootstocks reduced over time.

Additional analysis of the multiple variables assessed at each site could include multi-site analysis using generalised linear regression models or mixed effects models. This would provide estimates of the differences in rootstock performance between sites and over time, combining both spatial and longitudinal aspects/factors. One recommendation in order to achieve maximum value from such statistical analysis would be to consolidate a selection of rootstocks for which there is both historical and current data over a variety of sites and soil characteristics, but also continue to collect measurements and results for a minimum of two years in addition, to complement the 2015-16 data collection and strengthen the data on recent years. A number of variables and sites have only two years' worth of data (a single bi-annual season), for example many of the phenolic variables, restricting the ability to make conclusive findings.

Table 35. Summary of the interaction between rootstock, scion and region on the average yield of 20+ year old vines. Values represent means of all data collected across three to four decades of vineyard life.

	RIVERLAND									LANGHORNE CRK.	
	Chardonnay		Colombard		Shiraz			Cabernet Sauvignon		Shiraz	Cab. Sauv.
	rrch4	rrch5	rrco2	rrsh2	rrsh3	rrsh6	rrcs1	rrcs3	rrcs5	rlsh1	rlcs1
Own Roots			12.7							11.2	8.2
Teleki 5A			15.4								
5BB Kober			14.5								
Teleki 5C							18.0	25.7			14.9
SO4			14.2								
420-A			10.6								
140 Ruggeri	26.9	23.3	19.9	33.4	28.4		19.0	26.3		14.5	
99 Richter							19.1	26.3		13.9	
110 Richter			18.0	30.9						12.9	15.3
1103 Paulsen				32.5							
Ramsey	30.7	25.4	24.0	33.7	31.0		19.8	30.5			18.2
K51-40	29.8	20.8	19.8	32.3	28.5		15.4	25.1			
K51-32			17.8								
J17-48				28.7			18.3	28.4			
J17-69				32.1			17.6	25.0			
1616			15.9								
101-14	32.8	24.5	19.0	32.6	28.9		20.1	29.7			
Schwarzman			18.8								10.9
3309											
St.George											
Harmony			16.3								

Table 36. Summary of the interaction between rootstock, scion and region on the average TSS (°Brix) of fruit harvested from 20+ year old vines. Values represent means of all data collected across three to four decades of vineyard life.

	RIVERLAND									LANGHORNE CRK.		
	Chardonnay		Colombard		Shiraz			Cabernet Sauvignon		Shiraz	Cabernet Sauv.	
	rrch4	rrch5	rrco2	rrsh2	rrsh3	rrsh6	rrcs1	rrcs3	rrcs5	rlsh1	rlcs1	rlcs2
Own Roots			20.4							23.6	25.8	24.3
Teleki 5A			20.1									
5BB Kober			20.0									
Teleki 5C						27.7	23.8	23.7	27.3		25.6	
SO4			20.1									
420-A			20.0									
140 Ruggeri	22.1	22.5	19.3	22.3	24.1	27.0	23.2	23.9	26.5	22.6		
99 Richter						26.6	23.0	23.8	26.5	22.3		
110 Richter			20.1	22.0		27.1			25.8	22.8	25.8	
1103 Paulsen				21.6		26.6			27.0			24.0
Ramsey	22.2	22.3	19.0	22.0	23.5	26.0	23.1	23.2	26.1		24.7	
K51-40	22.2	22.1	19.8	23.0	24.5		24.2	23.8				
K51-32			20.2									
J17-48				22.3			23.6	23.7				
J17-69				22.3			23.8	23.9				
1616			20.6									
101-14	21.7	21.6	20.2	22.3	23.5	26.3	23.3	23.6	26.7			
Schwarzman			19.7			27.6			26.5		26.3	
3309												24.9
St.George												24.4
Harmony			20.1									

Table 37. Summary of the interaction between rootstock, scion and region on the average K^+ concentration (mg/L) of juice harvested from 20+ year old vines. Values represent means of all data collected across three to four decades of vineyard life.

	RIVERLAND									LANGHORNE CRK.	
	Chardonnay		Colombard	Shiraz			Cabernet Sauvignon			Shiraz	Cab. Sauv.
	rrch4	rrch5	rrco2	rrsh2	rrsh3	rrsh6	rrcs1	rrcs3	rrcs5	rlsh1	rlcs1
Own Roots			1462							1469	638
Teleki 5A			1482								
5BB Kober			1509								
Teleki 5C						1564	941	1339	1335		818
SO4			1465								
420-A			1397								
140 Ruggeri		962	1467	1077		1946	1119	1318	1294	1653	
99 Richter						1379	947	1269	1361	1637	
110 Richter			1443	815		1853			1269	1491	831
1103 Paulsen				997		1999			1489		
Ramsey		859	1513	880		1946	1131	1178	1282		934
K51-40		1289	1550	1147			1069	1305			
K51-32			1497								
J17-48				964			949	1455			
J17-69				993			964	1314			
1616			1482								
101-14		1345	1488	1040		1163	984	1318	1211		
Schwarzman			1526			1930			1260		772
3309											
St.George											
Harmony			1567								

Table 38. Summary of the interaction between rootstock, scion and region on the average Na^+ concentration (mg/L) of juice harvested from 20+ year old vines. Values represent means of all data collected across three to four decades of vineyard life.

	RIVERLAND									LANGHORNE CRK.	
	Chardonnay		Colombard	Shiraz			Cabernet Sauvignon			Shiraz	Cab. Sauv.
	rrch4	rrch5	rrco2	rrsh2	rrsh3	rrsh6	rrcs1	rrcs3	rrcs5	rlsh1	rlcs1
Own Roots			62.7							72.5	22.9
Teleki 5A			54.9								
5BB Kober			58.7								
Teleki 5C						42.1	11.4	23.7	20.9		27.0
SO4			60.5								
420-A			60.9								
140 Ruggeri		46.0	57.3	24.8		26.0	14.1	15.3	13.2	40.5	
99 Richter						17.1	11.4	13.3	15.9	46.7	
110 Richter			58.4	14.3		16.7			16.9	39.3	24.6
1103 Paulsen				14.3		16.0			17.0		
Ramsey		62.1	58.2	25.2		34.7	15.3	12.0	22.1		36.0
K51-40		37.5	61.1	35.2			26.1	16.8			
K51-32			53.7								
J17-48				11.3			8.3	12.0			
J17-69				10.6			7.4	11.8			
1616			64.1								
101-14		19.7	52.2	21.1		13.8	8.7	11.5	15.0		
Schwarzman			60.9			22.3			16.3		28.0
3309											
St.George											
Harmony			89.3								

Table 39. Summary of the interaction between rootstock, scion and region on the average Cl^- concentration (mg/L) of juice harvested from 20+ year old vines. Values represent means of all data collected across three to four decades of vineyard life.

	RIVERLAND									LANGHORNE CRK.	
	Chardonnay		Colombard	Shiraz			Cabernet Sauvignon			Shiraz	Cab. Sauv.
	rrch4	rrch5	rrco2	rrsh2	rrsh3	rrsh6	rrcs1	rrcs3	rrcs5	rlsh1	rlcs1
Own Roots			81.0							184.4	21.4
Teleki 5A			50.6								
5BB Kober			45.7								
Teleki 5C						155.3	56.3	44.7	60.7		11.3
SO4			51.4								
420-A			42.0								
140 Ruggeri		19.4	36.6	34.4		40.9	35.0	24.9	20.9	67.5	
99 Richter						32.4	21.4	18.8	24.3	84.2	
110 Richter			36.4	34.2		40.6			24.8	111.3	11.6
1103 Paulsen				29.9		42.9			22.9		
Ramsey		41.2	41.3	60.5		81.9	26.5	24.3	42.4		11.7
K51-40		92.9	69.2	160.3			111.0	65.9			
K51-32			33.0								
J17-48				42.3			20.4	17.8			
J17-69				92.9			30.6	59.6			
1616			35.7								
101-14		8.6	38.0	64.2		37.7	21.6	19.8	22.0		
Schwarzman			33.8			46.3			23.0		15.9
3309											
St.George											
Harmony			41.1								

Table 40. Summary of the interaction between rootstock, scion and region on the average anthocyanin concentration (mg/g) in juice harvested from 20+ year old vines. Values represent means of all data collected across three to four decades of vineyard life.

	RIVERLAND						LANGHORNE CRK.	
	Shiraz			Cabernet Sauvignon			Shiraz	Cab.Sauv.
	rrsh2	rrsh3	rrsh6	rrcs1	rrcs3	rrcs5	rlsh1	rlcs1
Own Roots							1.64	1.32
Teleki 5A								
5BB Kober								
Teleki 5C			0.91	0.76	0.87	0.85		1.37
SO4								
420-A								
140 Ruggeri	0.67	0.81	0.91	0.67	0.84	0.84	1.42	
99 Richter			0.88	0.7	0.84	0.9	1.46	
110 Richter	0.77		0.86			0.89	1.52	1.3
1103 Paulsen	0.65		0.85			0.82		
Ramsey	0.67	0.78	0.81	0.68	0.74	0.79		1.09
K51-40	0.68	0.82		0.76	0.81			
K51-32								
J17-48	0.8			0.78	0.81			
J17-69	0.7			0.74	0.87			
1616								
101-14	0.72	0.83	0.86	0.78	0.81	0.85		
Schwarzman			0.91			0.86		1.36
3309								
St.George								
Harmony								

Table 41. Summary of the interaction between rootstock, scion and region on the average tannin concentration (mg/g) in juice harvested from 20+ year old vines. Values represent means of all data collected across three to four decades of vineyard life.

	RIVERLAND						LANGHORNE CRK.	
	Shiraz			Cabernet Sauvignon			Shiraz	Cab.Sauv.
	rrsh2	rrsh3	rrsh6	rrcs1	rrcs3	rrcs5	rlsh1	rlcs1
Own Roots							4.14	6.08
Teleki 5A								
5BB Kober								
Teleki 5C			4.42	5.17	4.8	5.81		6.1
SO4								
420-A								
140 Ruggeri	3.27	2.96	4.32	4.82	4.65	5.91	3.88	
99 Richter			4.26	4.78	4.71	5.76	3.89	
110 Richter	3.29		4.26			6.03	4.11	5.85
1103 Paulsen	3.06		4.11			5.52		
Ramsey	2.92	2.69	3.9	4.81	4.29	5.35		5.45
K51-40	2.98	2.87		5.22	4.73			
K51-32								
J17-48	3.47			5.21	4.7			
J17-69	3.05			5.2	4.74			
1616								
101-14	3.02	2.89	4	5.16	4.63	5.61		
Schwarzman			4.34			5.82		5.97
3309								
St.George								
Harmony								

Section 2 Citrus rootstock assessments: Revisiting historic trial sites

2.1 Introduction

Initial citrus plantings in the Riverland were either on own roots, or used pure bred rootstocks such as Sweet orange, Cleopatra mandarin and Rough lemon, which provided some advantages in terms of yield and/or fruit quality. However, as plantings reached old age and replanting of existing orchards began it was recognised that these rootstocks were unable to cope with the disease and nematode load in soils which had previously contained citrus, and to a lesser extent other crops.

Hybrid rootstocks were the answer to this problem, and breeding programs have occurred across the globe, attempting to combine the most advantageous characteristics of a range of *Citrus* species, and some from other, related genera such as *Poncirus trifoliata*, a disease resistant species which is compatible with some *Citrus* species.

A range of these new generation rootstocks have been imported into Australia, or bred here, and SARDI has evaluated a number of them under local conditions and with locally popular varieties. During the period 1989 to 2002, a range of citrus rootstock trials were planted in the Riverland, principally at Loxton Research Centre. Initial evaluation of these trials was conducted for up to 10 years from planting, although most often measurements were not continued past six years of age due to funding limitations.

The now mostly mature trees in these trials were revisited over two harvests (2015 and 2016), and performance evaluated and compared with data collected during the 1980's to early 2000's.

2.1 Materials and methods

2.1.1 Site descriptions and trial analysis

The longevity, tree and cropping performance and fruit quality of trees in four historic rootstock trials were assessed across the 2015 and 2016 harvests. In all, 21 rootstock genotypes were assessed across four rootstock assessment trial sites. None of the trials included *Citrus* species on their own roots. Three of the trial sites were located on Loxton Research Centre, with the fourth being located on a private property between Loxton and Berri.

All the trials were laid out as randomised block designs. Experimental plots consisted of individual trees on which all measurements were undertaken. Site details are shown in Table 42 and the distribution of rootstock genotypes across the trial sites is described in Table 43.

Three of the trial sites had previously been assessed by Peter Gallasch and had associated datasets available for longitudinal comparisons of tree size, yield and various fruit quality parameters. Measurements reported in the current project were collected following the protocols used in the original data collection and recorded in files which were stored at Loxton Research Centre, and described below.

Longitudinal analysis was performed using the R software (R Core Development Team, version 3.1.3, 2015). Means and standard deviations were calculated and plotted as boxplots. Analysis of variance (ANOVA) was used to statistically test for differences between rootstocks and time periods within sites. Pairwise-t-tests were then employed when there were significant main effects and interactions. Results from all statistical analyses were assessed against a significance level of 0.05 and deemed to be statistically significant if the p-value was < 0.05.

Table 42. Description of SARDI's citrus rootstock trials located in the Riverland.

Trial ID.	Scions	Location	Planted	Replicates (n)	Historic data (years)	Row x tree (m)	Row orientation	Soil type *
12 Rootstocks Under Navel Orange	Washington Navel	Loxton Research Centre (34°26 S; 140°36 E)	1988	16	1990-1993	6.5 x 3.0	N-S	Loamy sand to sandy loam over calcium carbonate rubble
8 Rootstocks Under Navel Orange	Navelina Hockney Navel Summer Gold Navel	Loxton Research Centre (34°26 S; 140°36 E)	1997	9	2005-2007	6.5 x 3.0	N-S	Sandy loam over calcium carbonate rubble
Mandarin Rootstocks in Replant Soil	Imperial Mandarin	Solora Estate (35°21 S; 140°36 E)	1999	6	Nil	6.7 x 3.3	N-S	
Mandarin Rootstock Trial	Afourer Mandarin Murcott Tangor	Loxton Research Centre (34°26 S; 140°36 E)	2002	3	2004-2008	7.0 x 4.0	N-S	Sandy loam over calcium carbonate rubble

Table 43. Citrus rootstock genotypes available at SARDI's historic rootstock trials

Rootstock Parentage	Rootstock Genotype	12 Rootstocks Under Navel Orange	8 Rootstocks Under Navel Oranges	Mandarin Rootstocks in Replant Soil	Mandarin Rootstock Trial
Citrus jambhiri	Rough Lemon				
C. limonia	Rangpur Lime				
	Philippine Red Lime				
	Santa Barbara Red Lime				
C. reshni	Cleopatra Mandarin				
C. reticulata	Emperor Mandarin				
C. sunki	Sunki Mandarin				
C. sinensis	Sweet Orange				
C. taiwanica	Taiwanica				
C. volkameriana	Volkameriana				
Poncirus trifoliata	Trifoliata				
P. trifoliata x *C. paradisi*	Swingle Citrumelo				
	F80-5 Citrumelo				
	F80-7 Citrumelo				
P. trifoliata x *C. reshni*	Nelspruit 639				
P. trifoliata x *C. sinensis*	Benton Citrange				
	Carrizo Citrange				
	Troyer Citrange				
	Troyer 341 Citrange				
	C-32 Citrange				
	C-35 Citrange				

2.1.2 Rootstock/Scion Compatibility Assessments

Very early in the project the presence of multiple dead or missing trees in the "8 Rootstocks under Navel Oranges" trial was noted, and investigation revealed that the effected trees all had Navelina as the scion budded to one of three rootstocks (F80-5 or F80-7 citrumelo, or C-35 citrange). A dead tree stump was removed and dissected, and the discontinuity between the scion wood and the rootstock wood can be clearly seen in Figure 30.

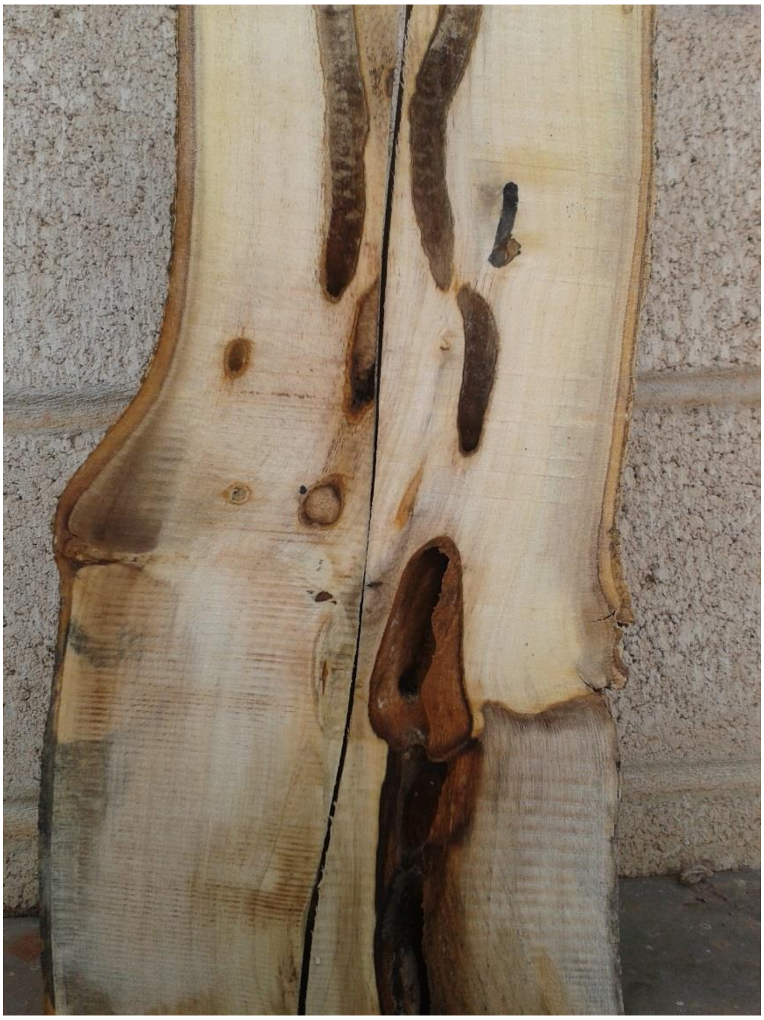

Figure 30. Example of incompatibility response found in the rootstock/scion union

As a result of this observation, all trials were assessed for tree health, using a simple scale of 1 to 5. In the case of three trials (8 Navel Rootstocks and the two Mandarin Rootstock trials) windows were cut in the bark of some or all trees in the trial to assess the presence of crease development at the bud union (Garnsey et al., 2001, Schneider and Pehrson, 1985) (Figure 31).

In addition, tree size was assessed by measuring tree height and canopy width to the nearest 0.1 m using a long graduated pole, to assess relative tree size, and this was compared to relative rankings of trees in historical data sets to determine any changes in relative performance. Also, trunk circumference was measured using a tape measure, at approximately 5 cm above and below the bud union. As well as comparing the bud union size between rootstocks, the relative size difference between the scion (above) and the rootstock (below) was assessed and compared, as an indication of the development of overgrowth by either scion or rootstock, which can lead to bud union girdling as trees develop (Owen-Turner, 1995).

Figure 31 Bud union crease indicating developing incompatibility between scion and rootstock

2.1.3 Yield and fruit quality

Fruit production was assessed across all replicates of the three trials at Loxton Research Centre. All the fruit from each tree was harvested and weighed at each harvest (2015 and 2016). At all four trial sites samples of 10 fruit per tree were collected from every tree, with fruit selected from all around the tree, from different heights above the ground and from the inside and outside of the canopy. The samples were transported from the field to laboratory cool room in labelled plastic bags, and stored in the cool room until processed in the laboratory, usually within a few days of collection.

After weighing each of the 10 fruit, the fruit were sliced in half and the inside (flesh only) and outside (flesh and rind) diameters measured, allowing determination of rind thickness. The fruit were then juiced and the juice weighed to determine percentage juice content.

Juice samples were collected and kept frozen until they were delivered to a commercial laboratory (Venus Citrus Fruit Packers, Loxton). Total soluble solids concentration was measured by digital refractometer and expressed as °Brix 20°C. Juice titratable acid (TA) concentration was measured by titration against 0.133 M NaOH. Sugar:Acid Ratio (SAR) and BrimA were calculated from these data.

In October 2016 a power failure to the freezer resulted in the defrosting and spoilage of all the juice samples collected for that harvest. As a result no sugar and acid data was collected in 2016.

2.2 Results and discussion

2.2.1 Outcomes from citrus rootstock investigations

12 Rootstocks Under Navel Orange

Location: Loxton Research Centre

Scion variety/clone: Local "Herps" clone of Washington navel orange

Trial design: 12 rootstocks X 16 replicates

Planted: 1988

Previous assessment: Four seasons; 1990 – 1993

Soil:

0-35	Moderately calcareous sandy loam
35-50	Highly calcareous light sandy clay loam
50-155	Very highly calcareous sandy clay loam (compact mixture of fine and rubbly lime and loamy soil)

Tree vigour: Measurements of tree height and width indicate considerable variation between rootstocks in the size of mature trees (28-29 year values in Figure 32). The canopies of the mature trees form a continuous hedgerow, and the trees are therefore competing for sunlight at the canopy level, and most likely for water and nutrients at root level.

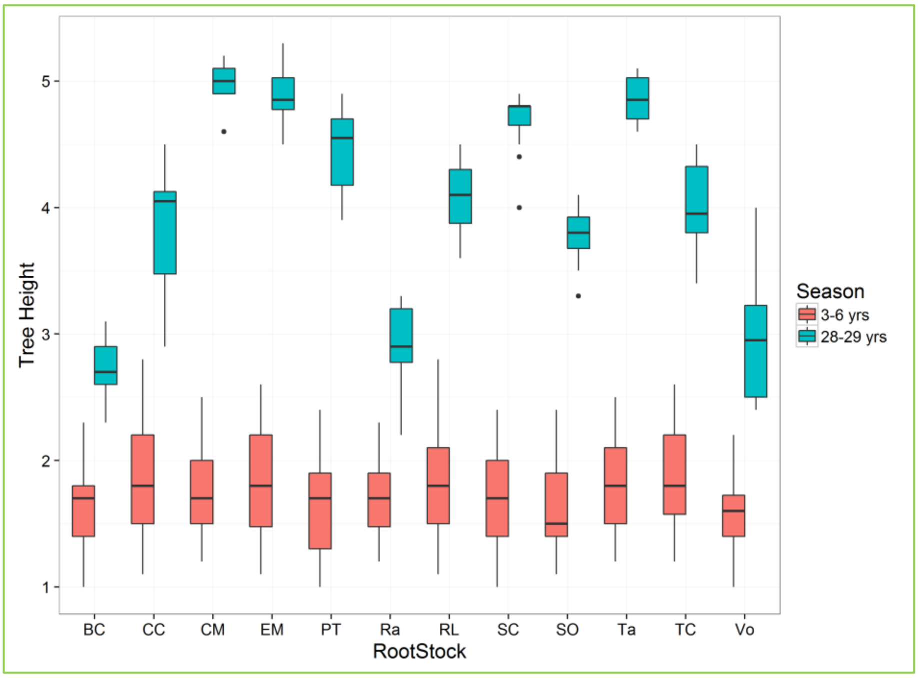

Figure 32 Tree height data for Washington navels on 12 rootstocks

Trees on Benton citrange (BC), Rangpur lime (Ra) and Volkameriana (Vo) in particular are smaller (both as young trees and at maturity), suggesting a lower level of vigour from the beginning. On the other hand, trees on Cleopatra mandarin and Trifoliata were slow to grow at first, but produced amongst the largest trees at maturity.

Compatibility: No obvious symptoms of incompatibility were observed at this site. Tree vigour differences appear to be the result of competition rather than compatibility issues.

Yield: There is some correlation between tree vigour and yield, especially in mature trees (compare 28-29 year values in Figure 32 and Figure 33). Thus the least vigorous rootstocks were also the lowest yielding. However, Sweet orange (SO) demonstrated low yield on a moderate sized tree, and Taiwanica (Ta) showed moderate yields on a large tree, indicating low yield efficiency by trees on these two rootstocks.

Yield in young trees (3-6 years, Figure 33) was quite variable, with zero yields on some trees and higher yields on other trees and in other seasons across all rootstocks. The citranges (Benton (BC), Carrizo (CC) and Troyer (TC)) all showed relatively high yield potential in these early years, but by years 28-29 yield on Benton had barely increased at all, and both Carrizo and Troyer had dropped behind the best performers.

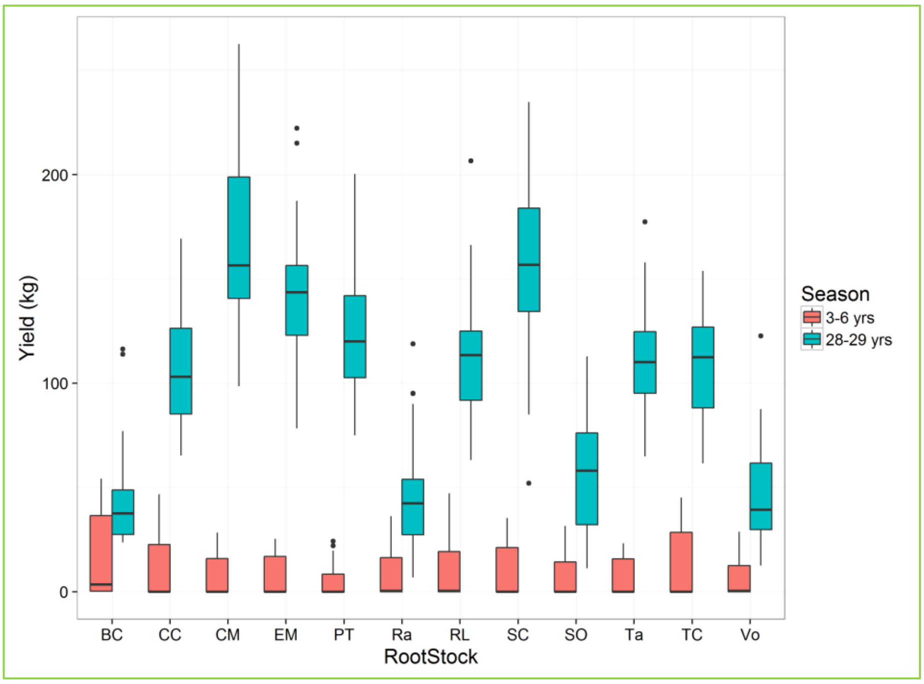

Figure 33 Yield per tree from Washington navels on 12 rootstocks

Fruit quality: Some differences in fruit quality were observed. Weight of individual fruit varied from year to year in a biennial cycle, with high yielding years producing smaller fruit and low yielding seasons producing large fruit. Juice percentage also varied biennially, with large fruit having lower juice content, and smaller fruit having higher juice percentage.

Rough lemon produced lower acid concentration on average than other rootstocks (Figure 34), but Brix levels were similar, resulting in higher Brix/acid ratios.

Rind thickness, both expressed as absolute thickness and as percentage of fruit size decreased significantly with tree age. Thus, young trees produced fruit with thicker rinds for the same sized fruit.

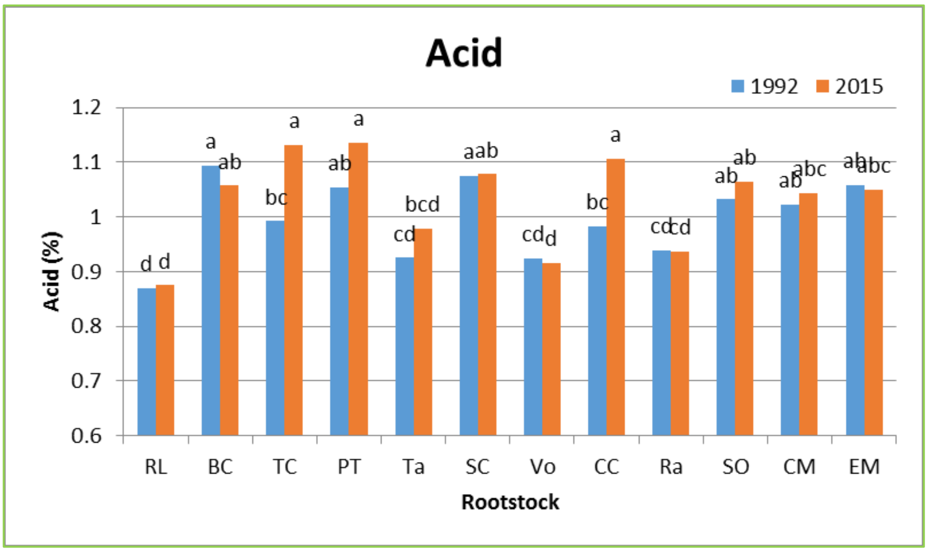

Figure 34 Juice acid concentration from Washington navels on 12 rootstocks

8 Rootstocks Under Navel Orange

Location: Loxton Research Centre

Scion variety/clone: Navelina 315 (Spanish clone)
"Hockney" navel
"Summer Gold" late navel

Trial design: 3 varieties x 8 rootstocks X 9 replicates

Planted: 1997

Previous assessment: Two seasons; 2005 & 2007

Soil:

0-35	Non calcareous sandy loam
35-180	Highly calcareous light sandy clay loam (compact mixture of fine and rubbly lime and loamy soil)

Tree vigour: No historical tree vigour or size data was found for this trial. Mature tree results varied between scions (Navelina, Hockney and Summer Gold).

Navelina trees showed highly variable vigour, with Sunki mandarin producing the smallest trees, and Cleopatra mandarin producing the largest trees. Tree vigour was severely compromised in Navelina on C-35 citrange, as well as F80-5 and F80-7 citrumelo, to the point where many of the trees of these combinations were dead (see "Compatibility" below).

Hockney trees displayed evidence of dwarfing on C-35 citrange, and to a lesser extent Sunki mandarin and F80-5 citrumelo. Cleopatra mandarin again produced the largest trees.

Summer Gold trees displayed more even tree size across rootstocks, but trees on C-35 citrange, Philippine Red lime and Sunki mandarin were the smallest, and Cleopatra mandarin the largest.

Compatibility: Of a total of 27 Navelina trees on F80-5 and F80-7 citrumelo, and C-35 citrange, only seven survived in 2016. Figure 35 shows the pattern of deaths over time, beginning in 2008, at age 10 years. In all other scion/rootstock combinations, all trees survived.

Observation of the bud union of affected trees indicated the development of a bud union crease, where woody tissue of the rootstock and scion grew independently, leaving a gap between scion and rootstock (Figure 31). Over time this creasing apparently led to the death of most of the trees affected. However, some of the remaining trees appeared to be in reasonable health despite the presence of a pronounced crease.

A SARDI Factsheet was produced and published on the PIRSA and Citrus Australia Limited (CAL) websites, warning of problems with Navelina on these rootstocks.

No symptoms of incompatibility were observed in Navelina trees on any of the other rootstocks, or any Hockney or Summer Gold trees on any rootstocks. The dwarfing observed in Hockney trees on C-35 and Sunki is thought to be the result of a response by the rootstock to viroids present in this variety (pers. comm. Graeme Sanderson, NSW DPI, Dareton).

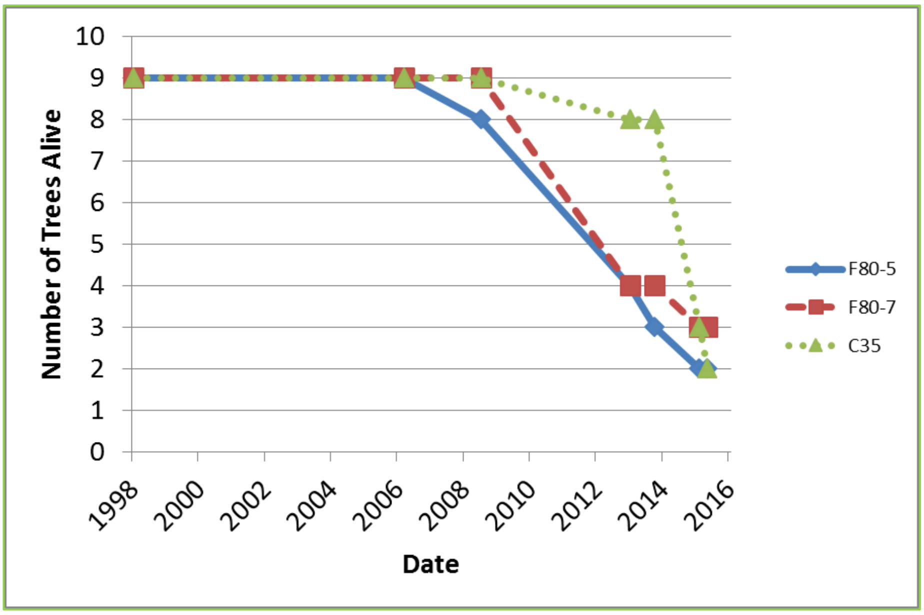

Figure 35 Tree survival over time for Navelina trees on three rootstocks

Yield:

Yield data are available for 2005, 2007 (Hockney and Summer Gold only), 2015 and 2016. Results vary between scions.

Yield from **Navelina** trees increased between the age of 9 years and 19-20 years on all rootstocks, although the increase from trees on Sunki mandarin (SM) was smaller than on any other rootstock, and this rootstock produced the lowest yields at maturity. Yields from C-35 citrange and F80-5 citrumelo trees was also low at 19-20 years of age, reflecting poor tree vigour and health due to incompatibility. Surprisingly, the surviving trees on F80-7 citrumelo yielded well, although only two of the original nine trees remained alive.

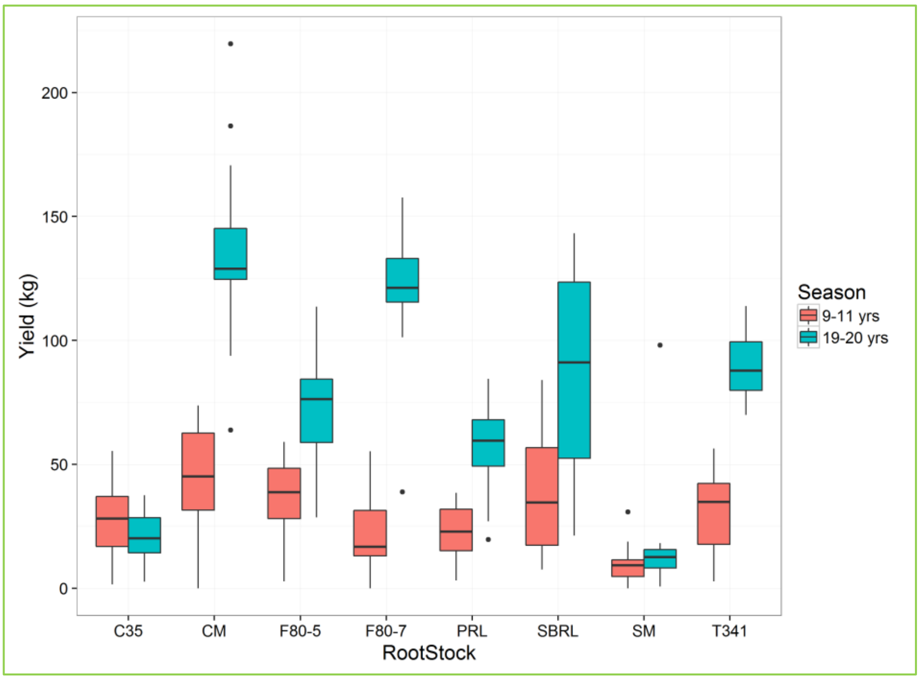

Figure 36 Yield per tree from Hockney navels on 8 rootstocks

Hockney trees on C-35 citrange and Sunki mandarin showed no significant increase in yield from 9-11 to 19-20 years of age (Figure 36), and trees on F80-

5 citrumelo and Philippine Red lime (PRL) showed only moderate increase in yield. Trees on Cleopatra mandarin (CM) and F80-7 produced the highest yields in mature trees.

Summer Gold trees on four rootstocks demonstrated no increase in yield between the ages of 9-11 and 19-20 years (C-35 citrange, Philippine Red lime, Santa Barbara Red lime (SBRL) and Sunki mandarin) (Figure 37).

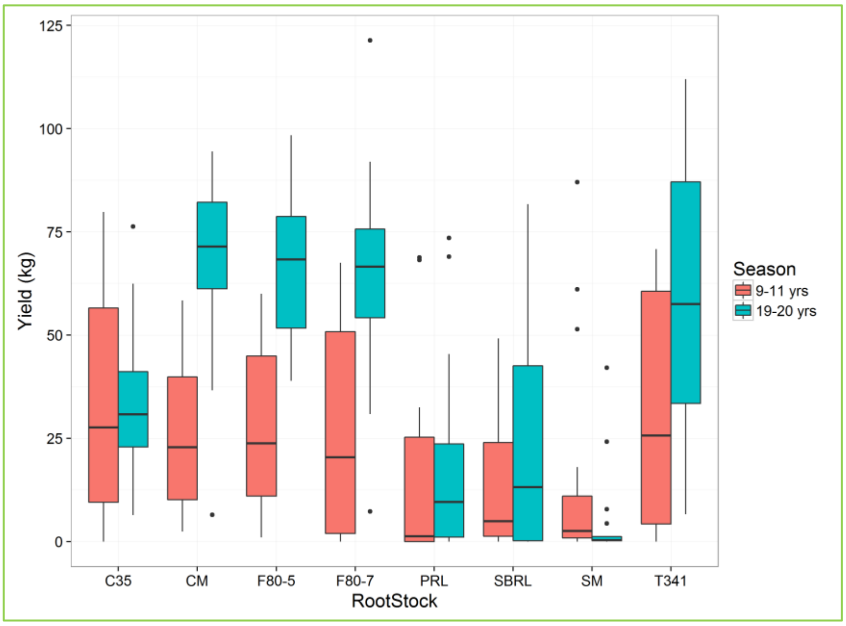

Figure 37 Yield per tree from Summer Gold navels on 8 rootstocks

Fruit quality:

Fruit quality measures can vary between seasons as a result of climatic conditions, crop load and time of harvest. As a result differences between rootstocks are expected to be more critical than between season variation.

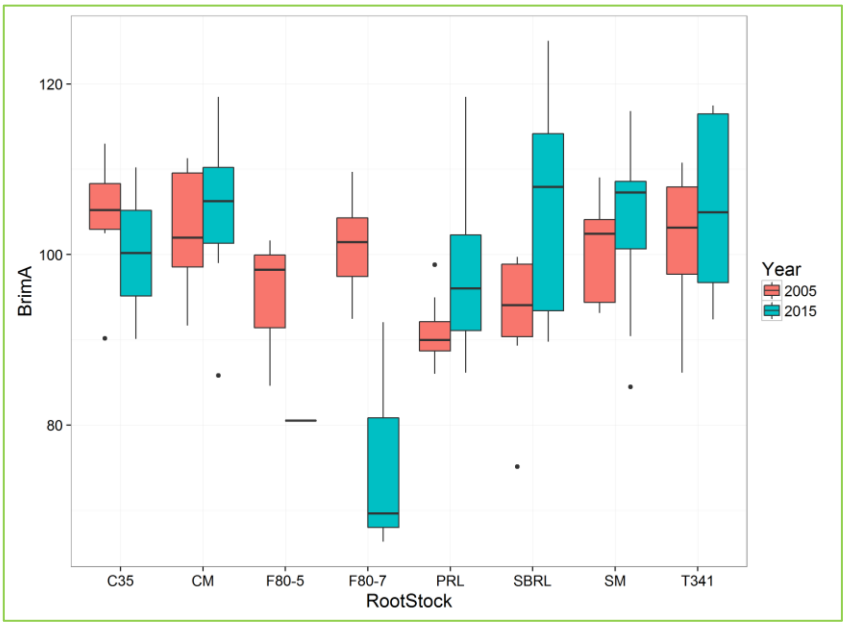

Figure 38 BrimA readings from Navelina trees on 8 rootstocks

Navelina trees showed higher Brix and acid levels in 2015 than in 2005, except for trees on F80-5 and F80-7 citrumelo, which showed lower Brix. As a result these rootstocks also produced lower Brix/acid ratio and BrimA scores in 2015 than in 2005, whilst most other rootstocks showed minimal change between seasons in these parameters (Figure 38). The data for these trees came from the very low number of surviving trees in the trial, and may reflect poor performance of these trees due to incompatibility symptoms affecting the trees' ability to grow and mature fruit.

Hockney trees showed no specific patterns in any fruit quality parameters.

Summer Gold trees on C-35 citrange demonstrated higher Brix (Figure 39), and as a result higher BrimA values, than other rootstocks in the 2015 harvest, but not in the 2005 harvest. The significance of this result is not clear.

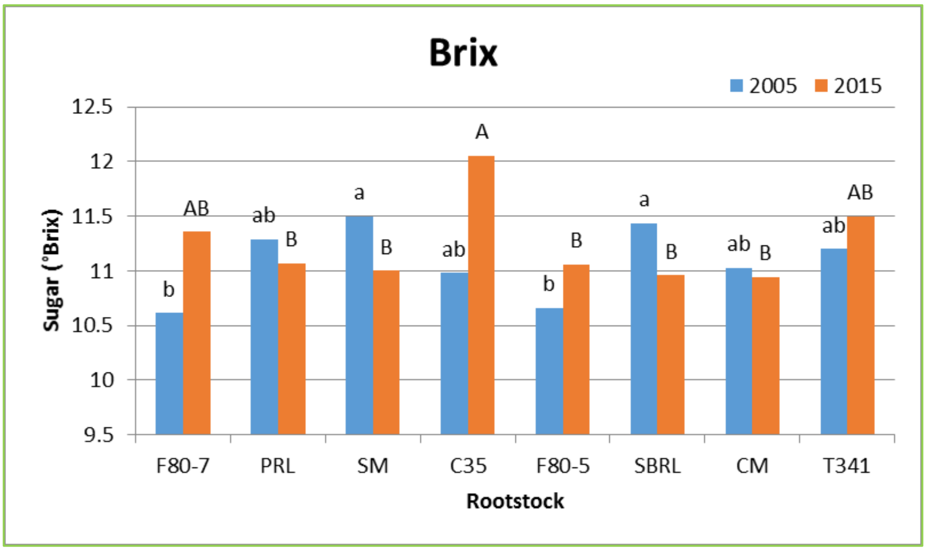

Figure 39 Brix readings from Summer Gold trees on 8 rootstocks

Mandarin Rootstocks in Replant Soil

Location: Solora Estate, Lock 4

Scion variety/clone: Imperial mandarin

Trial design: 9 rootstocks X 6 replicates

Planted: 1999

Previous assessment: None

Soil: Top soil depth variable from 50 to >130 cm
Subsoil ranging from non calcareous (no carbonate layer) to very highly calcareous (compact mixture of fine and rubbly lime and loamy soil)

Tree vigour: Tree health was visually assessed at this site, but no measurements of tree size were taken. Trees on most rootstocks scored above 3 for tree health on a scale of 0 to 4. The average score for trees on Volkameriana (VO) was 2.69, indicating a potential problem with this combination (Figure 40).

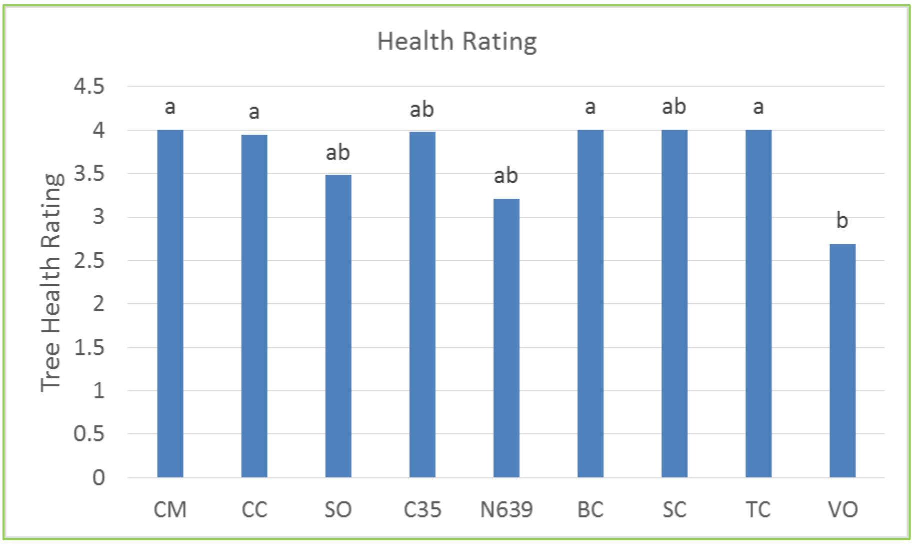

Figure 40 Average tree health rating by rootstock

Compatibility: The bud-union of every tree at this site was evaluated for overgrowth symptoms, specifically the difference in circumference of the trunk above and below the union, and the presence of “folding” at the union. “Folding” was assessed by the angle of woody tissue at the union, where “folding” was indicated by the presence of tissue at an angle greater than horizontal (see Figure 41).

Nelspruit 639, Swingle citrumelo and all citranges except Benton demonstrated “folding” on most trees. In addition to Benton citrange, trees on Cleopatra mandarin, Sweet orange and Volkameriana showed no evidence of “folding”. Interestingly, all the rootstocks affected have Trifoliata as a parent, as does Benton citrange.

The presence of “folding” at the bud-union indicates the potential for the bud-union to strangle itself as the folded tissue expands with tree growth.

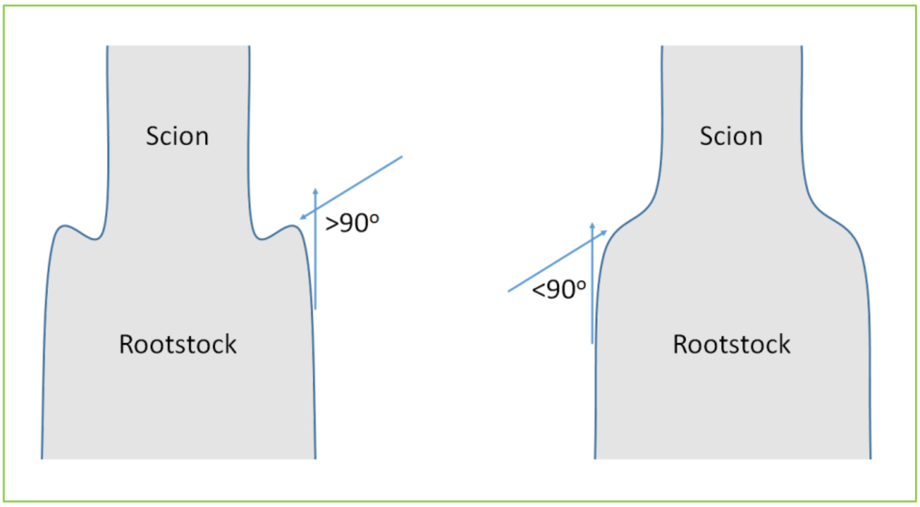

Figure 41 Bud-union folding in Imperial mandarin on Nelspruit 639

Trees on Nelspruit 639 also exhibited the greatest percentage difference in trunk circumference between above and below the union, with the circumference of the trunk below the union being 62% larger than that above the union (Figure 42).

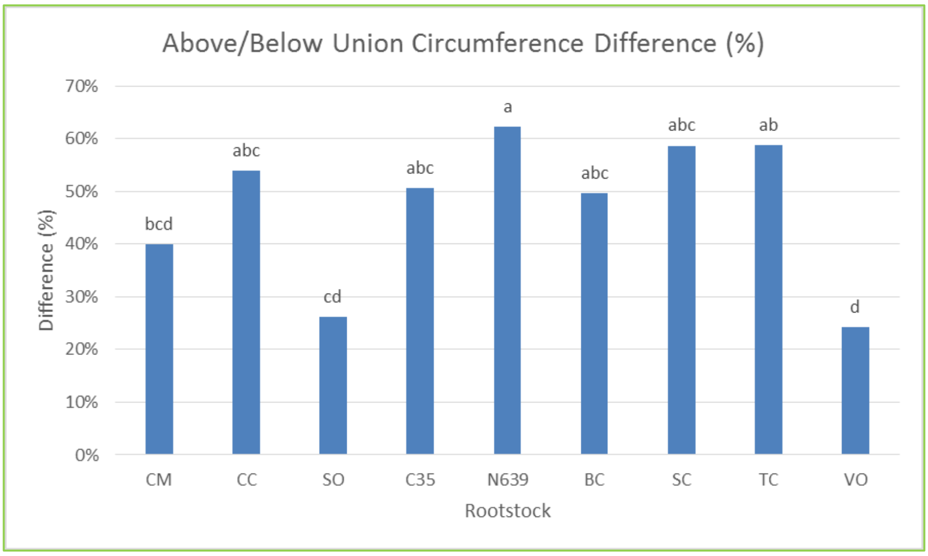

Figure 42 Percentage increase of below bud union trunk circumference over above union circumference in Imperial mandarin trees

Yield: Yield was not assessed at this site, the citrus industry indicated an interest specifically in bud-union health and fruit quality for Imperial mandarins.

Fruit quality: No significant trends were observed in fruit quality data from this trial.

Mandarin Rootstock Trial

Location: Loxton Research Centre

Scion variety/clone: Local Loxton clone of "Herps" Washington navel orange

Trial design: 2 varieties x 10 rootstocks X 3 replicates

Planted: 2002

Previous assessment: Four seasons; 2004 – 2006, & 2008

Soil:

0-60	Non calcareous sandy loam
60-80	Very highly calcareous light sandy clay loam (rubbly lime in sandy clay soil)
80-200	Very highly calcareous sandy loam (rubbly lime in sandy loam soil)

Tree vigour: Tree size data from 2004, 2006 and 2015 for both scion varieties clearly shows an increase in both height and width over time. However, both varieties also demonstrate the smallest growth on Swingle citrumelo (SC), especially for tree width (Figure 43 & Figure 44). Afourer trees on C-35 citrange also showed limited growth in terms of height increase.

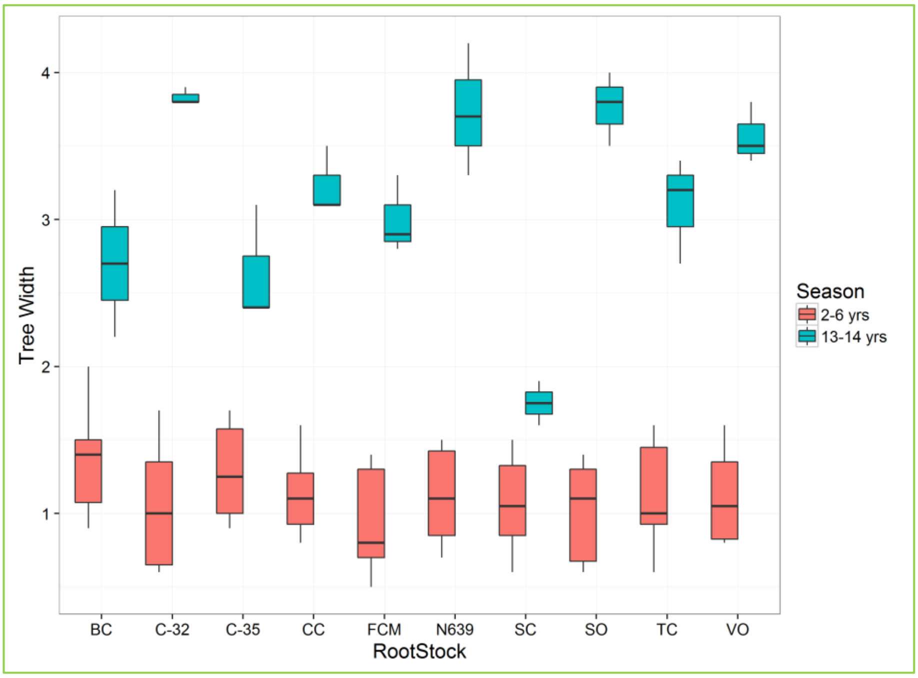

Figure 43 Tree width of Afourer mandarin on 10 rootstocks

The appearance of trees of both varieties on Swingle citrumelo indicates a tree health issue. Figure 45 shows a Murcott tree on Swingle citrumelo rootstock, with trees of other combinations in the background. The foreground tree exhibits stunted growth, yellow leaves and dead wood associated with dieback of new growth, and this is typical of trees on Swingle across the planting. Tree health was also poor in Murcott trees on C-35 citrumelo.

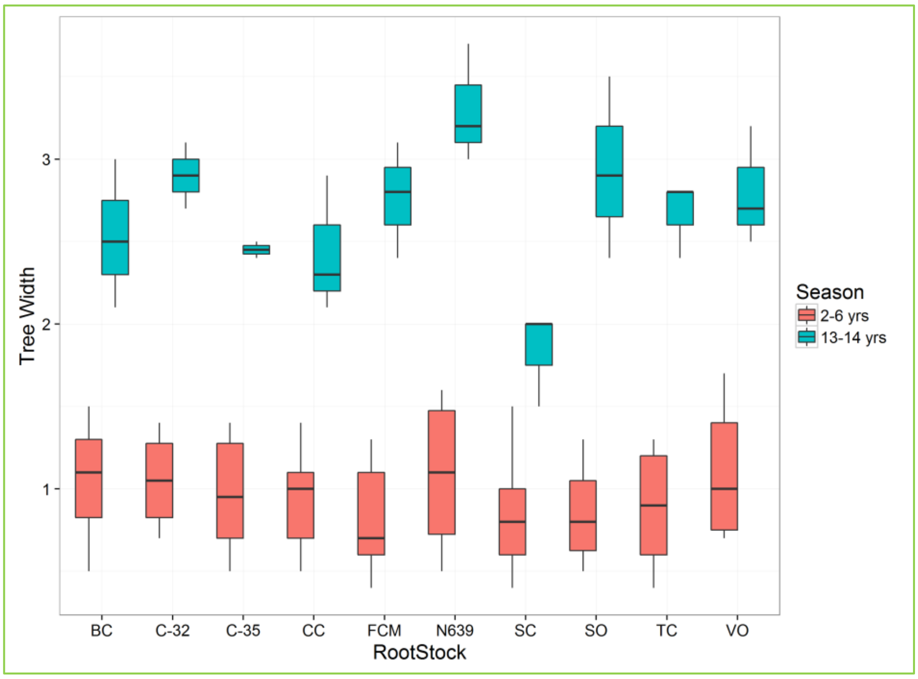

Figure 44 Tree width of Murcott mandarin on 10 rootstocks

Figure 45 Murcott on Swingle citrumelo, compare with healthy trees in background

Compatibility: The tree vigour symptoms described above indicate a potential compatibility issue with these two mandarin varieties on Swingle citrumelo. Observations were made of the bud-union of all trees in the trial planting, by removing a window of bark across the bud-union, at up to three positions around the trunk, and observing the presence or absence of bud-union creasing.

Creasing was observed at the bud-union in at least some **Afourer** trees on C-35 citrange, Nelspruit 639 and Swingle citrumelo. In trees on **Murcott**, creasing was observed on trees on C-35 and Troyer citrange, and Swingle citrumelo. As observed for the Imperial mandarin trial, all of the effected rootstocks have Trifoliata as a parent.

Yield: Yield data was collected from this trial in 2005, 2008, 2010, 2015 and 2016.

Afourer data shows a general increase in yield as trees mature, but yield from trees on Swingle citrumelo shows the lowest increase (Figure 46), including trees with zero yield in 2015 and/or 2016. This trend is linked to the tree vigour issues identified above.

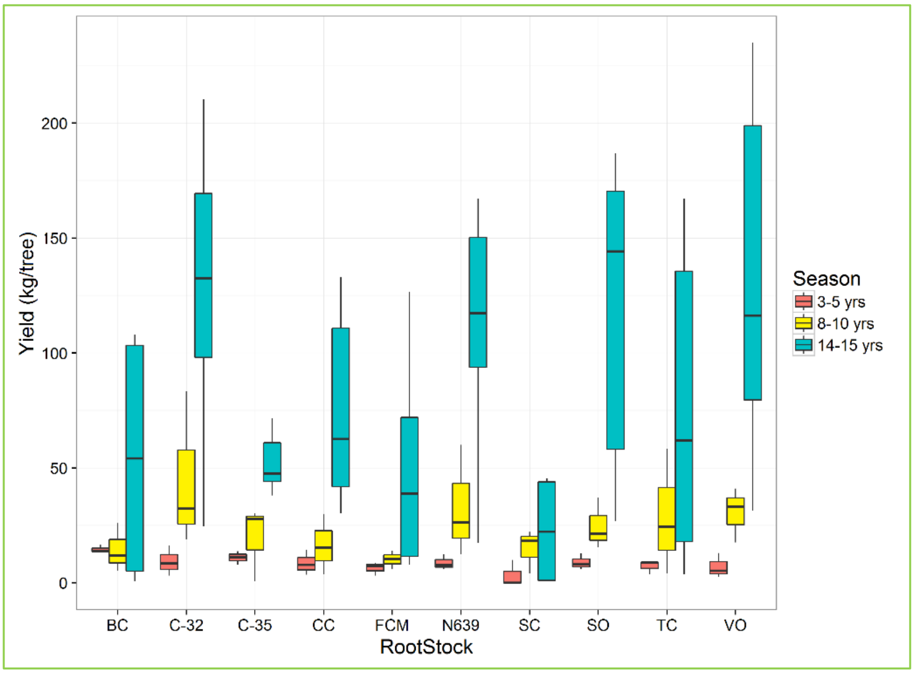

Figure 46 Yield per tree from Afourer mandarin on 10 rootstocks

Murcott data shows a similar trend, with Swingle citrumelo performance slightly better than under Afourer, but still quite poor (Figure 47).

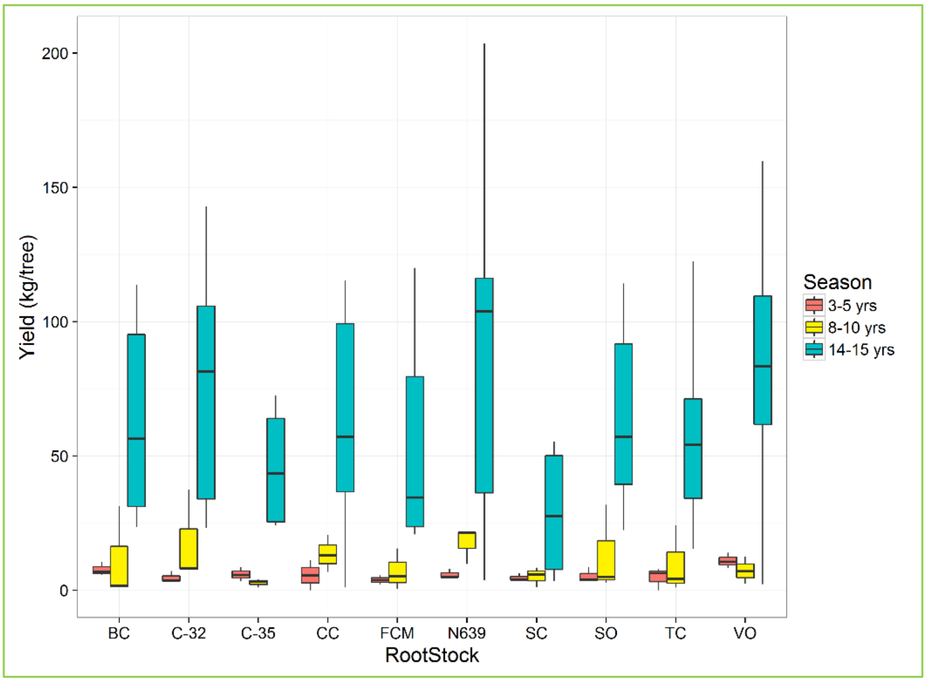

Figure 47 Yield per tree from Murcott tangor on 10 rootstocks

Fruit quality: Fruit quality data was collected only in 2015 and 2016. The only trends observed were for low juice content and high rind thickness (possibly related) in fruit from Afourer trees on Volkameriana.

2.2.2 Citrus rootstock characteristics: Summary of current and new knowledge

The matrix presented in Table 44 summarizes where issues were identified in specific scion/rootstock combinations found in the trials. In the table, cells coloured green indicate that no significant problems were identified. Yellow cells identify combinations which demonstrate some issues, of a moderate nature. Red cells identify combinations which are not recommended due to major issues resulting in tree death or very poor tree growth, health and yield.

The numbers in the yellow and red cells code for the type of issue identified, and are explained by the key at the base of the table.

Rough Lemon

Washington navels on Rough lemon (*C. jambhiri* Lush.) at Loxton produced moderate yields of fruit with low levels of Brix and acid. Although the low sugar and acid characteristics of trees on Rough lemon are well documented (Castle, 1987, Castle et al., 1993, Ferguson et al., 1990, Tribulato, 1979, Fallahi et al., 1991, Fallahi and Rodney, 1992), it is also well agreed that Rough lemon produces large crops of fruit (Castle et al., 1993, Castle, 1987, Ferguson et al., 1990, Fallahi et al., 1991, Fallahi and Rodney, 1992), which is not in evidence in this trial. Tribulato (1979) reports the development of "disorders of the graft union", but no decline symptoms in Morro orange trees on Rough lemon, and Ashkenazi (1988) reports that Shamouti orange is incompatible with Rough lemon.

Fruit from trees on Rough lemon is generally susceptible to disorders such as albedo breakdown (Treeby et al., 1995), and development of mould and wastage (Tindale, 1950) and rind disorders (Cronje, 2013) under storage. Ritenour et al. (2004) found variable performance, with low levels of stem end rind breakdown, but high levels of decay.

Irrespective of its performance in the Loxton trials, Rough lemon is not recommended for replant situations (von Broembsen, 1985, Hardy, 2004), limiting its usefulness in the Riverland.

Rangpur Lime (Rangpur)

In the Loxton trials Rangpur lime (*C. limonia* Osbeck) produced small trees and low yields. The literature suggests that Rangpur produces poor to moderate fruit quality (Castle, 1987, Ashkenazi, 1992) and is susceptible to most diseases and pests (Ferguson et al., 1990), as well as albedo breakdown (Treeby et al., 1995), and as a result it is not particularly popular in Australia.

Philippine and Santa Barbara Red Lime

The red limes (selections of Rangpur (*C. limonia* Osbeck) (Roose, 2009a)) performed relatively poorly under navel oranges at Loxton, with tree size and yield being less than optimal. There is little literature about these rootstocks, but in a trial with Atwood navel scions at Lindcove in California, similar results were obtained (Roose, 2009a). They are not recommended for planting in Australia.

Table 44 Identification of potential issues with scion/rootstock combinations represented in the revisited trials

Rootstock	Navelina Orange	Hockney Navel Orange	Summer Gold Navel Orange	Washington Navel Orange	Afourer Mandarin	Murcott Tangor	Imperial Mandarin
Rough Lemon				7			
Rangpur Lime				5,6			
Philippine Red Lime		6	5,6				
Santa Barbara Red Lime			6				
Cleopatra Mandarin							
Emperor Mandarin							
Sunki Mandarin	5,6	5,6	5,6				
Sweet Orange				6			
Taiwanica							
Volkameriana				5,6	7		4
Trifoliata							
Swingle Citrumelo					2,4,5,6	2,4,5,6	2
F80-5 Citrumelo	1,2	5,6					
F80-7 Citrumelo	1,2,7						
Nelspruit 639					2		3
Benton Citrange				5,6			
Carrizo Citrange							3
Troyer Citrange						2	3
Troyer 341							
C-32 Citrange							
C-35 Citrange	1,2	5,6	5,6		2,5	2,4	3

1 – Incompatible combination, significant tree death
2 – Bud union exhibits creasing
3 – Overgrowth by the rootstock, potential for girdling
4 – Poor tree health
5 – Tree size reduced
6 – Yield depressed
7 – Poor internal fruit quality

Performing well
Some concerns
Not recommended

Cleopatra Mandarin

Cleopatra mandarin (*C. reshni* Hort. ex Tan.) performed well in all of the Loxton trials. Navel oranges are known to perform well on Cleopatra mandarin (Ferguson et al., 1990, Castle et al., 2000). Production is low in early years, but increases as trees mature (Castle, 1987, Forner-Giner et al., 2003). Mandarin performance on Cleopatra is also known to be good (Ferguson et al., 1990), with the same issue of delayed bearing (Castle and Baldwin, 2006, Ashkenazi, 1992).

Evidence shows that fruit from trees on Cleopatra shows low levels of albedo breakdown (Treeby et al., 1995), and low susceptibility to decay under storage (Ritenour et al., 2004), but high levels of weight loss under storage (Alirezanezhad and Eamin, 2006, Machado et al., 2015).

Cleopatra mandarin is only recommended for soils which have not previously had citrus trees (Hardy, 2004).

Emperor Mandarin

Only present in the Washington navel trial at Loxton, Emperor mandarin (*C. reticulata* Blanco) performed well. Although not used widely, previous research suggests that Emperor performs similarly to Cleopatra mandarin (Stafford, 1972, Wait, 1988). As a result it also is not recommended for replant soils (Wait, 1988).

Sunki Mandarin

Sunki mandarin (*C. sunki* Hort. ex Tan.) under navel oranges at Loxton produced very small trees and very low yields. Sunki has been reported to sometimes produce a dwarfing effect (Castle, 1987), and low yield per tree may not be an issue if the trees can be planted closer together. However, when yield per trunk cross sectional area (TCSA, a measure of tree size) was evaluated, Sunki produced significantly less yield per TCSA than all other rootstocks when all scions in the Loxton trials were evaluated together, and the smallest yield per TCSA for each scion when evaluated separately.

Data from this trial indicates that Sunki mandarin is unlikely to produce high yields of fruit under Riverland conditions, even if the trees are planted at high density.

Sweet Orange

Within the Loxton trials, Sweet orange (*Citrus sinensis* [L.] Osbeck) performed well under mandarin scions, and adequately under Washington navel orange. Good performance of mandarins on Sweet orange is consistent with the literature (Castle, 1987, Castle et al., 1993, Ferguson et al., 1990).

Low yield in the navel orange trial may reflect the relatively close planting distance (6.5 x 3 m) and mature size of these trees. Sweet orange is recognized as being of intermediate vigour and to produce intermediate yields (Castle et al., 1993). It is possible that in this mature orchard surrounded by other more vigorous varieties, Sweet orange is unable to compete for space, light and nutrients, resulting in significantly reduced yields. In a uniform planting all on Sweet orange it is likely that this effect would not be apparent.

However, Sweet orange is not recommended for replant situations (Hardy, 2004, Gallasch and Staniford, 2003).

Sweet orange rootstock has been shown to produce fruit with low susceptibility to albedo breakdown (Treeby et al., 1995), but moderate susceptibility to mould and wastage in storage (Tindale, 1950), and high susceptibility to postharvest disorders (El-Zeftawi et al., 1989).

Taiwanica

Taiwanica (previously *C. taiwanica*, now considered a wild population of *C. aurantium* L.) originated in Taiwan, and has attracted interest as a rootstock due to its resistance to tristeza, exocortis and

Phytophthora species (Fallahi and Rodney, 1992). Yield performance reports are variable, with high yields reported for Moro blood orange (Incesu et al., 2013), Fairchild mandarin (Fallahi and Rodney, 1992) and Orlando tangelo (Fallahi et al., 1991); moderate yields for Valencia and Navel oranges (Zekri and Al-Jaleel, 2004); and relatively low yields for Clementine (Georgiou, 2002) and Nova mandarins (Georgiou, 2000).

At Loxton, Washington navel oranges on Taiwanica performed adequately in most respects, but yield was only moderate, and there is little else to recommend this rootstock over others.

Volkameriana (Volkamer lemon)

Volkameriana (*C. volkameriana* Ten. & Pasq.) is not widely used in Australia, but is available commercially. It is generally considered to have similar characteristics to Rough lemon (von Broembsen, 1985, Castle, 1987, Castle et al., 1993, Hardy, 2004).

At Loxton Volkameriana performed adequately under Murcott tangor, but tree size was reduced in Washington navel trees, and tree health was poor in Imperial mandarins. Ferguson et al. (1990) lists incompatibility with Satsuma mandarins but provides no source for the finding, and gives Volkameriana a rating of “Uncertain” in respect of compatibility with navel oranges and mandarins, due to less than 10 years of observations being available at that time. The majority of published papers report high vigour, large tree size and high yields in trees of a range of varieties on Volkameriana (Hardy, 2004, Castle et al., 2010, Castle et al., 1993, Tribulato, 1979, Fallahi and Rodney, 1992, Tuzcu et al., 1999, Georgiou, 2000, Georgiou, 2002, Tsakelidou et al., 2002, Zekri and Al-Jaleel, 2004, Waqar et al., 2007, Forner-Giner et al., 2010). However, there are a few instances where Volkameriana produced the smallest tree size (Tazima et al., 2013, Stenzel et al., 2003) and lowest yields (Tazima et al., 2015, Tazima et al., 2013). In addition, Tribulato (1979) reports disorders of the graft union but no impact on tree health in Moro orange trees budded to Volameriana, and (Ashkenazi, 1988) reports incompatibility between Volkameriana and Shamouti orange.

Fruit quality from trees on Volkameriana is known to be relatively poor (Castle et al., 1993, Hardy, 2004, Fallahi et al., 1991, Fallahi and Rodney, 1992, Tuzcu et al., 1999), and this trend was also found in the Loxton trials, with low juice content and thick rinds in Afourer fruit from trees on Volkameriana.

Volkameriana rootstock produces fruit with good storage performance, with low levels of decay, weight loss, juice percentage loss and decline in TSS and acid (Alirezanezhad and Eamin, 2006).

Trifoliata (Trifoliate orange)

Trifoliata (*Poncirus trifoliata* [L.] Raf.) is not commonly used in South Australia due to its low tolerance for high pH soils and saline water (Gallasch and Staniford, 2003), but grows well in heavier soils (Hardy, 2004). It was only used in one of the Loxton trial sites, where it gave moderate yields. Some of the literature indicates high fruit quality from trees on Trifoliata (Castle et al., 1993, Hardy, 2004, Castle, 1987), and the failure of trees at Loxton to produce high quality fruit may be the result of the trial being planted in sandy soil.

Although compatible with most orange varieties, including Washington navels, Trifoliata is known to express incompatibility symptoms with Roble orange (Garnsey et al., 2001), and some mandarins (Ashkenazi, 1988).

Fruit from trees on Trifoliata is recognized as having low levels of albedo breakdown (Treeby et al., 1995), and storing well, with low incidence of mould and wastage (Tindale, 1950) and good storage life (Fruit Research Institute Sichuan Agricultural Academy China, 1982). However, Hifny et al. (2012) found variable results under storage, with good retention of fruit firmness and SAR, but declining TSS and acid, and Arras and Chessa (1986) found high levels of decay.

Swingle Citrumelo (Citrumelo 4475)

Swingle citrumelo is the result of a cross between *P. trifoliata* (L.) Raf. and Duncan grapefruit (*C. paradisi* Macf.), and was bred in 1907 by Walter Swingle. It showed early promise as a replant rootstock for a wide range of varieties (von Broembsen, 1985, Castle, 1987, Castle et al., 1988). However, over time a range of compatibility issues have come to light.

In the Loxton trials, bud union creasing, lack of tree growth, poor tree health and depressed yields of Murcott tangors on Swingle are entirely consistent with the weight of published material from across the globe (Ashkenazi, 1992, Barbasso et al., 2005, Castle and Baldwin, 2006, Castle and Stover, 2000, Garnsey et al., 2001). Similar symptoms found in Afourer mandarin on Swingle at Loxton suggest that this problem may affect many more mandarin types beyond just Murcott (Garnsey et al., 2001, Ashkenazi, 1988). Imperial mandarin on Swingle at Loxton also showed signs of development of tissue abnormalities at the bud-union, although no obvious tree symptoms were observed.

Although the performance of Washington navel oranges on Swingle at Loxton was adequate, the literature indicates that symptoms consistent with incompatibility have also been observed in common orange and navel orange trees on Swingle (Castle and Stover, 2000, Garnsey et al., 2001, Schneider and Pehrson, 1985, Ashkenazi, 1988). However, other reports from some of the same authors show positive results in trials of oranges on Swingle (Castle et al., 2000, Castle et al., 2010), so the incompatibilities appear to be the exception rather than the rule. The author is not aware of any reports of compatibility issues in navel oranges on Swingle in Australia.

Fruit from trees on Swingle has performed well for decay under storage (Ritenour et al., 2004), but more work is needed on this rootstock.

F80-5 and F80-7 Citrumelo

These Citrumelo’s are the result of the same parental cross as Swingle (*P. trifoliata* (L.) Raf. by Duncan grapefruit (*C. paradisi* Macf.)), but were bred much later (1955) by Dr. Mortimer Cohen (Castle et al., 1988). Their performance is similar to that of Swingle (Bureau of Citrus Budwood Registration, 1990), although F80-7 is reported to produce “somewhat smaller sized trees” (Castle and Ferguson, 2003).

At Loxton, however, the majority of Navelina trees on both of these rootstocks died between the ages of 11 and 17 years, with all trees exhibiting the development of a bud union crease. This bud union crease is very similar to the symptoms reported by Garnsey et al. (2001), who found similar symptoms in Roble orange on a range of citrumelos, including F80-5, F80-7 and Swingle, associated with effects on tree canopy.

No incompatibility symptoms were observed in Hockney or Summer Gold navel trees on these citrumelo’s, although Hockney trees on F80-5 were small and low yielding.

In the absence of any clear advantage over Swingle, and in the light of the creasing issues identified, it is recommended that F80-5 and F80-7 not be promoted for commercial use in Australia.

Nelspruit 639 (x639)

Nelspruit 639 (also known as x639) arose from a cross between Cleopatra mandarin (*C. reshni* Hort. ex Tan.) and *P. trifoliata* (L.) Raf. Published information is positive, with good tree size and cumulative yields under Washington navels at eight years of age (Castle et al., 2000), and Murcott tangors at nine years (Castle and Baldwin, 2006). Navel fruit size is large on this rootstock (Castle et al., 2000, Castle and Ferguson, 2003). The rootstock is, however, susceptible to citrus blight (Castle and Ferguson, 2003).

At Loxton the rootstock also performed well under Murcott tangors, but there were bud union issues under Afourer and Imperial mandarins, and its use under these varieties cannot be recommended. In the absence of local trials under navels it is assumed that performance should be good, based on information from the USA, but further local evaluation would be recommended before large plantings are made.

Although little post-harvest storage work has been carried out, the small amount available shows that fruit performs well for levels of decay and stem end rind breakdown (Ritenour et al., 2004).

Benton Citrange

Benton citrange (*Citrus sinensis* [L.] Osbeck x *Poncirus trifoliata* [L.] Raf.) was originally bred specifically for use with Eureka lemon (Hardy, 2004), which shows incompatibility with many of the commonly used rootstocks, especially those with Trifoliata parentage. It has been tested with other citrus varieties, but has not performed exceptionally with any of them. Trial trees on Benton at Loxton performed well under Imperial and Afourer mandarin and Murcott tangor, but produced small trees and low yields under Washington navel.

Under Washington navels in Florida, Benton produced small trees with moderate yield (Castle et al., 2000), and under Murcotts in Florida it produced inconsistent tree size and was rated as "C"-grade, being deemed not promising enough to progress to yield evaluation (Castle and Baldwin, 2006). There are few compelling reasons to use this rootstock under Riverland conditions, except as a compatible rootstock for Eureka lemon.

Carrizo and Troyer Citrange

These two citranges are widely considered to have arisen from the same original selection (*Citrus sinensis* [L.] Osbeck x *Poncirus trifoliata* [L.] Raf.), and generally demonstrate only minor differences in performance (Castle, 1987, Castle et al., 1993, Hardy, 2004, von Broembsen, 1985, Castle et al., 2000). They also performed similarly to one another in the Loxton trials.

Symptoms of bud union creasing under Murcott tangor (Troyer only) and overgrowth of the rootstock under Imperial mandarins (both rootstocks) in the Loxton trials are indicators that these combinations may develop problems over their expected life span.

International literature reports high vigour and good early cropping from trees on Carrizo and Troyer (Hardy, 2004, Castle et al., 2010, Castle, 1987, Castle et al., 1993), although some variable performance (von Broembsen, 1985) and small fruit size in older trees (Hardy, 2004, Gallasch and Staniford, 2003) has been reported. Troyer and Carrizo in the Loxton Washington navel trial performed well in the early harvests, producing amongst the highest yields, but mature trees are no longer among the highest yielding in the trial.

Issues with compatibility have been reported in the literature, for Roble and Page oranges (Garnsey et al., 2001), and for mandarins and their hybrids (Castle et al., 1993, Ashkenazi, 1988), especially Murcott tangor (Castle and Stover, 2000, Garnsey et al., 2001). This information has arisen since Ferguson et al. (1990) published their recommendations that these citranges are compatible with oranges and mandarins in general. Subsequent experience has identified significant exceptions to the rule.

In addition to the above, an increase in rind creasing has been reported on these rootstocks (Gallasch and Staniford, 2003, von Broembsen, 1985).

It would be wise to avoid Carrizo and Troyer citrange when planting mandarin trees. Also, high early yields of Washington navel oranges may not be sustained into maturity. An economic approach may be taken to evaluating the benefits of high yields early in orchard life against long term yield projections, in deciding whether to use these rootstocks under navel orange plantings.

These citranges have been shown to produce fruit with moderate albedo breakdown susceptibility (Treeby et al., 1995), but good performance across the board for storage problems such as rind disorders (Cronje, 2013), chilling injury (McCollum et al., 2002), decay (Arras and Chessa, 1986) and general storage quality (Akpinar and Kaska, 1993). However, D'hallewin et al. (1994) found that fruit from trees on Troyer performed poorly for decay and declining SAR under storage, and Ritenour et al. (2004) found variable results across various citrus varieties and storage conditions.

Troyer 341

There is very little information about Troyer citrange 341 in the literature. Selected in South Africa as a variant of Troyer citrange (*Citrus sinensis* [L.] Osbeck x *Poncirus trifoliata* [L.] Raf.), and tested by Citrus and Subtropical Fruit Research Institute (1988), it was introduced into Australia in the 1990's (Gallasch, pers. comm.).

In the Loxton trials Troyer 341 performed adequately under Navelina, Hockney and Summer Gold navel, but was not outstanding. There is little evidence to recommend this selection over the standard Troyer citrange.

C-32 Citrange

Resulting from a cross between *Poncirus trifoliata* (L.) Raf. and Ruby Blood orange (*C. sinensis* [L.] Osbeck) (Hardy, 2004), C-32 has a limited history of evaluation, but has performed well in all trials reported to date. In trials in Florida, Hamlin sweet orange trees on C-32 performed equal best (Castle et al., 2010), and Washington navel orange trees on C-32 were in the most productive group (Castle et al., 2000). A general summary of the rootstock indicates that trees are "consistent in their vigor, large size, and excellent yield" (Castle and Ferguson, 2003).

Significantly, there have been no reports of bud union creasing or incompatibility symptoms in the literature to date. In the Loxton late mandarin trial both Murcott tangor and Afourer mandarin trees on C-32 were large and healthy, and returned high yields of fruit. In addition, there was no evidence of bud union crease found in any trees on C-32, whilst trees on Swingle citrumelo, Nelspruit 639, Troyer citrange and C-35 citrange showed bud union creasing in combination with at least one of these mandarin varieties.

C-35 Citrange

A sibling of C-32 citrange, C-35 citrange (*Poncirus trifoliata* (L.) Raf. x Ruby Blood orange (*C. sinensis* [L.] Osbeck)) is another citrange which demonstrated promising characteristics in early evaluation. At Loxton it has failed to live up to its early promise, with less than optimum performance under all scions with which it has been tested.

Under mandarin types C-35 has demonstrated bud union creasing leading to poor tree health and size (Afourer and Murcott), and rootstock overgrowth (Imperial). Although Ferguson et al. (1990) characterized C-35 as compatible with mandarins, Castle and Baldwin (2006) found wide differences in performance of Murcott on C-35 across soil types, with most trees performing poorly, and an overall rating of C given to the combination. In addition, Roose (2009b) found decline in Valencia trees on C-35 from around 10 years of age, and Garnsey et al. (2001) reported "strong" bud union symptoms and the presence of canopy effects in incompatibility observations of 'Roble' sweet orange on C-35.

Bud union creasing of C-35 trees budded with Navelina orange has led to widespread tree death at Loxton, and this combination should not be used. Forner-Giner et al. (2003) did not report the development of incompatibility symptoms in Navelina on C-35 in Spain, but these trees were only 10 years old, whilst those at Loxton were 15 years old when significant numbers of trees began to die.

Under other navel oranges, tree size and yield are depressed. Tree size reduction is a known characteristic of this rootstock (Castle and Ferguson, 2003, Castle et al., 2000, Roose, 2009b, Forner-Giner et al., 2003, Castle et al., 2010), but this reduction in tree size is expected to be compensated for by a higher yield efficiency (Castle and Ferguson, 2003, Hardy, 2004). In the Loxton trials, however, yield per trunk cross sectional area (TCSA) for trees on C-35 was moderate to low under both navel oranges and mandarins. Planting trees on C-35 at higher planting density may still not recover yield per hectare to the same level as obtained with other rootstocks at normal tree spacing.

References

AKPINAR, I. & KASKA, N. 1993. Investigations on the storage of the orange cultivars Washington Navel, Valencia and Moro grown on different citrus rootstocks. *Doga, Turk Tarim ve Ormancilik Dergisi,* 17**,** 11-21.

ALIREZANEZHAD, A. & EAMIN, A. A. 2006. Effect of eight citrus rootstocks on storage life of grapefruit cultivars Marsh and Ruby Red. *Iranian Journal of Agricultural Sciences,* 37**,** 447-455, en9.

ARRAS, G. & CHESSA, I. 1986. The effect of the rootstock on the storage quality of the orange cv. Washington Navel, selection Frost. *Notiziario di Ortoflorofrutticoltura,* 12**,** 209-215.

ASHKENAZI, S. 1988. *Incompatibility of some stock-scion citrus combinations in Israel,* Rehovot, Israel, Balaban Publishers.

ASHKENAZI, S. 1992. Growing Murcott in Israel. Rootstocks, quality and yield. *Alon Hanotea,* 46**,** 321-329.

BARBASSO, D. V., PIO, R. M. & CARVALHO, S. A. 2005. Compatibility of mandarin varieties and some hybrids in 'Swingle' citrumelo. *Laranja,* 26**,** 59-67.

BUREAU OF CITRUS BUDWOOD REGISTRATION 1990. A summary of citrumelo hybrid rootstocks. *The Citrus Industry,* 1990**,** 41-42.

CASTLE, W. S. 1987. Citrus Rootstocks. *In:* ROM, R. C. & CARLSON, R. F. (eds.) *Rootstocks for Fruit Crops.* John Wiley & Sons Inc.

CASTLE, W. S. & BALDWIN, J. C. 2006. Rootstock effects on Murcott tangor trees grown in a calcareous alfisol or a spodosol. *Proceedings of the Florida State Horticultural Society,* 119**,** 136-141.

CASTLE, W. S., BALDWIN, J. C. & GROSSER, J. W. 2000. Performance of 'Washington' navel orange trees in rootstock trials located in Lake and St Lucie Counties. *Proceedings of the Florida State Horticultural Society,* 113**,** 106-111.

CASTLE, W. S., BALDWIN, J. C. & MURARO, R. P. 2010. Rootstocks and the performance and economic returns of 'Hamlin' sweet orange trees. *HortScience,* 45**,** 875-881.

CASTLE, W. S. & FERGUSON, J. J. 2003. Citrus rootstocks and their on-site evaluation. *IFAS Extension.* Florida: University of Florida.

CASTLE, W. S. & STOVER, E. 2000. Rootstock reflections: Swingle citrumelo update. *Citrus Industry,* 81**,** 18-20.

CASTLE, W. S., TUCKER, D. P. H., KREZDORN, A. H. & YOUTSEY, C. O. 1993. Rootstocks for Florida Citrus. 2 ed. Florida: University of Florida.

CASTLE, W. S., WUTSCHER, H. K., YOUTSEY, C. O. & PELOSI, R. R. 1988. Citrumelos as rootstocks for Florida citrus. *Proceedings of the Florida State Horticultural Society,* 101**,** 28-33.

CITRUS AND SUBTROPICAL FRUIT RESEARCH INSTITUTE 1988. Sitrusonderstamme. *Information Bulletin, Citrus and Subtropical Fruit Research Institute, South Africa,* 196**,** 10-11.

CRONJE, P. J. R. 2013. Postharvest rind disorders of 'Nadorcott' mandarin are affected by rootsatock in addition to postharvest treatment. *Acta Horticulturae,* 1007**,** 111-117.

D'HALLEWIN, G., MURA, D., PIGA, A., PALA, M. & LOVICU, G. 1994. Rootstock effects on postharvest physiological and pathological behaviour of 'Avana' mandarin. *Acta Horticulturae,* 368**,** 395-402.

EL-ZEFTAWI, B. M., PEGGIE, I. D. & MINNIS, D. C. 1989. Postharvest treatments, storage temperature and rootstocks in relation to storage disorders and fruit quality of 'Valencia' oranges. *Journal of Horticultural Science,* 64**,** 373-378.

FALLAHI, E., MOUSAVI, Z. & RODNEY, D. R. 1991. Performance of 'Orlando' tangelo trees on ten rootstocks in Arizona. *Journal of the American Society for Horticultural Science,* 116**,** 2-5.

FALLAHI, E. & RODNEY, D. R. 1992. Tree size, yield, fruit quality, and leaf mineral nutrient concentration of 'Fairchild' mandarin on six rootstocks. *Journal of the American Society for Horticultural Science,* 117**,** 28-31.

FERGUSON, L. F., SACOVICH, N. & ROOSE, M. 1990. *California Citrus Rootstocks,* California, University of California.

FORNER-GINER, M. A., ALCAIDE, A., PRIMO-MILLO, E. & FORNER, J. B. 2003. Performance of 'Navelina' orange on 14 rootstocks in Northern Valencia (Spain). *Scientia Horticulturae,* 98**,** 223-232.

FORNER-GINER, M. A., HUESO, J. J., AGUERA, J. M. & FORNER, J. B. 2010. Performance of 'Clausellina' mandarin on four rootstocks. *Journal of Food, Agriculture & Environment,* 8**,** 328-331.

FRUIT RESEARCH INSTITUTE SICHUAN AGRICULTURAL ACADEMY CHINA 1982. Studies on rootstocks for Xianfeng orange (*Citrus sinensis*) in Sichuan province. *Acta Horticulturae Sinica,* 9**,** 1-10.

GALLASCH, P. T. & STANIFORD, M. 2003. Citrus Varieties and Rootstocks for the Riverland. Adelaide: South Australian Research and Development Institute.

GARNSEY, S. M., CASTLE, W. S., TUCKER, D. P. H., ROUSE, R. E., WUTSCHER, H. K. & KESINGER, M. C. 2001. Budunion incompatibilities and associated declines observed in Florida among trees on Swingle citrumelo and other trifoliate orange-related rootstocks. *Proceedings of the Florida State Horticultural Society,* 114**,** 121-127.

GEORGIOU, A. 2000. Performance of 'Nova' mandarin on eleven rootstocks in Cyprus. *Scientia Horticulturae,* 84**,** 115-126.

GEORGIOU, A. 2002. Evaluation of rootstocks for 'Clementine' mandarin in Cyprus. *Scientia Horticulturae,* 93**,** 29-38.

HARDY, S. 2004. *Growing Lemons in Australia - a Production Manual,* Sydney, New South Wales, NSW Department of Primary Industries.

HIFNY, H. A., ELRAZIK, A. M. A., ABDABBOH, G. A. & SULTAN, M. Z. 2012. Effect of some citrus rootstocks on fruit quality and storability of Washington navel orange under cold storage conditions. *American-Eurasian Journal of Agricultural & Environmental Sciences,* 12**,** 1266-1273.

ILAND, P., BRUER, N., EDWARDS, G., CALOGHIRIS, S. & WILKES, E. 2013. *Chemical Analysis of Grapes and Wine; Techniques and Concepts,* Adelaide, Australia, Patrick Iland Wine Promotions Pty Ltd.

INCESU, M., CIMEN, B., YESILOGLU, T. & YILMAZ, B. 2013. Rootstock effects on yield, fruit quality, rind and juice color of 'Moro' blood orange. *Journal of Food, Agriculture & Environment,* 11**,** 867-871.

MACHADO, F. L. D. C., DA COSTA, J. D. P., TEIXEIRA, A. D. S. & DA COSTA, J. M. C. 2015. The influence of rootstock and time of harvest on hte fruit quality during storage of in two grapefruit cultivars. *Acta Scientiarum Agronomy,* 37**,** 341-346.

MCCOLLUM, T. G., BOWMAN, K. D. & CASTLE, W. S. 2002. Effects of rootstock on fruit quality and postharvest behavior of 'Marsh' grapefruit. *Proceedings of the Florida State Horticultural Society,* 115**,** 44-46.

NICHOLAS, P. R. 1991. The effect of vine rootstocks on grape yield and quality in a warm high yielding irrigated area.: Final report to Grape and Wine Research and Development Corporation. Project No. DAS6GW.

NICHOLAS, P. R. 1997. Rootstock characteristics. *The Australian Grapegrower and Winemaker,* 400**,** 30

NICHOLAS, P. R. 2003. Standarised protocols for conducting grapevine improvement trials in Australia. Final report to Grape and Wine Research and Development Corporation. Project No. SAR 99/6.

NICHOLAS, P. R. 2006. Grapevine rootstock trials in South Australia. Adelaide, Australia: South Australian Research and Development Institute.

OLLAT, N., FERMAUD, M., TANDONNET, J. P. & NEVEUX, M. 1998. Evaluation of an indirect method for leaf area index determination in the vineyard: Combined effects of cultivar, year and training system. *Vitis,* 37**,** 73-78.

OWEN-TURNER, J. C. 1995. Rootstocks in Citrus. *Queensland Citrus Bulletin,* 1995**,** 6-16.

RAYMENT, G. E. & HIGGINSON, F. R. 1992. Saturation Extracts. *In:* RAYMENT, G. E. & HIGGINSON, F. R. (eds.) *Australian Handbook of Soil and Water Chemical Methods.* Inkata Press, Melbourne.

RITENOUR, M. A., DOU, H., BOWMAN, K. D., BOMAN, B. J., STOVER, E. & CASTLE, W. S. 2004. Effect of rootstock on stem-end rind breakdown and decay of fresh citrus. *HortTechnology,* 14**,** 315-319.

ROOSE, M. L. 2009a. 1986 Atwood navel orange rootstock trial at Lindcove. Riverside, California: University of California.

ROOSE, M. L. 2009b. Summary of Rootstock Trials (Roose Program. Updated 5/12/09). Riverside, California: University of California.

SCHNEIDER, H. & PEHRSON, J. E. J. 1985. Decline of navel orange trees with trifoliate orange rootstocks. *California Agriculture,* 39**,** 13-16.

STAFFORD, L. M. 1972. Influence of rootstocks on Navel orange yield and tree growth at Mildura, Victoria. *Australian Journal of Experimental Agriculture and Animal Husbandry,* 12**,** 203-208.

STENZEL, N. M. C., NEVES, C. S. V. J., GOMES, J. C. & MEDINA, C. C. 2003. Performance of 'Ponkan' mandarin on seven rootstocks in Southern Brazil. *HortScience,* 38**,** 176-178.

STEVENS, R. M., PECH, J. M., GIBBERD, M. R., WALKER, R. R. & NICHOLAS, P. R. 2010. Reduced irrigation and rootstock effects on vegetative growth, yield and its components, and leaf physiological responses of Shiraz. *Australian Journal of Grape and Wine Research,* 16**,** 413-425.

STEVENS, R. M., PITT, T. R., DYSON, C., PECH, J. M. & SKEWES, M. 2011. Salt tolerant rootstocks for long-term sustainability in the Limestone Coast. Final report to the Grape And Wine Research & Development Corporation. Project number: SAR 09/03.

TAZIMA, Z. H., NEVES, C. S. V. J., YADA, I. F. U. & LEITE JUNIOR, R. P. 2013. Performance of 'Okitsu' Satsuma mandarin on nine rootstocks. *Scientia Agricola,* 70**,** 422-427.

TAZIMA, Z. H., NEVES, C. S. V. J., YADA, I. F. U. & LEITE JUNIOR, R. P. 2015. Crop production of 'Okitsu' satsuma mandarin on nine rootstocks in Southern Brazil. *In:* SABATER-MUNOZ, B., MORENO, P., PENA, L. & NAVARRO, L. (eds.) *Acta Horticulturae.* Leuven, Belgium: International Society for Horticultural Science (ISHS).

TINDALE, G. B. 1950. Storage experiments. *Citrus News,* 26**,** 134-5, 137.

TREEBY, M. T., STOREY, R. & BEVINGTON, K. B. 1995. Rootstock, seasonal and fruit size influences on the incidence and severity of albedo breakdown in Bellamy navel oranges. *Australian Journal of Experimental Agriculture,* 35**,** 103-108.

TREGEAGLE, J. M., TISDALL, J. M., BLACKMORE, D. H. & WALKER, R. R. 2006. A diminished capacity for chloride exclusion by grapevine rootstocks following long-term saline irrigation in an inland versus a coastal region of Australia. *Australian Journal of Grape and Wine Research*, 12, 178-191.

TRIBULATO, E. 1979. Comparative observations on seven rootstocks for the orange cultivar Moro

Osservazioni comparative su sette portinnesti dell'arancio "Moro" Citrus sinensis (L.) Osbeck. *Tecnica Agricola,* 31**,** 15-32.

TSAKELIDOU, K., PAPANIKOLAOU, X. & PROTOPAPADAKIS, E. 2002. Rootstock effects on the yields, tree and fruit characteristics of the mandarin cultivar 'clementine' on the Island of Rhodes. *Experimental Agriculture,* 38**,** 351-358.

TUZCU, O., YILDIRIM, B., DUZENOGLU, S. & BAHCECI, I. 1999. Effects of different rootstocks on yield and fruit quality of Valencia and Shamouti orange cultivars

Degisik turuncgil anaclariiniin Valencia ve Yafa portakal cesitlerinin meyve verim ve kalitesi uzerine etkileri. *Turkish Journal of Agriculture & Forestry,* 23**,** 125-135.

VINEHEALTH AUSTRALIA. 2016. *Annual Report 2015-2016*. Adelaide SA. www.vinehealth.com.au

VINEHEALTH AUSTRALIA. 2017. *Rootstocks: protection against phylloxera*. www.vinehealth.com.au

VON BROEMBSEN, L. A. 1985. Citrus Rootstocks - The Choice You Have. Pretoria, South Africa: S.A. Co-operative Citrus Exchange Ltd.

WAIT, J. 1988. *Citrus Root Stocks* [Online]. The Rare Fruits Council of Australia. Available: http://rfcarchives.org.au/Next/Fruits/Citrus/CitrusRootstocks1-93.htm [Accessed 30/11/2016 2016].

WAQAR, A., NAWAZ, M. A., IQBAL, M. A. & KHAN, M. M. 2007. Effect of different rootstocks on plant nutrient status and yield in Kinnow mandarin (Citrus reticulata Blanco). *Pakistan Journal of Botany,* 39**,** 1779-1786.

WATERCONNECT. 2016. *Surface Water Data* [Online]. www.waterconnect.sa.gov.au : Department of Water, Environment and Natural Resources. [Accessed August 2016].

WINE AUSTRALIA. 2016. *Best practice management guide: Eutypa dieback* [Online]. www.research.wineaustralia.com : Wine Australia. [Accessed August 2016].

ZEKRI, M. & AL-JALEEL, A. 2004. Evaluation of rootstocks for Valencia and Navel orange trees in Saudi Arabia. *Fruits (Paris),* 59**,** 91-100.

Appendix A – Communication

Industry Workshops and Presentations

Skewes, M.A. (2014). *Rootstock longevity – project concept workshop*. Citrus Australia and AgriExchange, 1 December 2014, Loxton.

Pitt, T.R., Skewes, M.A., and Nicholas, P.R. (2014). *Rootstock longevity – project concept workshop*. Riverland Viticulture Technical Group committee meeting, 17 December 2014, Kingston on Murray.

Skewes, M.A. (2015). *SARDI current water use efficiency research*. Water use efficiency in horticulture workshop. Horticulture Innovation Australia and the Mallee Catchment Management Authority, 17-18 June 2015, Irymple.

Pitt, T.R., Skewes, M.A., Petrie, P.R., Stevens, R.M., Nicholas P.R., and McCarthy, M.G. (2015). *Sustained performance of rootstocks in Lower Murray vineyards*. Consolidated Co-operative Wineries, 9 December 2015, Glossop.

Skewes, M.A. (2016). *Longevity and sustained performance of rootstocks in Lower Murray horticulture; viticulture and citrus*. Citrus Australia SA Region (CASAR) grower workshop, 9 February 2016, Waikerie.

Skewes, M.A. (2016). *Longevity and sustained performance of rootstocks in Lower Murray horticulture; viticulture and citrus.* Citrus Australia SA Region (CASAR) grower workshop, 9 February 2016, Loxton.

Pitt, T.R. (2016). *Overview of SARDI's SARMS IRSP projects*. Horticulture Industry Network workshop, 5 April 2016, Urrbrae.

Pitt, T.R. (2016). *SARDI: Citrus, Almond and Viticulture Research*. 59th Riverland Field Days, 16-17 September 2016, Barmera.

Pitt, T.R., Skewes, M.A., Petrie, P.R., Stevens, R.M., Nicholas P.R., and McCarthy, M.G. (2016). *Does rootstock performance change with age?* Interactive online seminar via the Australian Wine Research Institute webinar series, 20 October 2016. www.awri.com.au/industry_support/courses-seminars-workshops/webinars/

Pitt, T.R., Skewes, M.A., Petrie, P.R., Stevens, R.M., Nicholas P.R., and McCarthy, M.G. (2016). *Does rootstock performance change with age?* Langhorne Creek – Viticulture Innovation Day, 11 November 2016, Langhorne Creek.

Pitt, T.R., Skewes, M.A., Petrie, P.R., Stevens, R.M., Nicholas P.R., and McCarthy, M.G. (2016). *Does rootstock performance change with age?* Riverland Vine Improvement Committee, 15 November 2016, Monash.

Industry Articles and Fact-sheets

Skewes, M.A. (2016) *Navelina Orange Rootstock Incompatibility.* Department of Primary Industries & Regions South Australia. PIRSA Factsheet. www.pir.sa.gov.au/research/research_specialties/sustainable_systems/water_resources_and_irrigated_crops

Skewes, M.A. (2016) *Growers warned against Navelina scion-rootstock combination*. Australian Citrus News. Autumn 2016, p14. www.citrusaustralia.com.au

Skewes, M.A., Grigson, G., Sanderson, G., Treeby, M. and Gallasch, P.T. (in preparation) *Rootstocks for Murcott and Afourer Mandarins – A Second Look* (working title)

Skewes, M.A. (2017) *Citrus Rootstock Technical Guide – Mature Tree Assessments*. Department of Primary Industries & Regions South Australia.

Pitt, T.R. (2017) *Viticulture Rootstock Technical Guide – Longevity and sustained performance of rootstocks for Australian vineyards*. Department of Primary Industries & Regions South Australia.

Conference Proceedings and Posters

Pitt, T.R., Skewes, M.A., Petrie, P.R., Stevens, R.M., Nicholas P.R., and McCarthy, M.G. (2015). *Sustained performance of rootstocks in Lower Murray vineyards*. Vineyard longevity: maintaining the asset. Proceedings of Australian Society of Viticulture and Oenology Seminar, 22-23 July 2015, Mildura Victoria. In press.

Pitt, T.R., Skewes, M.A., Nicholas P.R., Stevens, R.M., McCarthy, M.G., and Petrie, P.R. (2016). *Does rootstock performance change with age?* (poster). 16th Australian Wine Industry Technical Conference, 24-28 July 2016, Adelaide.

Pitt, T.R., Nicholas P.R., Cirami R.M., McCarthy, M.G., and Petrie, P.R. (2016). *Rootstock effects on yield, maturity and the incidence of bunch stem necrosis in Cabernet Sauvignon* (poster). 16th Australian Wine Industry Technical Conference, 24-28 July 2016, Adelaide.

Communication activities scheduled for 2017 (post-project)

Skewes, M.A., Pitt, T.R., Grigson, G.J. and Cox, J.W. (2017). *Revisiting Mature Citrus Rootstock Trials*. Citrus Technical Forum and Field Day (oral). 1-2 March 2017, Mildura.

Pitt, T.R. and Skewes, M.A. (2017). *Project Review*. PIRSA Executive, SARMS assessment panel and Industry representatives, March 2017, Location TBC.

Appendix B – Intellectual Property

There is no patentable intellectual property arising from this project. Research has focussed on the development of knowledge for industry and is contained herein.

Appendix C – Staff

Personnel	Organisation	Role
Mr Tim Pitt	SARDI	Principal Investigator
Mr Mark Skewes	SARDI	Research Scientist
Ms Jessica Tan	SARDI	Senior Research Statistician
Prof. Jim Cox	SARDI	Recipient Representative
Mr Nigel Fleming	SARDI	Research Scientist
Dr Sandra Olarte	SARDI	Technical Officer
Mr Gary Grigson	SARDI	Field Operations
Mr Brenton Mann	SARDI	Field Operations
Mr Ian Lange	SARDI	Field Operations

Appendix D – Budget Reconciliation