The effect of water stress on the performance of grafted vines with an emphasis on wine quality

Final report for the fulfillment of the Barossa Young Viticulturist award 2008

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The Phylloxera and Grape Industry Board of South Australia

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I applied for this fellowship after hearing about it at a growers meeting in the Barossa in 2008. I had already commenced a project within the region and thought The Barossa Young Viticultural Fellowship would allow me to further expand on this research, particularly in the field of wine quality. In addition, the fellowship gave me the opportunity to travel overseas to investigate how international rootstock breeding programs are responding to water shortages and the implications for wine quality.

Being the 2008 recipient of the fellowship certainly raised the profile of the project; in particular, the fellowship enabled me to access the winemaking sector within the Barossa as well as the viticulturists within the region, which has further added to the project outcomes.

Winning the fellowship has been a rewarding experience and I hope the outcomes presented in this report will be considered by grape growers, viticulturists and winemakers, faced with water shortages.

Catherine Cox
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Executive Summary

During the 2008-2009 growing season grape growers in the Barossa were again faced with severe water restrictions as a result of continuing drought in catchments and locally below average rainfall.

A noted characteristic of some American- *Vitis* rootstocks is reported drought tolerance (Carbonneau 1985, Nicholas 1997, Dry 2007). The current water-restricted environment in the Barossa has intensified the need for greater understanding of rootstock-scion interactions in relation to drought tolerance and the consequences of the environmental limitation on wine quality.

This research aims to determine drought tolerance of grafted vines grown in the Barossa and whether the rootstocks examined can mitigate the effects of water stress whilst continuing to provide a quality end product wine.

In the first season of this study, drought tolerance of rootstocks—as defined by an ability to sustain yield, remain vigorous and sustain a high leaf water potential ψ_{leaf} (Soar et al. 2006)—varied considerably between the rootstocks. Grafted vine yields varied between the treatments with zero irrigation; negatively affecting the yield irrespective of rootstock. Lower yields were due to lower berry weights total berry number and bunch weights.
Leaf water potential varied considerably between the rootstocks; own roots unirrigated followed by Ramsey and 1103 Paulsen unirrigated maintained the highest leaf water potentials of the unirrigated rootstocks.
In addition, the °Brix levels of the berries were affected negatively by zero irrigation: that is, the fruit of irrigated treatments had the highest °Brix levels for the majority of rootstocks studied. Wine quality was assessed by a panel of Barossa winemakers: there was no significant difference in wine quality between wines that received zero or control irrigation. However significant differences in wine quality were found between rootstocks under the same irrigation

regime. For example, a wine score of 14.1 for own roots irrigated was significantly lower than 140 Ruggeri irrigated with a wine score of 15.4.

Introduction

Rootstocks are renowned for protecting vines against phylloxera and nematodes. Increasingly, rootstocks have been used to address issues associated with increasing salinity levels and restricted water supply. Grapevine rootstocks have been further classified as drought tolerant or intolerant primarily based on their vigour and root systems (Nicholas 1997, Dry 2007). A rootstock's ability to cope with dry conditions may be attributed to an ability to grow a thick, plunging root system and is therefore advantaged in dry conditions through an ability to explore large volumes of soil for water (Soar and Loveys 2007, Dry 2007). Drought tolerance as defined by Soar et al. (2006) is the ability of the grafted system to maintain yield and vigour whilst also sustaining a high leaf water potential (ψ_{leaf}).

It is well known that grafting to a rootstock influences the scion (Virgona et al. 2003). Furthermore, many researchers (e.g. Ough et al. 1968, Cirami et al. 1984, Hedberg et al. 1986, Rühl et al. 1988, Ewart et al. 1993, Kaserer et al. 1996, Walker et al. 1998) have examined this conferred influence on final wine quality.

Wine quality, as distinct from wine grape quality, has long been evaluated by the concentrations, interactions and balance of soluble solids, organic acids and pH in the berries (Jackson and Lombard 1993, Coombe and Illand 2004). pH is one of the more important quality parameters that also happens to be influenced by rootstock as a result of higher or lower potassium concentrations in the berry and subsequent juice (Walker et al. 1998) Many authors have reported higher potassium content and therefore higher pH as a direct consequence of grafting a vine to a rootstock (Cirami et al. 1984, Hedberg et al. 1986, Rühl et al. 1988, Ewart et al. 1993, Kaserer et al. 1996, Walker et al. 1998). Juice pH can affect fermentation rates and the must of the juice (Ough et al. 1968). pH levels above 3.6 are detrimental to wine quality as above this level there is increased likelihood of microbial spoilage or the production of hydrogen sulphide (H_2S) and lowered colour intensity in the wine (Jackson and Lombard 1993).

In addition, some rootstocks may increase yield and sugar accumulation leading to a change in the types of organic acids (Ough et al. 1968, Rühl et al. 1988) such as lower tartaric and increased malic concentrations and in general lower flavour components (Ewart et al. 1993).

Water stress on the other hand is contradictory in its effects on wine quality and is influenced by the time at which water stress occurs within a season and by the degree of severity. For example, Jackson and Lombard (1993) found no relationship between water stress and the onset of veraison or the timing of ripening and harvest. However, yield, berry composition, pH, organic acids and total soluble solids were affected in other studies (Jackson and Lombard 1993, Roby et al. 2004, van Leeuwin et al. 2004, Bindon et al. 2008). Some water stress can improve wine quality particularly mild water stress which has been shown to increase the level of sugars which in turn stimulates anthocyanin development (Jackson and Lombard 1993, Roby et al. 2004, Van Leeuwin et al. 2004, Bindon et al. 2008). However, van Leeuwin et al. (2004) stated that when water stress becomes too severe, sugar accumulation is depressed as photosynthesis is reduced and carbon assimilation by the plant becomes limited. Early, and severe water deficits, are more detrimental to wine quality than post veraison deficits (Jackson and Lombard 1993)

Rootstock performance is unique to a vineyard soil and the vineyard's environmental conditions (Dry 2007). Therefore, it is important to assess the drought tolerance characteristics of a vineyard under specific environmental and management conditions imposed.
the Barossa Valley approximately 60km north east of Adelaide, is a premium wine grape growing location with the predominant varieties Shiraz, Cabernet sauvignon, Semillon, Grenache, Chardonnay and Riesling.
Nuriootpa is characterised by a moderate Mediterranean climate that receives moderate rainfall, high evapotranspiration and low relative humidity during the growing season (Dry and Coombe 2004).
In 2008 grapevine rootstocks accounted for 25% of 11228 hectares of total vineyard area planted in the Barossa Valley (PGIBSA 2009).
The main considerations for rootstock selection in the Barossa valley currently include (Dry 2007):

- Drought tolerance / water use efficiency
- Salinity tolerance
- Nematodes
- Soil lime content

in 2008 the main rootstocks used within the Barossa were (PGIBSA 2009):

- Ramsey
- 101-14

- 1103 Paulsen

The research aims of this project therefore were to:

- Investigate drought tolerance of rootstocks grown in the Barossa and
- Investigate whether the rootstocks examined can mitigate the effects of severe water stress whilst continuing to provide a quality end product that will reflect the desired wine quality and wine style of the Barossa.

Methodology

The experimental site is within a 7 hectare planting of Shiraz clone BVRC30 own roots and Shiraz clone BVRC30 grafted to 6 rootstocks:

- 140 Ruggeri
- 1103 Paulsen
- 99 Richter
- 110 Richter
- Ramsey
- Schwarzmann

The site was planted in 2003. The South Australian Research and Development Institute (SARDI) Research Centre site has an average rainfall of 500mm. Irrigation throughout the season is based on requirements from gypsum block readings- typically 0.5 ML/ha the source ranges from bore water or water from the Murray River via the Barossa Infrastructure Limited (BIL) scheme.

The soil is typically a Light Pass fine sandy loam A horizon overlying a red brown earth B horizon (Northcote 1954).

Each block is 10 rows in width with a maximum of 84 vines per row. Vine spacing is 2.25m and row width is 3m. Vines are trained to a bilateral cordon. Dripper spacing is approximately 0.75m (see appendices).

Each treatment plot comprised nine adjacent vines in a single row with a similar number of buffer vines in rows either side to minimize the impact of any water movement across the interow area. Treatments undergoing zero irrigation had their drip irrigation lines bypassed at vine position one and nine using flexible irrigation piping. In addition, vines at position one and nine were used as buffer vines. There were three replicate blocks of seven vines of zero irrigation per rootstock and three replicate blocks of seven vines of control (standard) irrigation per rootstock (see appendix 1) in each plot were used as buffer vines the first vines at either end of the treatment block (e.g. vine 1 and vine 9) are also used as buffer vines and are not used in the analysis. There are 3 replicate blocks of 7 vines of zero irrigation per rootstock and 3 replicate blocks of 7 vines of control (standard) irrigation per rootstock (see appendix 1). Control irrigation for the 2009 season was 0.5ML/ha.

Reproductive performance

Reproductive performance was assessed using the following measures:
Fruitset: fruitset measures the number of flowers that successfully turn into berries (May 2004). It is the number of berries in a bunch divided by the number of flowers on a bunch multiplied by 100 to give a percentage (normal fruitset is 50% or higher. Poor fruitset is at less than 30%) (Bessis 1993, cited in Dry et al. 2009).
Seeded: Berries that contain full complement of seeds, develop normally and vary in size.
Seedless: Small berries (4-7mm) that contain no seeds or only seed traces, seedless still go through veraison and soften yet, absence of seeds restricts proper development. Seedless berries make up less than 2% total bunch weight in Cabernet Sauvignon and less than 10% in Merlot (Dry et al. 2009).
LGO: Live Green Ovary (LGO) berries make up less than 1% of total bunch weight (Collins and Dry 2009). They contain no seeds and fail to develop and soften; LGOs remain green in colour.
Fruitfulness: Latent buds containing viable inflorescence primordia which correspond to the potential yield of the grapevine for the next season (Dry 2000, Sánchez and Dokoozlian 2005) assessed through the number of inflorescence primordia. This is determined through bud dissections at dormancy.
%PBN: Primary Bud necrosis (PBN) is a physiological disorder that results in the death of the primary bud on the inflorescence primordia at dormancy (Collins and Rawnsley 2005) This is determined through bud dissections at dormancy.

Coulure Index (CI) : An abnormal condition of fruitset whereby flowers fail to develop into an either a LGO or berry. Calculated from:

$$10 - \left\{ \frac{\text{no. of seeded berries/ bunch + no. of seedless berries/bunch + no. of LGOs / bunch)*10}}{\text{number of flowers per bunch}} \right\}$$

Millerandage Index (MI) : An abnormal condition of fruitset whereby the flowers develop abnormally into either seedless berries or LGOs. Calculated from:

$$10- \left\{ \frac{\text{(no. of seeded berries/ bunch)*10}}{\text{no. of seeded berries/ bunch + no. of seedless berries/bunch + no. of LGOs}} \right\}$$

(Dry et al. 2009)

Midday leaf water potentials

Midday leaf water potentials were taken at the commencement of the first irrigation on the 10th December 2008. A total of 5 vines per replicate were sampled and assessed for the midday leaf water potential. Three leaves from each vine were excised using a single edged razor blade through the petiole. The water potential was measured using a 3000 series leaf pressure chamber (soil moisture equipment corp, Santa Barbera, USA).

Maturity analysis- Veraison to Harvest

From veraison, maturity analysis was undertaken for each treatment block. 100 berries per plot were taken each week for analysis of Total Soluble Solids (TSS) °Brix, pH and titratable acid. In addition, a further 50 berries were collected for mean berry weight and frozen for analysis of anthocyanins and total phenolics (Iland et al. 2004). All analyses were performed in the viticulture laboratory at the University of Adelaide, Waite campus.

Grape and Wine analysis

Grapes from each plot were harvested by hand when between 23 and 24 °Brix. The number of bunches per vine and the weight of fruit harvested was recorded before the harvested grapes were pooled into rootstock and irrigation groups. The fruit was further divided into three winemaking replicates of approximately 30kg each resulting in a total of 42 fermentations. Wines were made at The University of Adelaide, Waite campus from the 2009 vintage.

The winemaking practices adopted were as follows:

Fruit was processed in a small de-stemmer and crusher into 30L food-grade plastic open fermenters. Yeast AWRI 796 was added at a rate of 25g/hl. No DAP added to the ferments. Ferments were hand-plunged twice per day and temperature controlled in a 15˚C room. pH was adjusted so all ferments were at the same pH value through additions of Tartaric acid. Ferments were racked off lees and pressed after 6 days or when the wines were at 2˚ Baume and inoculated with commercial malolactic (malo) culture after primary fermentation. They were racked after malo and 80 parts of SO_2 added. The wines were stored in large glass containers prior to pad filtration and bottling in August 2009.

Panel and tasting format

A panel of nine Barossa-based professional winemakers were assembled to assess the wines. Tasting results were subject to a statistical analysis to elucidate quality preferences and wine attributes for each treatment.

The tasting format was as follows;

- Each wine was judged using standard wine show scoring out of 20
- Each wine was assigned descriptors for key attributes (see appendix for attached scorecard)
- Each panel member tasted 42 wines in a randomly arranged single line-up

Statistical analysis

Statistical analysis of data was performed using Genstat (10th Edition, 10.1.0.72, Lawes Agricultural Trust 2007) statistical package using two way analysis of variance (ANOVA).

Results

Yield and juice composition

Rootstock and irrigation resulted in significant differences in yield (Table 2). The cessation of irrigation reduced yield from 5.18 kg to 3.85kg per vine. Lower yields were associated with higher millerandage index (MI), higher incidence of seedless berries, lower berry weight and lower bunch weight (Table 3). There were significant differences in yield between rootstocks with 99R being the lowest with 3kg per vine to own roots being the highest with 8.9kg per vine. There were significant rootstock x irrigation interactions. For own roots, 99R, 1103P, 140R and 110R there was a significant reduction in yield when irrigation was withdrawn, however, for Ramsey and Schwarzmann there was no significant reduction in yield when irrigation ceased.

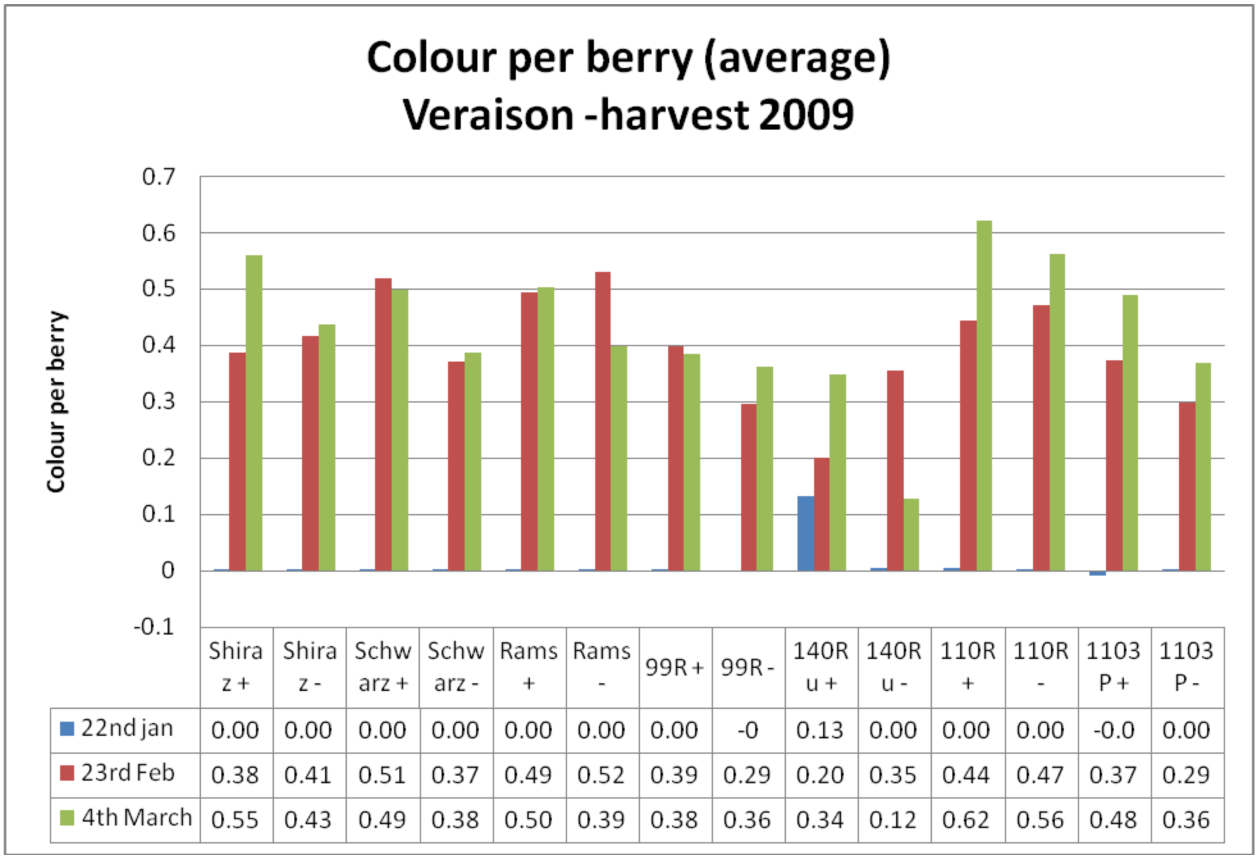
pH levels were highly significant for each of the rootstocks and irrigation combinations(Table 1). Lower pH levels were found for own roots, both irrigated and unirrigated. 99 Richter had the highest pH value; however, this was not significantly different to 99 Richter irrigated or 1103 Paulsen irrigated.

Titratable Acidity was significantly different for all the rootstock x irrigation treatments, but in particular it was highly significant between rootstocks (Table 1). Both own roots irrigated and unirrigated had the highest level of TA at harvest, whilst Schwarzmann irrigated had the lowest value.

Brix levels were highly significant across all rootstocks x irrigation treatments. In general the irrigated controls had the higher Brix readings relative to the unirrigated treatments. The highest Brix level was 1103 Paulsen irrigated, with the lowest Brix in unirrigated own roots (Table 1). Vines were harvested at an ideal ˚Brix range between 21 and 24 ˚Brix.

Colour (total anthocyanins) per berry was significantly different across all interactions (Table 1). Rootstocks 140 Ruggeri unirrigated and irrigated followed by and 99 Richter unirrigated and irrigated had the lowest colour per berry. 110 Richter irrigated followed by 110 Richter unirrigated and Shiraz irrigated had the higher colour levels in the berries at the final sample date. Maturity analysis data of colour accumulation (Figure 1) in the berries show 140 Ruggeri irrigated initially had the highest colour at commencement of veraison (22nd January) this however, plateau throughout the rest of the season. Most rootstocks had highest colour accumulation at last sample date- 4th of March. However, 140 Ruggeri unirrigated severely decreased in colour. This trend was also experienced, although to a lesser extent, in Ramsey unirrigated, Schwarzmann irrigated and 99 Richter irrigated

Phenolics per berry were significantly different across all interactions. Irrigated 140 Ruggeri had the lowest level. The higher levels of phenolics per berry were found in unirrigated 110 Richter, unirrigated own roots and unirrigated Schwarzmann respectively (Table 1).



	Shiraz +	Shiraz -	Schwarz +	Schwarz -	Rams +	Rams -	99R +	99R -	140Ru +	140Ru -	110R +	110R -	1103P +	1103P -
22nd jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0	0.13	0.00	0.00	0.00	-0.0	0.00
23rd Feb	0.38	0.41	0.51	0.37	0.49	0.52	0.39	0.29	0.20	0.35	0.44	0.47	0.37	0.29
4th March	0.55	0.43	0.49	0.38	0.50	0.39	0.38	0.36	0.34	0.12	0.62	0.56	0.48	0.36

Figure 1 Colour accumulation in the berries- veraison to harvest show that for the majority of rootstocks, colour increased up until harvest. Exceptions to this were found in 140 Ruggeri unirrigated, Ramsey unirrigated and 99 Richter irrigated.

Berry juice potassium at harvest

There was a wide range in berry juice potassium across rootstocks with own roots the lowest and 110R the highest (Table 4). Irrigated vines had lower berry juice Potassium than unirrigated, however there was a significant interaction between rootstock and irrigation for four of the rootstocks. Ceasing irrigation on own roots resulted in a decrease in berry juice potassium at harvest while for 99R, Schwarzmann and 140R ceasing irrigation resulted in a significant increased in berry juice potassium at harvest (Table 4).

Leaf water potential

Based on the Soar et al. (2006) definition, rootstocks that are able to maintain a high leaf water potential (LWP) are an indicator of drought tolerance. At the commencement of the irrigation season there was no significant difference in LWP between unirrigated and irrigated vines (Table 5). There were significant differences however, between rootstocks, with own rooted having the highest LWP and Schwarzmann the lowest and hence the most water stressed. In addition, there were differences in the irrigation treatment response for some rootstocks. For own roots, 99R and 140R there was no difference in LWP between unirrigated and irrigated. Irrigated Ramsey, Schwarzmann, and 1103P had lower LWP than unirrigated, perhaps indicating these vines were still transpiring, while the LWP of unirrigated 110R was lower than irrigated.

Wine tasting panel results

The highest scoring wines at the tasting were unirrigated 1103 Paulsen replicate W3 and irrigated 1103 Paulsen replicate W1 (Table 6). The lowest scoring wine was Ramsey unirrigated wine replicate W1 (Table 6). However, there was no significant difference between any of the rootstocks x irrigation treatments. The pooled results (winemaking replicates averaged) (Figure 2) show that, in general, the winemakers preferred the irrigated treatments although not significantly so.

140 Ruggeri irrigated, with winemaking replicates pooled, had the highest score. The lowest scoring treatment was Schwarzmann irrigated, followed closely by Shiraz own roots irrigated (Figure 2).

Table 1 Winemaking components of the Barossa rootstock irrigation trial. Statistical significance of the effects (rootstock, treatment and rootstock x treatment) and their interactions are given by: P<0.05 (*), P<0.01(**), P<0.001(***) and not significant (ns). Mean values were separated using Genstat (10th Edition, 10.1.0.72, Lawes Agricultural Trust 2007) statistical package with repeated measures two way ANOVA.

Rootstock x Irrigation	Treatment +/- (0.5ML/ha)	pH	TA	˚Brix	Colour per berry at harvest	Phenolics per berry at harvest
Own roots	+	3.47	5.26	20.7	0.55	0.36
Own roots	-	3.48	5.3	17.4	0.43	0.31
Ramsey	+	3.8	4.44	23.5	0.5	0.32
Ramsey	-	3.72	4.73	23.1	0.39	0.27
99 Richter	+	3.85	4.38	23	0.38	0.3
99 Richter	-	3.89	4.11	22.8	0.36	0.24
Schwarzmann	+	3.78	3.82	23.8	0.49	0.3
Schwarzmann	-	3.69	4.16	23	0.38	0.23
1103 Paulsen	+	3.88	4.31	24.8	0.48	0.29
1103 Paulsen	-	3.79	4.34	22.2	0.63	0.23
140 Ruggeri	+	3.79	4.19	23.3	0.34	0.25
140 Ruggeri	-	3.83	4.2	22.7	0.12	0.09
110 Richter	+	3.67	4.72	23.6	0.62	0.37
110 Richter	-	3.65	4.86	22.5	0.56	0.32
	P value LSD	*** 0.047	* 0.29	*** 0.76	* 0.06	*** 0.033

Irrigation	pH	TA	˚Brix	Colour per berry at harvest	Phenolics per berry at harvest
Irrigated	3.75	4.45	23.2	0.48	0.31
Unirrigated	3.72	4.53	22	0.37	0.24
P value LSD	ns	ns	*** 0.28	*** 0.012	*** 0.012

Rootstock	pH	TA	˚Brix	Colour per berry at harvest	Phenolics per berry at harvest
Own roots	3.48	5.28	19.1	0.49	0.33
Ramsey	3.76	4.59	23.3	0.44	0.29
99 Richter	3.87	4.24	22.9	0.37	0.27
Schwarzmann	3.73	3.99	23.4	0.44	0.26
1103 Paulsen	3.83	4.32	23.5	0.42	0.26
140 Ruggeri	3.81	4.19	23	0.23	0.17
110 Richter	3.66	4.79	23.1	0.59	0.35
P value LSD	*** 0.033	* 0.20	*** 0.53	*** 0.047	*** 0.023

Table 2 Yield components of the Barossa rootstock irrigation trial

Rootstock X irrigation	**Treatment +/- (0.5ML/ha)**	**Yield (kg/vine)**
Own roots	+	9.54
Own roots	-	8.29
Ramsey	+	3.47
Ramsey	-	3.15
99 Richter	+	3.73
99 Richter	-	2.26
Schwarzmann	+	3.53
Schwarzmann	-	3.11
1103 Paulsen	+	4.01
1103 Paulsen	-	2.85
140 Ruggeri	+	5.66
140 Ruggeri	-	3.43
110 Richter	+	6.32
110 Richter	-	3.87
Rootstock x irrigation treatment	P value LSD	* 1.081

Irrigation	**Yield (kg/vine)**
Irrigated	5.18
Unirrigated	3.85
P value LSD	*** 0.409

Rootstock	**Yield (kg/vine)**
Own roots	8.92
Ramsey	3.31
99 Richter	3
Schwarzmann	3.32
1103 Paulsen	3.43
140 Ruggeri	4.55
110 Richter	5.1
P value LSD	*** 0.764

Table 3 Measures of reproductive performance

Rootstock x Irrigation	Treatment +/- 0.5ML/ha	Bunch number	Bunch weight (g)	Total berry number	Flower number	Fruitset	CI	MI	seed ed	seed less	LGO
Own roots	+	96.1	105.1	120.6	180.8	64.3	3.34	2.76	87.5	32.8	4.09
Own roots	-	86.6	102.2	119.6	202	60.2	3.94	3.41	79.9	39.7	0.75
Ramsey	+	71.4	48.2	90.6	193.5	53.7	4.39	4.25	51.3	39.3	4
Ramsey	-	70.4	45.1	85.3	148.5	58.1	4.03	4.65	46	39.4	2.15
99 Richter	+	82.6	44.6	90	172	52.3	4.61	3.39	60.8	29.1	2.9
99 Richter	-	65.2	33.5	105.4	185.2	56.1	4.14	5.65	47.7	57.7	3.75
Schwarz	+	85.7	40.7	77.1	169.9	49	4.96	4.12	49.5	27.8	1.9
Schwarz	-	89.3	34.6	85.1	170	52.3	4.65	2.68	64.4	20.7	1.95
1103 P	+	82.8	49.5	97.8	176.5	57.9	3.71	4.26	58.8	39.1	8.75
1103 P	-	73.3	39.2	100.3	177	58.9	4.04	4.17	60.2	40.2	1.64
140 R	+	90.6	60.9	110.8	156.4	58.7	3.84	3.52	71	35.7	5.29
140 R	-	112.2	32	87	170.1	52.5	4.74	2.85	63.4	23.6	0.28
110 R	+	87.8	72.1	87.2	205	42.6	5.28	2.71	74.2	11.9	14.8
110 R	-	73.4	50.9	95.3	179	55.2	4.38	2.48	73.1	22.2	1.52
	P value LSD	*** 12.32	* 11.79	ns	ns	ns	ns	*** 1.12	ns	** 14.95	*** 2.58

Irrigation	Bunch number	Bunch weight (g)	Total berry number	Flower number	Fruitset	CI	MI	seed ed	seed less	LGO
Irrigated	85.3	60.1	96.2	179.1	54.1	4.3	3.57	64.7	30.8	5.96
Unirrigated	81.5	48.2	96.9	176	56.2	4.27	3.7	62.1	34.8	1.72
P value LSD	ns	*** 4.46	ns	ns	ns	ns	ns	ns	ns	*** 0.978

Rootstock	Bunch number	Bunch weight (g)	Total berry number	Flower number	Fruitset	CI	MI	seed ed	seed less	LGO
Own roots	91.3	103.6	119.9	191.4	62.2	3.64	3.09	83.7	36.2	2.42
Ramsey	70.9	46.6	88	171	55.9	4.21	4.45	48.6	39.3	3.07
99 Richter	73.9	39	97.7	178.6	54.2	4.38	4.52	54.3	43.4	3.32
Schwarz	87.5	37.7	81.1	169.9	50.7	4.8	3.4	56.9	24.2	1.93
1103 P	78	44.3	99.1	176.7	58.4	3.87	4.22	59.5	39.7	5.2
140 R	101.4	46.4	98.9	163.3	55.6	4.29	3.19	67.2	29.7	2.79
110 R	80.6	61.5	91.3	192	48.9	4.83	2.6	73 7	17	8.16
P value LSD	*** 8.71	*** 8.34	*** 17.23	ns	* 8.21	* 0.83	*** 0.79	*** 13.5	*** 10.5	*** 1.82

Table 4. Potassium levels in the grape juice at harvest.

Rootstock x irrigation	Treatment +/- (0.5ML/ha)	Potassium
Own roots	+	2374
Own roots	-	1959
Ramsey	+	2450
Ramsey	-	2392
99 Richter	+	2247
99 Richter	-	3091
Schwarzmann	+	2487
Schwarzmann	-	3366
1103 Paulsen	+	2529
1103 Paulsen	-	2851
140 Ruggeri	+	2691
140 Ruggeri	-	3507
110 Richter	+	3916
110 Richter	-	3547
Rootstock x irrigation treatment	P value LSD	*** 405.3

Irrigation	Potassium
Irrigated	2670
Unirrigated	2959
P value LSD	*** 153.2

Rootstock	Potassium
Own roots	2166
Ramsey	2421
99 Richter	2669
Schwarzmann	2926
1103 Paulsen	2690
140 Ruggeri	3099
110 Richter	3713
P value LSD	*** 286.6

Table 5. Midday leaf water potential measurements.

Rootstock x irrigation	**Treatment +/- (0.5ML/ha)**	**midday leaf water potentials**
Own roots	+	12.1
Own roots	-	12.2
Ramsey	+	14.3
Ramsey	-	13.2
99 Richter	+	15.5
99 Richter	-	15.8
Schwarzmann	+	16.5
Schwarzmann	-	15.6
1103 Paulsen	+	14.2
1103 Paulsen	-	13.3
140 Ruggeri	+	14.4
140 Ruggeri	-	15.2
110 Richter	+	12.3
110 Richter	-	13.8
Rootstock x irrigation treatment	P value LSD	*** 0.7803

Irrigation	**Treatment +/- (0.5ML/ha)**	**midday leaf water potentials**
Irrigated	+	14.19
Unirrigated	-	14.16
P value LSD		ns

Rootstock	**midday leaf water potentials**
Own roots	12.17
Ramsey	13.75
99 Richter	15.63
Schwarzmann	16.08
1103 Paulsen	13.74
140 Ruggeri	14.76
110 Richter	13.07
P value LSD	*** 0.55

Table 6. Winemaking panel assessment of wines and averaged wine scores.

Rootstock	Treatment +/- (0.5ML/ha)	Winemaking replicate number (1-3)	Wine panel results (scored out of 20) (averaged across panel)
Own Roots	+	W1	14.61
Own Roots	+	W2	14.50
Own Roots	+	W3	14.78
Own Roots	-	W1	13.78
Own Roots	-	W2	14.94
Own Roots	-	W3	14.17
Ramsey	+	W1	14.61
Ramsey	+	W2	14.00
Ramsey	+	W3	13.83
Ramsey	-	W1	13.28
Ramsey	-	W2	13.44
Ramsey	-	W3	13.44
99 Richter	+	W1	15.00
99 Richter	+	W2	15.00
99 Richter	+	W3	14.67
99 Richter	-	W1	14.17
99 Richter	-	W2	14.67
99 Richter	-	W3	15.56
Schwarzmann	+	W1	15.00
Schwarzmann	+	W2	14.78
Schwarzmann	+	W3	14.28
Schwarzmann	-	W1	15.06
Schwarzmann	-	W2	15.17
Schwarzmann	-	W3	15.39
1103 Paulsen	+	W1	15.67
1103 Paulsen	+	W2	14.56
1103 Paulsen	+	W3	15.39
1103 Paulsen	-	W1	15.39
1103 Paulsen	-	W2	15.56
1103 Paulsen	-	W3	15.67
140 Ruggeri	+	W1	14.61
140 Ruggeri	+	W2	14.72
140 Ruggeri	+	W3	15.11
140 Ruggeri	-	W1	15.33
140 Ruggeri	-	W2	15.28
140 Ruggeri	-	W3	15.61
110 Richter	+	W1	14.83
110 Richter	+	W2	14.83
110 Richter	+	W3	14.17
110 Richter	-	W1	14.50
110 Richter	-	W2	14.83
110 Richter	-	W3	14.44

Table 7 Top ten wines judged by winemakers.

Rootstock	Treatment +/- (0.5ML/ha)	Winemaking replicate number (1-3)	Wine tasting order line up (1-42)	Wine panel results (scored out of 20)
1103 P	-	3	24	15.67
1103 P	+	1	35	15.67
140 Ru	-	3	41	15.61
99R	-	3	2	15.56
1103 P	-	2	3	15.56
1103 P	+	3	6	15.39
1103 P	-	1	30	15.39
Schwarzmann	-	3	42	15.39
140 Ru	-	1	25	15.33
140 Ru	-	2	29	15.28

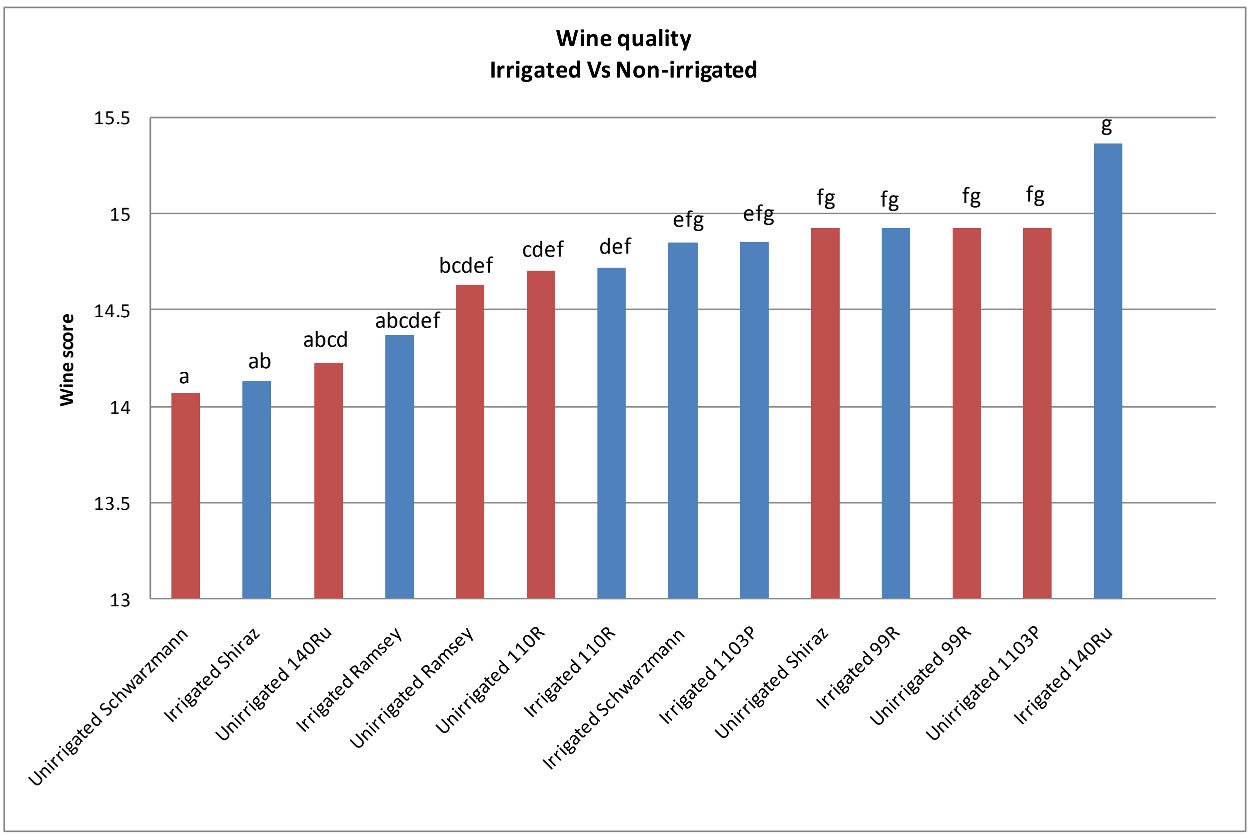


Figure 2 Pooled results of rootstock x irrigation treatments.

Discussion

Zero irrigation reduced yield for all rootstock combinations, however, the yield reduction was not significant for Ramsey and Schwarzmann. This supports previous findings by McCarthy et al. (1997), Pech et al. (2008), and Stevens et al. (2008). Shiraz scions grafted to unirrigated 99 Richter had the lowest yield followed by 1103 Paulsen and Schwarzmann. Unirrigated own roots were significantly higher in yield than all the rootstocks regardless of whether they were irrigated or not. McCarthy et al (1997), using yield as the primary index of drought tolerance, found own roots to be as drought tolerant as several rootstocks. In his study-which was a control or zero irrigation trial- Ramsey had the highest yield for unirrigated; however, not significantly higher when compared with own roots. In the current study, Ramsey performed poorly in terms of overall yield irrespective of irrigation treatment. However, Ramsey had the least negative effect on yield under zero irrigation. The current experiment found 110 Richter and 140 Ruggeri to have the highest yields of the unirrigated rootstock combinations (excluding own roots unirrigated which was significantly higher). This disputes the findings of McCarthy et al. (1997) who reported poor performance of 110 Richter rootstocks, both under irrigated and unirrigated circumstances. In the current study, 1103 Paulsen unirrigated was the second worst performing rootstock in yield after 99 Richter and confirms previous work by McCarthy et al. (1997) and other authors who concluded that 1103 Paulsen, and to a lesser extent 99 Richter, were not rootstocks with good drought tolerance in unirrigated or extreme drought situations. The sometimes contradictory responses reported here and those by McCarthy et al. (1997), even though within the same grape-growing region, highlight the influence differences of soil properties have on rootstock response. The soil type used by McCarthy et al. (1997) was a Sandy A horizon overlying a tight clay subsoil with restricted root growth compared to the current site of sandy-loam A horizon overlying a clay B horizon which roots can penetrate. The former site with its restricted root growth properties would have restricted root exploration by some rootstocks with vertical root morphology more so than at the current site. These different responses based on soil type and potential for root penetration highlight the need to evaluate rootstock performance in the specific site (2010 McCarthy pers comm.).

Yield differences in this study were due largely to berry weight, total berry number fruitset and bunch weight. Lower yields were associated with higher incidence of MI, more seedless berries, lower bunch weight and berry weight.

Rootstock and irrigation resulted in significant differences in juice ˚Brix. Pirie and Mullins (1977) reported higher sugar accumulation in water stressed berries relative to their size. In this experiment, rootstocks with lower yields had lower sugar levels than rootstocks with higher yield.

Water deficits at this experimental site were ongoing and therefore could be likened to early and severe water deficits by definition. Measurements of midday leaf water potential at the site found both the irrigated and unirrigated own roots Shiraz to have significantly higher leaf water potential values. This was followed by 110 Richter irrigated, Ramsey unirrigated, 1103 Paulsen unirrigated and 110 Richter irrigated. Based on the definition by Soar et al. (2006) both the irrigated and unirrigated Shiraz vines would be considered drought tolerant vines as they were able to maintain higher leaf water potentials (Soar et al. 2006). 110 Richter irrigated, Ramsey unirrigated, 1103 Paulsen unirrigated and 110 Richter irrigated would also be considered to be drought tolerant based on the definition by Soar et al. (2006) although to a lesser extent than the Shiraz vines.

In reports by van Leeuwin et al. (2004), when water stress becomes severe sugar accumulation is depressed as photosynthesis is reduced and carbon assimilation by the plant becomes limited. In the season reported here, severe water deficit did affect sugar accumulation, berry size and weight and, as a consequence, final yield.

Ough et al. (1968) and Rühl et al. (1988) concluded from their studies that yield, sugar and acid accumulation are significantly altered by rootstock type. The current work supports these initial findings and, in addition, yield, sugar and acid accumulation for grafted vines was also significantly affected by water stress.

Juice pH of all the rootstocks were significantly different; with significantly higher pH than the own root controls. This supports the work of previous authors (Cirami et al. 1984, Hedberg et al. 1986, Rühl et al. 1988, Ewart et al. 1993, Kaserer et al. 1996, Walker et al. 1998).
Potassium in the harvest juice was highly significant for all interactions and was found to be higher in the majority of unirrigated grafted vines- with the exception of irrigated 110 Richter

which had the highest potassium level. Unirrigated Shiraz, irrigated 99 Richter and unirrigated Shiraz had the lowest levels of potassium in their juice at harvest. The lower potassium content in the own roots irrigated and unirrigated supports work by previous authors (Cirami et al. 1984, Hedberg et al. 1986, Rühl et al. 1988, Ewart et al. 1993, Kaserer et al. 1996, Walker et al. 1998) who reported higher potassium concentrations from grafted vines.

Wine quality from grafted vines has in the past divided opinions in many regions in Australia. A wine tasting panel consisting of industry professionals was used for this trial. The results showed that there were no significant differences detected in the final wine quality between rootstocks or as a result of irrigation treatment. Statistical significance was detected in the rootstock by irrigation interaction. In this instance, winemakers distinguished significant quality preferences for rootstocks and their respective irrigation treatments. As a result, 140 Ruggeri irrigated had the best quality followed equally by the own roots unirrigated, 99 Richter both irrigated and unirrigated and 1103 Paulsen unirrigated. The wine least preferred by the judging panel was Schwarzmann unirrigated with own roots irrigated just slightly better. The preliminary results from the wine tasting demonstrate two key points. Firstly, the average wine quality scores of the rootstocks and the own root wines were not significantly different. Secondly, there were no detectable differences in wine quality when comparing irrigated and unirrigated treatments, either for rootstocks or for own rooted wines.

These findings, although preliminary, highlight the opportunities for using grapevine rootstocks in a water- challenged environment without adverse affects on final wine quality.

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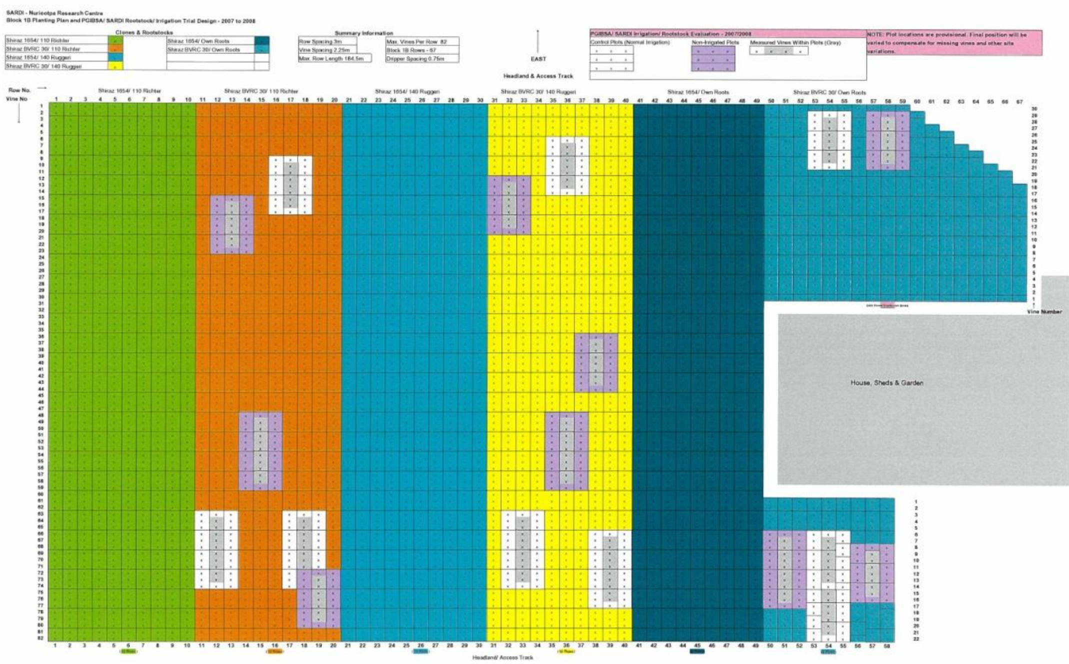
Appendices

Appendix 1. Example of trial design



Appendix 2. Example of zero irrigation treatment