Field assessment of selected rootstock hybrids for quality wine production



FINAL REPORT to
GRAPE AND WINE RESEARCH AND DEVELOPMENT CORPORATION

Project Number: **CSH 94/3**

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Research Organisation: **CSIRO Plant Industry, Horticulture Research Unit, Merbein**

Date: **May 2000**

PREFACE

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Field assessment of selected rootstock hybrids for quality wine production.

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Synopsis

The objectives of the project have been met. A number of CSIRO rootstock selections, originally identified as low potassium accumulators, when grafted with Shiraz and compared to standard rootstocks, have shown potential to produce high yields (i.e. equal to Ramsey) with enhanced grape juice composition and wine quality. The study also demonstrated the potential to select rootstocks to control vine vigour and manipulate the crop wood ratio and improve grape composition and wine quality. A number of the selections were tolerant to nematodes and phylloxera.

In meeting the objectives a number of very significant findings with implications for rootstock selection and management were found. These include:-

- High vine vigour had a detrimental effect on berry composition and wine quality, in particular pH, colour and phenolics. The negative effects of the standard rootstocks could be attributed to their high vigour. High vine vigour selections produced higher yields and larger berries. High yields and large berries were linked to high juice pH, high berry potassium concentrations, low berry colour and phenolics.

- Vine growth characteristics were linked to vine nutrient status, determined by petiole analyses at flowering and berry mineral element analyses at harvest. Selections with high vigour, yield and berry weights tended *to* have high potassium, phosphorus, sulphur, *boron and nitrogen concentrations and low* calcium concentrations in berries.

- Vine nutrient status, determined by petiole analyses at flowering, was linked *to* both vigour and yield. High vigour rootstock selections tended to have high petiole levels of nitrogen, phosphorus, calcium, boron and magnesium. High yields were associated with low petiole potassium and high phosphorus, nitrogen and magnesium levels. Large berries were associated with high petiole phosphorus and nitrogen levels.

- Vine nutrient status, determined by petiole analyses at flowering, had a significant effect on berry composition and quality across the rootstock selections. In particular, selections with high petiole nitrogen, phosphorus and calcium levels had high juice pH and high berry potassium concentrations. High petiole levels of nitrogen, phosphorus and sulphur had low berry colour and phenolics.

- Petiole levels of both nitrogen and phosphorus were below those published as adequate for almost all rootstock selections even though the higher levels produced negative attributes with respect to berry composition and quality. These results suggest that current petiole standards are inappropriate when wine quality is a consideration.

- Berry mineral element composition was correlated with berry and juice quality across the rootstock selections. High berry potassium, phosphorus, sulphur (except pH) and nitrogen concentrations were associated with high pH levels, high titratable acid, low colour and phenolics. Selections with high berry calcium, magnesium and boron tended to have higher sugar levels while high berry calcium concentration was also associated with high colour and phenolics.

Further research

- The project has established a strong link between rootstock vigour and yield and grape composition and wine quality. It provides a basis for management of existing problem rootstock plantings to enhance wine quality based on the control of vine vigour. The most appropriate techniques to achieve this require investigation
- The project has identified links between vine nutritional status of rootstock selections and wine quality. Further research is needed to identify the potential to address wine quality problems in existing rootstock plantings by correction of nutritional imbalances; in particular those linked to calcium and magnesium levels (i.e. sugar level and colour).
- Petiole nutrient standards currently adopted by industry have been developed from recommendations for sultana in the USA. This project demonstrated strong negative impacts of high potassium, phosphorus, sulphur and nitrogen status on berry composition and wine quality across the rootstock selections. However; the petiole concentration of both phosphorus and nitrogen were below those considered adequate in current recommendations. This suggests the need for further research to establish appropriate petiole standards that address quality wine production issues.
- The project has identified a major deficiency in plant physiology knowledge. There is a need to understand the basic physiological factors underpinning the control of vine vigour and the links with nutritional status.
- The project has identified a small number of promising rootstock selections for second phase evaluation. Before this can be considered however, phylloxera and nematode tolerance screening should be assessed in greater detail. It is anticipated that this will occur within a new GWRDC/DFRDC project, "A systematic and smarter approach to breeding and developing grapevine rootstocks adapted to Australian conditions".

Background

The warm irrigated regions, which produce 65% of Australia's winegrapes have played a significant role in the expansion of exports, a result of high productivity, low production costs and good quality. Redevelopment in the warm irrigated districts has led to a steady increase in the adoption of rootstocks, in particular Ramsey *(V.champini)* for nematode tolerance and improved production. Research and commercial experiences have demonstrated a negative impact of Ramsey and various other rootstocks on wine quality. This is associated with high potassium uptake by Ramsey and related effects on pH, organic acid composition and in red wine, on spectral parameters.

Previous CSIRO research focussed on the relationship between juice potassium concentration, juice pH and quality, summarised by Ruhl1993. (Ruhl, E. H. Rootstock evaluation for low juice pH. In: Proceedings Eighth Australian Wine Technical Conference, Melbourne, and Oct. 1992. 64-67, 1993). He demonstrated that *Vilis champini* genotypes, ego Ramsey, Dogridge, Harmony and Freedom result in high scion grape juice pH, while rootstock varieties like 140R, 1202, 50A and 101-14 result in low pH. Ruhl also found a close correlation between the potassium accumulation in petioles of ungrafted rootstock varieties and their effect on the grape juice pH. This provided a quick and easy screening method to evaluate 'low pH' rootstock hybrids.

In a previous GWRDC supported project, a large number of CSIRO rootstock hybrids were screened for low potassium uptake to identify potential low pH types: They included hybrids of *V berlandierl, V rupestrls, V rlparla, V champlm, V rotundifoha, V Cinerea* and *V IOngil.* Fifty selected hybrids with low potassium accumulation, good rooting and grafting ability and the rootstock varieties Ramsey, 1103 Paulsen, 140 Ruggeri, Freedom, Dog Ridge were grafted with Shiraz and planted in a replicated field trial on a nematode infested site at Koorlong (Victoria). The first significant crop was produced in 1993. The major purpose of this project was to use this site and evaluate these selections in full bearing, to identify those best suited to productive, high quality wine production. Preliminary screening of nematode and phylloxera tolerance of some selections, identified as having the greatest potential was also undertaken.

This project aimed to identify potential rootstock hybrids for producing high yields and optimal grape juice composition for quality wine production under Australian conditions. It was anticipated that selection of productive rootstocks to maintain or increase, wine quality would provide a further stimulus to the adoption of rootstocks for wine production, particularly in the warm irrigated districts, which produce 65% of Australia's wine grapes. Further benefits to the winemaker would result from a reduced need for grape juice pH adjustment as rootstock control of potassium accumulation and associated influences on organic acid composition and spectral parameters will reduce the need for tartaric acid additions during winemaking. Hence, outcomes of the project should ensure that the wine industry is able to continue to improve economic efficiencies without detrimental effects on quality.

Summary of Materials and Method

Previous research by CSIRO had selected 55 rootstock hybrids produced from a diverse range of parent species for low potassium uptake combined with good rooting and grafting ability. They were grafted with Shiraz and planted in a replicated field trial on a nematode infested site in spring 1989. The standard rootstocks, i.e. Ramsey, 1103 Paulsen, 140 Ruggeri, Freedom, Dogridge were also included. Once established the vines were spur pruned with cordons developed on a 2wire, vertical trellis. Significant crops were produced for the first time in season 1993. The experimental layout of the trial was a fully randomised block design (6 blocks with 2 vine plots of each of the 60 selections, i.e. a total of 720 vines). Data collection extended over the 1995-98 harvest seasons.

The main tasks included:

- Measurement of winter pruning weights as an assessment of vine vigour (1995-98)
- Collection of petiole samples to assess vine nutrient status at flowering in spring (1996)
- Collection and processing of berry samples prior to harvest for determination of berry weight, sugar, pH, titratable acidity and storage for later measurement of berry colour and phenolics and mineral element measurements (1995-97)
- Yield measurement at harvest (1995-98)
- Small-scale wine making of the selections showing most potential (1996 and 1997). In both years 2 winemaking replicates were produced from bulked up samples of the field replicates for 12 selections and 140R and Ramsey
- Analysis of the colour and phenolic properties of all berry samples and wine samples using standard spectrophotometric techniques
- Sensory evaluation of the wines by an industry panel
- Analysis of mineral element .composition of all berry samples and. petiole samples by ICP and nitrogen analyser. (Note: petiole measurements were compared with published standards. Robinson, J. B., M. T. Treeby and R. A. Stephenson. 1997. Fruits, vines and nuts. In *Plant Analysis: an Interpretation Manual,* ed. D. J. Reuter, J. B. Robinson and C. Dutkiewicz, 349-382. Collingwood, Vic.: CSIRO Publishing.)
- Screening of 12 promising selections for phylloxera tolerance. This task was undertaken in collaboration with DNRE Rutherglen Research Institute and organised by Dr.G.Buchanan. A routine bioassay technique was performed on excised root pieces collected from the field at Merbein. The phylloxera strain was sourced from Whitlands, Victoria. Shiraz and Schwarzmann were used as controls.
- Screening of promising selections for nematode tolerance in collaboration with Dr. G. Walker, S.A. Dept. of Primary Industries. Forty pots of the 12 most promising selections were grown in the glasshouse at Merbein. Ten pots were inoculated with one of 3 nematode species (i.e. *M incognita, M.hapla and M.javanlca*). The remaining 10 pots were used as controls. Assessments included measurement of root weight, the number of nematode juveniles in each pot, the number of nematode juveniles per unit root weight and ranking selections based on nematode root galls.

Results

1. Effects of rootstock on measured variables.

The effects of rootstock on vine performance parameters, berry and juice composition and petiole nutrient levels were assessed by analysis of variance over the seasons. The mean results over the seasons (where appropriate) are presented in the figures below. In general, interactions between rootstock selection and season were absent or only had minor influences on the outcomes. To facilitate comparisons of the selections, the results are presented after sorting the selection means according to vigour.

1.1 *Vine performance parameters*

a. Pruning Weight

The pruning weight results show potential to develop and select rootstocks to cover a wide range in vine vigour. Overall, there was more than a 10-fold difference in vine vigour between the rootstock selections, measured as pruning weight, ranging from 0.3-4.8 kg per vine (Fig. 1). Of all the selections, the standard rootstock Dogridge produced the highest pruning weight. The other standard rootstocks, Ramsey, 1103P, 140R and Freedom were similar in vigour, i.e. mean pruning weights of about 2.5 kg per vine. Although there were significant differences between seasons in pruning weight, the interaction with rootstock selection was not significant. The means for 1995, 1996, 1997,1998 were 1.83, 1.83,2.20, and 1.70 kg per vine respectively.

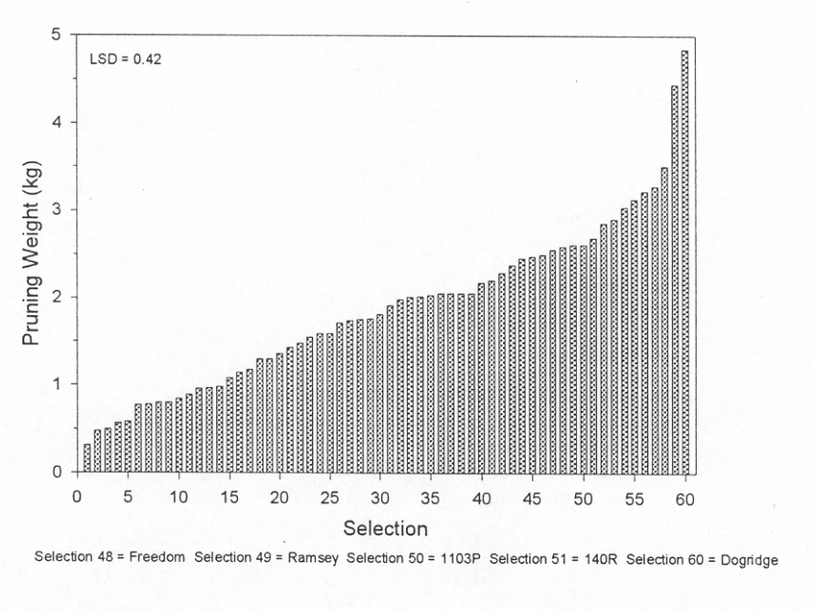


Figure 1. Mean pruning weight (kg per vine) of the 60 rootstocks over 4 seasons (1995-98).

b. Yield

Yield results presented in Fig. 2 show about a 4-fold difference in yield between the rootstocks if the very poor performance of selection 2 is ignored. Selections above selection 19, i.e. those with a pruning weight above 1.5 kg per vine, produced yields ranging from 10.0-15.8 kg per vine. The standard rootstocks vine yields were 11.62 kg for Freedom, 12.45 kg for 140R, 12.69 for Dogridge, 13.22 for 1103P and 14.41 for Ramsey. Although there were significant differences between seasons yield, the interaction with rootstock selection was only just significant ($p < 0.05$).

The means for 1995, 1996, 1997, 1998, were 8.99, 12.50, 7.77 and 13.48 kg per vine respectively.

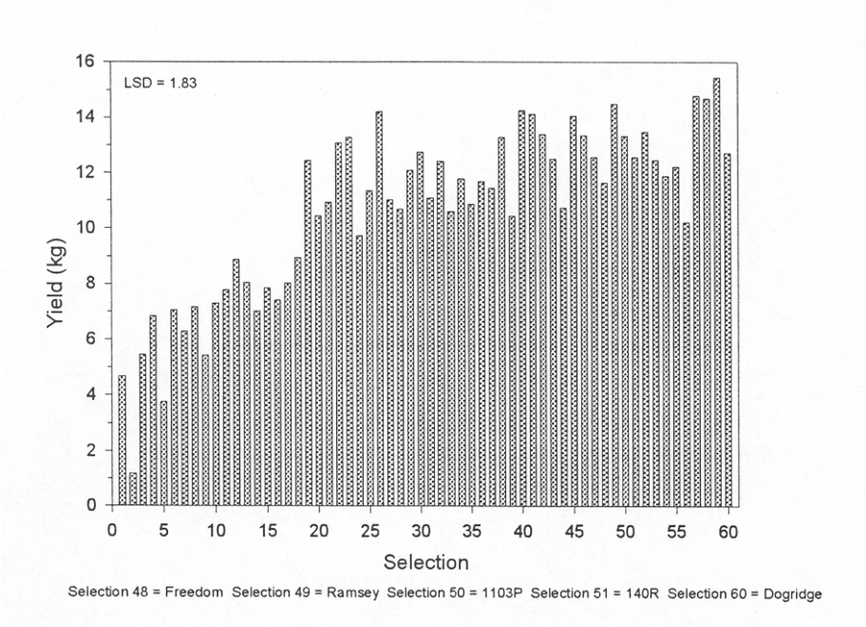


Figure 2. Mean yield (kg per vine) of the rootstocks over 4 seasons (1995-98).

c. Berry weight

There were significant differences in berry weights across the 60 rootstocks, ranging from 1.13g to 1.51g (Fig 3). Except for Dogridge, which had the largest berries (1.47 g), berry weight differences between the standard rootstocks were not significant, ie 1.42 g for 1103P, 1.43 g for Freedom and Ramsey, 1.44g for 140R. Berry weight means for 1995, 1996, 1997, 1998 were 1.43 g, 1.16g, 1.41 g and 1.48 g respectively.

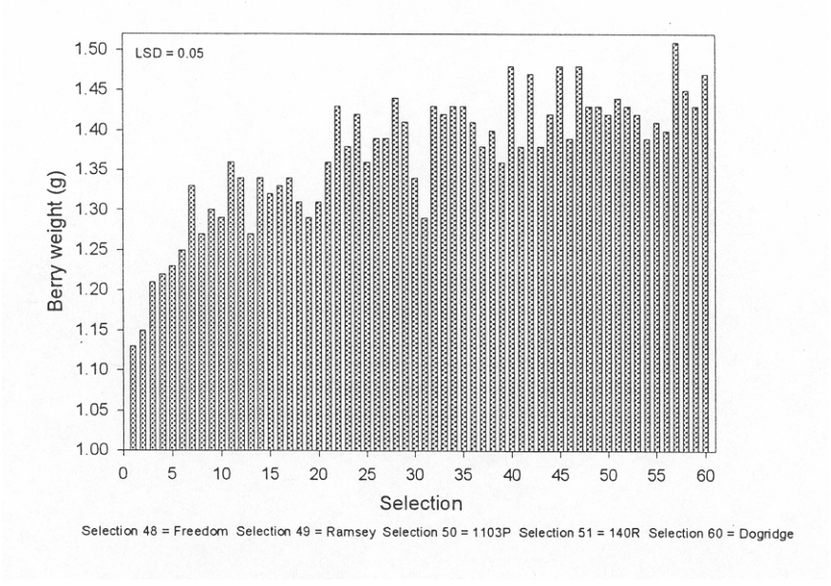


Figure 3.Mean berry weight (g) of the 60 rootstocks over 4 seasons (1995-98).

d. Fresh and Dry Petiole weight

Fresh and dry petiole weights were recorded when collected for mineral analyses at flowering in Spring of 1996. The results, included as a further measure of vine vigour (Fig 4), show a 4-fold difference in fresh petiole weight ranging from 0.38 g to 1.05 g. The standard rootstock, Freedom produced the largest fresh petioles of the 60 selections, ie. 1.07 g. Fresh petiole weights of other standards were 1.01 g for 1103P, 0.94 g for Dogridge, 0.87 g for 140R and 0.83 g for Ramsey.

Petiole dry weights (Fig 5) show a 2.5-fold difference ranging from 0.06 g to 0.05g. The standard rootstocks, Freedom and 1103P had the largest dry petioles of all the 60 selections, ie. 0.15g. Dry petiole weights of the other standards were Dogridge and 140R, 0.13g and Ramsey 0.11g.

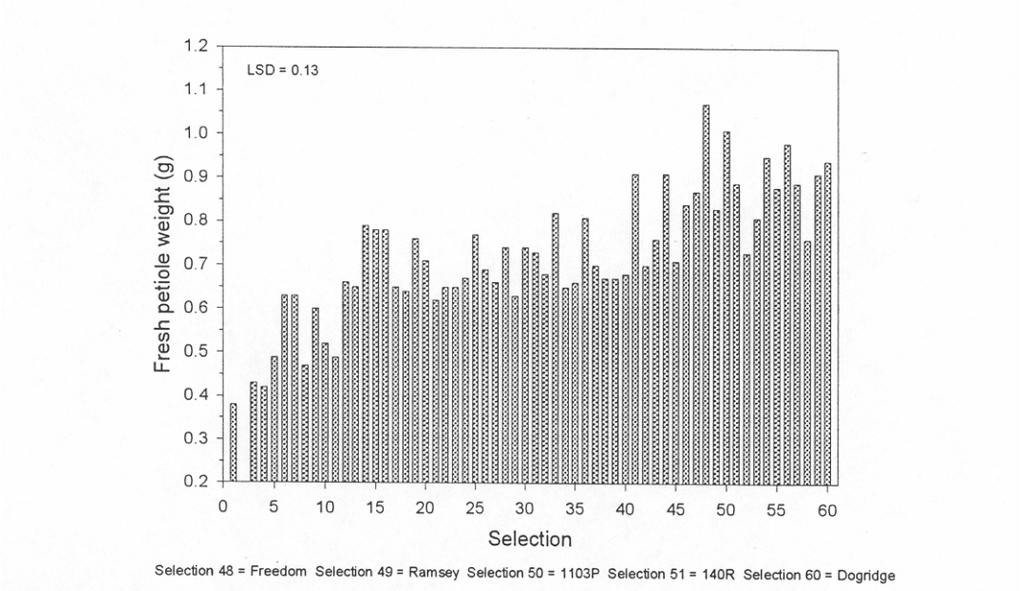


Figure 4. Mean fresh petiole weight (g) of the 60 rootstocks in spring 1996.

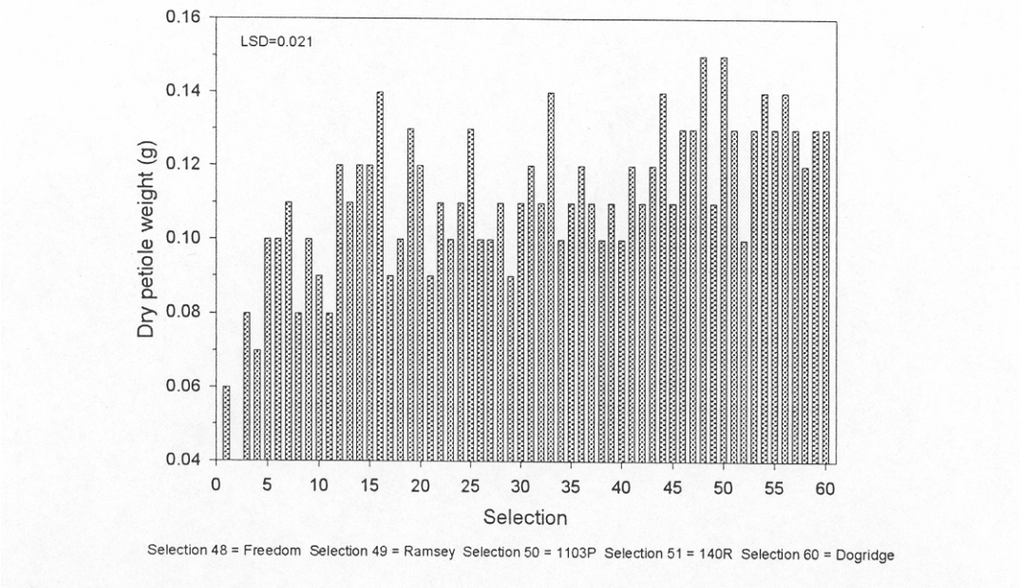


Figure 5. Mean dry petiole weight (g) of the 60 rootstocks in spring 1996.

e. Crop to wood ratio

The ratio, crop: pruning wood, is frequently used as a measure of vine efficiency, ie. The capacity of a vine to produce a mature crop compared to its vegetative growth. Across the 60 rootstocks there was a 6-fold difference in the efficiency ration ranging from 2.5-14.5. Except for the poor performing selection 2, high vigour rootstocks tended to be less efficient than low vigour selections. Dogridge had the lowest efficiency ratio of all the rootstocks, ie. 3, except selection 2. The other standard rootstocks had a similar values around 5, with Ramsey the highest followed by 1103P, 140R and Freedom.

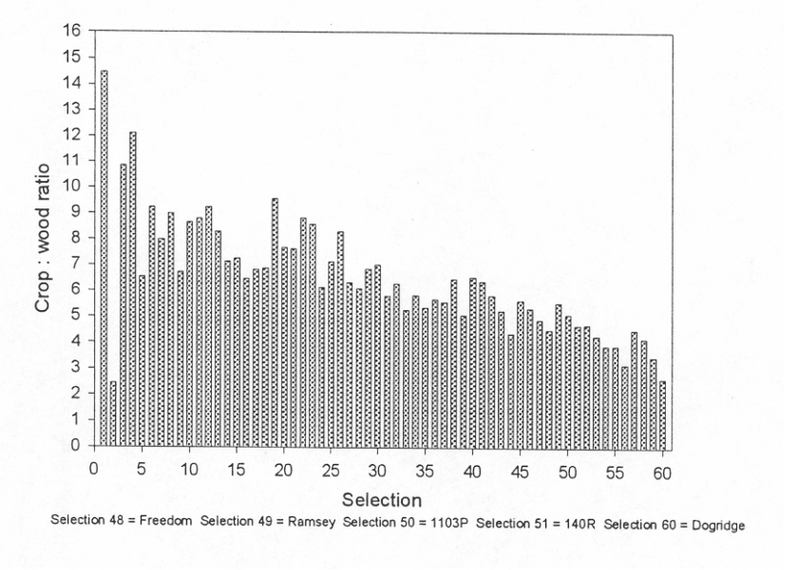


Figure 6. Calculated crop to wood ratio (Yield: pruning weight) of the 60 rootstocks over the 4 seasons 1995-1998.

1.2 Berry quality parameters

Following an initial comparison of fresh and frozen berries in 1995, berry quality parameters were assessed using frozen berries over 3 seasons, 1995-1997. The results are presented below.

a. Fruit maturity, Total Soluble Solids (°Brix)

The results show potential to select rootstocks for high levels of total soluble solids compared to those currently used. Differences in fruit maturity between the rootstocks were significant, ranging from 24.0 to 27.7 °Brix over the 3 seasons (fig. 7). None of the standard rootstocks produced fruit of high maturity. Ramsey had the lowest level, 25.5 °Brix, followed by Dogridge, 25.7 °Brix, 1103P, 25.9 °Brix, Freedom, 26.1 °Brix, and 140R 26.6 °Brix. Interestingly, both low and high sugar rootstocks were found across the complete selection range, sorted by vine vigour.

Seasonal differences were significant due to harvest at different maturities to fit in with winery harvest schedules. The means harvest maturities were 24.4 °Brix in 1995, 26.4 °Brix in 1996 and 26.9 °Brix in 1997. The interaction between rootstock and season was just significant, $p < 0.05$.

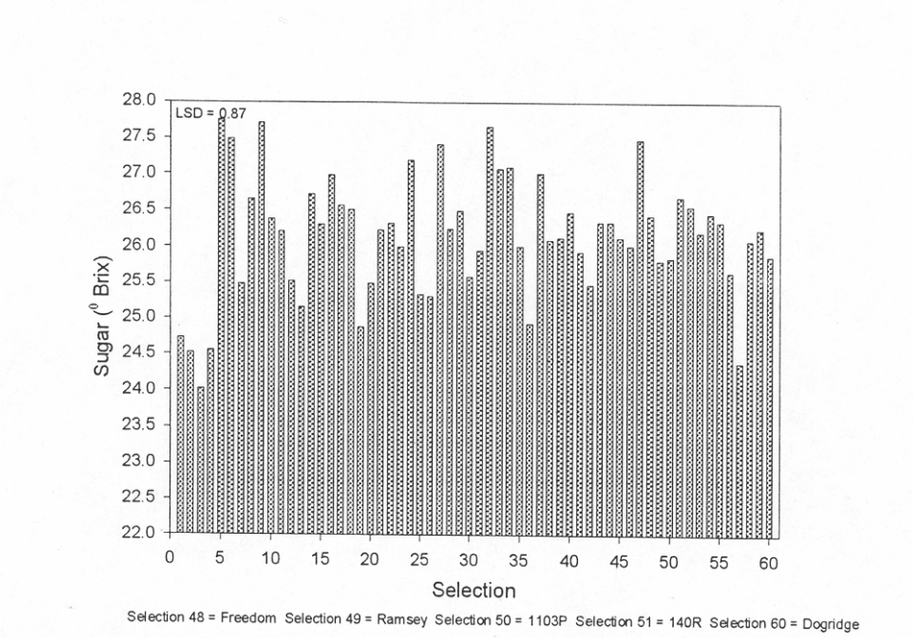


Figure 7. Mean total soluble solids (°Brix) of the 60 rootstocks over 3 seasons (1995-97).

b. Berry pH

Large differences in pH values across the 60 rootstocks, ranging from 3.6-4.07 (Fig 8) indicate potential to select rootstocks for lower pH compared to existing rootstocks. All of the standard rootstocks produced relatively high pH values. Dogridge had the highest pH, ie 4.04 followed by Ramsey, 3.91, Freedom, 3.90, 1103P, 3.88 and 140R, 3.81. Significant seasonal effects on pH reflected fruit maturity differences at harvest, ie 3.66 in 1995, 3.78 in 1996 and 3.87 in 1997.

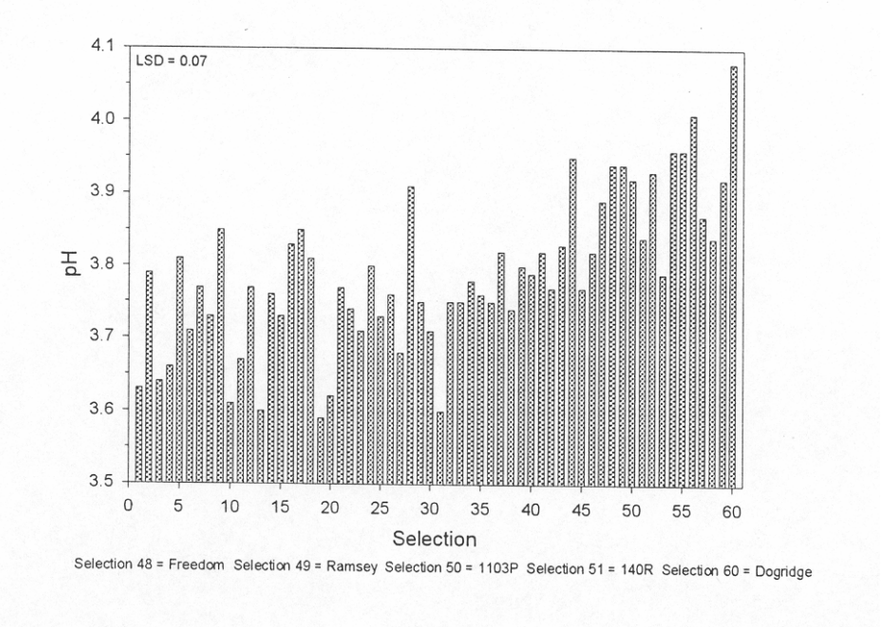


Figure 8. Mean berry pH of the 60 rootstocks over 3 seasons (1995-97).

c. Titrable acidity g/L

There were very large differences in titratable levels across the 60 rootstocks, ranging from 3.2 g/L to 5.1g/L (fig. 9). Of the standard rootstocks, Dogridge had the highest level, ie. 5.4 g/L followed by 140R, 4.5 g/L, 1103P and Freedom, 4.4g/L, and Ramsey, 4.1g/L. Significant seasonal differences reflected harvest maturities, ie 5.1 in 1995, 3.6 in 1996 and 3.89 in 1997.

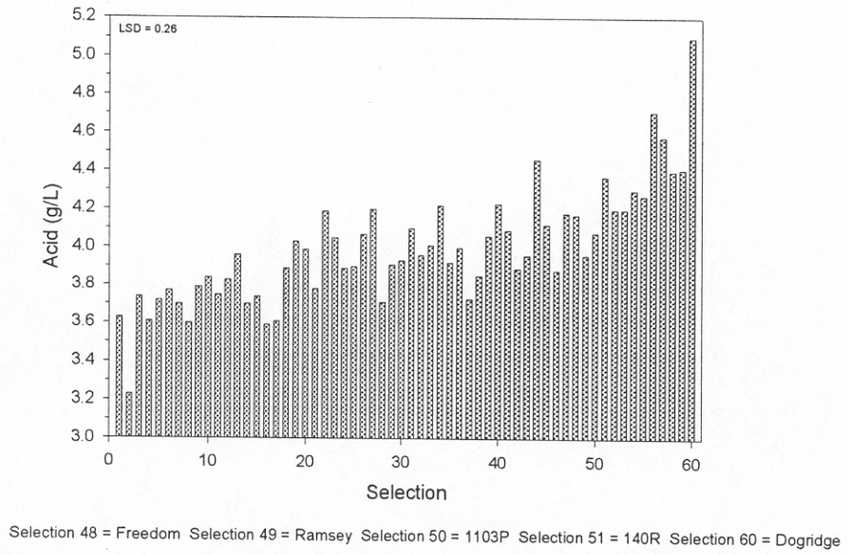


Figure 9. Mean titratable acidity (g/L) of the 60 rootstocks over 3 seasons (1995-97).

d. Berry Anthocyanins, colour (Absorbance, AU 520)

A large, 2.5 fold difference in juice colour was measured across the 60 rootstocks, ranging from 6.5-15.4 AU (Fig 10). All of the standard rootstocks, had low colour levels, ie. between 7.8 and 8.9 AU for Freedom and Ramsey respectively, compared to many of the unnamed selections. Seasonal effects on colour were significant and quite large, ie. 7.5 AU in 1995, 7.1 AU in 1996 and 13.5 AU in 1997.

e. Berry Phenolics (Absorbance, AU 280)

Large differences in phenolics were measured across the 60 rootstocks, ranging from 18-31 AU (Fig 11). Phenolic levels in the standard rootstocks were not significantly different, and compared to many of the unnamed selections relatively low, ie. from 21.2 AU for Freedom to 19.0 AU for Ramsey. Seasonal effects on phenolics were significant and large, ie. 20.7 AU in 1995, 13.6 AU in 1996 and 31.8 AU in 1997.

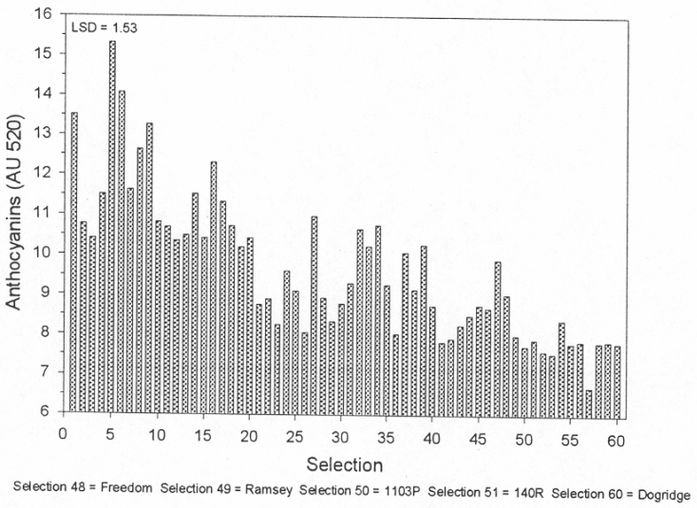


Figure 10. Mean berry anthocyanins, colour (absorbance, AU 520) of the 60 rootstocks over 3 seasons (1995-97).

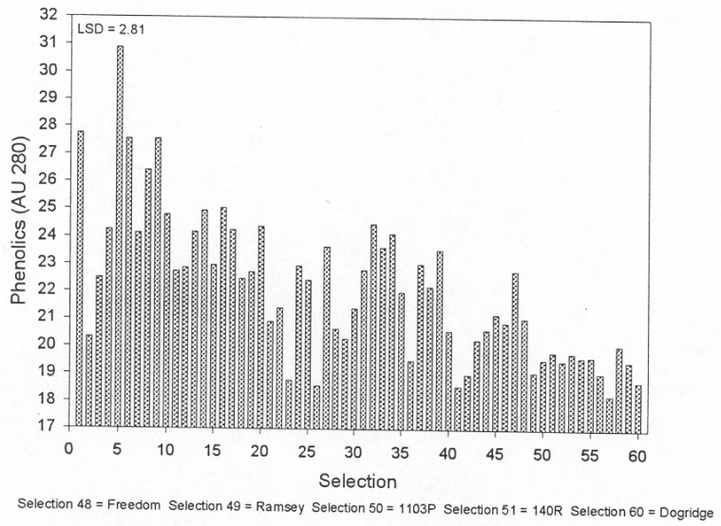


Figure 11. Mean berry phenolics (absorbance, AU 520) of the 60 rootstocks over 3 seasons (1995-97).

1.3 Berry Mineral Content

a. Potassium

A large, 2-fold difference in potassium content in berries was determined across the 60 rootstocks (Fig.12). The range from 1500 to 3300 ppm supports the original proposition that rootstocks can be selected to manipulate berry potassium content and hence juice and wine quality. Dogridge had the highest potassium level in berries, ie. 3335 ppm, of all the 60 rootstocks. Compared to many of the unnamed selections the other standard rootstocks also

tended to have high potassium levels, ie. Freedom, 2780 ppm, Ramsey, 2482 ppm, 1103P, 2465 ppm and 140R, 2417 ppm. Significant seasonal effects on berry potassium contents were also determined, ie. 2246 ppm in 1995, 1771 ppm in 1996 and 2393 ppm in 1997.

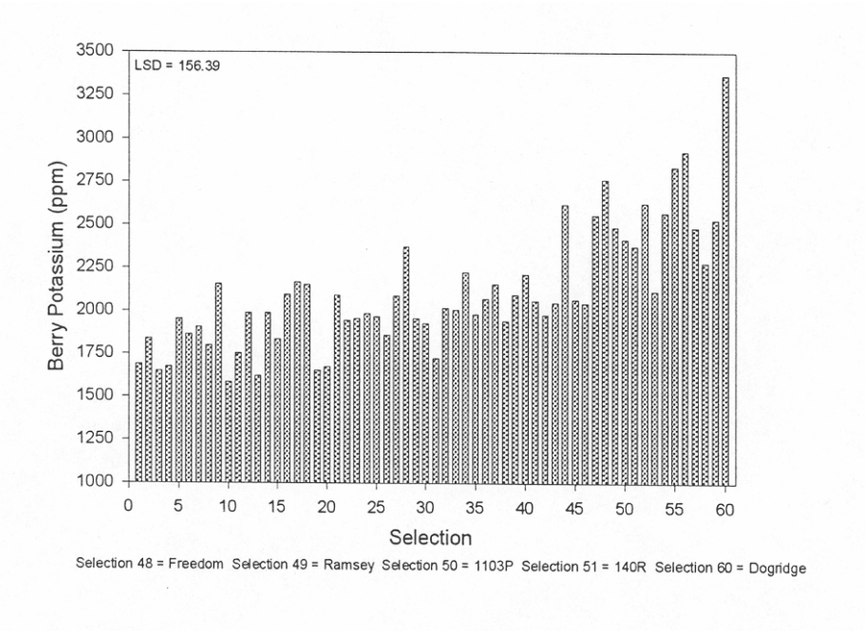


Figure 12. Mean berry potassium content (ppm) of the rootstocks over 3 seasons (1995-97)

b. Sodium

A large, almost 4-fold difference in sodium content in berries, ranging from 40-150 ppm, was produced across the 60 rootstocks (fig 13). Sodium levels in the standard rootstocks were in the mid-low range, ie. Dogridge, 88 ppm, Ramsey, 72 ppm. 1103P and Freedom, 56 ppm and 140R, 50 ppm. Significant seasonal effects on berry sodium contents were also determined, ie. 96 ppm in 1995, 66 ppm in 1996 and 64 ppm in 1997.

c. Magnesium

Berry magnesium contents ranged from 126-166 ppm across the 60 rootstocks (Fig. 14). Magnesium levels of the standard rootstocks tended to be in the mid-high range, ie. Dogridge, 165 ppm, 140R,158 ppm, Ramsey, 153 ppm, Freedom 151 ppm and 1103P, 148 ppm. Significant seasonal effects on berry magnesium contents were also determined, ie. 162 ppm in 1995, 142 ppm in 1996 and 144 ppm in 1977.

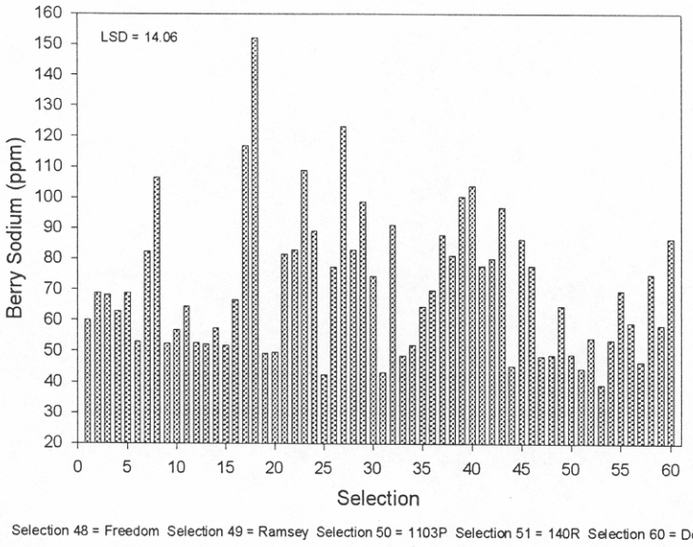


Figure 13. Mean berry sodium content (ppm) of the 60 rootstocks over 3 seasons (1995-97).

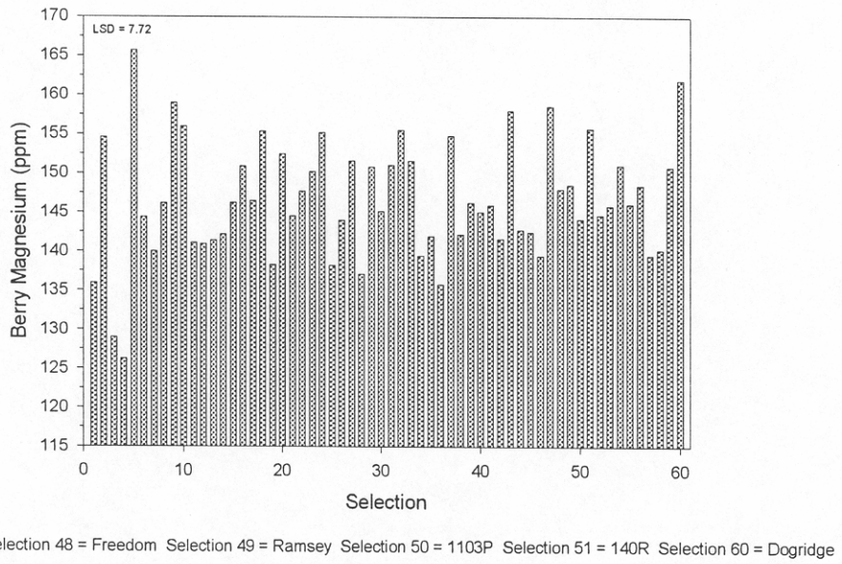


Figure 14. Mean berry magnesium content (ppm) of the 60 rootstocks over 3 seasons (1995-97).

d. Calcium

Berry calcium contents ranged from 110-170 ppm across the 60 rootstock (Fig 15). Except for Dogridge with a berry content of 143 ppm, the standard rootstocks were in the lower, ie 140R, 128 ppm, Ramsey, 127 ppm, Freedom, 125 ppm and 1103P, 122 ppm. Seasonal differences in berry calcium contents were significant, but small, ie. 132 ppm in 1995, 131 ppm in 1996 and 128 pp, in 1997.

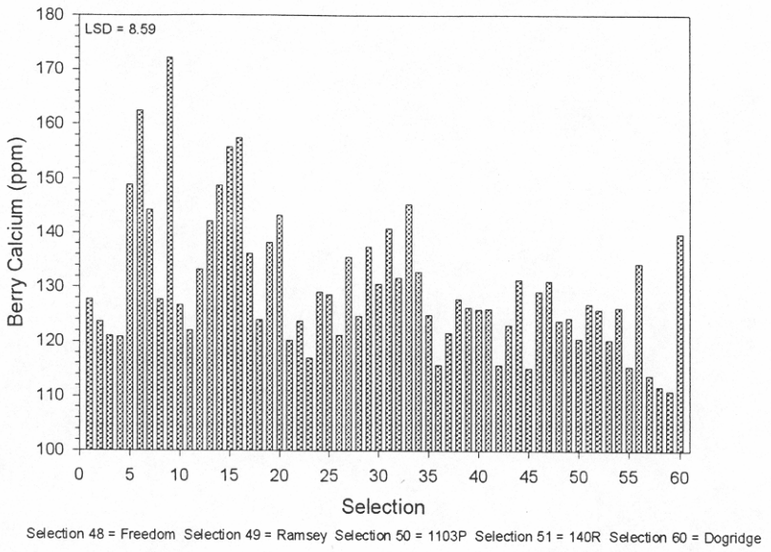


Figure 15. Mean berry calcium content (ppm) of the 60 rootstocks over 3 seasons (1995-97).

e. Phosphorus

Berry phosphorus contents ranged from 110-250 ppm across the 60 rootstocks 9fig 16). Dogridge had the highest value of all the selections, ie. 252 ppm. The other standard rootstocks all were similar and in the mid-upper range, ie. 1103P, 199 ppm, Freedom, 191 ppm, Ramsey, 189 ppm and 140R ppm in 1995, 144 ppm in 1996 and 190 ppm in 1997.

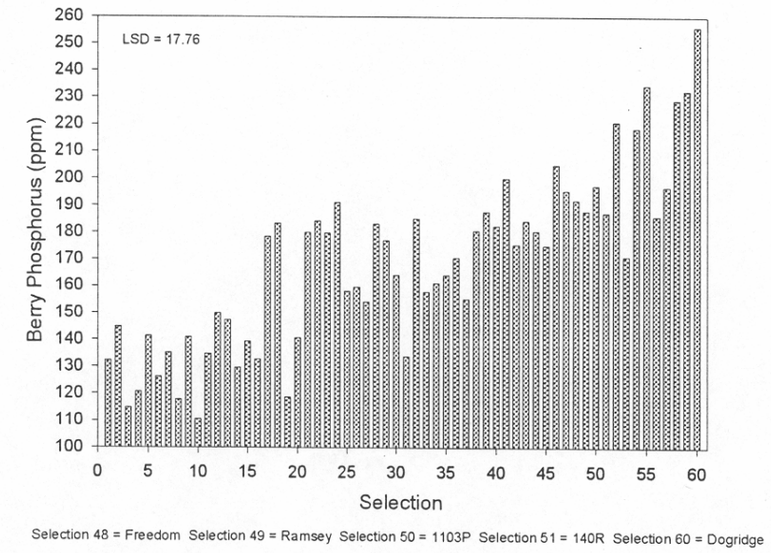


Figure 16. Mean berry phosphorus content (ppm) of the 60 rootstocks over 3 seasons (1995-97).

f. Sulpher

Berry sulphur contents ranged from 63 ppm to 105 ppm across the 60 rootstocks (Fig 17). The standard rootstocks all had relatively high berry sulphur values, ie. Dogridge, 102 ppm, 1103P and 140R, 92 ppm Ramsey, 91 ppm and Freedom, 82 ppm. Seasonal differences in berry sulphur contents were also significant, ie. 75 ppm in 1995, in 1996 and 97 ppm in 1997.

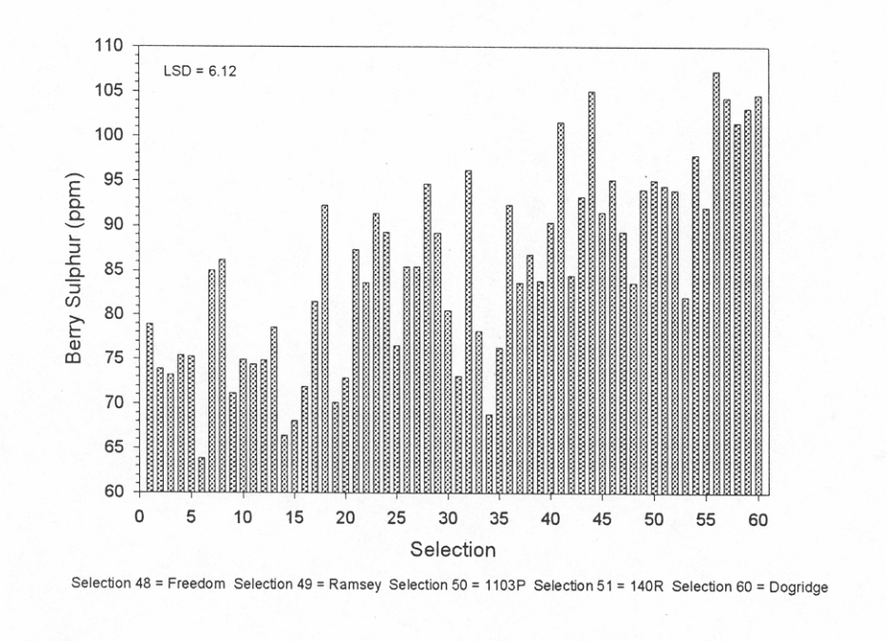


Figure 17. Mean berry sulphur content (ppm) of the 60 rootstocks over 3 seasons (1995-97).

g. Boron

Berry boron contents ranged from 5.6-19.4 ppm across the 60 rootstocks (fig 18). Boron contents of berries from the standard rootstocks also covered a wide range, ie 140R, 16.6 ppm, Dogridge, 16.0 ppm, Ramsey and 1103P, 14.3 ppm and Freedom, 11.0 ppm. Seasonal effects in berry boron levels were significant, ie. 11.9 ppm in 1995 and 1996 and 15.3 ppm in 1997.

h. Nitrogen

Berry nitrogen contents were determined in 1997 only. The results show a 5-fold difference in berry nitrogen contents across the 60 rootstocks, ie. 0.02-0.11% (Fig 19). The standard rootstocks tended to have levels in the upper range being highest for Dogridge, 0.10%, followed by Ramsey and 1103P, 0.07%, Freedom and 140R, 0.06%.

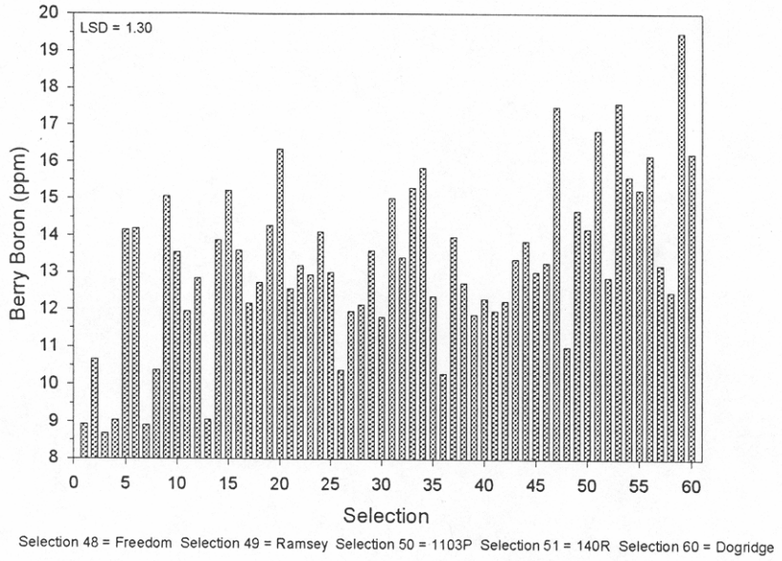


Figure 18. Mean berry boron content (ppm) of the 60 rootstocks over 3 seasons (1995-97).

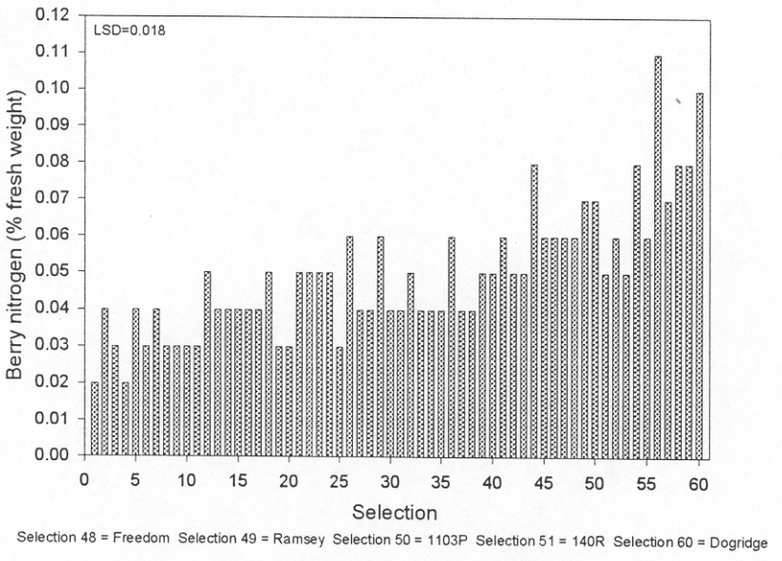


Figure 19. Mean berry nitrogen content (% dry weight) of the 60 rootstocks in 1997.

1.4 Petiole mineral content

The mineral contents of petioles were analysed at flowering in spring 1996 to provide an indication of vine nutrient status with respect to published standards (Robinson et al. 1997) and to provide comparative data in relation to berry juice composition. Where appropriate the range from published data is presented in the figures as horizontal lines. (Note: data for selection 2 is missing).

a. Potassium

More than half of the rootstocks resulted in petiole potassium concentrations, which exceeded the published adequate range, ie. above 3.0 % dry wt. (Fig 20). None of the rootstocks had inadequate potassium concentrations in petioles, ie below 1.8% dry wt. All of the standard rootstocks had high petiole potassium contractions, ie. Ramsey, 4.65% dry wt., Freedom, 4.60 % dry wt., Dogridge and 1103P, 3.51 % dry wt., and 140R, 3.17% dry wt.

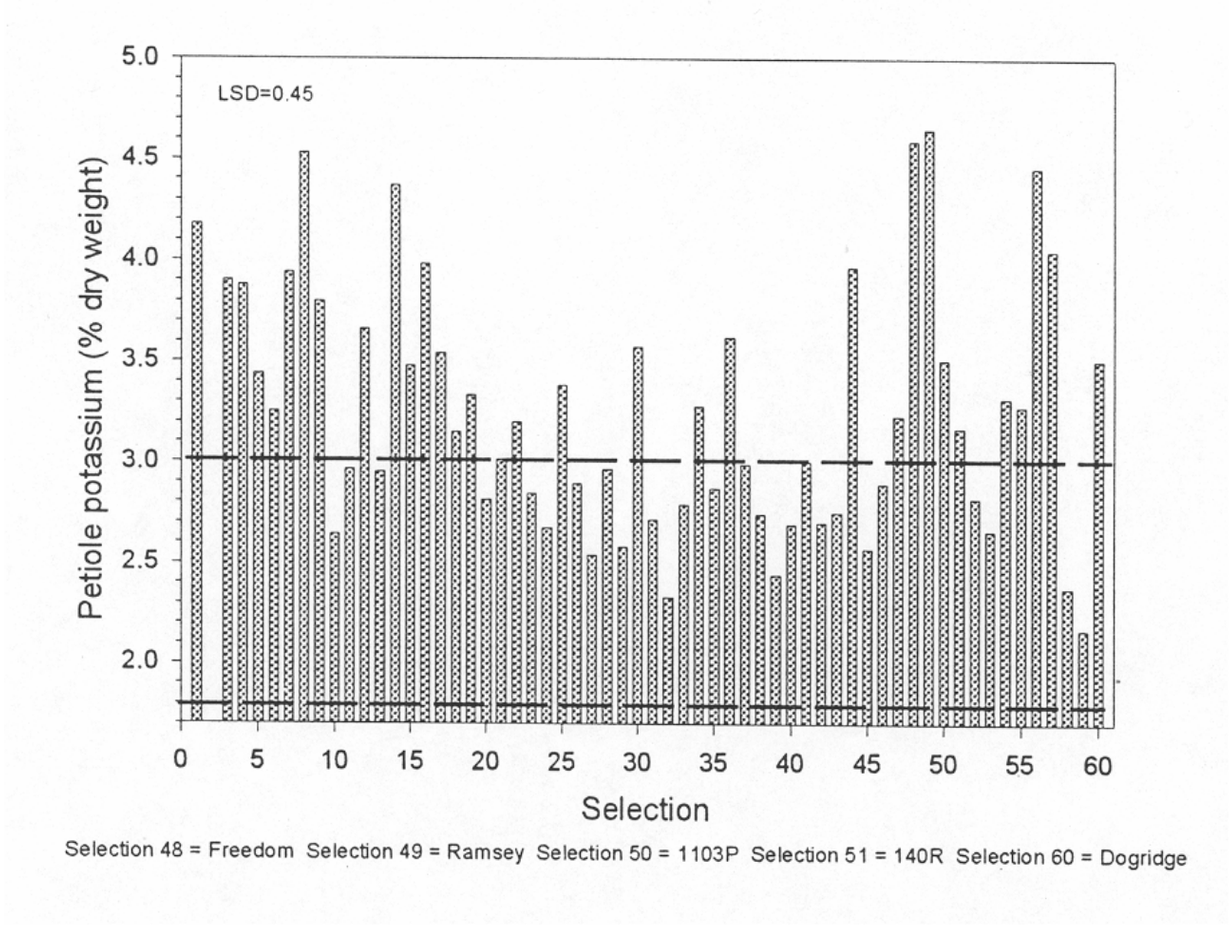


Figure 20. Mean petiole potassium concentration (% dry wt.) of the 60 rootstocks in spring 1996.

b. sodium

None of the rootstocks had petiole values, which exceeded the toxic level of 0.5% dry wt. (Fig 21). There was however a wide range in petiole sodium concentrations ie. 0.06- 0.19% dry wt. Petioles of sodium concentrations of the standard rootstocks were low and not significantly different, ie. between 0.067 and 0.089.

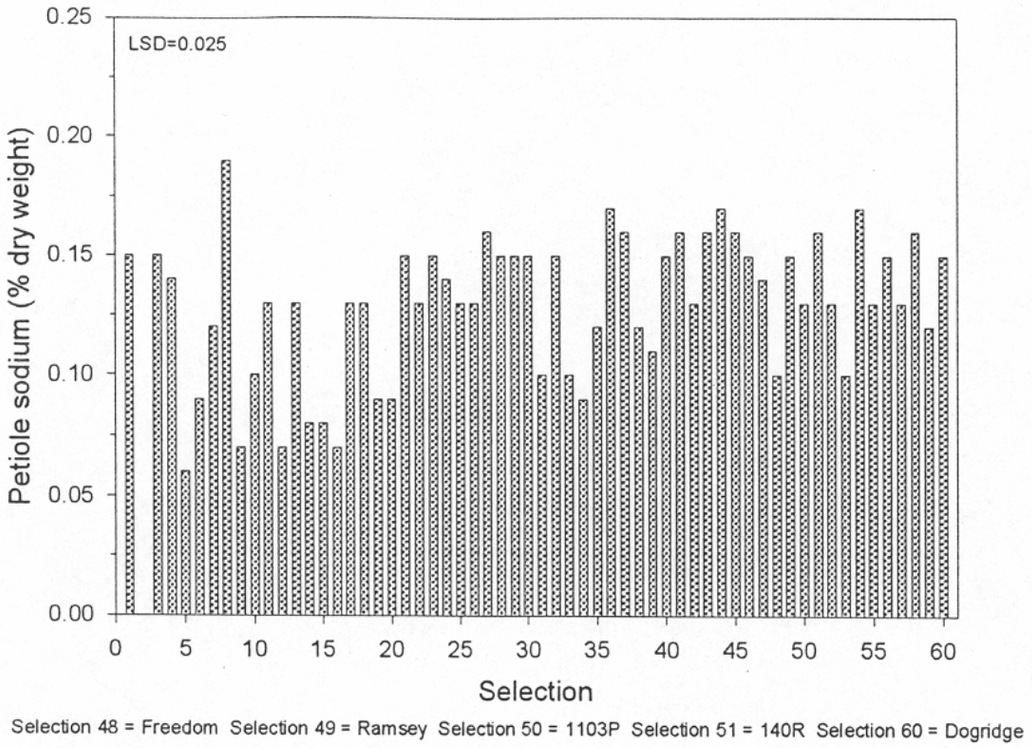


Figure 21. Mean petiole sodium concentration (% dry wt.) of the 60 rootstocks in spring 1996.

c. Magnesium

Almost all the rootstocks had adequate levels of magnesium in the petioles, ie. > 0.4% dry weight (fig 22). Although there were significant differences between the standard rootstocks, all had more than adequate petiole magnesium concentrations, ie. Freedom 0.45% dry wt., Ramsey 0.48% dry wt., 1103P, 0.55% dry wt., 140R, 0.57% dry wt and Dogridge, 0.79% dry wt.

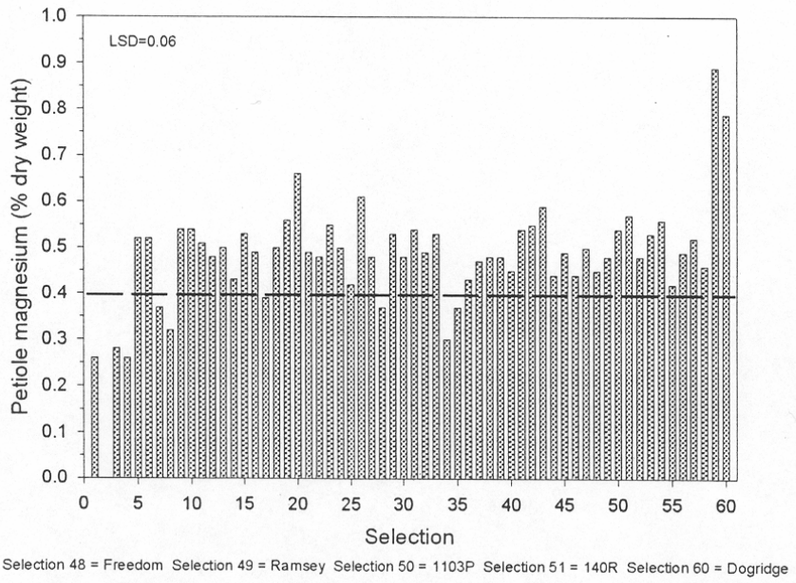


Figure 22. Mean petiole magnesium concentration (% dry wt.) of the 60 rootstock selections in spring 1996.

d. Calcium

Petiole calcium concentrations for the rootstocks were almost all in the published adequate range, ie. 1.2-2.5% dry wt. (Fig 23). Except for Dogridge, petiole calcium concentration of the standard rootstocks were similar and in the mid range, ie about 1.5% dry wt. Dogridge petioles had the highest calcium concentration of all the selections, ie. 2.5%.

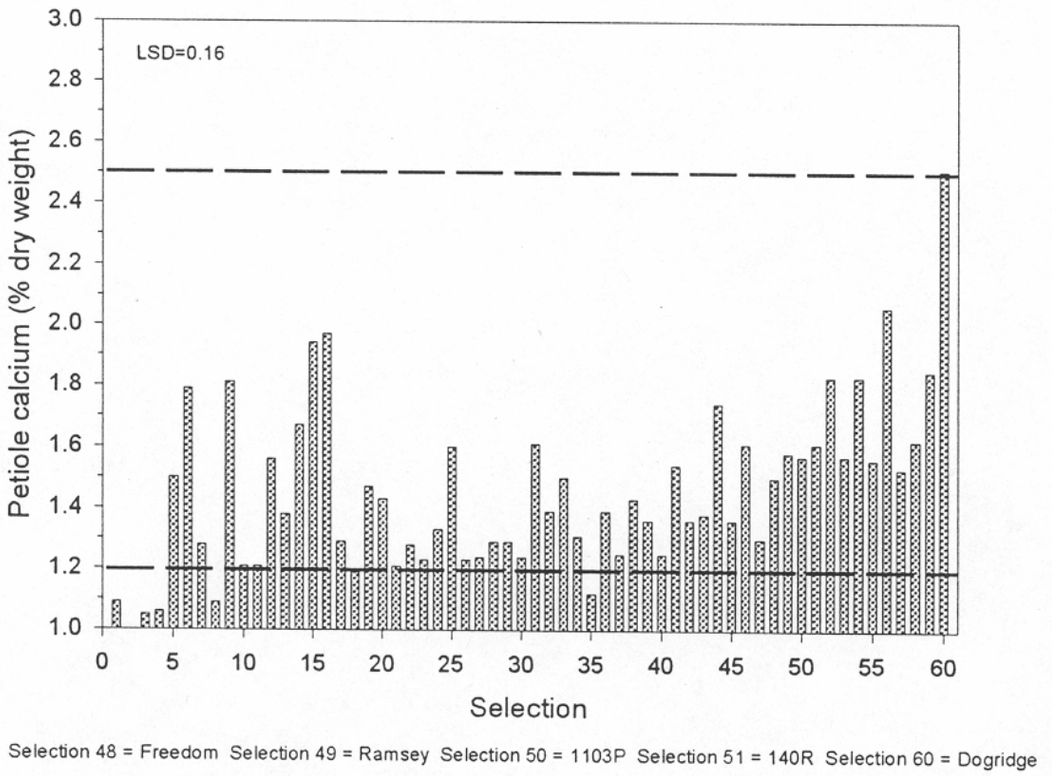


Figure 23. Mean petiole calcium concentration (% dry wt.) of the 60 rootstocks in spring 1996.

e. Phosphorus

A large proportion of the rootstocks appeared to result in deficient levels of phosphorus with levels below the published adequate range of 0.25-0.5% dry wt. (Fig 24). There were significantly different petiole phosphorus concentrations across the standard rootstocks, ie. Freedom, 0.13% dry wt., 1103P, 0.24% dry wt., Ramsey, 0.25%dry wt., 140R, 0.29% dry wt and Dogridge, 0.38% dry wt.

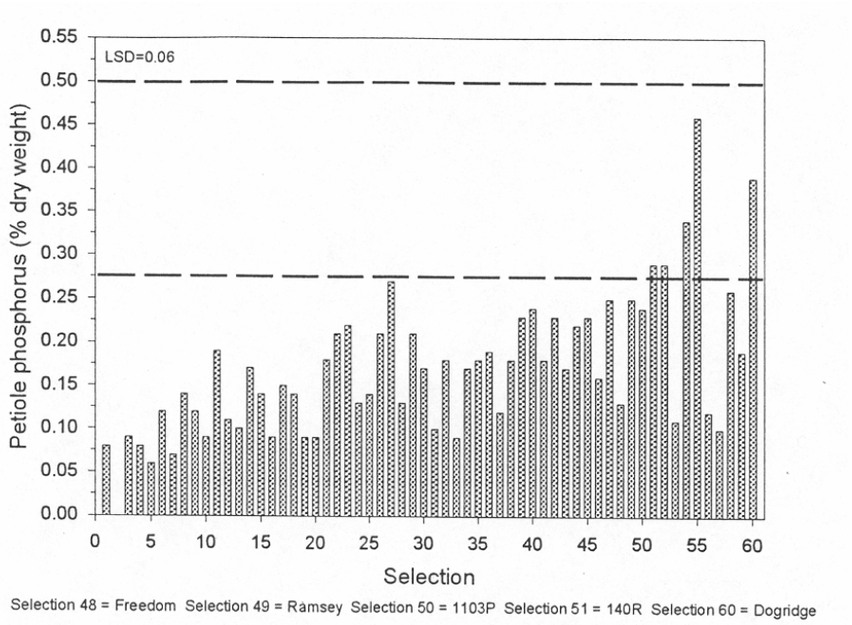


Figure 24. Mean petiole phosphorus concentration (% dry wt.) of the 60 rootstocks in spring 1996.

f. Sulphur

There was a large variation in petiole sulphur concentration across the rootstocks (Fig. 25) with many selections lying outside the recommended adequate range, ie. 0.10-0.14% dry wt. (Michael Treeby pers.com). A small number, mainly low vigour selections, appeared to be deficient in sulphur with levels below 0.1% while about 30% had excessive levels above 0.14% dry wt. Although there were significant differences between standard rootstocks, all were within the adequate range for petiole sulphur concentration, Freedom, 0.10% dry wt., 1103P, 0.13% dry wt., Ramsey and Dogridge, 0.15% dry wt. and 140R, 0.16% dry wt.

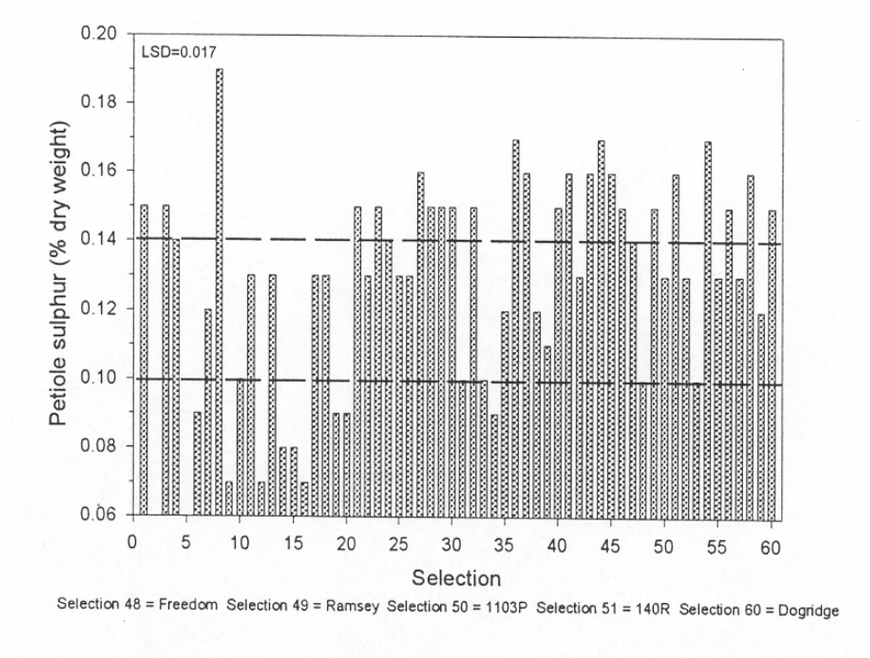


Figure 25. Mean petiole sulphur concentration (% dry wt.) of the 60 rootstocks in spring 1996.

g. Boron

Almost all the rootstocks had petiole concentrations of boron within the adequate range of 37-70 ppm dry wt. Except for Freedom, 52.8 ppm dry wt., the standard rootstocks tended to have similar, but quite high boron concentrations, ie. Between 65-70 ppm dry wt.

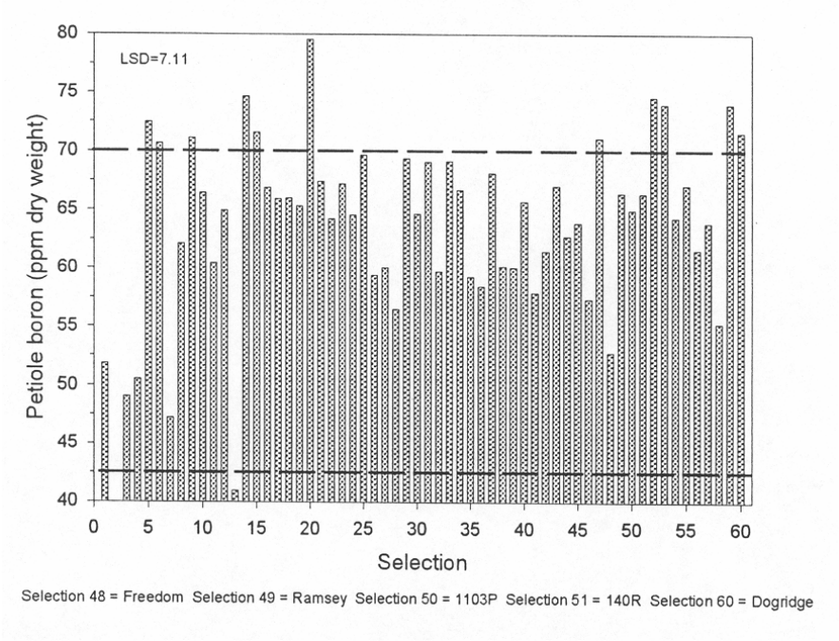


Figure 26. Mean petiole boron content (ppm dry weight) of the 60 rootstocks in spring 1996

h. Nitrogen

A large proportion of the rootstocks appeared to result in deficient levels of nitrogen with petiole concentrations falling below the published adequate range of 0.8-1.1% dry wt. (Fig 27). Petiole nitrogen concentration of all the standard stocks were all within the adequate range, ie. Freedom 0.83% dry wt., Ramsey, 0.91% dry wt., Dogridge, 0.93% dry wt., 1103P, 1.08% dry wt. and 140R, 1.09% dry wt.

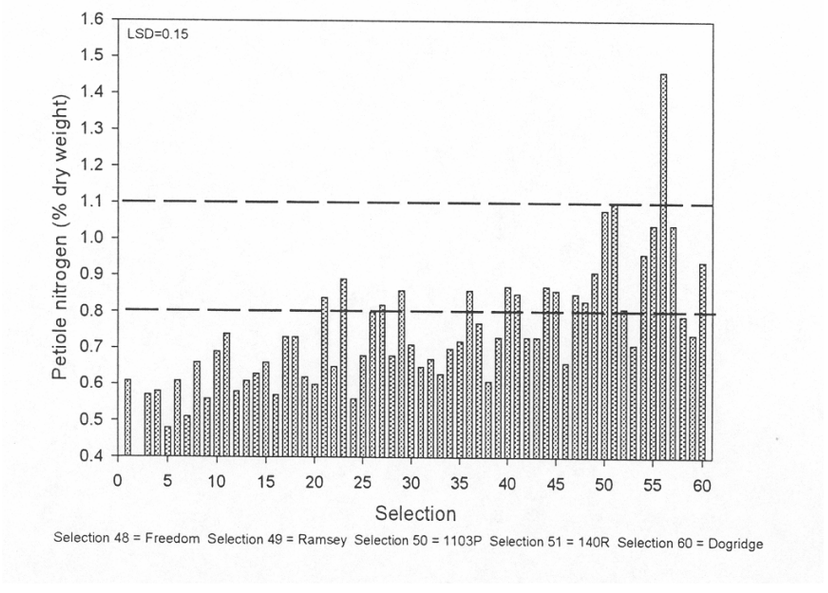


Figure 27. Mean petiole nitrogen content (% dry weight) of the 60 rootstocks in 1996.

2. Regression analyses between measured variables using rootstock means over site and seasons.

Simple linear and multiple linear regression techniques were applied to the mean rootstock data, to identify associations between the measured variables from rootstock responses independent of site and seasonal effects. (note: petiole data was from one year only, ie. 1996. Berry nitrogen levels were from one year only, ie. 1997).

2.1 Relationships between vine growth characteristics

Highly significant linear relationships between the mean values of all the measured growth characteristics across the 60 rootstocks were produced (Table 1.). The ratio of yield: pruning weight is included as it is frequently used as a measure of vine balance and production efficiency. The main results indicate that high vigour rootstocks are likely to produce high yields, but in a less efficient manner than low vigour rootstocks with lower yields. Differences in berry and petiole weights across the 60 rootstocks were also linked to vine vigour. High yielding rootstocks were less efficient as indicated by the negative crop to vegetative growth ratio but produced larger berries and petioles.

Table 1. Correlation matrix between measured vine growth characteristics over the 60 rootstocks. Bold type indicates highly significant correlations, $p < 0.001$.

	Pruning weight	Yield	Yield: pruning weight	Berry weight	Petiole fresh wt.
Yield	**.77**				
Yield: Pruning wt	**-.75**	**-.42**			
Berry weight	**.77**	**.83**	**-.61**		
Petiole fresh wt.	**.76**	**.61**	**-.78**	**.64**	
Petiole dry wt.	**.63**	**.47**	**-.71**	**.52**	**.92**

Yield response to increasing pruning weight was accurately described by a logarithmic relationship across the rootstock selections (Fig.28). When pruning weights were below 1.5kg, the response between yield and vigour was linear, ie. about 1.0kg yield per 0.1 kg pruning weight. A maximum yield limit of about 15.0 kg was achieved for high vigour selections with pruning weights greater than 1.5kg. The results clearly show that rootstock selection can be used to manipulate the yield: vigour relationship.

Berry weight response to increasing pruning weight was also accurately described by a logarithmic relationship Fig 29. There was a sharp increase in berry weight from 1.1g to 1.4g up to a pruning weight of 1.5kg. A maximum berry weight between 1.4 and 1.5 g was produced by higher vigour selections. High yielding rootstock selections also had large berries. A significant linear relationship was found between berry weight and yield. (Fig. 30).

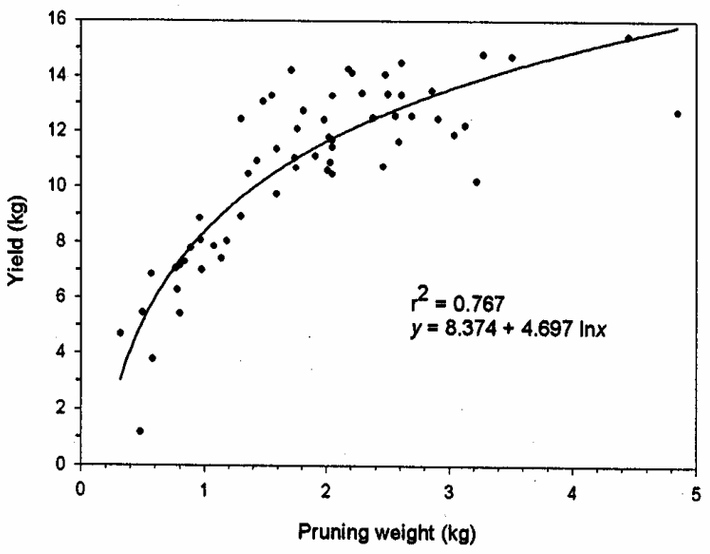


Figure 28 . Relationship between yield and pruning weight across the 60 rootstocks.

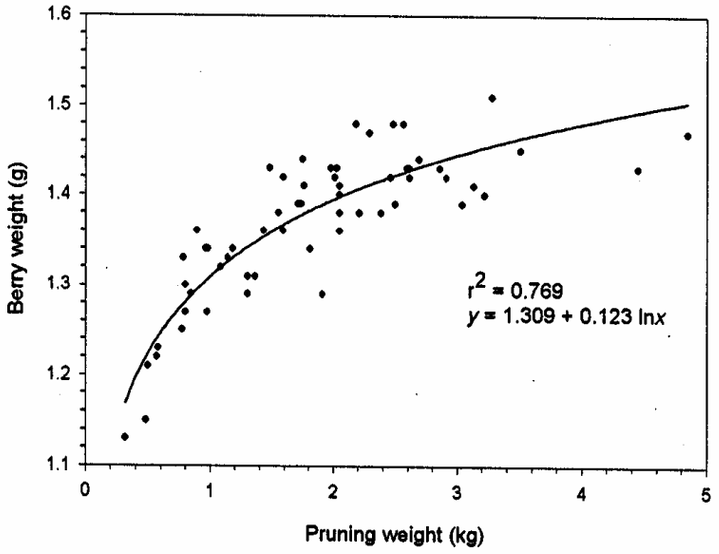


Figure 29. Relationship between berry weight and pruning weight across the 60 rootstocks.

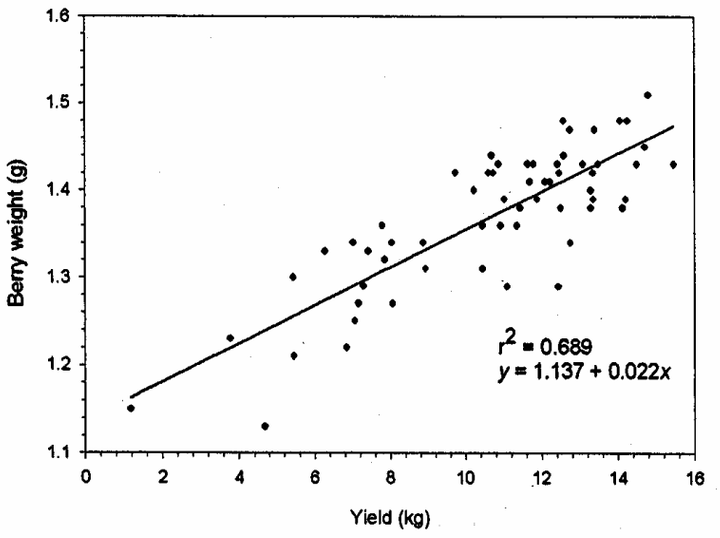


Figure 30. Relationship between berry weight and yield across 60 rootstocks.

2.2 Relationships between berry quality parameters and vine growth characteristics

Relationships between berry quality parameters and vine growth characteristics are presented on Table 2. The absence of significant relationships between growth characteristics and °Brix indicated that fruit maturity level could not be related to vine vigour, yield or berry weight across the 60 rootstocks. By contrast, highly significant correlations between pruning weight and quality parameters demonstrate the negative impact of high rootstock vigour on pH, potassium levels, colour and phenolics despite leading to higher acid levels. Similarly, yield responses indicate negative effects of yield on quality (ie. colour, phenolics and potassium level), no effect on pH and a positive response with acidity. Efficient rootstocks (ie. those with a high crop to vegetative growth ratio) produced a positive response with respect to quality as indicated by lower pH and improved colour and phenolic levels but had little effect on potassium level. The highly significant berry weight responses across the rootstocks indicate negative effects of berry weights on pH, colour, phenolics and potassium level. Similar responses were also determined with respect to petiole weight and negative quality attributes. Interestingly, the relationships were stronger with fresh petiole weights compared to dry petiole weights.

Table 2. Correlation coefficients between berry quality parameters determined over 3 seasons and vine growth characteristics across the 60 rootstocks. Bold type indicates highly significant correlations, p< 0.001.

Berry quality	Pruning weight	Yield	Yield: pruning weight	Berry weight	Petiole fresh wt.	Petiole dry wt.
°Brix	.07	.03	-.26	.27	.06	.07
PH	**.70**	.32	**-.73**	**.55**	**.68**	**.52**
Acid	**.85**	**.66**	**-.53**	**.66**	**.65**	**.55**
Colour	**-.76**	**-.81**	**.54**	**-.72**	**-.68**	**-.49**
Phenolics	**-.69**	**-.71**	**.52**	**-.62**	**-.67**	**-.44**
Potassium	**.81**	**.80**	.20	**.61**	**.73**	**.55**

The relationship between juice pH and pruning weight was best described as a linear function (Fig. 31) although for any pruning weight the range was about 0.2 pH units. Similarly, the relationship between juice pH and berry weight could be described as a linear function although the 2nd order polynomial produced a slightly more accurate fit (Fig 32). For any berry weight the range in pH was about 0.3 units.

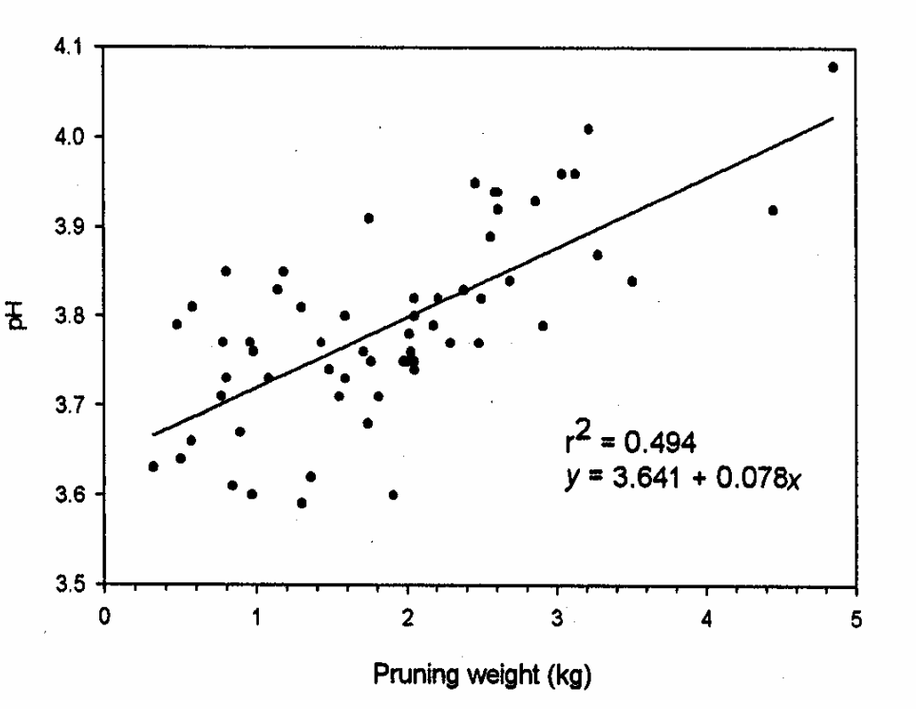


Figure 31. relationship between juice pH and pruning weight across the 60 rootstocks.

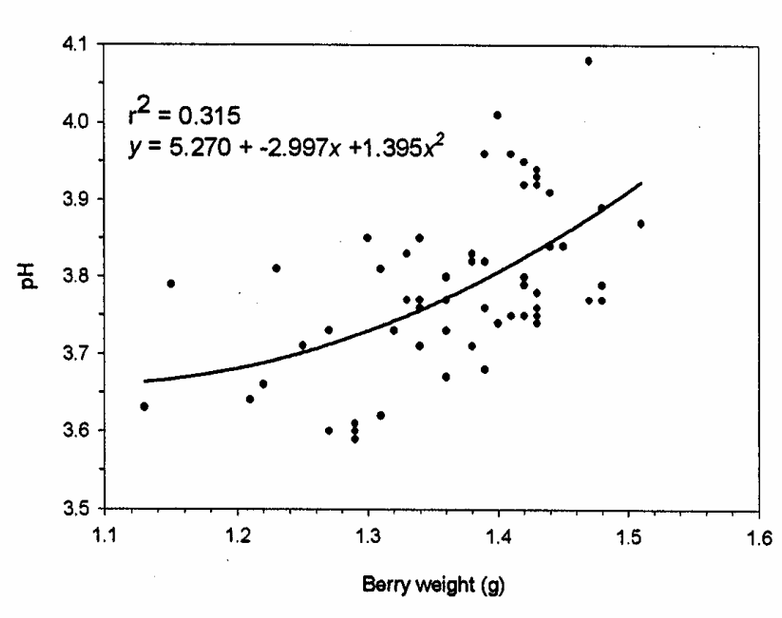


Figure 32. Relationship between juice pH and berry weight across the 60 rootstocks.

Berry potassium concentration was closely linked to vine growth characteristics Table 2. The strong linear relationship between vine vigour and berry potassium across the 60 rootstocks is described in Fig.33. At any pruning weight the range was consistent, ie. about 600 ppm.

The relationship between berry potassium and yield was not strong and best described by a 2nd order polyomial function (Fig. 34). Increasing yields produced a greater range in berry potassium levels, ie. up to 1200 ppm. The relationship between potassium level and berry weight was also best described by a 2nd order polynomial function although the range was up to 1000 ppm with larger berries (Fig. 35).

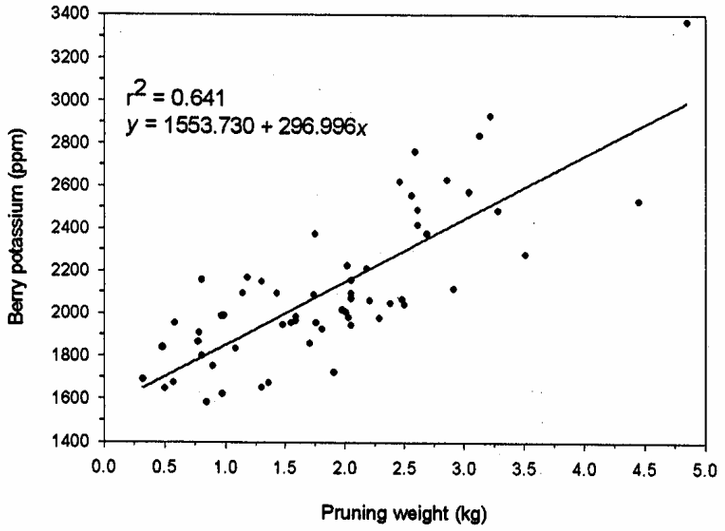


Figure 33. Relationship between berry potassium level and pruning weight across the 60 rootstocks.

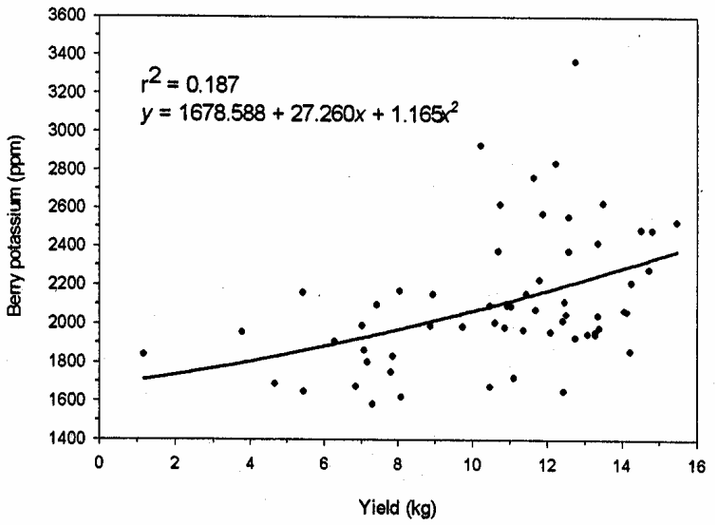


Figure 34. Relationship between berry potassium level and yield across the 60 rootstocks.

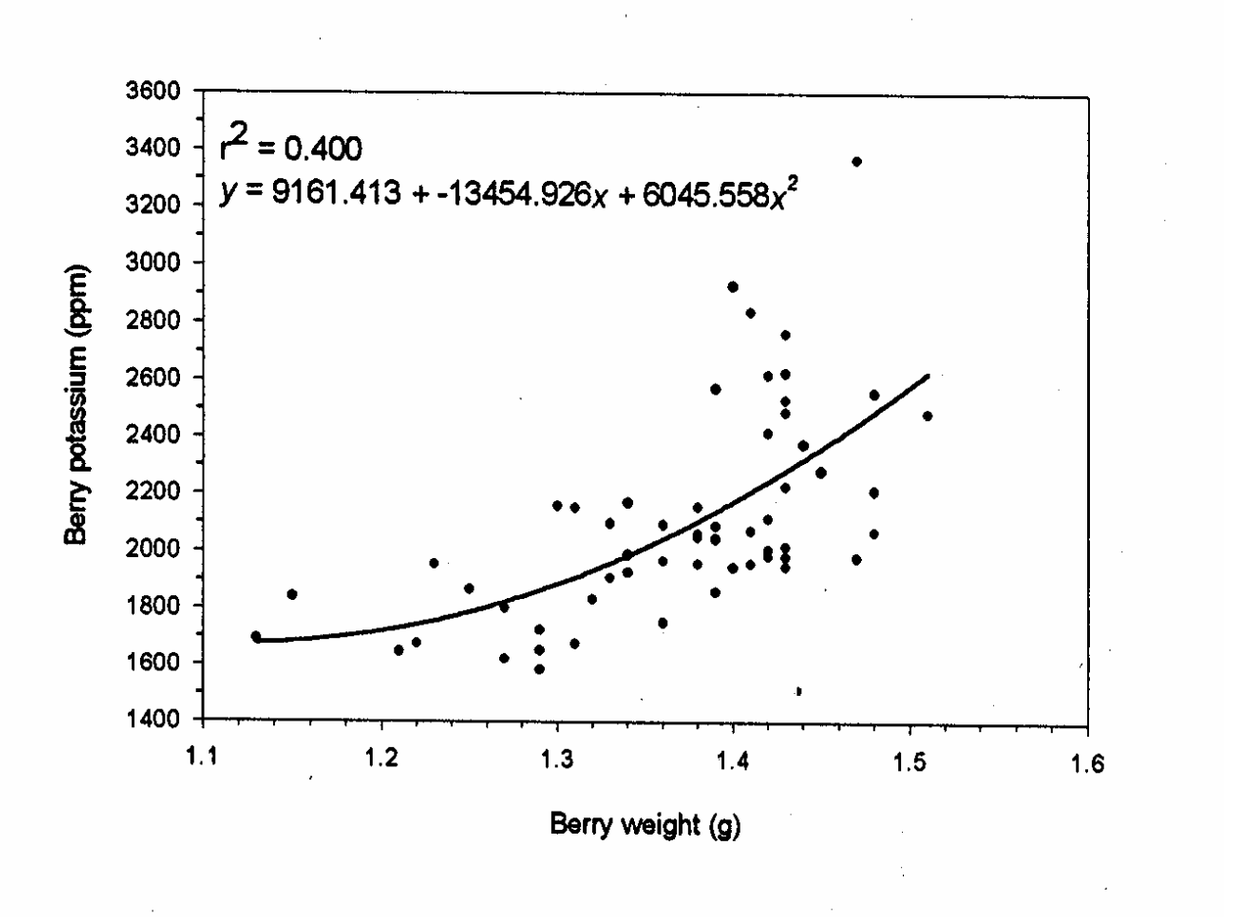


Figure 35. Relationship between berry potassium level and berry weight across the 60 rootstocks.

Vine growth characteristics of the 60 rootstocks were also correlated to other key quality parameters, ie berry colour (anthocyanins) and phenolics, Table 2. The relationship between anthocyanin level and pruning weight, best described by a reciprocal function, shows a rapid drop in colour up to a pruning weight of 1.5 kg with little further effect at high vigour (Fig.36). The highly significant negative linear relationship between colour and yield indicates that higher yielding rootstocks could be expected to have lower berry colour (Fig.37). Similarly the significant reciprocal relationship between colour and berry weight indicated that rootstocks with larger berries are likely to have lower colour (Fig.38).

The relationship between total berry phenolics and pruning weight, best described by a reciprocal function, shows a rapid drop in phenilics up to a pruning weight of 1.5kg although there was a larger range in phenolic levels at lower pruning weights (Fig 39). There was little further effect of vigour on phenolics at higher pruning weights. The highly significant negative linear relationship between phenolics and yield indicates that higher yielding rootstocks could be expected to have lower phenolics (Fig.40). Similarly the significant reciprocal relationship between phenolics and berry weight indicates that rootstock with larger berries are likely to have lower phenolics (Fig. 41).

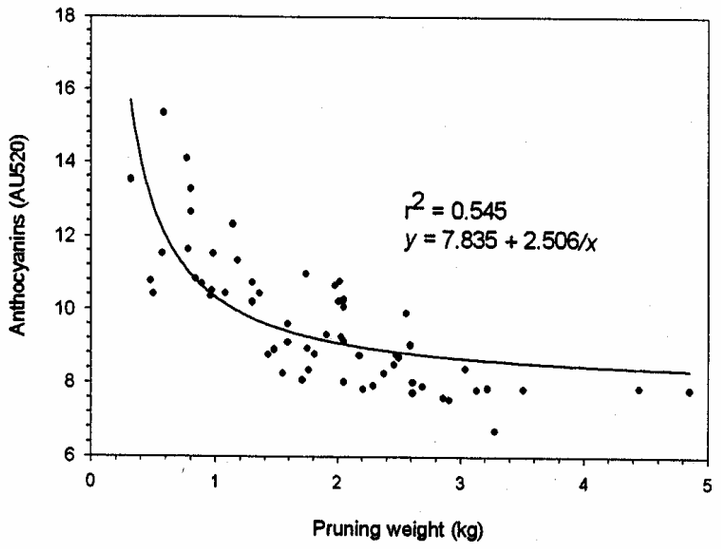


Figure 36. Relationship between anthocyanins and pruning weight across the 60 rootstocks.

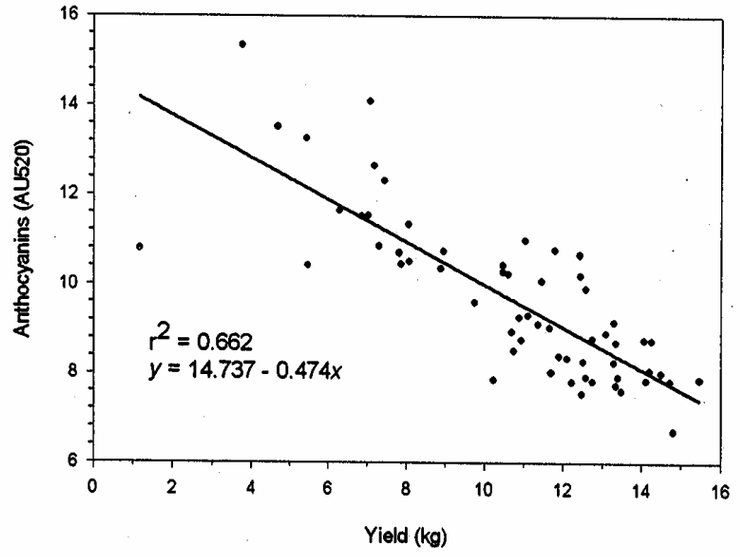


Figure 37. Relationship between anthocyanins and yield across the 60 rootstocks.

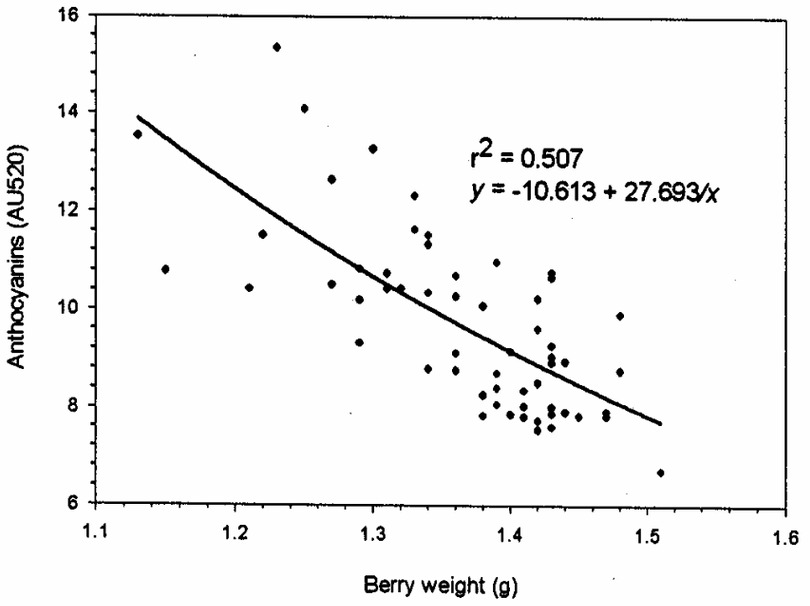


Figure 38. Relationship between anthocyanins and berry weight across the 60 rootstocks.

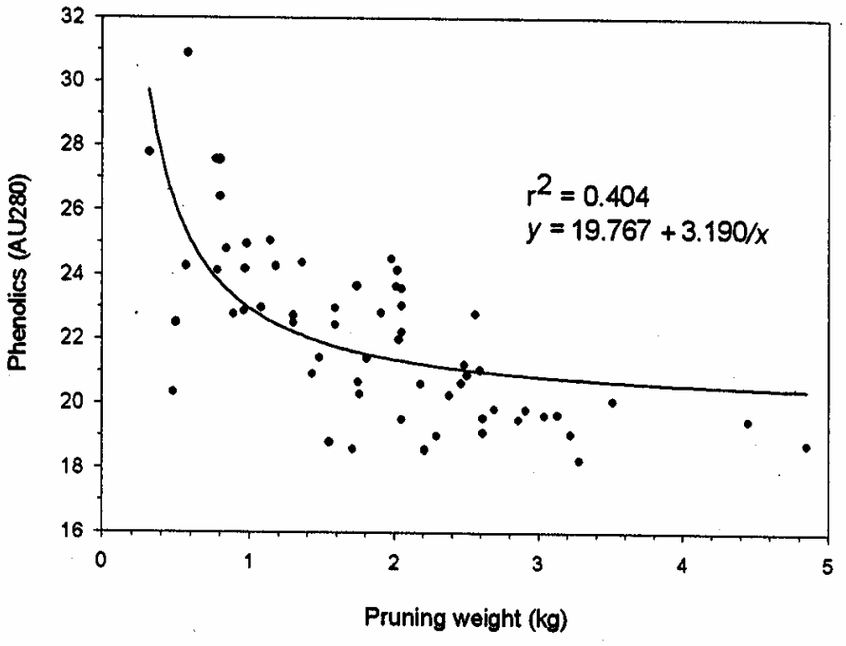


Figure 39. Relationship between berry phenolics and pruning weight across the 60 rootstocks.

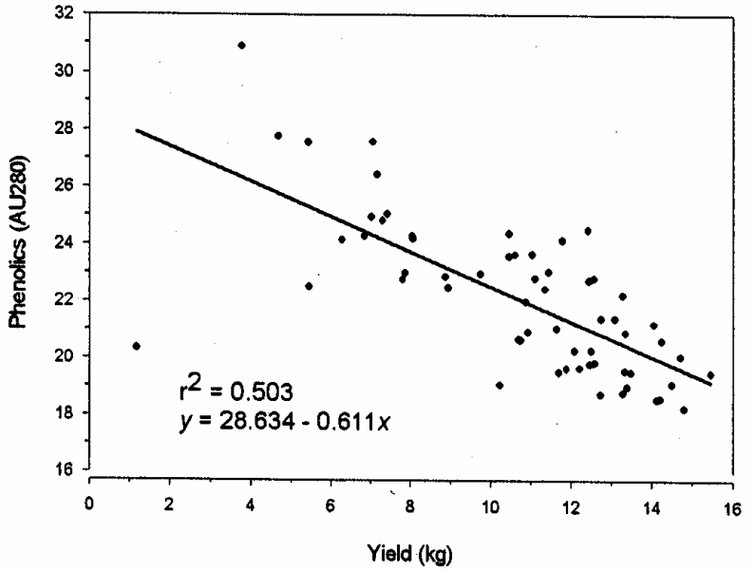


Figure 40. Relationship between berry phenolics and yield across the 60 rootstocks.

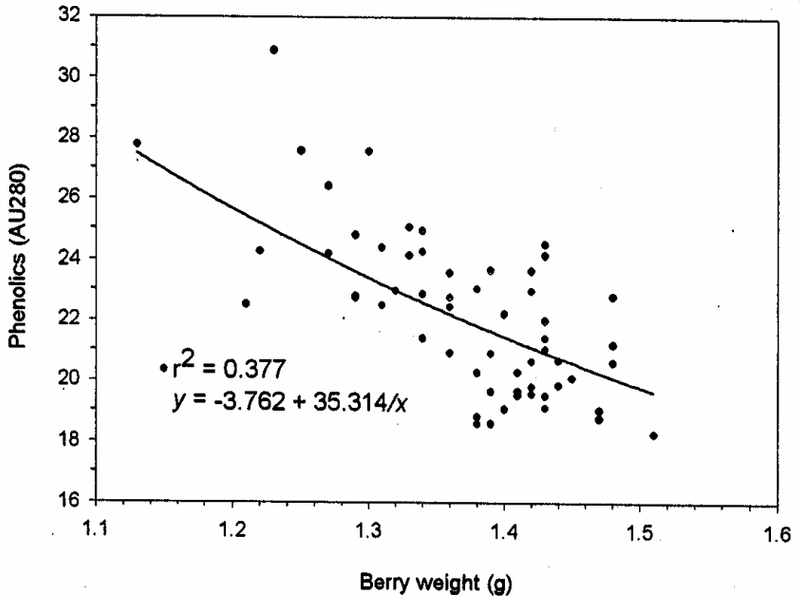


Figure 41. relationship between berry phenolics and berry weight across the 60 rootstocks.

2.3 Relationships between petiole or berry mineral contents and vine growth characteristics

Highly significant correlations were found between rootstock growth characteristics and mineral element contents in petioles, determined at flowering and in berries at harvest (Table 3). They indicate that high rootstock vigour is associated with and high petiole levels of nitrogen, phosphorus, calcium, boron, and magnesium (in order of significance) and high berry levels of phosphorus, nitrogen, potassium, sulphur and boron (in order of significance) and low calcium levels in berries. High yields were associated with high phosphorus, nitrogen, magnesium and low

potassium levels in petioles and high phosphorus, sulphur, nitrogen, potassium and low calcium levels in berries. Across the rootstocks, berry weight was positively linked to high levels of phosphorus and nitrogen in petioles and high phosphorus, nitrogen, potassium, sulphur and boron levels in berries. High petiole fresh weights were associated with high petiole levels of calcium, nitrogen, magnesium and phosphorus and low levels of sodium and high berry levels of potassium, nitrogen, phosphorus, sulphur and boron. Similar relationships were determined for petiole dry weights except for phosphorus and nitrogen in petioles, sulphur in berries and the inclusion of a negative relationship with sodium in both petioles and berries.

Table 3. Correlation coefficients between petiole (at flowering) and berry mineral content and vine growth characteristics across the 60 rootstocks. Bold type indicates highly significant correlations, p< 0.001

	Pruning weight	*Yield*	*Yield: Pruning weight*	*Berry weight*	*Petiole fresh wt.*	*Petiole dry wt.*
Petioles						
Potassium	-.22	**-.41**	.20	-.30	.09	.03
Calcium	**.55**	.14	**-.56**	.23	**.63**	**.64**
Magnesium	**.52**	**.42**	**-.45**	.33	**.45**	**.46**
Sodium	-.39	-.24	**.42**	-.25	**-.57**	**-.59**
Phosphorus	**.63**	**.55**	**-.51**	**.57**	**.41**	.21
Sulphur	.31	.38	-.11	.28	.08	-.13
Boron	**.55**	.17	-.34	.21	.22	.27
Nitrogen	**.65**	**.52**	**-.55**	**.54**	**.62**	.39
Berries						
Potassium	**.80**	**.43**	**-.71**	**.61**	**.73**	**.55**
Calcium	**-.41**	**-.50**	.16	-.36	-.12	.04
Magnesium	.19	-.02	**-.44**	.12	.20	.22
Sodium	-.09	.04	.07	.05	-.30	**-.42**
Phosphorus	**.86**	**.69**	**-.69**	**.71**	**.66**	**.46**
Boron	**.75**	**.61**	**-.53**	**.61**	**.54**	.34
Nitrogen	**.55**	.36	**-.54**	**.43**	**.52**	**.55**
	.83	**.57**	**-.65**	**.62**	**.71**	**.55**

2.4 Relationship between petiole and berry mineral contents

The correlation coefficients presented in table 4 indicate relationships between petiole and berry mineral contents across the 60 rootstocks. They are included to relate the standard measurement of vine nutrient status at flowering with berry nutrient levels. The results show that potassium and calcium levels in petioles were not indicative of berry levels. By contrast, petiole and berry levels of magnesium, sodium, phosphorus, sulphur, boron and nitrogen were highly correlated.

Other highly significant correlations indicate positive associations between:-

- Petiole calcium levels and berry levels of potassium and boron;
- Petiole magnesium levels and berry levels of boron and nitrogen;
- Petiole phosphorus levels and berry potassium, sulphur and nitrogen levels;
- Petiole sulphur levels and berry phosphorus levels;
- Petiole boron levels and berry magnesium levels;
- Petiole nitrogen levels and berry levels of potassium, phosphorus, sulphur and nitrogen.

Petiole sodium was negatively correlated with boron levels in berries and petioles sulphur negatively correlated with calcium levels in berries.

Table 4. Correlation coefficients between petiole and berry mineral contents across the rootstocks.

Petioles	K	Ca	Mg	Na	P	S	B	N
Berries								
K	.19	**.60**	.29	-.38	**.62**	.21	.22	**.68**
Ca	.23	.38	.05	-.23	-.35	**-.58**	.25	-.40
Mg	-.21	.31	**.59**	-.28	.17	-.13	**.55**	.11
Na	-.24	-.38	-.08	**.68**	.17	.39	-.14	-.02
P	-.26	.40	.39	-.18	**.72**	**.72**	.14	**.57**
S	-.10	.24	.28	.02	**.51**	**.51**	.10	**.68**
B	-.22	**.58**	**.62**	**-.67**	.26	-.26	**.77**	.30
N	.06	-.04	**.43**	-.32	**.57**	.36	.07	**.75**

2.5 Relationships between petiole or berry mineral contents and berry quality parameters.

The correlation coefficients presented in Table 5 indicate relationships between berry quality parameters and either petiole mineral contents or berry mineral contents. The results show that petiole potassium level was not related to any of the berry quality parameters. By contrast, negative impacts of high berry potassium on quality parameters are indicated by the highly significant positive relationship with pH, and negative impacts on quality parameters related to high petiole nutrient status are indicated by highly significant correlations between:-

- Petiole calcium levels and berry pH and potassium level
- Petiole phosphorus levels and berry pH and potassium levels and reduced colour and phenolics
- Petiole sulphur levels and reduced colour and phenolics
- Petiole nitrogen levels and berry pH sand potassium levels and reduced colour and phenolics.

Table 5. Correlation coefficients between berry quality parameters determined over 3 seasons and petiole and berry mineral contents across the 60 rootstocks. Bold type indicates highly significant correlations, p< 0.001.

Petioles	*K*	*Ca*	*Mg*	*Na*	*P*	*S*	*B*	*N*
°Brix	-.24	.17	.16	-.20	.16	-.20	**.46**	-.08
PH	.21	**.58**	.25	-.28	**.55**	.18	.21	**.58**
Acid	-.11	**.53**	**.49**	**-.46**	**.55**	.24	.17	**.68**
Colour	.25	-.19	-.33	.23	**-.53**	**-.45**	-.04	**-.65**
Phenolics	.17	-.20	-.33	.17	**-.55**	**-.48**	.01	**-.68**
Potassium	.19	**.60**	.28	-.38	**.62**	.21	.22	**.68**
Berries								
°Brix	.21	**.41**	**.63**	.18	.14	-.20	**.47**	.03
PH	**.94**	-.15	.31	.00	**.76**	.18	**.41**	**.78**
Acid	**.72**	-.23	.17	-.15	**.68**	**.64**	**.49**	**.80**
Colour	**-.49**	**.64**	.10	.06	**-.70**	**-.68**	-.24	**-.68**
Phenolics	**-.49**	**.64**	.12	-.20	**-.67**	**-.67**	-.15	**-.69**
Potassium		-.17	.27	-.05	**.79**	**.67**	**.46**	**.82**

The significant positive correlation between berry magnesium and berry sugar levels across the 60 rootstocks, identified in Table 5, is shown as a linear function in Fig.42. While there were a number of outliers, where high magnesium levels did not lead to high maturity, the overall trend is evident. The association between berry maturity and magnesium contents across the rootstock selections had not previously been reported. It indicates that plant nutrition, ie. berry magnesium contents, may play a significant role in fruit maturation. It is possible that reported ripening problems with existing rootstocks such as Ramsey may be related to their nutritional status.

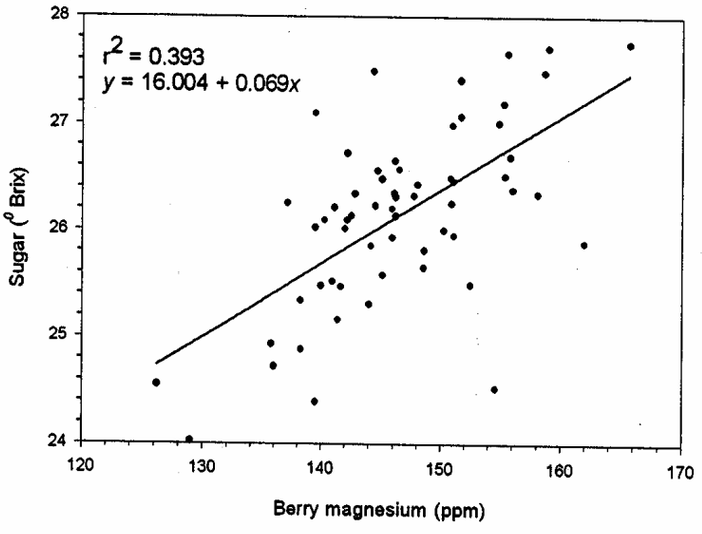


Figure 42. Relationship between berry magnesium and berry sugar levels (^{0}Brix) across the 60 rootstocks.

A number of highly significant correlations across the 60 rootstocks between were juice pH and berry mineral contents were identified in Table 5. The very strong, linear relationship between pH and berry potassium is shown in Fig.43. The relationship indicates that almost 90% of the variation in pH across the selections can be accounted for by the variation in berry potassium contents.

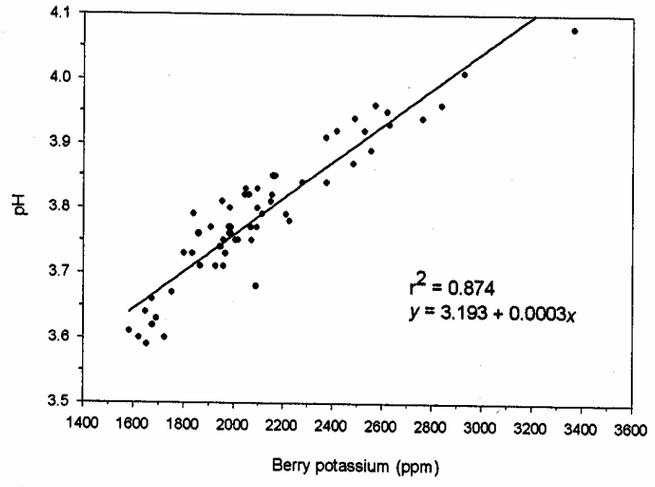


Figure 43. Relationship between pH and berry potassium over the 60 rootstocks.

The s tents are shown in Figs. 44 and 45 respectively. In both cases the pH range at a particular nutrient level was about 0.3 pH units.

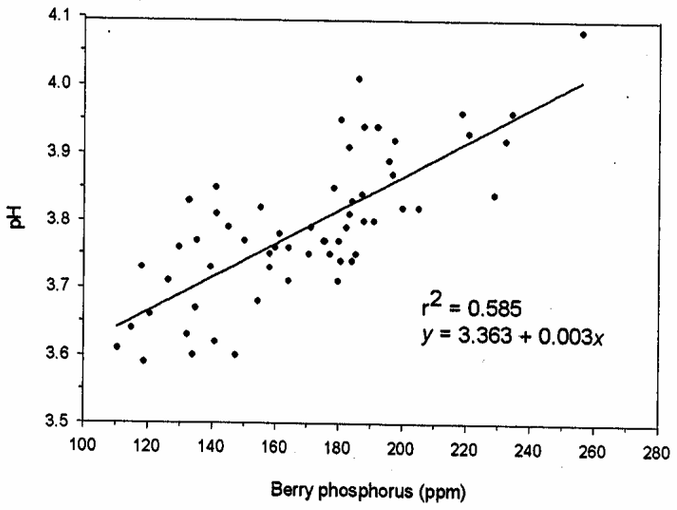


Figure 44. Relationship between pH and berry phosphorus over the 60 rootstocks.

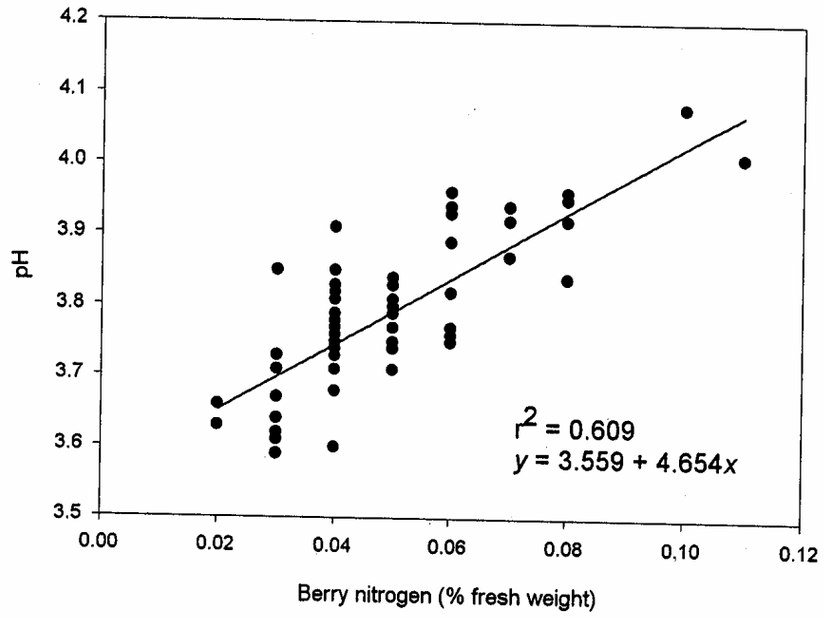


Figure 45. Relationship between pH and berry nitrogen over the 60 rootstocks.

As described above, berry potassium content was a highly significant factor related to pH across the 60 rootstocks. Berry potassium content was also correlated with other mineral ion contents (Table 5). The highly significant linear relationships between berry potassium level and phosphorus, sulphur and nitrogen are shown in Figs. 46-48 respectively.

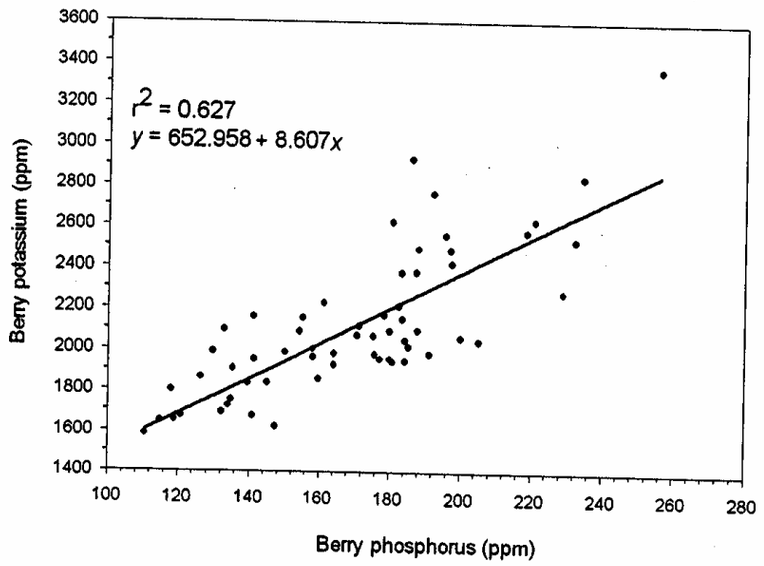


Figure 46. Relationship between berry potassium content and berry phosphorus over the 60 rootstocks.

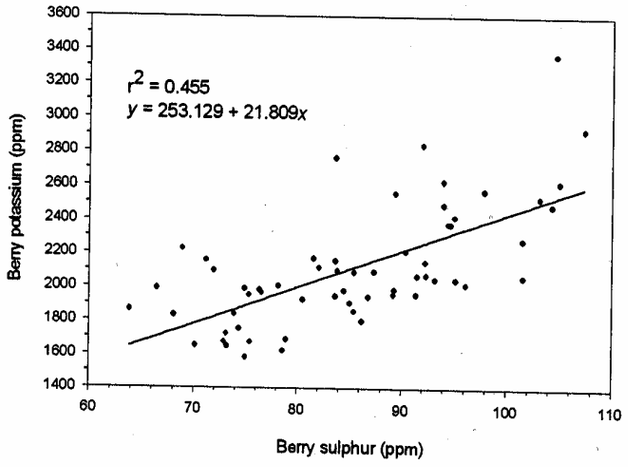


Figure 47. Relationship between berry potassium content and berry sulphur over the 60 rootstocks.

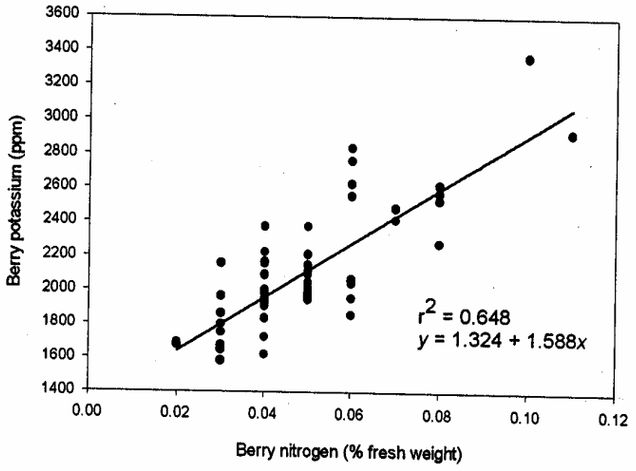


Figure 48. Relationship between berry potassium content and berry nitrogen over the 60 rootstocks.

Berry colour and phenolics were correlated with mineral ion contents (Table 5). Many of these relationships have not been reported previously. The negative relationship between colour (anthocyanins) and berry potassium was best described by a reciprocal function, although there was a wide range in colour levels at low potassium levels, ie < 2200ppm (Fig.49). A positive linear relationship between berry calcium and colour is described in Fig. 50. The relationships between berry colour and phosphous and sulphur were best described by a reciprocal function (Figs. 51, 52). The highly significant negative relationship between colour and berry nitrogen

was also best described by a reciprocal function (Fig.53). Overall, the results suggest that problems with colour and development with existing rootstocks may be due to nutritional imbalances leading to high potassium, phosphorus, sulphur and nitrogen contents and low calcium contents in berries.

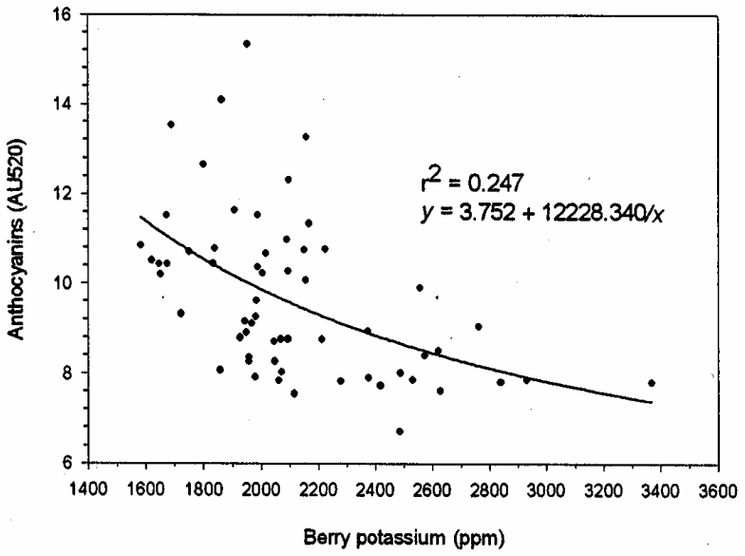


Figure 49. Relationship between colour (anthocyanins) and berry potassium over the 60 rootstocks.

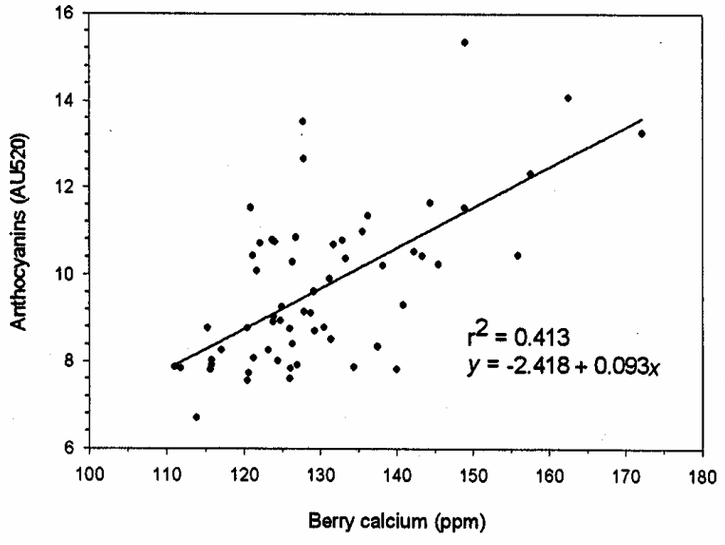


Figure 50. Relationship between colour (anthocyanins) and berry calcium over the 60 rootstocks.

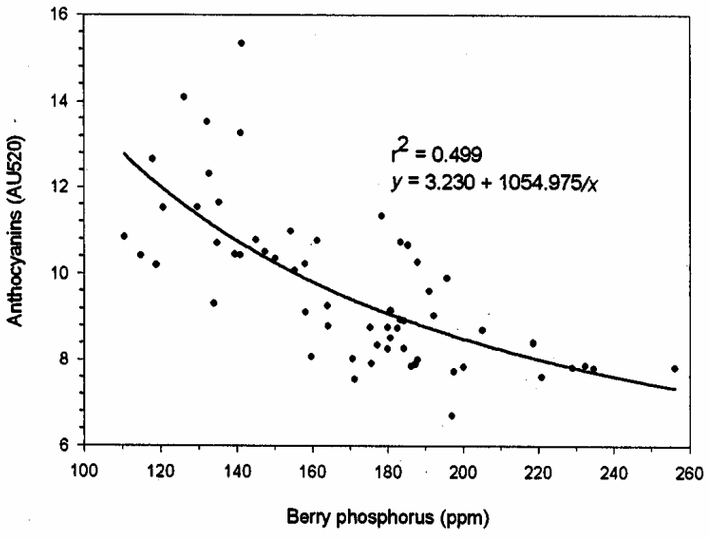


Figure 51. Relationship between colour (anthocyanins) and berry phosphorus over the 60 rootstocks.

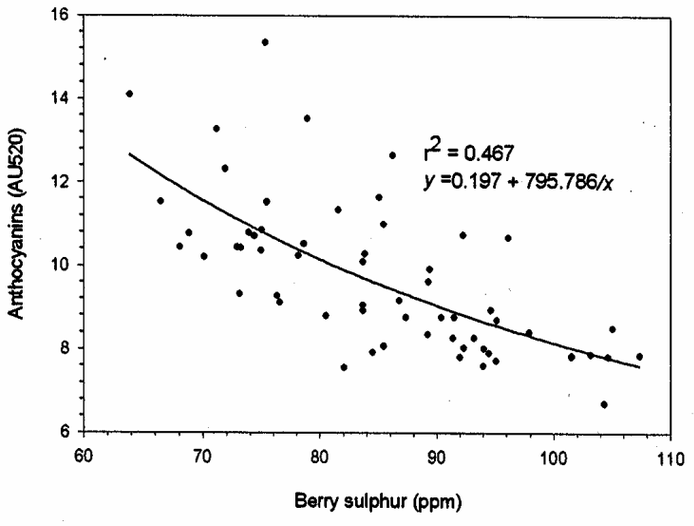


Figure 52. Relationship between colour (anthocyanins) and berry sulphur over the 60 rootstocks.

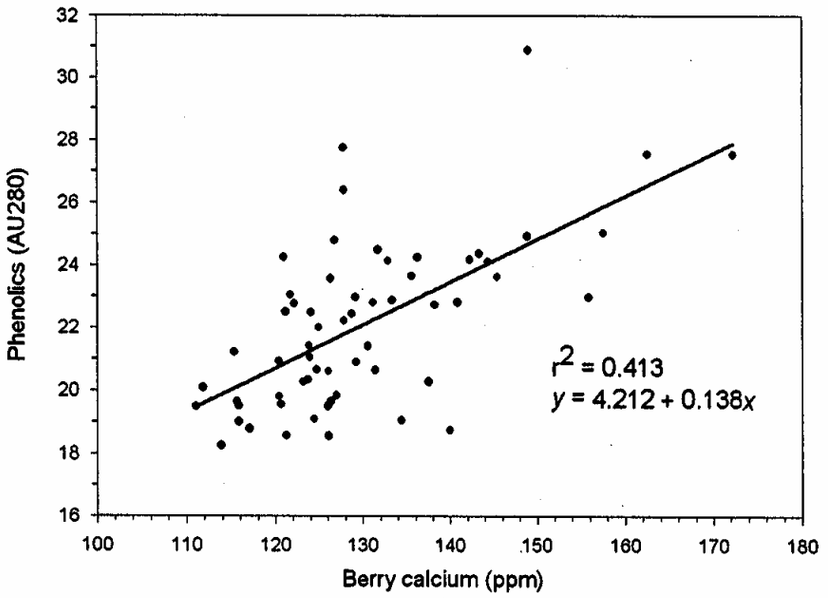


Figure 55. Relationship between phenolics and berry calcium over the 60 rootstocks.

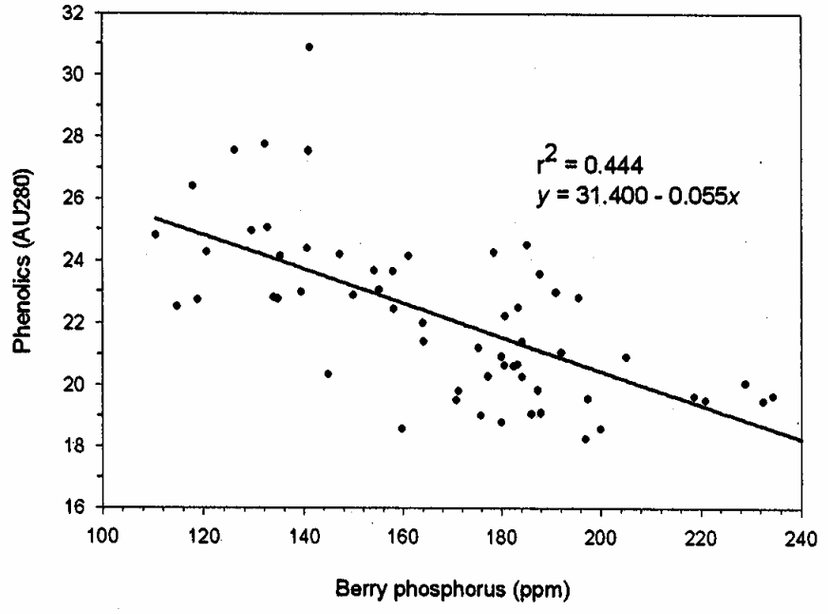


Figure 56. Relationship between phenolics and berry phosphorus over the 60 rootstocks.

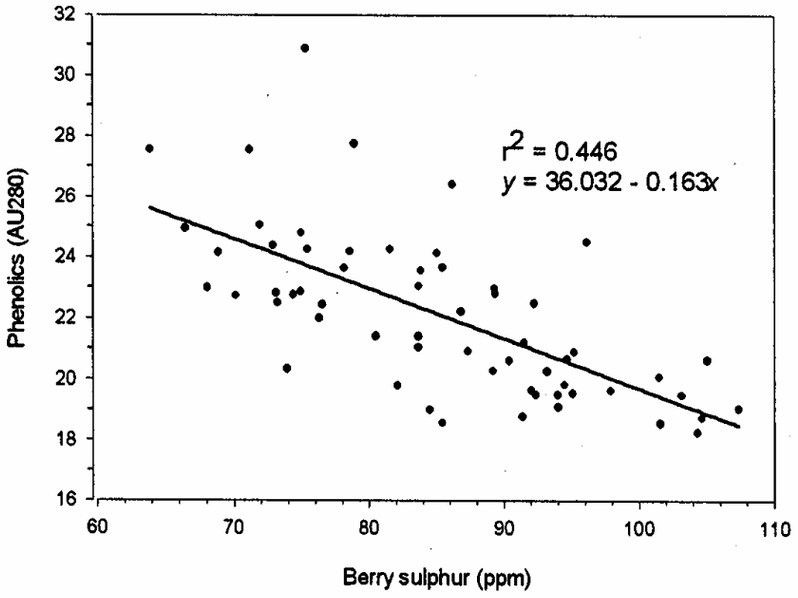


Figure 57. Relationship between phenolics and berry sulphur over the 60 rootstocks.

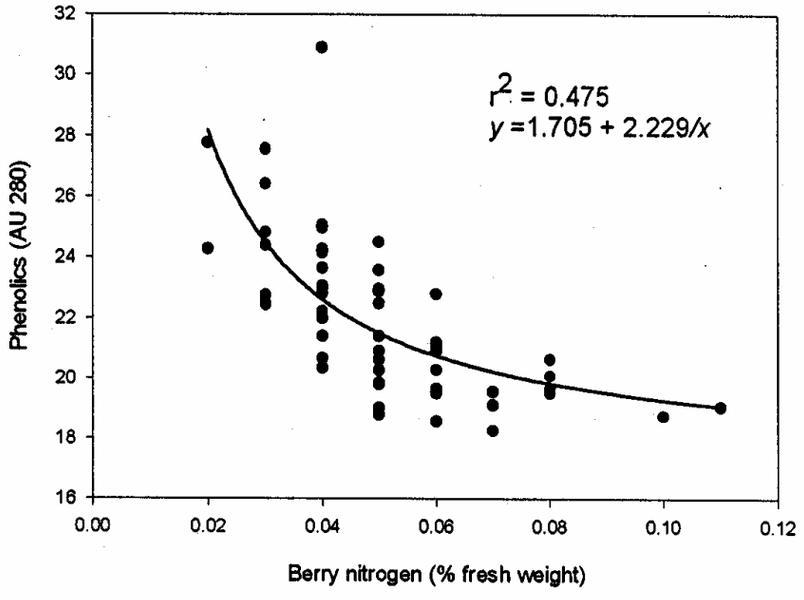


Figure 58. Relationship between phenolics and berry nitrogen over the 60 rootstocks.

3. Nematode and Phylloxera tolerance studies

Nematode and phylloxera tolerance screening techniques were undertaken for a limited number of rootstock selections. The selections were identified as showing strong potential based on the first year performance with respect to juice potassium levels, vigour, yield and parentage. Wines were also produced from these selections.

3.1 *Nematode screening*

Tolerance of 10 rootstock selections to 3 nematode species was assessed in the pot trials in a number of ways (Tables 3a-d). Overall, the studies proved quite difficult due to differences in propagation of some selections, differences in their growth and the large variability between replicates, ie as indicated by the standard errors. Large differences in root weight were recorded across the selections and the control varieties, ie. Sultana, Ramsey and 140R (Table 3a). The standard rootstocks, Ramsey and 140R had some of the lowest root weights, ie. about 60g. compared to selection 45 with 122g. *M incognita* reduced the root weight of the Sultana control and selections 12, 25, 30 and 31. *Mjavanica* reduced the root weight of the Sultana control and selection 31. *M hapla* addition had no effect on root weight of the Sultana control or any selection.

Table 3a. Mean root weight (g) of selected rootstocks after application of nematode treatments to potted vines, ie. control, M incognita, M javanica, and M hapla (n = 10*, standard deviations are presented in brackets. Numbers in bold indicate significant differences to the control).*

Sorted code	Control	*M. incognita*	*M. javanica*	*M. hapla*
Sultana	87.0 (20.1)	**67.0** (15.0)	**60.0** (15.7)	78.3 (8.1)
12	78.7 (15.8)	**41.4** (20.5)	-	-
13	73.6 (10.3)	81.1 (17.0)	77.8 (23.9)	71.0 (9.9)
17	84.5 (11.3)	108.2 (26.9)	103.4 (35.5)	67.4 (10.0)
25	77.7 (39.5)	**28.9** (21.5)	75.7 (7.0)	75.7 (7.0)
26	83.7 (14.1)	74.4 (26.8)	73.1 (59.5)	97.6 (5.8)
30	111.5 (31.9)	**47.1** (23.2)	88.8 (33.9)	79.6 (8.1)
31	67.3 (9.3)	**21.8** (17.3)	**25.8** (26.4)	74.0 (9.1)
38	101.3 (13.8)	107.3 (44.6)	99.6 (9.9)	93.6 (19.4)
45	122.2 (44.3)	84.3 (18.5)	138.8 (18.6)	88.5 (14.1)
49 Ram.	55.5 (7.4)	69.2 (17.2)	73.1 (12.0)	53.9 (11.5)
51 140R	66.2 (13.2)	70.8 (4.4)	70.4 (11.3)	67.5 (6.2)
57	58.9 (11.7)	66.2 (15.9)	66.9 (23.8)	68.6 (15.5)

Despite the minimal effects on root growth, most selections supported significant numbers of juvenile nematodes in the soil of each pot (Table 3b). *M incognita* juveniles were not found in the soil of Ramsey and selections 12 and 13 while selections 17, 26, 30, and 31 developed higher numbers than the Sultana control. Selections 25, 38, 45 and 57 had similar or fewer *M incognita* juveniles than 140R. *M. javanica* juveniles were absent from the soil of Ramsey and selections 13 and 57 while selections 17, 25, 26, 30, 31 developed higher numbers than the Sultana control. Selections 38 and 35 had similar *incognita* juvenile numbers to 140R. *M hapla* juveniles did not establish in the soil of most selections, including the Sultana control, except *for* selections 13, 17 and 25. (Note: *M incognita* and *M hapla* were not applied to selection 12 due to limited availability of material.)

Table 3b. Mean number of nematode juveniles in the soil of each pot of the selected rootstocks after application of nematode treatments to potted vines, *ie. control, M incognita, M javanica, and M hapla (standard deviations are presented in brackets).*

Sorted code	***M. incognita***	***M. javanica***	***M. hapla***
Sultana	3373 (3449)	509 (992)	0
12	0	-	-
13	0	0	4143 (3243)
17	15663 (12209)	14494 (13966)	1975 (1364)
25	666 (529)	10784 (13658)	35 (0)
26	33768 (33050)	9586 (10582)	0
30	9529 (10302)	9330 (7046)	0
31	6570 (4512)	5833 (4902)	0
38	33 (8)	154 (152)	0
45	37 (0)	19 (2)	0
49 Ram.	0	0	0
51 140R	495 (673)	26 (0)	0
57	94 (0)	0	0

A key measure of nematode tolerance is the number of juveniles per unit root weight (Table 3c). *M incognita* did not establish on the roots of Ramsey or 140R and selections 12, 13, and 45 while selections 25. 30,31 and 38 had similar or fewer numbers juveniles than the Sultana control. Selections 17 and 26 had higher numbers of *M incognita* juveniles than the Sultana. *M javanica* did not establish on the roots of Ramsey or 140R and selections 13, 25, 31, 45 and 57 and produced only low juvenile numbers with the Sultana control and selection 38. Selections 17, 26 and 30 had the highest numbers of M *javanica* per root sample. M *hapla* juveniles were only detected at very low numbers with root samples of selection 13.

.Table 3c. Mean number of nematode juveniles per 109 of roots of the selected rootstocks after I *application of nematode treatments to potted vines, ie. control,* M *incognita, M javanica, and* M *hapla (the standard error of each mean is presented in the brackets).*

Sorted code	*M. incognita*	*M. javanica*	*M. hapla*
Sultana	80 (38.6)	6.6 (1.6)	0
12	0	-	-
13	0	0	2.8 (1.5)
17	1178 (298)	126 (22.7)	0
25	56.9 (53.9)	0	0
26	456 (142)	126 (25.8)	0
30	125 (65.0)	83 (39.0)	0
31	83.3 (22.1)	0	0
38	6.6	1.2	0
45	0	0	0
49 Ram.	0	0	0
51 140R	0	0	0
57	0	0	0

An index of nematode root galling was also determined across the selections as an indicator of tolerance to nematode species (Table 3d). *M incognita* produced trace levels of galls with Ramsey and 140R and selections 13, 38, and 57, <25% galls with the Sultana control and selections 12, 25, 30 and 45 while roots of selections 17 and 26 had up to 50% galls. *M javanica* produced no galls with 140R and selection 57, trace levels with Ramsey and selectIons13, 38 and 45, <25% galls with the Sultana control and selections 17, 25, 30, and 31 and up to 50% galls with selection 26. *M hapla* gave 0 galls or only trace levels with all rootstocks.

Table 3d. Index of nematode galling (0 = 0, 1 = trace, 2 < 25%, 3 < *50%, 4*< 75%, 5> 75%) *on the root of the selected rootstocks after application of nematode treatments to potted vines, ie. control, M incognita, M javanica, and M hapla.*

Sorted code	*M. incognita*	*M. javanica*	*M. hapla*
Sultana	2	2	1
12	2	-	-
13	1	1	0
17	3	2	1
25	2	2	1
26	3	3	1
30	2	2	1
31	3	2	1
38	1	1	1
45	2	1	0
49 Ram.	1	1	0
51 140R	1	0	0
57	1	0	0

3.2 *Phylloxera screening*

A total of 12 rootstocks were screened in two separate bioassay experiments (Table 3e). The phylloxera tolerance of 5 selections (12, 20, 25, 31 and 34), assessed by the number of phylloxera survivors on main roots was not significantly different to that of Schwarzmann. Selection 13 also showed some resistance to phylloxera as establishment did not occur on main roots. Selection 17 was very susceptible to phylloxera. Phylloxera survival on the remaining selections was intermediate to those of Shiraz and Schwarzmann. (Note: the phylloxera screening was only undertaken with the Whitlands biotype. It is recommended that phylloxera tolerance be tested with other biotypes found in Australia).

Table 3e. Mean number of phylloxera survivors established in total or on main roots of selected rootstocks In 2 bioassays. (Note initial number =30 and 20 for bioassays 1 & 2 respectively). Rootstocks selections identified with the same subscript do not differ significantly (p=.001).

Bioassay 1

Sorted code	*Total Phylloxera Survivors*	*Phylloxera survivors on main roots*
Shiraz	20.7d	20.1c
Schwarzmann	0.0a	0.0a
12	3.7ab	3.7a
13	7.3b	2.0a
17	22.7d	22.0c
20	2.4a	2.1a
25	0.9a	0.9a
31	3.3ab	2.9a
57	15.0c	11.3b

Bioassay 2

Sorted code	*Total Phylloxera Survivors*	*Phylloxera survivors on main roots*
Shiraz	14.9c	14.3d
Schwarzmann	0.0a	0.0a
26	10.4b	5.7b
30	13.2c	4.3b
34	0.0a	0.0a
38	13.8c	10.6c
45	13.1c	8.6c

3.3 *Summary of rootstock selection screening results*

Nematode and phylloxera tolerance/resistance are key selection criteria for assessing new rootstocks for Australian conditions. Using the phylloxera and nematode screening results (in particular the results of juveniles per unit root weight and galling) it is possible to assess each selection against these criteria. Selections 17 and 26, and most probably 30 should be eliminated because of their susceptibility to both pests types. Selections 12 (subject to further nematode screening with all types) and 13 would be acceptable because of their tolerance to both pest types. Selections 38,45 and 57 gave acceptable nematode results but would be eliminated because of their phylloxera susceptibility. While selections 25 and 31 had adequate phylloxera tolerance, their nematode tolerance remains doubtful, in particular the tolerance of selection 31 to *M incognita.* Selections 20 and 34, which had adequate phylloxera tolerance, require screening against nematodes.

4. Evaluation of selections by small scale winemaking

Small scale wines were produced at harvest in 1996 (15/3) and 1997 (19/3) from selections identified as showing strong potential, based on the first year performance with respect to juice potassium levels, vine vigour and yield, and parentage. The selections were compared to Ramsey and 140R. The results including the mean yield data are presented in Table 4a, in order of vine vigour (pruning weight).

Table 4a. Meanyield; °Brix, pH and titratable acidity of juice and wine samples of 12 rootstock selections' and Ramsey and 140R in 1996 and 1997. Juice and wine data are means of two winemaking replicates.

1996

Sorted code	Yield Kg	°Brix	Juice pH	Juice Acid g/L	Wine pH	Wine Acid g/L
12	9.68	26.9	3.68	5.28	3.70	6.10
13	9.10	25.7	3.62	4.89	3.72	6.57
17	8.43	27.0	3.87	4.86	3.76	6.51
20	12.47	26.6	3.54	6.37	3.72	6.84
25	13.58	25.6	3.83	4.95	3.73	6.18
26	14.43	26.5	3.79	5.04	3.81	5.98
30	14.58	26.7	3.81	5.00	3.84	6.05
31	11.42	26.9	3.65	6.82	3.83	6.51
34	14.54	27.5	3.88	4.79	3.85	6.00
38	16.53	27.2	3.83	4.52	3.79	6.32
45	16.13	26.9	3.79	4.85	3.82	6.08
49 Ram	15.80	25.9	3.83	4.21	3.85	5.83
51 140R	14.12	27.7	3.77	6.05	4.03	5.96
57	19.23	25.2	4.00	4.91	3.92	5.57

1997

Sorted code	Yield Kg	°Brix	Juice pH	Juice Acid g/L	Wine pH	Wine Acid g/L
12	6.55	26.1	3.82	4.62	3.75	5.33
13	4.95	26.1	3.65	4.91	3.49	5.92
17	4.78	25.0	3.59	4.48	3.78	5.67
20	6.36	25.1	3.61	5.14	3.69	5.69
25	6.94	27.1	3.83	4.20	3.54	5.89
26	10.46	27.4	3.73	4.31	3.63	5.55
30	9.14	27.2	3.74	3.92	3.50	5.49
31	9.21	26.9	3.76	4.91	3.65	5.61
34	9.04	27.7	3.82	4.23	3.79	5.52
38	9.75	26.8	3.74	4.07	3.69	5.41
45	10.51	28.1	3.82	3.96	3.71	5.33
49	11.23	26.7	4.02	4.77	3.96	5.44
51	9.84	27.8	3.90	4.96	4.01	5.32
57	11.53	27.4	3.96	4.16	3.89	5.09

Yields in 1996 (ie. 8.4-9.2) were much higher than those recorded in 1997 (ie. 7.8-11.5) yet the selections ripened at similar times. All selections reached very high sugar levels in both seasons. Sugar levels across the selections ranged from 25.7-27.7 °Brix in 1996 and 25.0-28.1 °Brix in 1997. Despite the relatively small differences in maturity large differences in juice pH were found, ie 3.54-4.00 in 1996 and 3.59-4.02 in 1997. Titratable juice acid levels ranged from 4.21- 6.82 g/L in 1996 and 3.92-5.14 g/L in 1997. Differences in wine pH between the selections ranged from 3.70- 4.03 in 1996 and 3.49-4.01 in 1997. Such results indicate the potential to select rootstocks to manipulate wine pH as both control rootstocks had high pH levels in both seasons. Wine titratable acid levels were higher in 1996 than in 1997, ranging from 5.57-6.84 1g/L in 1996 and 5.09-5.92 g/L in 1997.

Wines in 1997 had slightly higher colour densities in 1997 compared to 1996, ranging across the selections from 3.04-5.75 in 1996 and 3.43-4.90 in 1997 (Table 4b). Wine hue values, which indicate wine brightness (higher values are browner duller wines) ranged from 0.66 to 0.89 in 1996 and 0.76-0.91in 1997. Ramsey and 140R tended to have higher hue values in both seasons than the other selections. Ionised anthocyanins ranged from 27.1-70.2 in 1996 and 24.8-50.5 in 1997 with the standard rootstocks tending to low levels in both seasons. Total anthocyanins ranged from 321- 535 in1996 and 345-458 in 1997. The standard rootstocks tended to have low levels of total anthocyanins in both years. The % of ionised anthocyanins ranged from 7.8-13.1 in 1996 and 6.6-11.4 in 1997 with the standard rootstocks having low values. Overall, differences in wine colour between the selections can be attributed to effects of both total anthocyanins and the % in the ionised form. Wine phenolic levels ranged from 38.8-60.7 in 1996 and 44.0-60.2 in 1997 with the standard rootstocks tending to have low levels. In both years, differences between wine sensory scores of the selections were small, ie.14.7-15.6 in 1996 and 13.9-15.5 in 1997. Interestingly, wines from Ramsey rootstock received high scores from the industry taste panel in both years.

Identification of superior rootstock selections based on wine sensory evaluation was not possible as scores were similar in both years. However the differences in wine composition and spectral properties provided a basis to identify potential superior selections (Tables 4a, b). With respect to the low vigour, low yielding selections (ie. 2, 13, 17) all produced a low pH wine in both years, although selection 17 had the highest value. Selection 17 produced the most intense wines of the 3 selections, ie. having the highest colour density, ionised anthocyanins, total anthocyanins, % ionised anthocyanins and phenolics. The brightest wines with the lowest hue were produced by selection 13 which also had the highest titratable acidity.

Six moderate vigour selections had similar yields to the higher vigour, 140R over the 2 seasons (ie. selections 20, 25, 26, 30, 31, 34). Compared to 140R, wines of these 6 selections had lower pH, higher acid, lower hue, higher ionised anthocyanins, higher % ionised anthocyanins. Except for selection 31, tasting scores were equal to or higher than 140R. Colour density of the six selections was lower than 140R in 19:6 and generally higher in 1997, except selection 31. Total anthocyanin levels were equal to or higher than 140R, except for selection 31 m 1996. Overall, the best of the 6 selections 25 as its wines received high scores in both seasons and had low pH, high colour density, low hue, high ionised anthocyanins, high total anthocyanins and high phenolics. The worst performing selection was 34 as its wines had the highest pH m both seasons low acid high hue low ionised anthocyanins and low % ionised anthocyanins.

Table 4b. Mean wine colour density, hue, ionised anthocyanins, total anthocyanins, % ionised anthocyanins, total phenolics and wine panel score of 12 rootstock selections and Ramsey and 140R in 1996 and 1997. Juice and wine data are means of two winemaking replicates.

1996

Sorted code	Yield Kg	°Brix	Juice pH	Juice Acid g/L	Wine pH	Wine Acid g/L
12	9.68	26.9	3.68	5.28	3.70	6.10
13	9.10	25.7	3.62	4.89	3.72	6.57
17	8.43	27.0	3.87	4.86	3.76	6.51
20	12.47	26.6	3.54	6.37	3.72	6.84
25	13.58	25.6	3.83	4.95	3.73	6.18
26	14.43	26.5	3.79	5.04	3.81	5.98
30	14.58	26.7	3.81	5.00	3.84	6.05
31	11.42	26.9	3.65	6.82	3.83	6.51
34	14.54	27.5	3.88	4.79	3.85	6.00
38	16.53	27.2	3.83	4.52	3.79	6.32
45	16.13	26.9	3.79	4.85	3.82	6.08
49 Ram	15.80	25.9	3.83	4.21	3.85	5.83
51 140R	14.12	27.7	3.77	6.05	4.03	5.96
57	19.23	25.2	4.00	4.91	3.92	5.57

1997

Sorted code	Yield Kg	°Brix	Juice pH	Juice Acid g/L	Wine pH	Wine Acid g/L
12	6.55	26.1	3.82	4.62	3.75	5.33
13	4.95	26.1	3.65	4.91	3.49	5.92
17	4.78	25.0	3.59	4.48	3.78	5.67
20	6.36	25.1	3.61	5.14	3.69	5.69
25	6.94	27.1	3.83	4.20	3.54	5.89
26	10.46	27.4	3.73	4.31	3.63	5.55
30	9.14	27.2	3.74	3.92	3.50	5.49
31	9.21	26.9	3.76	4.91	3.65	5.61
34	9.04	27.7	3.82	4.23	3.79	5.52
38	9.75	26.8	3.74	4.07	3.69	5.41
45	10.51	28.1	3.82	3.96	3.71	5.33
49	11.23	26.7	4.02	4.77	3.96	5.44
51	9.84	27.8	3.90	4.96	4.01	5.32
57	11.53	27.4	3.96	4.16	3.89	5.09

Wine was also produced from 3 high vigour, high yielding selections (ie. 38, 45, 57). Over the 2 seasons, the yields of selection 38 and 45 were similar to Ramsey while for selection 57, the yield was higher, ie. 15.4 kg/vine compared to13.5 kg/vine. Selections 38 and 45 produced wines with better composition and spectral properties than Ramsey while almost without exception wines of selection 57 were of lower quality.

The correlations presented in Table 4c indicate strong linkages between vine growth characteristics of the rootstock selections and wine quality parameters. High vigour, determined by measurement of pruning weight, had a negative impact on wine quality in both years, ie. high pH and hue values and low titratable acidity, colour density, ionised anthocyanins, total anthocyanins, % ionised anthocyanins and phenolics. High yields produced similar responses except for hue in 1996 and wine pH in 1997. Larger berries produced negative effects on all quality parameters in 1997 and on wine pH, titratable acidity, and % ionised anthocyanins in 1996. The juice composition variables, °Brix and titratable acidity were not correlated across the selections with any wine quality parameter in either year. While not always significant in both seasons, high juice pH and potassium levels produced negative impacts on quality parameters, ie. high wine pH and hue values, low acidity, ionised anthocyanins and % ionised anthocyanins.

Table 4c. Correlation matrix between vine growth measurements, juice composition and a range .of wine quality parameters. For simplicity only significant correlations are presented, p<0.05.

1996	*PH Wine*	*Acid wine*	*Col. Dens.*	*Hue*	*Ion. Antho.*	*Total Antho.*	*% ion. Antho.*	*Phen.*
Pruning wt.	.83	-.71	-.44	.66	-.73	-.49	-.76	-.55
Yield	.57	-.69	-.63		-.76	-.54	-.74	-.63
Berry weight	.66	-.69					-.66	
^{O}Brix								
PH		-.75		.54			-.69	
Acid								
Potassium	.76	-.72		.78			-.66	
1997								
Pruning wt.	.58	-.68	-.60	.64	-.69	-.63	-.60	-.71
Yield		-.71	-.65	.61	-.71	-.63	-.60	-.78
Berry weight	.78	-.78	-.54	.88	-.83	-.57	-.80	-.69
^{O}Brix								
PH	.61	-.61		.72	-.86		-.87	
Acid								
Potassium	.70	-.56		.85	-.86		-.89	

Interrelationships between the various wine quality parameters across the rootstock selections are described by the significant correlations presented in Table 4d. They indicate that selections with high wine pH produce detrimental effects on wine quality, ie. low acid, high hue values, low ionised and % ionised anthocyanins. Selections with high acid produced brighter wines with a lower hue, with higher colour densities, ionised anthocyanins and % ionised anthocyanins. Across the selections colour density was related positively to with total anthocyanins, ionised anthocyanins, % ionised anthocyanins and total phenolics. High colour density and phenolics was linked to lower sensory scores 1996 but in 1997 the situation was reversed.

Table 4d Correlation matrix between the various wine quality parameters. For simplicity only significant correlations are presented; $p<0.05$.

1996	*PH Wine*	*Acid wine*	*Col. Dens.*	*Hue*	*Ion. Antho.*	*Total Antho.*	*% ion. Antho.*	*Phen.*
Acid wine	-.62							
Col. Dens.								
Hue	.69	-.84						
Ion. Antho	-.64	.69	.86	-.67				
Total Antho.			.87		.83			
% ion. Antho	-.72	.93	.57	-.82	.86			
Phenolics			.92		.86	.93		
Score			-.56					-.56
1997								
Acid wine	-.65							
Col. Dens.		.58						
Hue	.78	-.70						
Ion. Antho	-.75	.73	.73	-.73				
Total Antho.			.85		.69			
% ion. Antho	-.75	.72	.54	-.79	.95			
Phenolics		.66	.80	-.51	.63	.83		
Score			.54					

Publications

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Acknowledgments

Nematode and phylloxera tolerance assessments were conducted by Dr Greg Walker, Angela Corrie and their research teams. Their input is gratefully acknowledged. Glenda Kelly and David Emanuelli provided technical support to the project.

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