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CSIRO

Climate change ready varieties and management technologies that reduce GHGs in the vineyard



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Abstract

This project successfully established a new field trial to evaluate new scion and rootstock combinations under different plant densities. Narrow row, high density plantings were established to compare to the typical Australian wide row, low density plantings. The scion-rootstock combinations were chosen to investigate the effect on plant vigour and yield. To reduce inputs and minimise greenhouse gas (GHG) production from tractor usage the trial was planted with mildew resistant varieties that do not require regular spray application. A new dwarf scion selection was included in the trial to evaluate its potential to be grown over several seasons without the need for pruning and thus contribute to reduced management costs and reduced GHG production. Further evaluation of the trial over several seasons will determine the potential cost savings to industry and reduction in vineyard GHG of the new scion-rootstock combinations that might be achieved under high and low density plantings.

Executive Summary

It has been stated that global intensification of agriculture will be required to not only address the challenges of climate change but also the limited availability of land and water resources (The Royal Society 2009). A study in California found that the largest known contributor to greenhouse gases (GHGs) in the vineyard was fuel usage (Carlisle et al. 2010) to manage plant growth and control diseases such as mildews. Intensification of vineyard production by increasing vine density was investigated in Australia by McCarthy in 1992 and encouraging results were obtained but the disadvantage was managing vine vigour.

This report describes the establishment of a new experimental trial site to re-examine the potential for sustainable intensification of Australian viticulture to achieve lower inputs and higher outputs per unit land. Since 1992, new management techniques have been developed and new grapevine selections produced that may be better suited to low input intensive viticulture.

CSIRO has bred new grapevine selections suited to the warm-hot Australian conditions. The scion selections are resistant to powdery and downy mildews. Some of these new scions (no-prune) require little or no canopy management or winter pruning. In addition, CSIRO has bred new rootstocks tolerant or resistant to root pathogens (phylloxera and root-knot nematodes) and these rootstocks may modify scion vigour and water use efficiency.

The objective of this project was to establish a new experimental field site partitioned into low and high density plots. The experimental design included the planting of four scion selections (two white and two red berry selections) either on own roots or grafted onto three different rootstocks. Data on vineyard input costs, plant vigour, water use and berry quality were collected.

The experimental vineyard was successfully established although it took longer than expected due to the limited supply of plant material for grafting and as a result, no wine was produced in the final year. The details of the data collected are described in the report with a number of promising outcomes highlighted below.

The study found that no mildew infections were observed on the plants during the term of the trial even though no spraying for mildews was done on site. Not having to spray for mildews is a considerable cost saving in terms of labour, chemicals and GHG production from tractors. Other benefits included reduced exposure of vineyard staff to chemicals and surrounding areas to spray drift lessening potential health risks and reducing the social impacts in the peri urban fringe/rural areas.

The no-prune scion selections performed as expected and no pruning or canopy management was required for these selections either on own roots or grafted onto rootstocks. Pruning and labour costs associated with pruning have been reported to be a significant industry cost (30% of operating expenditure). Also of interest was that the analysis of berry composition indicated that the no-prune vines had similar composition to berries from normal vines, suggesting that wine made from the grapes of no-prune vines should have similar attributes to normal vines.

Preliminary data suggested that rootstocks might have an effect on vine vigour and some berry components but the major finding was that rootstocks did not markedly change the vigour (measured indirectly by LAI and visual observation) of the no-prune vines. It was found that under the same irrigation regime, 54% less water was used per plant in the high density plot compared to the low density plot. This suggested that the water use efficiency might be greater in high density blocks, however, further study is required over several seasons with different irrigation treatments to investigate water use efficiency in relation to yield and wine quality attributes.

The study found that a number of changes to vineyard management would occur if future research at the site demonstrated significant advantages to adopting mildew resistant no-prune vines or higher density plantings. Irrespective of plant density, the use of mildew resistant vines would provide considerable benefits to vineyard management by reducing the need for labour, chemicals and tractor usage. A future scenario with adoption of no-prune vines would allow vines to be grown under high density conditions and require little or no canopy management or pruning, further reducing management costs.

This project developed a unique trial site to evaluate new scion and rootstock material and to investigate management methods that reduce costs and inputs (sprays, labour, water and pruning). Further research is required over several seasons to fully investigate the potential benefits of the plant selections and management treatments at this trial site. The preliminary results in this report are very encouraging but multi-seasonal data from mature vines are required to fully assess the advantages and disadvantages of the experimental treatments in terms of management costs, water use efficiency, yield per hectare and fruit and wine quality. One disadvantage of a high density block in Australia will be the establishment cost which was found to be 1.34 times more expensive in this study due mostly to the additional posts and vines. This initial cost will have to be measured against the operating costs over the life of a high density vineyard and potential returns.

Sustainable intensification of Australian viticulture while maintaining yield and wine quality is challenging, but continued use of this experimental site for research will provide important information on what might be achievable and provides a demonstration to the Australian wine industry of the advantages, disadvantages and challenges of different vineyard intensification scenarios under predicted climate scenarios of increased temperatures and reduced water availability.

The research results and outcomes described in this project report would not have been possible without the valuable contributions of the people listed in the Acknowledgement section.

Acknowledgments

The authors of this report would like to thank CSIRO staff; Ian Dry, Harley Smith and Peter Clingeleffer. Mike McCarthy is especially thanked for his valuable contribution to the project as well as staff (Roger Maywald and Treva Hebberman) at the SARDI Nuriootpa Research Station. The authors also appreciate the assistance of Glenavon Nurseries and Yalumba Nursery for allowing the testing of experimental propagation protocols.

This research would not have been possible without SARDI providing land for the trial site and access to on-site facilities.

1. Background

Successful adaptation to climate change and reducing greenhouse gases (GHGs) in the vineyard can be achieved through industry adoption of new varieties and rootstocks. CSIRO has bred new grapevine varieties that require fewer sprays for mildew control that produce robust wine styles in a warm-hot environment. CSIRO has also bred new varieties that potentially do not require management of vineyard vigour by pruning and developed new rootstocks that assist in controlling vine vigour and have high water use efficiency (high crop water use index) and pest resistance. A high and standard (low) density experimental vineyard containing these new varieties and variety-rootstock combinations was established to investigate vineyard management and measure the potential cost savings through reduced inputs (fuel, water, sprays) and reduction in the release of GHGs through less fuel usage. Elite scions and rootstocks that have high productivity, high water use efficiency, efficient water use and produce desirable wine styles under future conditions of increasing hot summer temperatures will be evaluated. A field trial comparing both low and high density plantings of new elite scions and rootstocks will demonstrate to industry the benefits of the new varieties and the management strategies required for high density vineyards that aim to produce more from less land.

One of the largest known contributors to greenhouse gases (GHGs) in the vineyard is fuel usage (Carlisle et al. 2010) to manage plant growth and control diseases such as mildews. World agriculture will be forced to undergo dramatic rapid changes to address the challenges of climate change, limited resources (water, land, energy) and population growth well before the projected population peak in 2050 (The Royal Society 2009). This can only be achieved by sustainable intensification of agriculture using fewer inputs and higher outputs per unit land. It has been demonstrated that vines grown as high density plantings in Australia yield more per hectare and are more water use efficient (McCarthy 1992). Establishment of a trial block of elite mildew resistant plants on own roots and grafted to new elite CSIRO rootstocks would allow the collection of data on potential cost savings, reduction in inputs, yield/ha and water use efficiency.

1.1 Industry Context

The grape and wine industry in Australia faces increasing temperatures and reduced water availability as a consequence of climate change. Reducing the carbon footprint of the industry in the vineyard is best achieved by reducing fuel usage by fewer passes of machinery used for spraying to control mildews and control vine vigour. In addition to these inputs, the cost of water is also becoming a major factor. Profitability of the industry is dependent not just on production costs but also in having a desirable, unique product in the market that buyers and consumers want. During the last growth phase of the Australian wine industry, land was not an issue, resulting in vineyard layouts with wide inter-rows. However, the realisation that at a global level resources are scarce and arable land limited is causing a rethink of how crops are grown with a move to intensification of agriculture to try and achieve increased production from less land and with fewer inputs. European growers already have high density vineyard plantings with overhead harvesters capable of

navigating 0.95-1.5 m inter-row spacing but the vines are highly managed.

The GWRDC Strategic RD&E Plan 2012-17 identified research priorities in climate adaptability (1.1), grapevine germplasm (1.2) and improved vineyard profitability (1.3) using sustainable management practices (1.4). This project was undertaken to evaluate the potential for cost minimisation and improved profitability by reducing inputs and maximising outputs through efficient utilisation of land, water and appropriate rootstock-scion combinations that reduce the requirement for spraying for mildews and reduced vine vigour management.

2. Project Aims

This project had the following objectives:

1. Establish a high density planting in a no-spray block of:
    a) elite mildew resistant vines on own roots and grafted to vigour modifying rootstocks resistant to root pests
    b) new mildew resistant no-prune vines on own roots and grafted onto vigour modifying rootstocks resistant to root pests.

2. Collect data on fuel usage, plant performance, water use efficiency and yield per hectare to investigate the difference between the treatments and identify the best scion/rootstock combinations that produce the largest reduction in inputs, GHG emissions and least vigour management costs.

3. Investigate the trade-off between intensification achieved by high density plantings and potential changes required to vineyard management.

4. In the third year, initiate winemaking to assess the attributes of wine made from the different treatments.

3. Methods

The project established a new vineyard block to investigate different plant density treatments using new experimental scion material resistant to mildews and with either normal growth characteristics or a new dwarf form that may not require pruning (no-prune type). These scions were planted on either own roots or grafted onto Ramsey and new experimental CSIRO rootstocks characterised as either low or high vigour with tolerance or resistance to nematodes and phylloxera.

3.1 Vineyard establishment

A 140 m long new vineyard was established at the SARDI Nuriootpa site covering nearly 0.4 ha. The vineyard was set up on nearly flat land having uniform soil properties and nutrient status. The row posts were positioned to produce five 3 metre wide rows (low density plot) and eight 1.5 metre wide rows (high density plot).

Figure 1. Experimental vineyard. (a) view from the east end of the plot, (b) view from the west end showing wider rows, (c) view from the west end showing narrow rows.



There are 23 panels in the plot running from east to west. The experimental plot was surrounded by border rows and border panels on all four sides. The plot was divided in two sections lengthwise, to accommodate different scion-rootstock combinations. Panels 3 to 13 are considered as the east half of the plot and panels 13 to 22 as the west half of the experimental plot.

The area of the low density plot and the high density plot was 58.8% and 41.2%, respectively. Vines were planted 2.12 m apart in the wider rows and 1.27 m apart in the narrow rows. Thus, the plant density in the low density section of the plot has ~1,570 plants/ha and the high density plot has a ~5,250 plants/ha.

Each row was provided with two drip lines to allow the future application of different water treatments. Toro Turbo-Key® Drip emitters capable of delivering water at the rate of 4 L/h were installed in the drip line at every plant position. The irrigation pressure was set to 25 psi. The irrigation of the whole experimental plot was controlled by a four station irrigation set up. Stations 1 & 2 were dedicated to the low density plot and stations 3 & 4 were dedicated to the high density plot.

A single line cordon wire was fitted 1 m above ground for trellising vines. A pair of foliage wires was installed on either side of the line posts for vine trellising and lifting. For normal vines (grafted and on own roots) the foliage wire was installed 25 cm above the cordon wire. For no-prune microvines (grafted and on own roots) the foliage wire was installed 10 cm above the cordon wire.

3.2 Plant material

Two elite normal vines and two No-Prune dwarf 'microvines' and three different types of pest tolerant/resistant rootstocks were planted in the trial. All the grapevines used in the trial were powdery mildew and downy mildew resistant. The plant material is listed below.

Normal vines: White berry vine (white_v, plant ID 39_17_09_1) and red berry vine (red_v, plant ID 37_14_11_4).

No-Prune dwarf microvines: White microvine (white_mv, plant ID V34) and red microvine (red_mv, plant ID V4).

Rootstocks: Ramsey, M6262 (Merbein 6262) and C114. All three rootstocks are either tolerant or resistant to nematodes and phylloxera.

Table 1 shows the planting distribution of the different vine and vine-rootstock combinations.

Table 1. Planting distribution of the different vine and vine-rootstock combinations and planting density () in rows and sections of the experimental plot.

Row number	East half (Panel 3 to 12)	West half (Panel 13 to 22)
1	Border plants (low)	Border plants (low)
2	red_v + Ramsey (low)	white_v + Ramsey (low)
3	red_v (low)	white_v (low)
4	red_v + M6262 (low)	white_v + M6262 (low)
5	red_v + C114 (low)	white_v + C114 (low)
6	white_mv (high)	white_v (high)
7	white_mv + M6262 (high)	white_v + M6262 (high)
8	white_mv + C114 (high)	white_v + C114 (high)
9	red_mv (high)	red_v (high)
10	red_mv + M6262 (high)	red_v + M6262 (high)
11	red_mv + C114 (high)	red_v + C114 (high)
12	white_mv + Ramsey (high)	red_v + Ramsey (high)
13	Border plants (high)	Border plants (high)

Plant propagation and grafting

All four scions on own roots were generated through propagation by green cuttings in a mist chamber. The cuttings were placed in a potting mix and kept in growth chambers (25° C) in a humid environment for about a month. Afterwards they were transferred to glasshouses and raised in flood drain tanks. The glasshouse

temperature was set to 23° C but the temperature range was ±10 °C during the growing period.

The rootstocks were propagated either by woody cuttings or green cuttings and raised in a glasshouse as described above. The normal vines were grafted onto short rootstock cuttings (up to 25 cm) either by means of bud grafting or green grafting. The dwarf microvines were grafted onto long rootstock cuttings (about 90 cm in length) either by bud grafting or green grafting. Grafted plants were grown in glasshouses before planting in the field. Standard plant protection measures were taken in the glasshouse to ensure healthy growth of all grafted vines, vines on own roots and rootstocks.

Field planting

The first major field planting was carried out in October 2014. On this occasion 761 plants were planted, of which 260 were on own roots and 501 were grafted vines of all combinations of rootstock and scions. Another 72 grafted plants were planted in November 2014. Most of these plants survived. By March 2015 another 38 plants were planted to replace the dead plants and to fill up gaps. More grafted plants were planted during the 2015-16 season to replace dead plants and to fill gaps.

Difficulty was experienced obtaining a supply of rootstock material suitable for grafting and in producing roots on long canes. A poor grafting response was also observed for the long canes of M6262 and C114 and was a major obstacle in producing enough grafted microvine plants.

Vine management

Following the field planting in Spring 2014 plants were regularly irrigated. Easy N liquid fertiliser (42.5% N) was applied at a rate of 1 g per plant, once per month from January to April, to help plant establishment and growth. Irrigation was ceased in late April for each season. Irrigation for each season was resumed in early October. In the 2015-16 season the plants were fertilised a total of four times with mono-ammonium phosphate (MAP 39) from October 2015 to February 2016 at 15 g/plant. For vine establishment during the project all rows were irrigated under one irrigation regime.

Figure 2. Narrow rows of the experimental block. (a) normal vines and (b) no-prune dwarf microvines.



3.3 Plant measurements

LAI (leaf area index) measurements

Leaf area index was measured on selected panels of vines from each treatment using an LAI-2200C Plant Canopy Analyzer (LI-COR, Lincoln, Nebraska USA) on a clear sunny day. Cover guards from each plant in the panel were removed before the LAI measurement. The lens of the Canopy Analyzer was covered with a cap having a 45° opening.

Pruning weight

Prunings were collected at the end of the season after leaf fall from all plants in selected panels. The panels selected for pruning weight measurements were the same panels used for LAI measurement. For pruning, canes were removed to leave a spur of two buds. Over-grown cordons were also cut back to halfway between adjacent plants. All pruned material from each panel was collected and weighed. The total pruning weight of a panel was divided by the number of plants in that panel to obtain an average pruning weight per vine. Pruning was done only on normal vines and not the no-prune microvines.

Berry sampling and analysis

Berries were harvested from randomly selected bunches on plants from each treatment. The berries were destemmed and 30 randomly picked berries were weighed. Berries from three plants selected at random from each treatment were also sampled for chemical analysis.

Brix measurement

Three plants were selected randomly from each treatment. A single berry was collected from 4-5 bunches from each plant in a plastic bag on 15 February 2016. The berries were squeezed into a plastic bag and a drop of juice was used to measure Brix using a table top Bellinger+Stanley RF-M710 digital Brix meter.

Berry chemical analysis

Ten berries were randomly picked from bunches collected from three randomly selected plants from each treatment. The berries were crushed in a plastic bag and 2 mL of must was transferred to a 2 mL Eppendorf tube and centrifuged for one minute at 13,000 rpm. Approximately 0.6 mL of the supernatant was analysed using an Oenofoss^{TM} analyser for Brix, pH, total acidity, volatile acidity, alpha amino nitrogen, ammonia, tartaric acid, malic acid and density.

Determination of phenolics in red berries

Thirty berries selected at random from three red berry plants of both normal and microvine vine types from different treatments were weighed and frozen in liquid nitrogen. The frozen berries were ground to a fine powder using a motorised grinder cooled with liquid nitrogen. The ground powder samples were stored in a -20° C freezer until analysed for phenolics. For phenolic analysis, one gram of frozen powder was weighed and 10 mL of 50 % (v/v) ethanol (pH 2.2) was added and incubated for one hour in a 10 mL falcon tube. The tubes were inverted every 10 minutes. The mixture was then centrifuged for five minutes at 3,500 rpm. Supernatant (1 mL) was then pipetted into 10 mL HCl, mixed thoroughly and allowed to stand for three hours. 300 µL of this sample was read at 700 nm, 520 nm and 280 nm for absorbance using a UV/VIS (FLUOstar Omega) spectrometer (BMG Labtech, Germany) against a blank sample. All measurements were carried out in triplicate and averaged. The data were subjected to a one-way ANOVA and the means were separated using post-hoc Tukey HSD Test.

4. Results and Discussion

4.1 Field trial design and vineyard establishment

The layout and design of the experimental field trial is described in the Methods section. The site chosen for the experiment had a uniform soil map. The treatments were:

1. Four scions on own roots. A normal red berry scion (red_v), a normal white berry scion (white_v), a no-prune dwarf low vigour white berry scion (white_mv) and a no-prune low vigour red berry scion (red_mv).

2. The four scions were also grafted onto three different rootstocks with different vigour conferring properties. Ramsey is a standard industry rootstock of high vigour, C114 is a new CSIRO rootstock of high vigour and M6262 is a new CSIRO rootstock of low vigour.

The above selections on own roots or grafted onto the different vigour modifying rootstocks were planted at both high and low density. No sprays for mildew control were used in the experimental block and this provided a saving in management costs.

The new site was planted with the new scion selections and this necessitated the propagation and grafting of new plant material not readily available in commercial nurseries.

4.1.1 Plant propagation and grafting

Rootstock canes for root striking and grafting were procured from commercial nurseries in South Australia. There was a suitable supply of Ramsey and M6262 canes during the period of the project, however, the supply of C114 rootstock canes was severely restricted and not enough material was available for grafting in the 2014/15 season and the 2015/16 season. This necessitated propagation and growth of this rootstock material under glasshouse conditions and development of green grafting techniques to provide enough material for the field trial.

4.1.1.1 Grafting onto short canes

Short cane grafting is typical in the Australian industry for commercial grafting of woody material and dormant buds. Bud grafting onto short canes was very successful for all four scions and the three rootstocks. As there was a severe shortage in the supply of C114 canes during the term of the project, C114 plants were propagated in the glasshouse. Short green canes were then cut from this material and a method was developed for the simultaneous green grafting and rooting of this C114 green material under mist chamber and glasshouse conditions.

4.1.1.2 Grafting onto long canes

Grafting onto long rootstock canes is an experimental method and is not typical for the grape industry. Long rootstock canes were used for grafting microvine scions to

just below the cordon wire as a method to hasten the establishment of cordons and avoid the need to wait 1-2 years for cordon establishment.

Initially efforts were made to produce roots on long canes (120 cm) using the conventional rooting method on hot beds. Rooting of C114 long canes was 90% successful. However, rooting of both M6262 and Ramsey long canes was very poor and the success rate ranged between 2-4%. To increase the number of long canes of M6262 and C114 suitable for grafting, an air layering method sometimes used for tropical tree propagation was attempted at one of the commercial nursery suppliers during the growing season of 2014/15. For M6262 about 20% rooting success was achieved from air layering. Rooting of C114 from air layering was highly successful (100%). The air layered cuttings (23 of M6262 and 15 of C114) were then established in the glasshouse prior to grafting, with a survival rate of 50% for both types of rootstock. Buds were grafted onto these canes but the majority of the grafted buds did not burst, suggesting a possible unknown physiological effect inhibiting bud burst. In the spring of 2015 rooting of long canes of M6262 and C114 was again trialled at a commercial nursery with canes producing roots grafted two months later (Table 2). Unfortunately a severe heatwave a month later killed most of the grafted vines at the nursery. As an alternative strategy, short canes were grown to a suitable height and green grafted with microvine scions in the field or glasshouse. This green grafting was quite successful with Ramsey but less so with C114. Green grafting with M6262 was challenging because of the less vigorous growth which produced thinner shoots.

Table 2. Success of rooting and bud grafting on long canes of M6262 and C114 rootstocks. Spring 2015.

Rootstock variety	Canes struck	Canes with roots	Grafted with red_mv buds	Grafted with white_mv buds	% Grafting success
M6262	350	50	30	15	40
C114	100	90	70	20	20

The establishment of the experimental vineyard required the planting of new scions on own roots and grafting of different scion-rootstock combinations. This material was not available from commerical nurseries and the availability of the material in the numbers required was found to be limiting during the course of this project. This necessitated propagation of material, including a number of novel propagation techniques, during the course of the project, delaying the completion of the vineyard planting. It was found during propagation of the material that producing roots on long canes of the low vigour rootstock M6262 and high vigour rootstock Ramsey was difficult in contrast to induction of roots on short canes of these two rootstocks. While it was not essential to use long rootstock canes to graft on buds of white_mv and red_mv it was considered to be a way to produce a full cordon and hence fruit production in a shorter time than would normally be possible when establishing a vineyard.

Despite the delays in obtaining suitable plant material, the first objective of the project was achieved in establishing a high density planting in a no-spray block of

both normal and no-prune scions that were mildew resistant and grafted onto vigour modifying rootstocks that were resistant or tolerant to root pests.

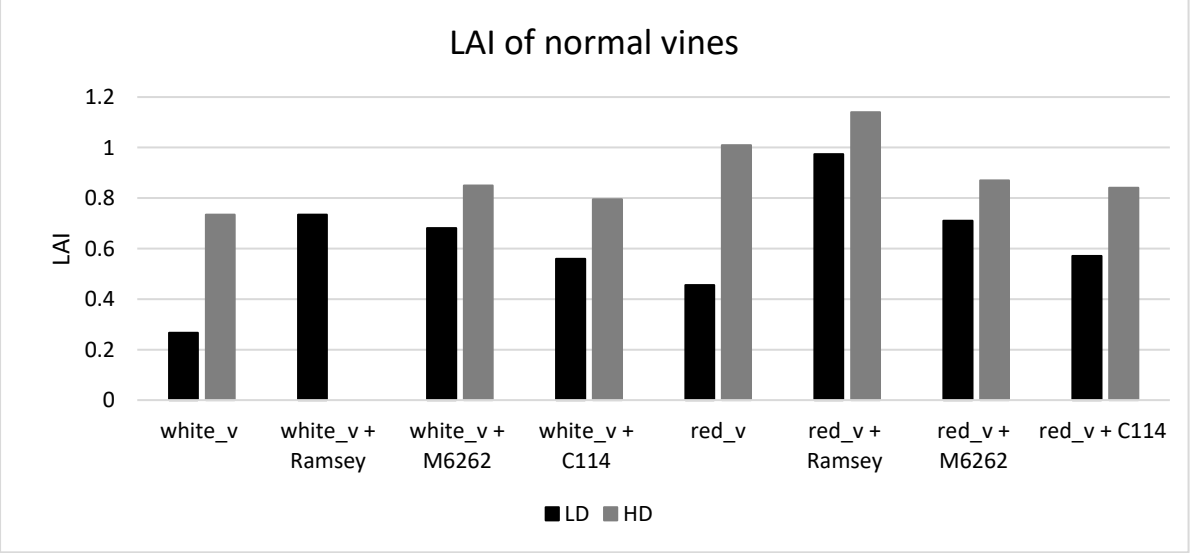
4.2 Plant performance

As a result of the delays in establishing the field site, the vines were too young for collecting sensible yield data or for making wine for comparative purposes. To encourage vine growth to fill the cordon wire during the last year of the project the vines with fruit had some fruit removed early in the season. Measurements were collected near the end of the season to investigate vigour differences and berry quality parameters.

4.2.1 Leaf Area Index (LAI)

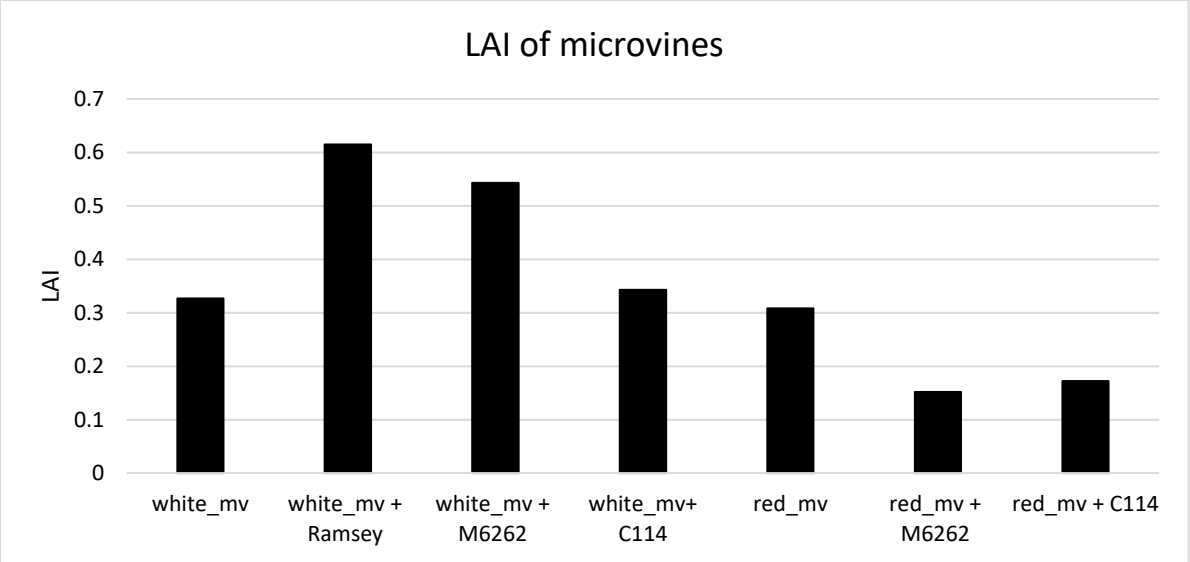
Leaf Area Index was measured towards the end of 2015-16 growing season from one selected panel of each treatment. Panels that were selected for LAI measurement had plants of uniform growth. The LAI data are graphically presented in Figures 3 and 4. There was a clear difference in LAI between the low density (LD) and high density (HD) plots of both normal white (white_v) and red vines (red_v), as seen in Figure 3. LAI values from the high density panels were consistently higher than for the low density panels. This was not unexpected as foliage growth was more crowded in the high density plot with five plants per panel compared to the low density three plants per panel.

Figure 3. Leaf Area Index (LAI) of the normal white and red own rooted and grafted vines in the high density (HD) and low density (LD) plots. (No error bar was added as data represent LAI measurements from a single panel from each treatment)



In Figure 3, LAI data for own rooted vines were also compared to grafted vines for both white and red vines. Red normal vines (red_v) in general had an overall better canopy growth and higher LAI than the white_v vines. Also, it appears from Figure 3 that grafting across all rootstocks improved canopy growth in both red and white normal vines especially in low density plots. Ramsey as the rootstock had the most pronounced positive effect on LAI for the red_v scion. Although C114 is considered a high vigour rootstock, vines grafted onto C114 had rather lower LAI. During the season, it was observed that C114 rootstocks continuously produced trunk and root suckers and this likely competed with the scion growth. This was not the case with Ramsey and M6262.

Figure 4. Leaf Area Index (LAI) of the white_mv and red_mv vines as affected by rootstock vigour grown under high density. (No error bar was added as data represent LAI measurements from a single panel from each treatment)



The effect of rootstock on the canopy growth and thereby LAI of white (white_mv) and red microvines (red_mv) is depicted in Figure 4. Like in the normal vines, the rootstock Ramsey was found to confer the most canopy growth for the microvine scions. Also similar to normal vines, the microvines had reduced LAI values when grafted onto C114. White_mv and red_mv vines did not differ greatly in LAI when grown on own roots.

Comparison of LAI values in Figures 3 and 4 indicates that under high density growing conditions the microvine scions had a lower LAI (0.152 - 0.615) than the normal vines (0.735 – 1.14).

4.2.2 Pruning weight

Pruning weights provide a baseline measure of the vine vigour which reflects vine growth over the season and can be influenced by the plant genotype and management practices. However, pruning weight does not represent total biomas

production by the vine, rather it provides a relative measure of vine vigour. Pruning weight is also useful in identifying areas in the vineyard that are not uniform in growth. Pruning weights can be analysed in several ways such as, pruning weight per vine, per linear unit distance of the row, average cane weights and yield to pruning weight ratio (Ravaz Index). Pruning weights collected from a vineyard having different planting and row distances and different cultivars or rootstock scion combination do not compare the same unit.

Figure 5a. Pruning weight per panel of the normal white (white_v) and red (red_v) vines as affected by rootstock. (No error bar was added as data represent measurements from a single panel from each treatment)

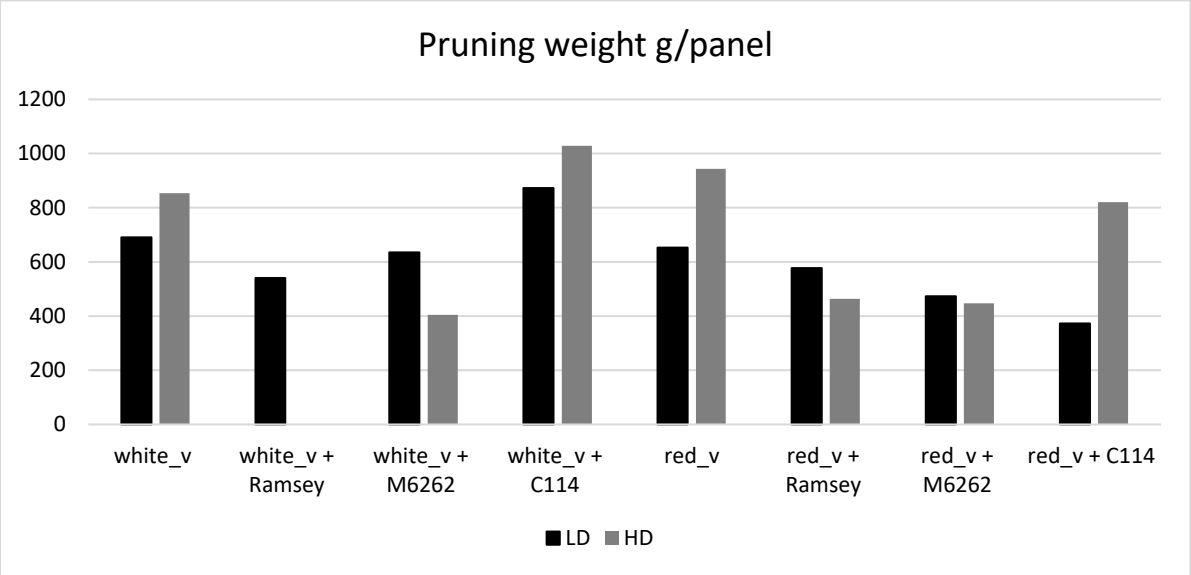
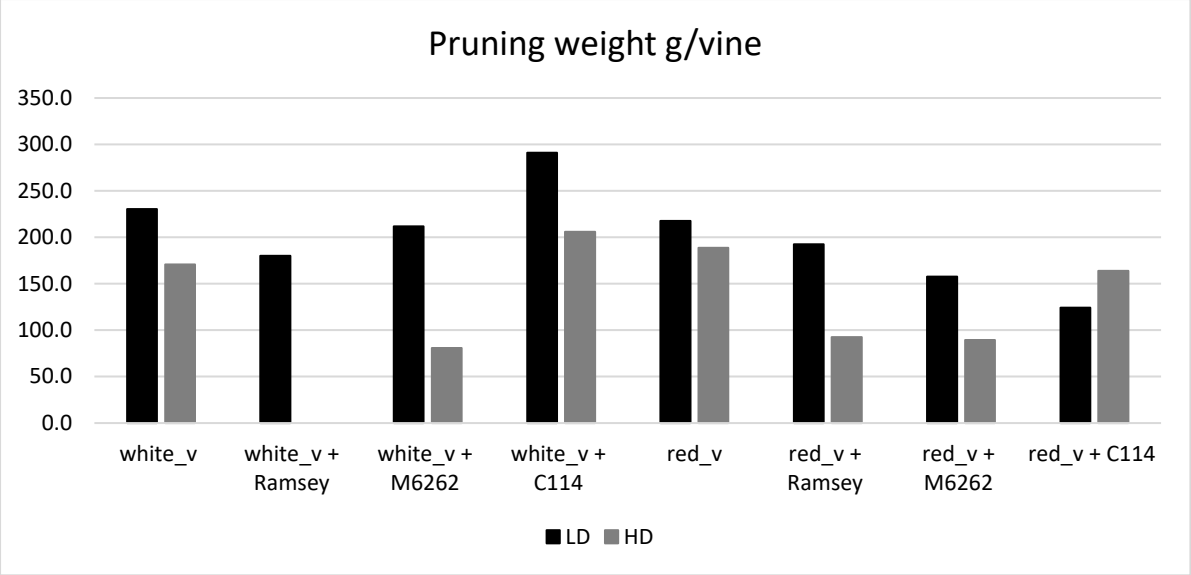


Figure 5b. Pruning weight per vine of the normal white (white_v) and red (red_v) vines as affected by rootstock. (No error bar was added as data represent measurements from a single panel from each treatment)



Figures 5a and 5b present per panel and per vine pruning weight data respectively, collected during the winter of 2016 after leaf drop. Figure 5a shows that the pruning weight of own rooted vines was higher in the high density plot than the low density plot. Results were variable for the rootstock combinations and this likely reflects the preliminary nature of the results representing only one season and the young age of the plants. Figure 5b shows that the per vine pruning weight in the low density plots were higher than the high density plots for all treatments except red_v + C114. This might be explained by the individual vines in the low density plots being able to harness more underground nutrients and water and above ground sunlight due to less competition. There was a paradigm shift when both white and red vines were grafted on rootstocks of different vigour. For both white and red vines grafted onto high vigour Ramsey or low vigour M6262 rootstock the per vine pruning weights were almost half in the high density plot compared to the low density planting (Figure 5b).

When the pruning weight data (Figure 5a) are viewed in conjuction with the LAI data (Figure 3) it can be seen that the own rooted vines and vines grafted on C114 follow the same trend, while the pruning weight of the vines grafted on either Ramsey and M6262 shows a reversal in the trend (in both white and red normal vines).This may indicate that underground resource capture is contributing more to pruning weight than above ground sunlight capture. However, the results should be treated with caution as the data presented here were collected from only one season when the plants were still in the establishment phase. Moreover, the pruning weight data were not representative of the whole field and the sample size was limited. It is necessary to follow up this analysis in future seasons with larger and more representative samples in order to conclusively determine the effect of rootstock vigour on dormant pruning weight and thereby relative vine vigour.

Pruning weight data were not collected for red_mv and white_mv scions on rootstocks and own roots as these treatments did not require pruning due to the no-prune phenotype of the vines.

4.3 Berry analysis

4.3.1 Berry weight

Figure 6 shows the berries of the four vine types used in this experiment. Table 3 shows the berry weights from each treatment. Berries varied in size and weight between the four scions in the trial. Variations were also noticeable within the vine types due to planting density and rootstocks used for grafting. Several environmental and genetic factors may influence berry size. These include drought, nutrient availability, light interception and temperature at various developmental stages and also seed number in individual berries (Dai et al. 2011; Ribéreau-Gayon et al. 2006). There is also natural variability in berry weight and size within a single bunch, a single vine and between individual vines (Tarter and Keuter, 2005).

Figure 6: Berries of four vine types photographed on 15 February 2016. (a) white_v, (b) red_v, (c) white_mv, (d) red_mv

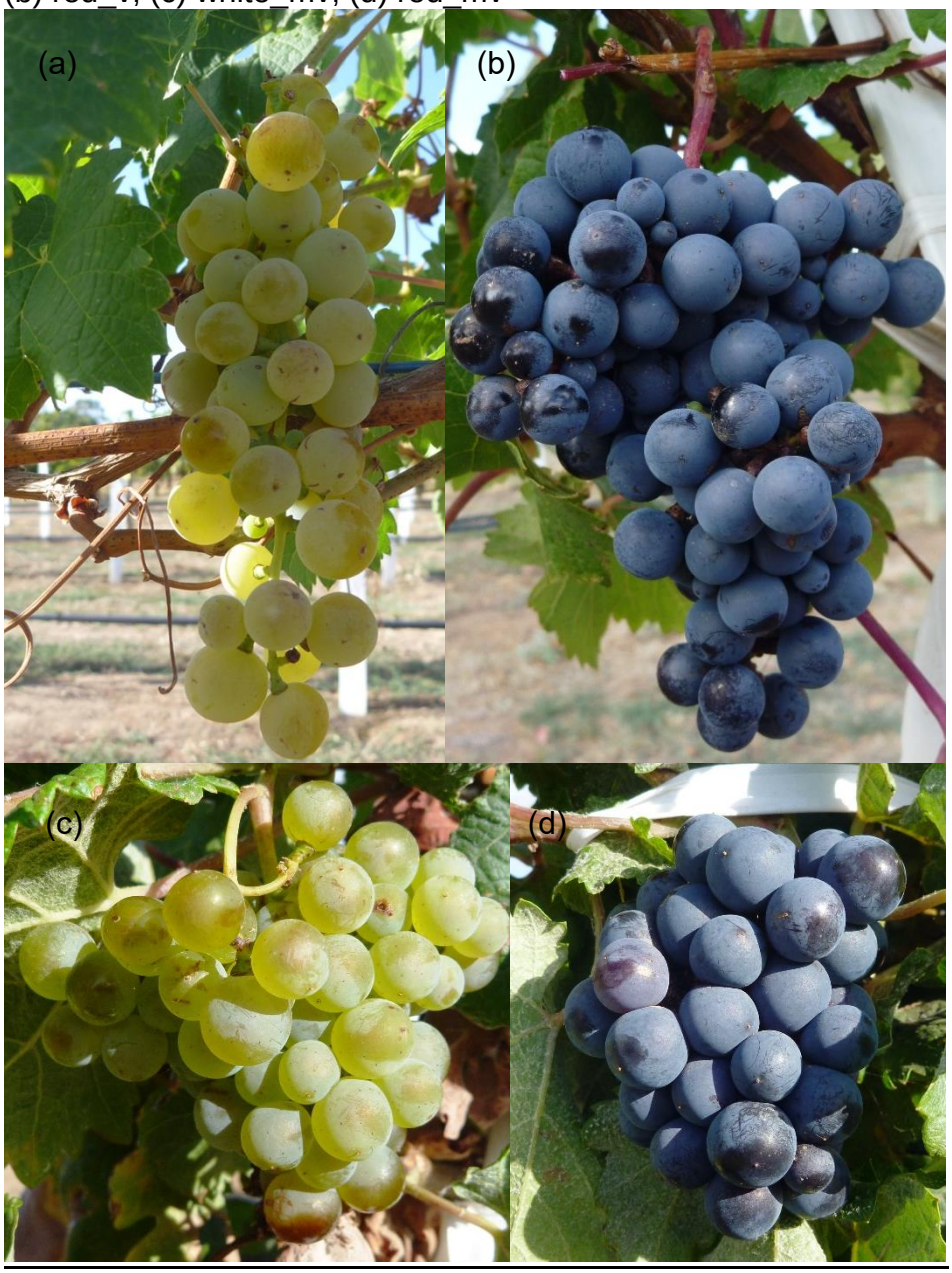


Table 3. Berry weight from different treatments collected 1 March 2016.

Plant Material	Planting density	30 berry weight (g)	Average berry weight (g)
white_mv	High	25.06	0.84
white_mv + M6262	High	25.6	0.85
white_mv + C114	High	22.18	0.74
white_mv + Ramsey	High	25.5	0.85
red_mv	High	25.17	0.84
red_mv + M6262	High	23.42	0.78
red_mv + C114	High	24.46	0.82
white_v	Low	39.45	1.32
white_v	High	40.73	1.36
white_v + Ramsey	Low	39.92	1.33
white_v + M6262	Low	38.84	1.29
white_v + M6262	High	34.84	1.16
white_v + C114	Low	38.93	1.30
white_v + C114	High	43.64	1.45
red_v	Low	26.8	0.89
red_v	High	25.79	0.86
red_v + M6262	Low	25.4	0.85
red_v + M6262	High	26.57	0.89
red_v + C114	Low	24.17	0.81
red_v + C114	High	25.5	0.85
red_v + Ramsey	Low	26.1	0.87
red_v + Ramsey	High	24.33	0.81

In general it appears that the berries from microvine scions may be smaller than berries on normal scions. However, these are preliminary data obtained from the first season of bearing. It will be necessary to collect data over several seasons to determine if different plant densities and scion-rootstock combinations have an effect on berry weight at maturity.

4.3.2 Brix values

Figure 7 shows the mean Brix values from three plants of each treatment. The data were grouped based on the four scions used in the experiment. Brix measured on a particular day indicates the maturity status of the berries on that day and the influence of the experimental treatment on berry maturity. No-prune microvine berries showed the least variability in Brix when grafted on either M6262 or C114 rootstock. The white_mv berries showed some degree of variability between individual plants when grafted on Ramsey. The microvine data suggest that the rootstocks used in this experiment may have little effect on the berry maturity as determined by Brix levels.

Both normal white and red vines show variation in berry Brix values due to plant density and rootstock treatment. This was more pronounced in red normal berries. Figure 8 shows that red normal berries had a lower value when grafted onto Ramsey and C114 when data were pooled across planting densities compared to plants on own roots and grafted onto the low vigour rootstock M6262. This may indicate that the low vigour rootstock hastened ripening while the high vigour rootstocks slowed down ripening. Rootstock effect on berry TSS has previously been reported to be inconsistent (Keller et al., 2012; Ruhl et al, 1998). In addition, the effect of rootstock on fruit ripening could be scion specific as was found by Nuzzo and Matthews (2006) and was found to have no effect in the case of Cabernet Sauvignon. Again, while interesting, these data should be considered with caution since they are only from a single season. A reliable conclusion on whether there is any effect of the treatments in question on berry maturity and ripening date will only be reached after evaluating data over several successive seasons.

Figure 7. Berry Brix measured for each experimental treatment on 15 February 2016. Data show the average of measurements taken for three individual plants from each treatment. Error bars indicate standard deviations of the means.

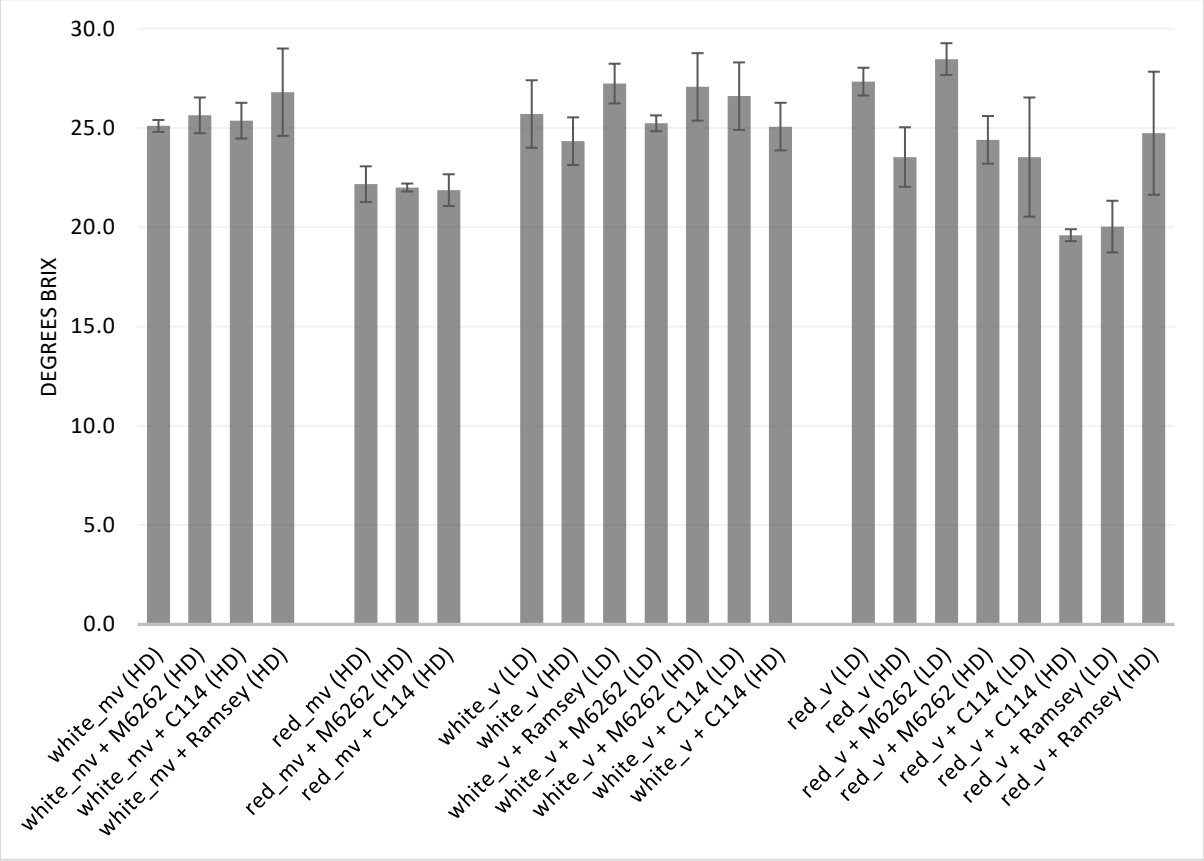
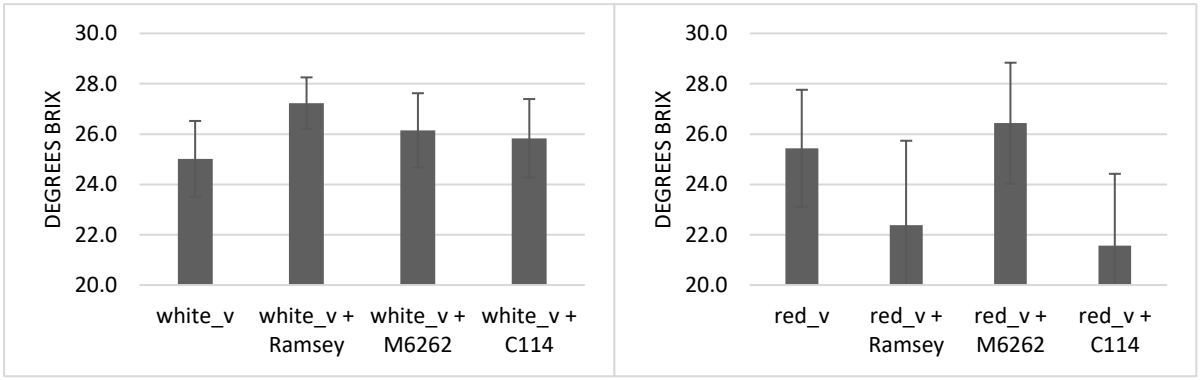


Figure 8. Berri Brix of white_v and red_v berries averaged by pooling data from high density and low density vines. Error bars indicate standard deviations of the means.



4.3.3 Berry chemical analysis

Rootstocks can affect berry chemical composition indirectly through its influence on nutrient uptake and scion vigour (Chou and Li, 2014; Ruhl et al. 1988). To determine whether rootstocks had caused any variation in berry chemical composition, musts from all treatments were analysed using an OenoFoss^{TM} analyser which utilises Fourier Transform Infrared (FTIR) technology to scan samples in the full mid-infrared spectrum. Results of must analysis using the Oenofoss^{TM} analyser for Brix, pH, total acidity, volatile acidity (VA), yeast assimilable nitrogen (YAN), alpha amino nitrogen, ammonia, tartaric acid, malic acid and density are shown in the Table 4.

In Table 4 the data were organised into groups of the four scions used in the experiment. The pH of the berries ranged between 3.41 to 4.19 across all scions. The effect of rootstocks on berry pH appeared to be small. Similarly the effect of rootstocks on berry Brix was minimal as well. It has been previously reported by Reynolds and Wardle (2001) that fruit pH and TSS of Gewurztraminer and Riesling grapes showed non-significant variation when grafted onto Couderc 3309, Kober 5Bb, Teleki 5C and SO4 rootstocks. Several other authors (Koundouras et al, 2009; Harbertson and Keller, 20012 and Keller et al, 2012) also reported that rootstocks had only a minor effect on fruit pH and soluble solids. The Brix or TSS measured by Oenofoss did not correlate with Brix measured by Brix meter. This discrepancy may be explained by the fact that berry Brix is a highly heterogeneous character (Friedel et al. 2016) and is thus subject to sampling error and influenced by sample size.

Table 4. Result of must analysis of berries of different treatments collected 1 March 2016 and measured by Oenofoss™ on the same day.

Plant Material	Planting density	pH	Total Acid (g/L)	Malic acid (g/L)	Tartaric acid (g/L)	TSS (°Brix)	Density (g/mL)	VA (g/L)	YAN	Alpha Amino (mg/L)	Ammonia (mg/L)
white_mv	High	3.92	4.2	1.2	7.6	23.6	1.1	0.09	444.7	266.0	218.0
white_mv + M6262	High	4.10	4.0	2.2	7.4	24.6	1.1	0.17	288.3	191.7	117.8
white_mv + C114	High	3.79	4.2	0.8	7.9	24.2	1.1	0.11	225.0	142.0	101.3
white_mv + Ramsey	High	3.89	4.2	1.3	6.4	25.0	1.1	0.14	308.8	193.1	141.1
red_mv	High	3.63	7.2	3.4	7.4	19.9	1.1	0.11	261.2	175.9	104.1
red_mv + M6262	High	3.80	6.5	3.9	7.0	18.9	1.1	0.13	281.9	194.2	107.0
red_mv + C114	High	3.59	8.4	3.6	7.7	19.7	1.1	0.00	241.0	167.5	89.7
white_v	Low	3.86	4.9	2.2	7.0	24.4	1.1	0.17	298.9	222.0	93.8
white_v	High	3.98	3.9	1.5	7.6	25.1	1.1	0.18	292.2	216.7	92.0
white_v + Ramsey	Low	4.19	4.1	2.4	7.5	25.2	1.1	0.27	467.6	356.8	135.2
white_v + M6262	Low	4.07	3.9	2.0	7.6	24.0	1.1	0.21	326.3	246.8	96.9
white_v + M6262	High	3.88	4.7	1.7	9.4	26.0	1.1	0.13	236.2	168.6	82.5
white_v + C114	Low	4.08	3.9	1.8	7.4	26.5	1.1	0.21	375.2	273.2	124.4
white_v + C114	High	3.75	4.9	1.9	7.7	24.7	1.1	0.16	229.6	161.0	83.6
red_v	Low	3.54	6.9	1.4	11.0	22.7	1.1	0.11	354.0	227.6	154.1
red_v	High	3.44	7.6	2.0	10.7	22.2	1.1	0.12	297.8	191.0	130.3
red_v + M6262	Low	3.94	4.5	1.1	8.6	25.0	1.1	0.20	352.4	252.5	121.8
red_v + M6262	High	3.72	5.2	1.0	8.8	23.9	1.1	0.16	259.7	169.0	110.6
red_v + C114	Low	3.41	8.2	2.1	11.4	21.1	1.1	0.09	337.1	215.1	148.7
red_v + C114	High	3.27	8.3	1.6	12.1	22.9	1.1	0.14	236.3	151.7	103.2
red_v + Ramsey	Low	3.63	7.0	2.4	9.6	21.9	1.1	0.11	377.0	250.1	154.7
red_v + Ramsey	High	3.49	7.9	2.3	11.5	22.0	1.1	0.13	334.1	223.9	134.4

Figure 9. Chemical composition of berries as affected by rootstocks compared to that of own rooted (OR) vines. Data from Table 4 were averaged over all rootstock and planting density treatments and plotted next to berry composition data of OR vines. Error bars represent standard deviation (SD) of the mean values. Here the SD can also be considered as an indicator of the effect of rootstock on berry chemical composition, i.e. the larger the SD value for the grafted vines compared to OR vines, the larger the effect of rootstocks.

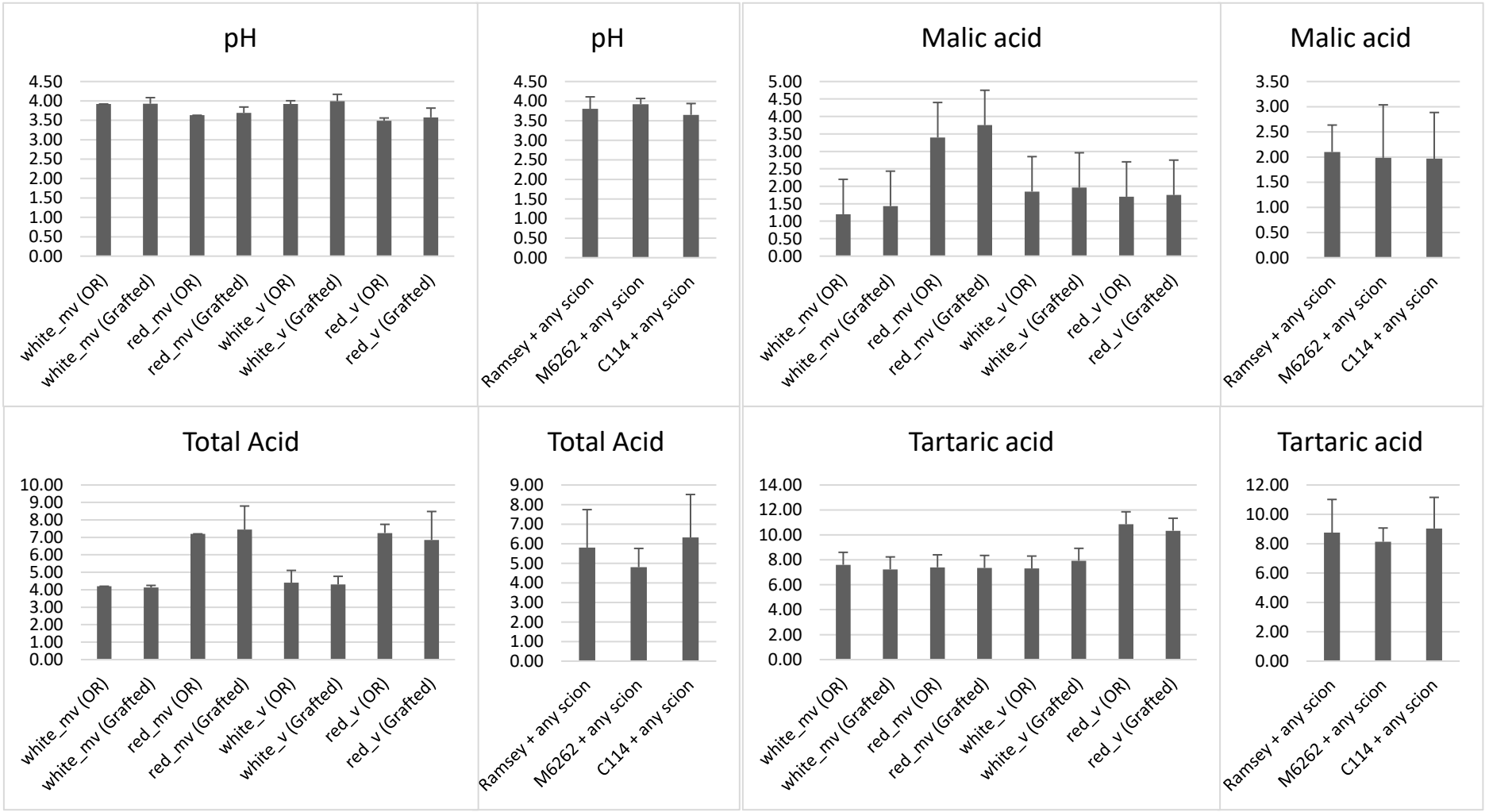
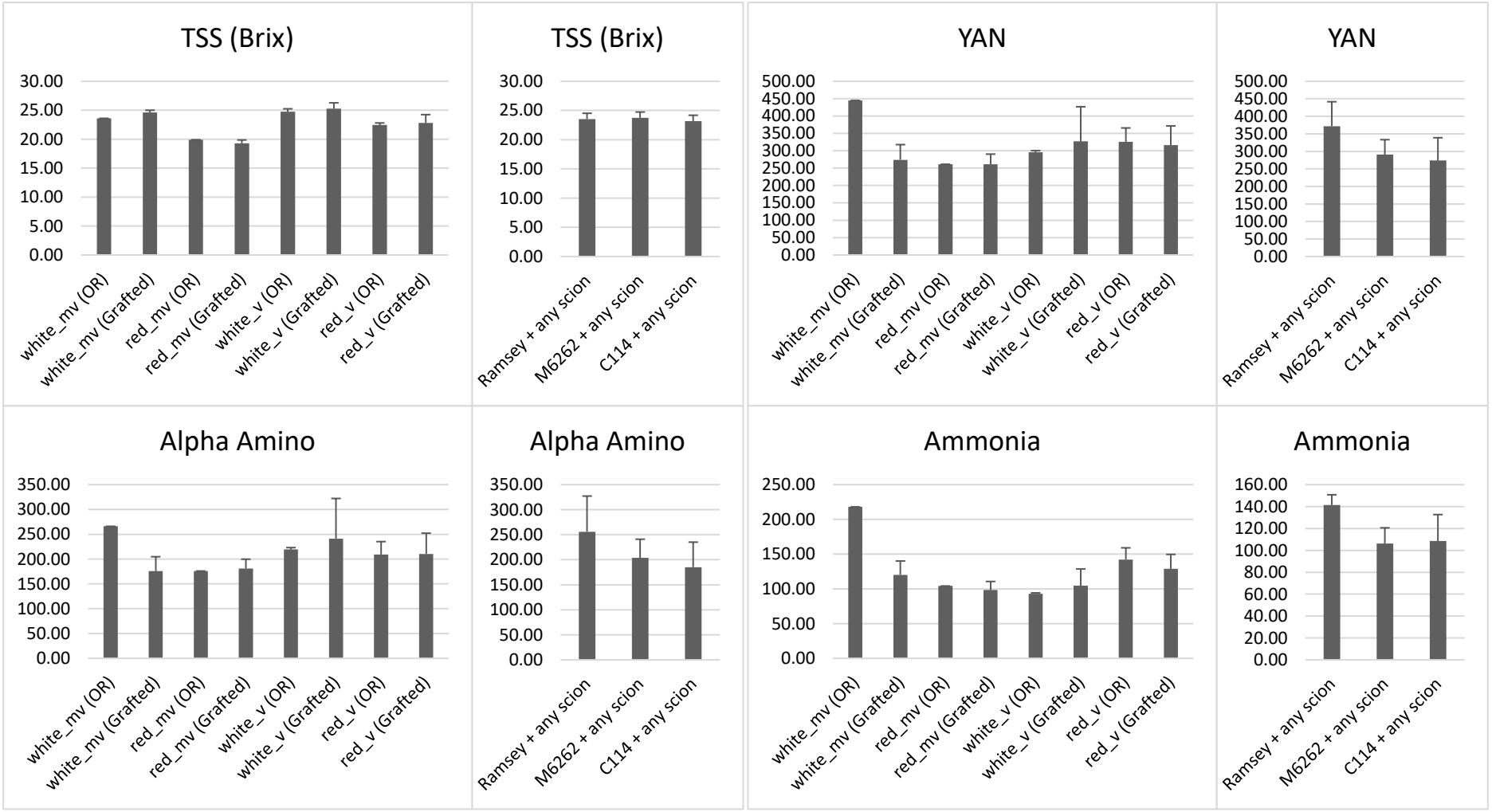


Figure 9. (continued)

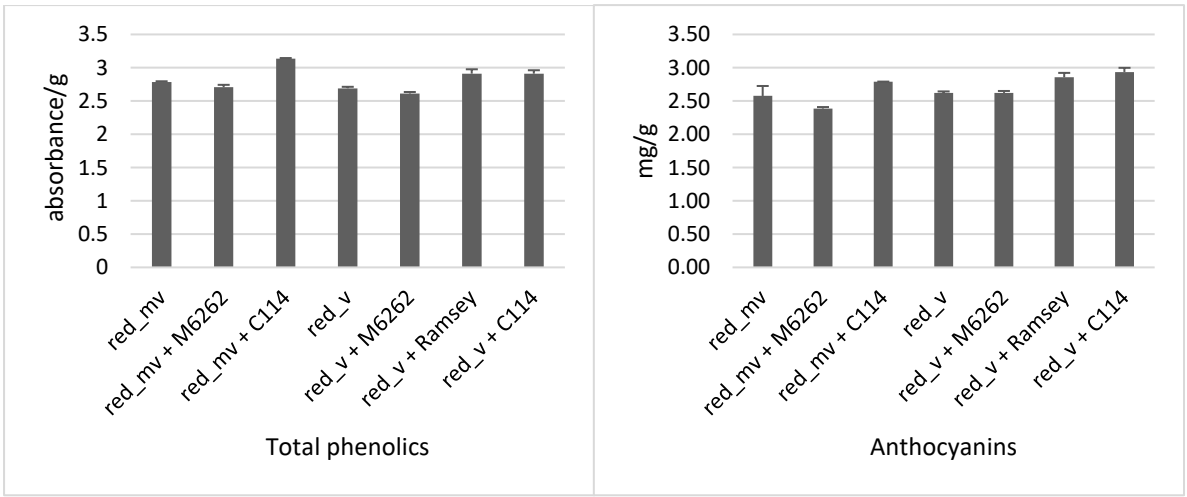


The total acid content appears to have been affected considerably in most vine types by all rootstock genotypes used in this experiment (Figure 9). Data in Table 4 show that the total acidity of the red berries was distinctly higher than the white berry types. Considering the Brix data in Table 4, it appears that the white berries were at a more advanced state of maturity on the day of sampling compared to that of the red berries. This means that in the white berries the reduction in malic acid was greater than the red berries which might have contributed towards the lower total acid content in the white berries. H^+ ions liberated as a result of dissociation of acids are measured to calculate pH. However, the relationship between the 'total acid' and pH in grape berries is not as direct as it is in the case of acids dissolved in pure water. The presence of various kinds of acids and their salts e.g. potassium bitartrate in berries affects pH and the relationship between acidity and pH in must is rather complex. This may be why the pH values of the red and white berries did not vary as markedly as that of total acid.

The amino nitrogen (N) content of the berry is important for vinification because it is used as a nutrient for yeast and bacteria during alcoholic and malo-alcoholic fermentations (Huang and Ough 1989, Ough et al 1991). Figure 9 indicates that berry Yeast Assimilable Nitrogen (YAN), Alpha Amino Nitrogen and Ammonia were affected by rootstocks of all genotypes more pronouncedly in normal vines than in the microvines. The effect of all three genotypes on these nitrogen resources of berry was comparable. Holzapfel and Treeby (2007) reported that rootstocks are responsible for the overall amounts of amino acids in Shiraz grape juice. They presented data showing that under various N supply regimes the amount of total free amino, assimilable and non-assimilable amino N varied considerably in Shiraz grape juice for Shiraz grafted onto three different rootstocks.

The concentration of total phenolic substances and anthocyanins of the berries determines the oenological potential of the berry in red wine production. Figure 10 shows the mean concentration of total phenolics and anthocyanin levels in red berries from scions grown on own roots and grafted onto different rootstocks.

Figure 10. Concentration of total phenolic substances and anthocyanins of the red berries at final harvest on 1 March 2016 as affected by rootstocks. Error bars represent standard deviations of means of three replicated measurements.



The effect of rootstocks on the concentration of berry phenolic substances and anthocyanin has been reported to be both significant and insignificant in the literature. Koundouras et al. (2009) reported that rootstock genotype did not affect the concentration of skin phenolic substances. Similar findings were reported where rootstocks had a small influence on the concentration of anthocyanins and tannins in grape berry skin and seeds when grown under deficit irrigation (Harbertson and Keller 2012). However, from a three year study, Berdeja et al. (2014) found that Pinot Noir berries of plants grafted onto 110R accumulated more total anthocyanins than berries of plants grafted onto 125AA at all developmental stages.

One-way ANOVA followed by post-hoc Tukey HSD Test was performed to see if the concentration of total phenolic substances and anthocyanins differed significantly among the own rooted red_mv and red_v red berries and berries from the grafted plants. There was no significant difference between the concentration of total phenolic substances of the own rooted red_mv berries and berries collected from red_mv grafted onto M6262. However, a significant difference was found ($p<0.01$) between own rooted red_mv berries and berries collected from red_mv grafted onto C114 and also between berries collected from red_mv grafted onto M6262 and berries collected from red_mv grafted onto C114. A statistically significant difference ($p<0.01$) was also found in anthocyanin concentration of berries from own rooted vines, berries collected from red_mv grafted onto M6262 and berries collected from red_mv grafted onto C114. However, no significant difference was found either in the concentration of total phenolic substances or anthocyanins of red_v berries when means were compared between own rooted vine berries and berries collected from vines grafted on either of the three rootstocks (Ramsey, M6262 and C114).

While it was not possible to make wine in the final year of the project, it was possible to collect berry data to indicate if there was likely to be wine differences between treatments. The preliminary berry data suggest that rootstocks have an influence on total acid and phenolic and anthocyanin levels in red grapes. Of significance is the observation that berries from the no-prune white_mv and red_mv scions have berry quality parameters similar to normal vines suggesting that wine made from these dwarf vines should have similar attributes to wine produced from normal vines.

4.4 Estimated costs for high and low density plantings

4.4.1 Estimated establishment costs

The block used in this experiment was redeveloped from an existing SARDI vine block. The previously planted vines and trellises were removed and a new experimental plot was established to fit the experimental planting layout. New irrigation systems were installed with remote monitoring and control. Table 5 summarises field development costs in the 2013-14 financial year. In Table 6 an estimate of costs of own rooted and grafted plant materials is presented based on current commercial nursery pricing.

Table 5. Field development in the 2013-14 financial year.

Field development cost	Cost excl. GST	Low density	High density	Cost incl. GST	Low density	High density	Cost/ha			
							Cost excl. GST		Cost incl. GST	
							Low density	High density	Low density	High density
Trellis and post removal	1,224.82	720.19	504.63	1,374.30	808.09	566.21	3,322.70	3,325.92	3,728.20	3,731.83
Vineyard set-out	644.35	378.88	265.47	708.79	416.77	292.02	1,747.99	1,749.69	1,922.81	1,924.68
Knocking strainers and posts	1,723.00	1,013.12	709.88	1,895.31	1,114.44	780.87	4,674.16	4,678.70	5,141.60	5,146.60
Mark out and deep rip for planting	123.75	72.77	50.99	137.50	80.85	56.65	335.71	336.04	373.01	373.37
Irrigation system installation	4,241.16	2,493.80	1,747.36	4,712.40	2,770.89	1,941.51	11,505.43	11,516.61	12,783.81	12,796.24
Posts and strainers	2,700.10	1,038.50	1,661.60	2,970.11	1,142.35	1,827.76	4,791.23	10,951.39	5,270.36	12,046.53
Drip tube wire	1,058.25	622.25	436.00	1,164.00	684.43	479.57	2,870.82	2,873.61	3,157.70	3,160.77
Cordon and foliage wire	616.00	362.21	253.79	677.60	398.43	279.17	1,671.09	1,672.71	1,838.20	1,839.98
Installation of cordon wire	631.53	371.34	260.19	701.65	412.57	289.08	1,713.22	1,714.88	1,903.44	1,905.29
Cobra clamp, poly joiner and vine clip	249.06	146.45	102.61	273.96	161.09	112.87	675.65	676.31	743.20	743.92
Total	**13,212.02**	**7,219.51**	**5,992.52**	**14,615.62**	**7,989.91**	**6,625.71**	**33,308.00**	**39,495.86**	**36,862.33**	**43,669.21**

Table 6. Estimated cost of plant materials per hectare for low and high density planting based on current commercial nursery prices.

Plant costs	Pricing for >5000 vines	Low density (1570 vines/ha)		High density (5250 vines/ha)	
		Cost excl. GST	Cost incl. GST	Cost excl. GST	Cost incl. GST
Own rooted vines	$1.70 per vine	2,669.00	2,935.90	8,925.00	9,817.50
Grafted vines	$4.80 per vine	7,536.00	8,289.60	25,200.00	27,720.00

Table 7. Cost of inputs in the 2014-15 financial year

Input categories	Total costs	Low density plot (330 positions)	High density plot (748 positions)	Cost/ha($)		Cost/plant($)	
				Low density	High density	Low density	High density
Irrigation water	1,773.54	796.32	977.22	3,673.91	6,440.74	2.41	1.31
Fertiliser	557.65	250.38	307.27	1,155.18	2,025.15	0.76	0.41
Mowing / inter row space management	400.00	235.20	164.80	1,085.12	1,086.18	0.71	0.22
Weed control including fuel and spraying costs	400.00	235.20	164.80	1,085.12	1,086.18	0.71	0.22
Insect control including fuel and spraying costs	200.00	56.00	144.00	258.36	949.09	0.17	0.19
Spraying for control of mildews	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	3,331.19	1,573.10	1,758.09	7,257.69	11,587.34	4.77	2.35

Table 8. Costs of inputs in the 2015-2016 financial year

Input categories	Total costs	Low density plot (330 positions)	High density plot (748 positions)	Cost/ha($)		Cost/plant($)	
				Low density	High density	Low density	High density
Irrigation water	1,512.00	678.89	833.11	3,132.12	5,490.93	2.06	1.11
Fertiliser	172.21	77.32	94.89	356.73	625.39	0.23	0.13
Mowing / inter row space management	1,776.22	1,044.42	731.80	4,818.53	4,823.22	3.16	0.98
Weed control including fuel and spraying costs	467.50	274.89	192.61	1,268.24	1,269.47	0.83	0.26
Insect control including fuel and spraying costs	576.00	161.28	414.72	744.08	2,733.37	0.49	0.55
Spraying for control of mildews	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	4,503.93	2,236.80	2,267.13	10,319.71	14,942.38	6.78	3.03

Costs for field development subheadings were apportioned based on the percentage area of the high and low density blocks except for posts and strainers. Cost for posts and strainers were apportioned based on the numbers of post and strainers used in the rows for the high and low density blocks.

It can be seen from Table 5 that costs calculated on a per hectare basis were higher to establish a high density block ($39,495) compared to a low density block ($33,308). This difference is due mainly to the extra posts required for the additional rows in a high density block. The information in Table 6 also shows that it is more expensive to purchase plant material for a high density block due to the high number of plants (5,250) that can be planted in a hectare compared to a low density site (1,570). This cost difference is approximately 3.3 times, regardless of whether grafted or own rooted vines were purchased.

Combining vineyard establishment costs and plant material it was found that the initial cost of establishing a high density block was 1.34 times more expensive than a low density vineyard.

4.4.2 Estimated management costs

Tables 7 and 8 show the running costs over two seasons calculated on a per hectare and per plant basis, excluding pruning costs.

4.4.2.1 Estimated costs involving fuel usage and associated GHGs

Management costs involving GHG production from vehicles included mowing of inter-row spaces, weed control and insect control (mites and caterpillars). Averaged over two seasons it was found that costs per ha were 1.2 times higher in a high density block compared to a low density block but when calculated on a per plant basis the opposite was found with a 2.5 times advantage to managing a high density block.

The use of mildew resistant scions in both low and high density plots meant that there were no costs for mildew spraying and no associated GHG production (Tables 7, 8). A 2007 GWRDC report (AHA viticulture, 2007, RD 05/03-3) indicated that average costs per hectare across a number of regions was $95-$1849 for pest and disease control in 2006. A 2010 GWRDC report (Scholefield Robinson Horticultural Services Pty Ltd and EconSearch Pty Ltd, 2010, GWR 08/04) stated that powdery ($76 million per annum) and downy mildew ($63 million per annum) had the largest negative economic impact of all pests and diseases.

4.4.2.2 Estimated costs for irrigation and water usage efficiency

Town water was used for the experimental block to ensure reliability of supply but was more expensive than the traditional water supply for irrigation in the Barossa Valley. The volume of water used in the low density plot based on volumes recorded by irrigation stations 1 and 2 was 44.9% of the total flow. The volume of water used in the high density plot was 55.1% of total flow. The fertiliser was applied through a

separate irrigation line and the cost for the high and low density plots was apportioned using the same method as for irrigation water.

It can be seen from Tables 7 and 8 that less water (54%) was used on a per plant basis in the high density block than the low density block but due to the number of plants per ha the cost was higher when calculated on a per ha basis. The data suggest that either the high density plants were more efficient at using water or that the plants in the low density block, or both blocks, did not require the amount of water that was applied. During the term of this project and to ensure establishment of the vines, no water stress was applied to the vines. Future irrigation studies at this trial site would be necessary to determine the minimum amount of irrigation water than can be applied and the water use efficiency of the different scion-rootstock combinations under high and low growing densities.

4.4.2.3 Management inputs

The estimated input costings for this trial site are higher than a commercial property due to the site location and the experimental nature of the work. The Regional Vineyard Benchmarking Report (Scholefield Robinson Horticultural Services Pty Ltd, 2008) surveyed commercial enterprises in the Barossa Valley to estimate operating costs for 2006/07. It was reported that the average operating cost was $3,734 per ha but it is not possible to directly compare the costs reported here to the values in the regional benchmarking report. However, some general conclusions can be made. The greatest commercial expenditure in the Barossa was pruning (30%), labour (29%) and water (31%) (Scholefield Robinson Horticultural Services Pty Ltd, 2008). This trial site was established to investigate the reduction of inputs by evaluating a new no-prune scion type and reducing labour and use of machines by not having to spray to control downy and powdery mildew. Future research at this site over several seasons should provide data on potential operating cost savings, water use efficiency of the vines, yield per ha and wine quality.

5. Outcomes & Conclusion

CSIRO has bred new grapevine selections that require fewer sprays for mildew control and produce robust wine styles in a warm-hot environment. CSIRO has also bred new selections that potentially do not require management of vineyard vigour by pruning and developed new rootstocks that assist in controlling vine vigour and have improved water use efficiency and root pest tolerance or resistance. High density vineyards containing these new scions and scion-rootstock combinations would be potentially transformational for the Australian grape and wine industry, delivering increased productivity per ha due to decreased inputs (fuel, labour, water), improved pest and disease resistance and decreased greenhouse gas emissions under expected challenging climate scenarios of increased temperatures and reduced water availability.

To properly evaluate these new selections a new research trial site was successfully established in this project to compare the selections under low and high density vine plantings. Unfortunately, the lack of readily available plant material delayed the completion of planting in the first year and this subsequently delayed some aspects of plant performance evaluation. No wine making was done in the final year. However, a number of promising outcomes have arisen from the project. Firstly, no spraying for downy and powdery mildew was conducted on the site and no mildew infections were observed on the plants. This result was very encouraging as not only were there cost reduction benefits by not having to spray, but also reduced release of GHGs due to lower usage of tractors on the site. Other benefits included reduced exposure of vineyard staff to chemicals and surrounding areas to spray drift, which may lessen potential health risks and reduce the social impacts in the peri urban fringe/rural areas where there are significant areas of viticulture and where there is always potential for conflict over what is perceived by some as indiscriminate chemical use. Secondly, the no-prune selections performed as expected and no pruning or canopy management was required for these selections. Pruning and labour costs associated with pruning are a significant industry cost (30% of operating expenditure). Preliminary data suggested that rootstocks might have an effect on vine vigour and some berry components but a major finding was that rootstocks did not markedly change the vigour of the no-prune vines (as measured indirectly by LAI and visual observation). Also of significance was that analysis of berry composition indicated that the no-prune vines had similar composition to berries from normal vines suggesting that wine made from the grapes of no-prune vines should have similar attributes to normal vines. It was found that under the same irrigation regime, 54% less water was used per plant in the high density plot compared to the low density plot. This suggests that the water use efficiency might be greater in high density blocks compared to low density blocks, however, further study is required over several seasons with different irrigation treatments to investigate water use efficiency in relation to yield and wine quality attributes.

There are a number of changes to vineyard management that might result if future research at the site demonstrated significant advantages to adopting mildew resistant no-prune vines or higher density plantings. European vineyards have narrow row, high density plantings but also have high management demands. This trial is evaluating different rootstocks under Australian conditions to determine if the use of a low vigour rootstock assists in canopy management in a high density

planting by reducing canopy growth without affecting yield or fruit quality. Irrespective of plant density, the use of mildew resistant vines would provide considerable benefits to vineyard management by reducing the need for labour, chemicals and tractor usage. A future scenario with adoption of no-prune vines would allow vines to be grown under high density and require little or no canopy management or pruning, further reducing management costs.

6. Recommendations

6.1 Future Research Directions

World agriculture will be forced to undergo dramatic, rapid changes to address the challenges of climate change, limited resources (water, land, energy) and population growth well before the projected population peak in 2050 (The Royal Society, 2009). This can only be achieved by sustainable intensification of agriculture using fewer inputs and higher outputs per unit land. This project established a trial site to investigate intensification of viticulture under Australian conditions.

Further research is required over several seasons to fully investigate the potential benefits of the plant selections and management treatments at this trial site. The preliminary results in this report are very encouraging but multi-seasonal data from mature vines are required to fully assess the advantages and disadvantages of the experimental treatments in terms of management costs, water use efficiency, yield per hectare and fruit and wine quality.

6.2 Industry Context and Adoption Scenarios

Maintaining a competitive wine industry into the future will depend in part on successfully adapting to climate change, reducing costs and producing a desirable product. This project developed a unique trial site to evaluate new scion and rootstock material and to investigate management methods that reduce costs and inputs (sprays, labour, water and pruning). The continued use of this research site for measurements of plant performance (yield/ha), water use efficiency, and fruit and wine quality will provide important information on whether this can be achieved without affecting yield and wine quality and the potential gains from sustainable intensification of Australian viticulture.

As stated above, there is a general scientific consensus that sustainable intensification of agriculture will be required to meet the demands of an increasing global population. The research trial developed in this project, and future data collected from it, will provide a demonstration to the Australian wine industry of the advantages, disadvantages and challenges of different vineyard intensification scenarios. Adoption by industry of new management methods or new plant material is more likely if industry can visit trial sites to observe for themselves. A potential pathway to adoption once multi-seasonal data have been collected would be to arrange trial site visits and meetings at the site to discuss the trial site results.

Appendix 1 Communication

A seminar was held at the Next Generation Planting Material Workshop on 14 May 2015, titled “Breeding powdery and downy mildew resistance into our germplasm”.

Appendix 2 Intellectual Property

No patents were taken out during the term of this project. New CSIRO plant selections, rootstocks and scions, used in this project have not been released to the public.

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Appendix 4 Staff

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Appendix 5 Other Material and Raw Data

Raw data are held at CSIRO.