Wine Australia: Ex post cost benefit analysis of selected R&D projects supported by Wine Australia/GWRDC/AGWA investment

FINAL REPORT

IDA Economics Pty Ltd

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1. Overview

Background

Wine Australia commissioned IDA Economics Pty Ltd to undertake an ex post cost benefit study of a range of selected projects funded by the Grape and Wine R&D Corporation GWRDC)/Australian Grape and Wine Authority (AGWA)/Wine Australia.

Seventeen projects were selected by Wine Australia, covering

- Flavour
- Refrigeration
- Trunk disease
- Nutrition.

Analytical approach

The analytical approach used in the analysis follows the methodology outlined by the Council of Rural Research and Development Corporation Chairs.

- R&D investment — (GWRDC/AGWA/Wine Australia), co-investor and grower in kind (measured as real 2015 Net Present Values)
- Implementation costs —cost incurred by growers or others in adopting the R&D findings
- Net benefits to growers — how has the R&D (when adopted) reduced growers' costs, improved their productivity, improved market access/returns, or reduced risks in these three areas, *relative to otherwise*
- Adoption — what has been industry uptake to date and what can be expected in the future from the R&D investment to date.
- Industry level benefits (net benefits to growers given adoption levels, measured as real 2015 Net Present Values).

Findings

Flavour

The 'flavour' projects covered selected flavour and aroma R&D undertaken by the CSIRO, AWRI the University of Western Australia and the CRC Viticulture between 1999 and 2010. Taken together the investment can be broadly described as being both of an applied (direct) benefit and strategic benefit.

A prime focus has been upon developing an analytical base for better assessing flavours and aromas and enabling growers and more particularly wineries to address specific taint issues through identification of specific taints as well as taking steps to address the issue. This has enabled 'tactical' responses during a vintage. The R&D investment has delivered:

- capability in research and analysis
- analytical tools
- targeted future research directions (ie a focus for future R&D)

- some, but limited, specific management recommendations for grape growers/winemakers.

Using the CRC for Viticulture and Econsearch approaches to assessing the benefits of the R&D investment in AWRI, the industry benefits have been estimated given the success of the R&D in delivering analytical techniques and updating the earlier analysis to reflect 2015 data. The principal areas of benefit are improved management strategies to address Halophenol taint; Brett taint and Smoke Taint.

The potential industry benefits arising from the better understanding of flavours and aromas are both cost savings (for example, avoiding processing wine that has a significant adverse taint) and potential revenue increases. The estimated benefits are a minimum since a range of other benefits have not been included.

The investment returns are summarised in Table 1.

Table 1: Investment in flavour R&D: Investment analysis (2015 NPV, 5% discount rate)

Benefits ($m)	$370
Costs ($m)	$38
Net Benefits ($m)	$332
B/C	10
IRR	33%

Refrigeration

Two AWRI projects addressing winery refrigeration efficiency were analysed. The R&D produced a spreadsheet based calculator enabling wineries to assess the cost savings from addressing a range of energy uses; cases studies to demonstrate the scope of cost savings and, regional nodes to promote the calculators and provide local access to technical support.

The investment return based on the case study cost savings and a conservative adoption scenario is summarised in Table 2.

Table 2: Investment in refrigeration R&D: Investment analysis (2015 NPV, 5% discount rate)

Present value of benefits	$m	$0.84
Present value of R&D costs	$m	$0.53
Net Present Value	$m	$0.31
Benefit/cost ratio		1.6
Internal Rate of Return	%	12%

Trunk disease

Wine Australia identified five trunk disease projects for analysis, primarily focussed on petri and eutypa diagnosis and management. Benefits were quantified for eutypa.

The AGWA R&D eutypa projects, through identifying and promoting better management and control, potentially improves vine vigour, avoids production losses and vine deaths and, reduces control costs.

Using probable future disease incidence, vineyard area and prices at the regional level, the benefits from increased adoption of control and remediation measures were estimated.

Table 3: Investment analysis: Eutypa R&D projects: Investment analysis (2015 NPV, 5% discount rate)

Present value of benefits	$m	$28.5
Present value of R&D costs	$m	$3.7
Net Present Value	$m	$24.8
Benefit/cost ratio	ratio	8
Internal Rate of Return	%	24%

Vine nutrition and management

The four projects analysed focussed on nitrogen management and multi-seasonal issues of heat stress and berry development. Outputs from the projects comprised workshops, field days, advisory material and reports produced during the projects and on completion with subsequent material incorporating the R&D findings. Information arising from the R&D has been incorporated in viticulture training and teaching.

In the absence of adoption data suggesting changes in grower management, scenarios of possible adoption were developed. Impacts in terms of cost savings, yield and quality improvements were examined. Possible environmental benefits were noted.

The investment analysis is summarised in Table 4.

Table 4: Investment analysis: Vine nutrition and management (2015 NPV, 5% discount rate)

	Total investment	Wine Australia investment
Benefits ($m)	$60	$60
Costs ($m)	$7	$7
Net Benefits ($m)	$53	$53
B/C	9.1	9.1
IRR	40%	40%

Return on investment

The estimated benefits and costs of the Wine Australia (and more particularly its predecessors, GWRDC and AGWA) show that the returns on the grower, Commonwealth Government and co-investor monies have been significant.

In all four areas the Net Benefits are highly positive with both the B/C ratios above 1 and the Internal Rates of Return well in excess of 5% (the discount rate used).

Issues

The analysis highlighted several challenges which are common across most benefit cost studies in the rural sector.

Limited data on the extent of a problem and its economic consequences. While data were available for some diseases, this was typically historical. In the absence of indicative data it is difficult to establish a baseline, develop the otherwise case and postulate the extent to which R&D or other factors have contributed to a change in disease status or addressing production losses/values.

Adoption. Wine Australia's R&D typically addresses improving management options for growers/winemakers. Typically then there are no overall indicators of the extent to which management has changed and the proportion of production that is impacted. Wine Australia

(under GWRDC) has outlined that project design will be different into the future and out of that there will be better data to some degree.

> *In the future, GWRDC (Wine Australia) will place an even stronger emphasis on extension and adoption of R&D. This will involve consideration of extension and adoption of R&D from the initial project design through to completion of the project. A combination of existing and new extension and adoption strategies will be used to support the delivery of GWRDC investment outputs and to help achieve best practice.*
>
> *The value of GWRDC's investments is only truly realised when R&D outcomes are taken up and effectively implemented.*[1]

However, more up front and within project attention to adoption issues and strategies will not address the information gap of what is happening within industry once the R&D is completed. That too leaves a gap as to the lessons learned and implications for future project design.

For the present analysis it has meant that adoption has had to be treated using scenarios of what might have happened and what might happen in the future.

Measuring the more easily measured. For all project areas the quantified benefits are those that were reasonably able to be measured/estimated. Some within industry benefits were not able to be measured and for some projects there were off site/other industry benefits which were not measured (such as broader environmental benefits). The resulting analysis is therefore conservative.

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1 GWRDC, *Adoption Strategies Discussion Paper*, 2012.

2. Background

Context

Wine Australia commissioned IDA Economics Pty Ltd to undertake an ex post cost benefit study of a range of selected projects funded by the Grape and Wine R&D Corporation GWRDC)/Australian Grape and Wine Authority (AGWA)/Wine Australia. For the purposes of this report all project funding by GWRDC and AWGA is referred to as funding by Wine Australia.

Four areas were identified:

- Flavour
- Refrigeration
- Trunk disease
- Nutrition.

Wine Australia nominated 17 projects to be assessed. The projects and key financial details are shown in Table 5. The total investment (simple total, nominal dollars) is around $19.4m (45% funded by GWRDC/AGWA) – the total in real present value terms is much larger and is reported for the respective project areas).

The degree of sophistication in BCA essentially comes down to the availability of key data or the ability to make reasonable credible estimates based on available data and judgments. The key data issues (typically) are:

- R&D investment — (GWRDC/AGWA/Wine Australia), co-investor and grower in kind
- Implementation costs —cost incurred by growers or others in adopting the R&D findings
- Net benefits to growers — how has the R&D (when adopted) reduced growers' costs, improved their productivity, improved market access/returns, or reduced risks in these three areas, *relative to otherwise*
- Adoption — what has been industry uptake to date and what can be expected in the future from the R&D investment to date.

Table 5: Selected projects for analysis: By program area

ProjectNo	ProjectTitle	Research Organisation
Flavour		
CSP 05/04	Vines to wine - linking fruit quality to wine flavour and aroma (CSIRO Flagship)	CSIRO Plant Industry
CSP 0905	Understanding and managing the timing of berry ripening and the flavour-ripe/sugar-ripe nexus	CSIRO Plant Industry
AWRI 06-01 stream 1.1	Defining and controlling important volatile compounds in wine and their impact on wine aroma and flavour	The Australian Wine Research Institute
UWA 04/01	Environment, site and selected management influences on the composition and sensory characteristics of Chardonnay growing in selected sites within a coastal, cool Mediterranean climatic region	The University of Western Australia
CRV 6AWR	Viticultural control of flavour compounds in wine	Cooperative Research Centre for Viticulture
Refrigeration		
AWR 0902	Improving Winery Refrigeration Efficiency	The Australian Wine Research Institute
AWR 1306	project 4.3.1: Node project at Griffith	The Australian Wine Research Institute
Trunk disease		
CRV 99/12	Managing grapevine trunk diseases (Black goo decline, esca, Eutypa dieback and others) that threatens the sustainability of Australian viticulture (2.2.1) - NO FINAL REPORT - continued as CRV 99/12N	Cooperative Research Centre for Viticulture
CRV 99/12N	Managing grapevine trunk diseases (Petri disease, esca, eutypa dieback and others) that threaten the sustainability of Australian viticulture (CRV 2.2.1)	The University of Adelaide
CRV 03/06S	Diagnosis and management of Eutypa dieback (CRV 2.2.4)	The University of Adelaide
SAR 06/01	Sustaining grapevines infected with eutypa dieback	South Australian Research and Development Institute
GWR IN0905	Eutypa dieback management	South Australian Research and Development Institute
SAR 1001	Optimising management of eutypa dieback	South Australian Research and Development Institute
Nutrition		
CRV 99/19b	Grapevine nutrition : Research to Practice (4.4.3)	Cooperative Research Centre for Viticulture
GWR IN1108	Post-harvest care of vines: irrigation and nutrition	Charles Sturt University
NWG 0601	Winegrowing Futures - Theme 3 - Mulitseasonal impacts on vine productivity and grape composition	National Wine Grape Industry Centre
NWG 0601	Winegrowing Futures - Theme 4 - Optimising resource use and protecting the environment Exp. 4.5 - Grapevine nutrient reserves and their impact on grape yield variability and yield estimation	National Wine Grape Industry Centre

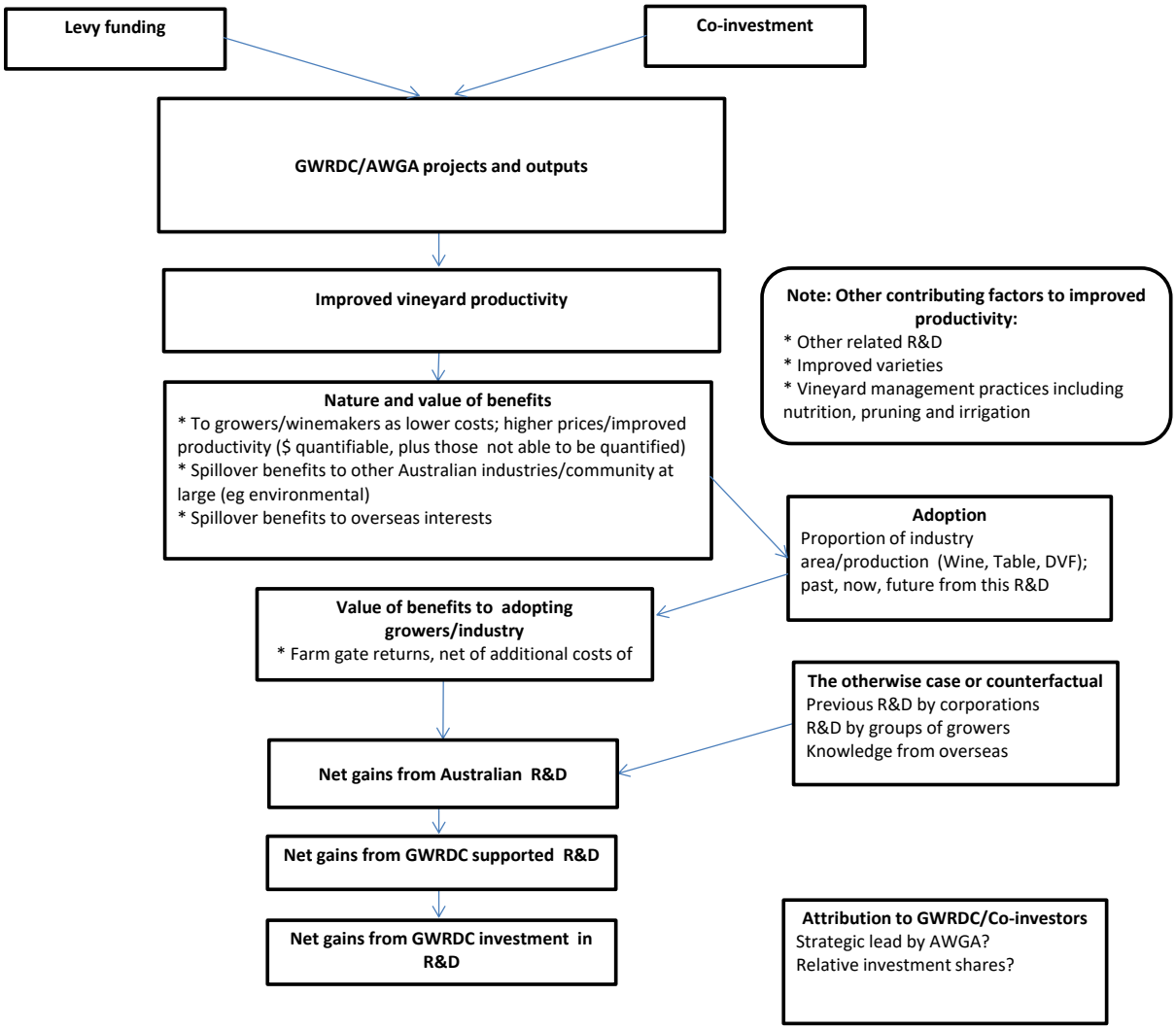
Source: Wine Australia

Analytical approach

The analytical approach used in the analysis follows the methodology outlined by the Council of Rural Research and Development Corporation Chairs (see CRRDCC, *Guidelines for Evaluation*[2]).

A summary of the approach is presented in Figure 1.

Figure 1: Ex post Cost benefit analysis: Summary of approach



The specific questions within the approach, albeit generalised, are presented in Table 6.

[2] http://www.ruralrdc.com.au

Table 6: Issues and approach: Ex post cost benefit analysis

Issue	Notes
R&D Investment: AGWA and others (real, 2014 present value terms, 5% discount rate)	GWRDC/AGWA R&D investment
	Grower/Winemaker/distributor co-investment (in kind, cash).
	Other agency co-investment (eg research organisation, CSIRO, AWRI)
Rationale for AGWA investment	Stated rationale for AGWA investment
Ex ante and other Benefit Cost Analysis (BCA)?	Any BCA or summary evaluation prior to commencing the investment - either originally or in subsequent years. Brief literature review of previous Australian studies and overseas studies
R&D outputs	What did the R&D produce: eg information, decision tools
Benefit (profit change) to winemakers/growers	How did growers winemakers/growers benefit - lower operating costs (eg disease control, lower fertiliser costs through targetting/timing of applications, lower winemaker electricity costs); higher prices (less discount for off flavour/taint); improved productivity (longer vine life/higher yields)
Adoption pathway	How were the R&D findings communicated to growers/wine makers (to date) and what is planned. Has he information impacted upon teaching?
Observed effect on the industry	Typically it is difficult to observe an industry level effect. For example, lower losses in new planting due to better disease control in planting material or lower electricity cost across the industry. Hence a bottoms up approach is used - gains for average/representative grower/winemaker, adoption overtime.
Counterfactual: The otherwise case without GWRDC/AGWA investment	Would growers/wine makers made the same changes without industry level investment? Where would they have gained the knowledge/supporting information/advice?
How long will the benefits last	If not addressed above, for how long will the benefits last before the information becomes redundant (disease issues addressed by other strategies) or superseded by new information
Investment analysis	
	Present value of the benefits (real 2015 values): industry benefits over and above the counterfactual
	Present value of the costs (R&D investment) (real 2015 values)
	Present value of the net benefits (real 2015 values)
	Benefit cost ratio (PV Benefits/PV costs)
	Internal Rate of Return (Discount rate which results in present value of net benefits of zero)
Attribution to AGWA	Proportion of net returns to R&D that can be attributed to AGWA involvement. Base case: relative funds contribution.
Other benefits to growers/winemakers that have not been quantified	Unquantified benefits (eg enhanced industry capability to respond to disease incident)
Benefits outside of the Australian wine industry	Eg spillover benefits to other Australian horticulture (eg use of information with respect to nutrient management, flavour management). Benefits to wider community, eg. reduced nutrient leaching adversely impacting on producers in other industries. Benefits to overseas interests (growers/winemakers)

3. Flavour

Projects

Wine Australia has identified five projects focussed on flavour for analysis.

- CSP 05/04: Vines to wine - linking fruit quality to wine flavour and aroma (CSIRO Flagship)
- CSP 0905:Understanding and managing the timing of berry ripening and the flavour-ripe/sugar-ripe nexus
- AWRI 06-01 stream 1.1: Defining and controlling important volatile compounds in wine and their impact on wine aroma and flavour
- UWA 04/01: Environment, site and selected management influences on the composition and sensory characteristics of Chardonnay growing in selected sites within a coastal, cool Mediterranean climatic region
- CRV 6AWR: Viticultural control of flavour compounds in wine.

Investment

The investment in the selected flavour projects is shown in Table 7.

Table 7: R&D investment in selected flavour projects (dollars of the day)

Project	Start	End	Status	Research partner/ co-investor	Total investment	Wine Australia
CSP 05/04	01/12/2005	31/08/2011	Finished	CSIRO Plant Industry	$7,702,180	$3,877,434
CSP 0905	01/01/2010	30/06/2014	Finished	CSIRO Plant Industry	$3,258,707	$1,613,868
AWRI 06-01 stream 1.1	01/07/2006	30/06/2013	Finished	The Australian Wine Research Institute	$10,261,038	$5,130,519
UWA 04/01	01/07/2004	31/12/2008	Finished	The University of Western Australia	$755,500	$200,000
CRV 6AWR	1999	2006	Finished	Cooperative Research Centre for Viticulture	$2,899,829	$479,581
Total					$24,877,254	$11,301,402

Source: Wine Australia

Project summaries

Project: CSP 05/04: Vines to wine - linking fruit quality to wine flavour and aroma CSIRO Flagship program

Context

The future competitiveness of the Australian wine industry will depend on its ability to reliably export a high quality product at reasonable cost and to produce new wine styles suited to changing market needs. Expansion of the industry into new markets will require the generation of a product suited to the new consumers. A major determinant of consumer preference is the flavour and aroma of the wine. However, little is understood of how compounds in the grape berries contribute to the final flavour and aroma characteristics of the wine and how the biophysical environment, within-vineyard variability and management influences flavour development

Aims

To determine the links between grape composition and the volatile compounds and sensory attributes of the resultant wine

Outputs

In broad terms the projects have enhanced the capacity of the industry to manage flavour issues, in terms of identification and some extent vineyard location and within vineyard management of the factors influencing flavour. Further, potentially, this better understanding should enable better marketing of Australian wine through better understanding the flavours that influence consumer choice an relating this back to vineyards and productions systems within the vineyard.

In more specific terms the outputs are as follows.

- Identified a number of grape and wine target compounds that are associated with particular wine sensory attributes
- Developed new methods for investigating the relationship between berry metabolism and wine composition
- Studies into the changes in berry composition during development show that the timing of grape flavour compound accumulation post-veraison is different depending on the class of compound
- Continued to show the potential benefits that could be gained by vineyard mapping and selective harvesting of parcels of grapes
- Demonstrated that irrigation strategies and yield manipulation have the potential to alter the sensory properties of wines produced from grapes within a single vineyard block
- Enhanced the Australian wine industry's capability to conduct research into grape and wine flavour and aroma.

Knowledge transfer

The findings from the projects have been communicated to industry through the following.

- Scientific papers, but more particularly from a broad industry perspective, a non-technical summary provided to industry publications
- Presentations of work in progress and findings at the triennial Wine Industry Technical Conference and Trade Exhibition
- Seminar series at the University Campus
- Briefings to companies as requested as well as responding to individual requested fro information.

Further project outputs have enabled and been utilised in subsequent industry R&D.e.

Outcomes

The projects have identified target compounds and have shown that management of the vineyard can alter wine sensory attributes. However, further practical trials are needed to extend these results to enable generic recommendations to be developed and to test the applicability of methods of volatile measurements on grapes under the hectic conditions at vintage.

The 2011-12 CSIRO Annual Report outlined that under the Food Futures Flagship Roadmap, the Quality Biosensors theme had a near, medium and long term focus. Specifically:

- Short term 1-3 years: Development of test technology, odours predicting grape and wine quality identified.
- Medium term 4-9 years: Biosensor developed and adoption commenced in defence domain. Applications for food safety and quality in development. Flavour potential of wine grapes optimised.
- Long term 10 + years: Develop biosensors and improve current technology to optimise flavour in food and beverage value chain, adding $750 million per annum.

Further, the CSIRO reported that:

> *"the Flagship's development of biosensor technology has progressed, with a US patent lodged for a method that can detect an odour continuously. This will allow instant odour monitoring for applications including disease detection in humans, and safety and quality evaluation throughout the food supply chain"*[3]

CSP09/05 Understanding and managing the timing of berry ripening and the flavour-ripe/sugar-ripe nexus

Abstract

The primary aim of this project was to further our understanding of berry ripening and how its onset and progression are controlled by endogenous plant growth regulators (PGRs). The knowledge gained was used to develop and test methods for manipulating the timing of veraison/harvest using exogenous PGRs in both laboratory and field settings. We have demonstrated the ability to delay ripening and harvest time and increase ripening synchronicity through PGR application while maintaining similar wine sensory properties. In

[3] CSIRO, *Annual Report 2011-12*, Part 2, pg. 20.

addition, experiments were conducted to get a better understanding of the influence of harvest time versus sugar levels on wine flavour/aroma volatiles

Aim

Further understand berry ripening and how its onset and progression are controlled by endogenous plant growth regulators (PGRs). Changes in market requirements and climate have generated new challenges for the grape and wine industries. Grapes of all varieties are ripening earlier in the season leading to 'seasonal compression' (harvesting season is considerably shortened), leading to bottlenecks in grape intake and processing - resulting in wastage, increased costs and reduced wine quality. These issues have been exacerbated by the apparent disconnect between sugar accumulation and the accumulation of flavour and aroma compounds (more rapid sugar accumulation but under-ripe flavour potential).

Summary

The project has considerably enhanced knowledge of berry ripening, demonstrated some of the potential for PGRs in controlling ripening and has made progress towards a practical application of new techniques to usefully manipulate it.

(PGRs) are key signalling molecules that control and coordinate plant development, including grape berry ripening. This makes them ideal targets for altering ripening in a global manner.

Progress in understanding the metabolism and action of a number of key PGRs, control of the initiation of grape berry ripening, (major determining factor in harvest timing).

The project concentrated on PGRs and timing of ripening initiation.

- Endogenous auxins delay ripening and can also be applied to fruit to delay its ripening. New tools have been developed to study the effects of auxins, which have led to the possibility of novel fit for purpose synthetic versions.
- Ethylene (involved in the control of ripening in a range of fruit) has shown that it can be used to delay ripening if applied at the appropriate time. Ethylene also interacts with auxins and so knowledge of its action is required to better tailor any manipulation of ripening.
- Aminoethoxyvinylglycine (AVG) inhibits both ethylene and auxin production and has the potential to significantly advance ripening.
- Scientific evidence regarding the relative influence of berry harvest date and sugar content on wine volatile composition has been produced -- while many flavour/aroma metabolites with a positive influence on wine style are related to sugar content, some with negative effects require time to decrease. Thus extending hang time may not improve the positive aspects of wine flavour but will reduce the concentration of negative flavours.

These scientific outcomes have been applied under commercial vineyard conditions to develop new ways of managing berry growth and ripening.

- Substantial and predictable delays in ripening, and therefore harvest, have been demonstrated in both white and red wine cultivars in different vineyards, under different climates during a number of seasons using a range of different auxins.
- Apart from delaying harvest, other benefits have included an increase in the synchronicity of berry ripening. Wine metabolite levels, and in some cases sensory properties, have been significantly altered but these changes were not dramatic and

may simply reflect the delayed fruit ripening later in the year under slightly different climatic conditions.

AWRI 06-01 Stream 1.1: Australian Wine Research Institute: Defining and controlling important volatile compounds in wine and their impact on wine aroma and flavour

Summary, AWRI Annual Report 2010

AWRI's research targets aromas and flavours responsible for important varietal and bottle-age characters, and characters associated with oak, wine microorganisms, and oxidation, as well as taints, 'off-flavours', 'reduced', and 'green' characters. Our objectives are to determine the chemical nature of hitherto unrecognised important volatile wine components; enhance our understanding of the relationship between wine composition and sensory properties; develop analytical methods for important wine components and their precursors; and determine the effect of viticultural and oenological techniques and wine storage conditions on the formation and fate of these compounds. Characterising key compounds of the aroma and flavour in unique Australian wine styles remains a priority, with activity in a number of topical areas of research. On an on-going basis, lead compounds are being identified, and measurement capability is being developed for varietal and fermentative aromas which contribute to mint, spice, tropical and berry characters in Australian wines. We also aim to identify new compounds which impact on wine aroma. Methods for analysis of sulfur compounds and precursors are being investigated, including application of methods to determine the impact of a number of sulfur compounds on reductive characters or off-flavours in wine. The capacity to react quickly to assess taint and fault issues is continually being strengthened, with synthetic and analytical chemistry playing key roles in providing resolution of these unforeseen events.

Eucalyptol

From our thorough investigations we have gained strong evidence that the majority of eucalyptol present in Australian red wine is derived from eucalyptus trees grown in close proximity to vineyards. This confirms the anecdotal evidence surrounding this wine aroma and flavour compound. We have determined that wine eucalyptol concentrations are affected by normal red wine fermentation conditions; the distance of grapevines to Eucalyptus trees; and potentially the level of MOG included in a ferment. Wine eucalyptol concentrations are relatively unaffected by the presence of two terpenoid precursors; the type of closure used; and storage conditions, at least up to 12 months, and probably beyond.

Varietal thiol precursor studies

Along with other analytical methods being developed for free thiol analysis, AWRI ultimately hope to optimise precursor formation and selective release and relate fruit composition and varietal characters to the corresponding grape and wine chemistry.

Unravelling yeast metabolism of varietal thiols

AWRI has continued to investigate yeast genes that encode carbon-sulfur β-lyase enzymes. Previous studies, using strains with single gene deletions, suggested that several genes may be responsible for the release of varietal thiols. Until each gene has been investigated, the thiol-releasing capabilities of yeast strains under winemaking conditions will remain difficult to predict. By placing genes encoding two putative thiol-releasing enzymes (Str3p and Irc7p) under the control of a strong promoter (i.e. by ensuring that these enzymes are present in the

yeast at all times and in higher than 'normal' concentrations) we have observed enhanced 3MH release during fermentation of Sauvignon Blanc.

Overview

The AWRI final report notes that:

> *"The results of this research stream have greatly increased our knowledge of the main volatile compounds involved in wine flavour… While there are several key sensory attributes of wines where the cause is still not known, the work in this stream has given producers unprecedented ability to avoid off-flavours and taints while controlling positive flavours (pg. 2).*

The AWRI website notes the implications of the research for producers in the following terms.

- Understanding the eucalyptus/mint compound 1,8-cineole (eucalyptol). Two publications and the implications for producers have been highlighted as "producers now have the option of simple practices to adjust this aroma in their wines, by ensuring, for example, that rows close to *Eucalyptus* trees are harvested separately, and that those grape-lots, and those with MOG, are kept separate during processing. Harvester settings can also be adjusted to minimise MOG, or rows closest to trees can be hand-harvested in order to reduce MOG" [4]
- In the general area of identifying key aroma compounds in Shiraz grapes and wine, the AWRI notes that, "Tools have been developed which allow producers to alter the level of the pepper compound, rotundone, in wines, through skin contact and harvest time. Information regarding differences in sensitivities among people, including winemakers, to rotundone has been elucidated. This enables industry trials to be supported which aim to improve viticultural management of rotundone concentrations by targeting individual vineyards, sections of vineyards and clonal selection" [5]
- Studies on 'tropical fruit' thiols and precursors have shown that "storage of crushed grapes post-harvest, whether through transport in harvester bins or cold storage was found to give a very large increase in concentrations of the precursors, providing a practical means of enhancing levels in wines, with smaller differences related to level of sulfur dioxide or ascorbic acid addition"[6]

Project: UWA 04/01: University of Western Australia: Environment, Management and Compositional Quality of Fruit and Wine of the grape cv "Chardonnay'

Aim

A research project was undertaken to evaluate site variation in the Margaret River region and its impact on sensory attributes of Chardonnay wine made from the fruit of the clone

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4 http://www.awri.com.au/research_and_development/research-topics/wine_aroma_and_flavour/18-cineole-eucalyptol-in-commercial-australian-wine/

5 http://www.awri.com.au/research_and_development/research-topics/wine_aroma_and_flavour/identification-of-key-aroma-compounds-in-shiraz-grapes-and-wine/

6 http://www.awri.com.au/research_and_development/research-topics/wine_aroma_and_flavour/analysis-of-wine-thiols-and-precursors/

'Gingin'. Eleven sites were evaluated spanning the latitudinal range of the region and its soils over the period from 2004 to 2007.

Findings and recommendations

The project has identified issues for further research, some of which is being undertaken in the on-going evaluation of the data.

1. There appears to be a strong influence of location (management?) on fermentation performance which is not related to nitrogen nutrition or technical aspects of the fermentation as we practiced it.
2. A new approach to 'ground-truthing' remotely sensed biomass has been proposed. Evaluation of this is on-going but should provide a method for relating individual vine biomass to remotely sensed imagery values (PCD or soil and land form).
3. Three site factors were shown to be well related to vine biomass for three of the sites: elevation (-ve); radiometric count (+ve) and depth to hardpan (SAV) (+ve). Work is on-going to complete these analyses for the remaining sites.
4. Trunk diameter is proposed as a simple system for estimating vine biomass variation within particular sites. Cane cross section also provides a useful, non-destructive way of estimating leaf area though pruning weight may also be used though this measure is more site specific. It is likely that both measures will need independent calibration for particular cultivars.
5. The modelling approach developed for mapping climate is being applied to other regions within WA and prospectively could be a useful tool for all regions, minimising the need for individual weather stations. The techniques has been used to model climate for Margaret River under a climate change regime and work is in progress to model the prospective impact on vine phenology and wine quality.
6. In the years of vine-monitoring there was evidence of a general increase in vine biomass and for rigid vine management, rather than adaptive management leading to vines pruned sub-optimally and to reduced functional fertility. Improved training for farm hands could lead to more optimal pruning that takes account of within block variation and to higher levels of flower initiation which in a few instances was seriously low. In no instance was the average flower initiation at optimal levels though it was close to that in some vineyards.

Conclusion

This study showed that vineyard origin has an effect on wine sensory properties, with some vineyards giving rise to wines with distinctive sensory properties. However, winemaking variability apparently associated with site rather than technical factors gave rise to differences in the vines that were as large as the vineyard effect in some cases, casting some doubt on conclusions that can be drawn regarding wines produced from several vineyards. Resolution of the factors, whether biological or technical that caused this variation is a pre-requisite to undertaking rigorous comparisons of sites in a study such as this. Project: CRV 6AWR: Cooperative Research Centre for Viticulture: Viticultural control of flavour compounds in wine

Aim

To gain information on the impact of grape-derived volatiles on wine flavour, the identity and chemical nature of compound(s) responsible for black pepper aroma in Shiraz wines and develop a precise, relatively simple analytical method for key grape derived wine flavour compounds developed and communicated to enable future research on viticultural and oenological controls of flavour formation.

Executive Summary

Aim to have rapid and accurate analytical methods for determining 95% of known important flavour compounds in wine, as well as methods to determine at least several flavour precursors in grapes. So far, rapid and accurate analytical methods have been developed for more than fifty volatile wine components that are likely to be important to wine aroma and flavour. Of these compounds, 48 are derived directly or indirectly from the grape. Development of analytical methods for wine lactone, two grape-derived wine lactone precursors, three important grape derived thiols (mercaptans) which confer various fruit characters to a wide range of wines, and several grape-derived precursors for important volatile wine phenols is in progress A hitherto unknown wine flavour compound, derived from grape glycoconjugates, has been identified as 2,3,6-trimethylbutadiene (TPB). The threshold of TPB in a white wine was determined to be 40 ng/L. This makes it one of the post potent wine flavour compounds known. TPB was most commonly found in Semillon, and to a lesser extent, Chardonnay wines.

A sensory descriptive analysis study on a set of 20 commercial Riesling wines and 20 one to two-year old commercial unwooded Chardonnay wines has been completed. The data set should enable insights to be made into the relationships between the concentration of particular volatile compounds and the intensity of Riesling and Chardonnay wine flavour attributes once all chemical analyses have been completed. Several potential damascenone precursors have been synthesised and all of these give damascenone in high yield and extremely rapidly.

These findings led the researchers to re-evaluate the mechanism by which damascenone is formed in young wine. The information obtained from this work will be used to devise methods for measuring the damascenone potential of grapes. Similarly, the researchers intend to use the sulphur compounds to develop methods for measuring this aspect of flavour potential in grapes.

Project status

The Interim Final Report (*Viticultural control of flavour compounds in wine*) dated 15 November 2003 reported work in progress and the findings to that point. The Wine Australia website reports that the project was completed 30 June 2006. The Interim report is listed as the Final Report.

Project CRV 6AWR aimed to have rapid and accurate analytical methods for determining 95% of known important flavour compounds in wine. Rapid and accurate analytical methods were developed for more than fifty volatile wine components that are likely to be important to wine aroma and flavour.

R&D outputs: Summary of R&D project findings

The outcomes from project CSP 05/04 suggest that significant capability has been established that will enable improved management of flavours through advanced in vineyard

management. While the project concludes that further R&D is required to enable generic recommendations, it is probable that individual winemakers have begun to use the information generated to date to alter their vineyard management as well as look to develop market niches through having greater confidence as to the basis of the flavours.

Project CSP 09/05 focussed on better understanding endogenous plant growth regulators as a means of manipulating veraison/harvest. One of the potential benefits from this work would be dealing with compressed vintages- growers could slow down or enhance ripening to better fit into harvesting schedules without impacting on wine quality- this would avoid wineries having to purchase more processing capacity. It is probable that winemakers are individually assessing the associated financial aspects as a compressed harvest is a very likely consequence of climate change: everything ripening at the same time means wineries have to have more 'processing capacity' – tanks and crushers.

A key emphasis of AWRI 06-01 Stream 1.1 has been characterising key compounds of the aroma and flavour that delivers unique Australian wine styles. The recognition that grape leaves can act as a source of flavour has been identified as an area 'worthy' of further study (not previously recognised, at least in respect of eucalyptus), along with other issues, for example, the potential for targeting thiol precursors as a quality measure of the tropical flavour potential in grapes. Measurement capability is being developed. Increased capability in these areas enables a faster response to situations which may present marketing opportunities or problems (for example, smoke taint). Capability development is the main outcome at present. That said, the analysis of eucalyptol present in Australian red wine has led to better managing the location of vineyards relative to Eucalyptus trees and in harvesting programs. Further, tools have been developed which allow producers to alter the level of the pepper compound, rotundone, in wines, through skin contact and harvest time. Studies on 'tropical fruit' thiols and precursors have shown that storage systems of crushed grapes post-harvest have a major effect on concentrations of the precursors.

Project UWA 04/01 showed that vineyard origin has an effect on wine sensory properties. However, winemaking variability apparently associated with site rather than technical factors gave rise to differences in the wines that were as large as the vineyard effect in some cases, casting some doubt on conclusions that can be drawn regarding wines produced from several vineyards. Resolution of the factors, whether biological or technical, that cause variation was identified as a pre-requisite to undertaking rigorous comparisons of sites.

Project CRV 6AWR aimed to have rapid and accurate analytical methods for determining 95% of known important flavour compounds in wine. Rapid and accurate analytical methods were developed for more than fifty volatile wine components that are likely to be important to wine aroma and flavour. Significantly a hitherto unknown wine flavour compound, was identified. The threshold of TPB in a white wine was determined to be 40 ng/L. This makes it one of the post potent wine flavour compounds known. TPB was most commonly found in Semillon, and to a lesser extent, Chardonnay wines.

Ex ante and other benefit cost studies

CRC for Viticulture ex ante analysis

The CRC for Viticulture undertook an ex ante analysis of a range of projects funded by GWRDC under the 7 year R&D Plan 2006. [7] The projects examined included the *Research program 1: Stream 1.1 Flavour*. Analysis of the Program outlined the following.

- Input: 8 full time staff, plus in-kind support from wine companies. Investment estimated at $9.7m ($2006)
- Key activities: Discovery of key wine flavours
- Outputs: Knowledge of key compounds responsible for Shiraz flavour, eucalypt flavour, tropical fruit flavour as well as smoke taint.
- Usage: Wine producers and grape growers to enable changes in production practices to enhance or reduce key flavours. Research results to be disseminated through publications, AWRI extension activities. "Selection of clones for new vineyards, negligible cost, established vineyard regrafting a substantial cost but may change from undesired variety to Shiraz. Changes to leaf removal, shoot thinning practices or whole bunch ferment should not require additional effort or cost. Monitoring costs $150 per sample. Potential users = 8% of total crush (cool climate 40%, Shiraz 20%); average sample rate 1 per 400 tonne = $48,000 pa". 90% likelihood that research delivers these outputs to enable usage; 20% probability of usage, given the outputs are generated.
- Impacts: "Smoke diagnostic assays are used to assess whether grapes are suitable for harvest. Savings: harvesting, transport, winery operating, storage and bottling of tainted wines. Reject of clean grapes. Assume smoke impacts 5% of the total crush each year, 80,000 tonnes. In 2006 due to limitations of analytical technology 15% wrongly accepted and 15% wrongly rejected = $34 million tainted wine (3.57$/L) and $12 Million wasted grapes (1000 $/tonne)" Probability of usage occurring, 90%; probability of monetary impacts occurring, 85%
- Expected benefits $294m against expected costs of $9.45m; B/C ratio of 31.

AWRI ex post analysis: Econsearch assessment

AWRI's submission to the Review of the GWRDC-AWRI Investment Agreement 2006-2013[8] summarised independent analysis undertaken by Econsearch (commissioned by AWRI) of "the industry impact of the resolution and avoidance of selected, common taints and faults through the AWRI's activities". The analysis showed that the AWRI activities resulted in a NPV value of $264m on an incremental RD&E investment of $8.6m, comprising:

- *Brettanomyces* management and avoidance ($49m on an RD&E investment of $3.2m)

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7 7 Year RD&E Plan 2006, GWRDC Impact Assessment V2, Excel spreadsheet, undated

8 AWRI submission to the Review of the GWRDC-AWRI Investment Agreement 2006-2013, DRAFT, April 2012.

- halophenol taint mitigation and avoidance ($124m benefits on an RD&E investment of $1.5m)
- smoke taints mitigation and avoidance ($41m benefits on an RD&E investment of $1.5m) and
- general help-desk services ($50m benefits on an RD&E investment of $1.5m).[9]

The Econsearch analysis[10] covers, *inter alia*, cost benefit analyses for AWRI's problem solving capacity" through the AWRI Help Desk and cost benefit analysis of case studies halophenol taint; Brett taint; smoke taint with reported benefits and investment values (as reported above). The analysis applied the standard cost benefit framework (changes in activity compared to a counterfactual; investment return reported as Net Present Value in real 2011 dollars, using a 5% discount rate and 30 year time frame, beginning 2006-07). In summary, the approach adopted to estimate the benefits in each area was as follows.

- Based on a survey of users of the AWRI help desk the benefits were estimated for avoided winery costs and avoided impact to brand. NPV $50m (2011dollars).
- The halopenol case study outlined (and quantifies) the benefits in terms of avoided lost wine sales; avoided wine disposal; avoided dispute resolution costs and reduced equipment replacement costs. NPV of $124m (2011 dollars).
- The Brett case study identified benefits from avoided losses from downgraded wine and reduced winery management costs. NPV $42m (2011 dollars).
- The smoke taint case study detailed the basis of the estimated benefits as avoided losses from downgraded wine and management costs, and reduced testing costs. Industry consultations had suggested that the primary benefit of the AWRI technology (for assessing smoke taint) was that it allowed discrimination between 'good' and 'bad' grapes, before they were harvested and thus allowing a reduction in 'wasted' processing costs. The AWRI involvement was estimated to have brought forward by seven years the capacity to identify and deal with smoke taint (before grapes were harvested). NPV $41m (2011 dollars).
- Nonetheless the specific data estimates (for example % of crop impacted; % losses; $/t cost savings) were not presented in the analysis. This is in contrast to the CRC Impact Analysis which had spelled out the basis of the estimated expected benefits.

Two issues for the present ex post analysis are:

- whether the ex ante CRC Impact assessment and more particularly the ex post Econsearch analysis (undertaken in 2012) are applicable in a 2015 ex post context; and
- the extent of benefits from the other GWRDC flavour focussed R&D investments, specifically, the projects outside of the AWRI.

With respect to the Econsearch analysis, its 2012 analysis remains applicable today. That is, given the basis of the analysis, whether undertaking the same detailed analysis today would show the nature and extent of the benefits to be much the same (Table 8). However, for

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9 *ibid*, pgs 4-5.

10 Econsearch, Economic analysis of AWRI Projects and Activities: AWRI Problem Solving Capability, Final Report, Report prepared for AWRI, May, 2012.

purposes of comparability with the other ex post studies, the Econsearch estimated benefits and costs need to be converted from real 2011 present value dollars to 2015 real present value dollars.

Further, consideration has to be given to the level of investment in the AWRI projects.

- The Econsearch analysis uses total investment in the AWRI (GWRDC as well as AWRI investment). The investment includes monies invested from 1998-99 onwards (for Brett taint). Including all the monies invested in the project is appropriate.
- The Wine Australia project list supplied for the present analysis only lists the investment in AWRI 06-01 stream 1.1 (1 July 2006 to 30 June 2013) (totalling $10.3m total investment with $5.1m sourced from GWRDC, 'simple' arithmetic totals).
- The Econsearch estimates of the GWRDC investment (2007 to 2013), which includes the helpdesk were totalled at $7.2m, and $4.3m excluding the help desk, (simple arithmetic totals). The Econsearch assessment reported minimal collaborator investment.
- Thus, overall the Econsearch analysis has likely underestimated the total investment in the AWRI project 06-01 stream 1.1.

Table 8: Econsearch 2012 benefit analysis: AWRI flavour projects: Applicability for 2015 analysis

Project area	Main benefit	$ Value of main benefits ($m PV	Key factors	RD&E and implementation	Benefit approach/value in 2015
AWRI help desk	Avoided winery costs	$39.00	Bringing forward problem solving	$3.40	Applicable; no change in AWRI role; counterfactual or major change in underlying costs/prices
	Avoided impact on brand	$14.30			Applicable; no change in AWRI role; counterfactual or major change in underlying costs/prices
Halophenol Taint	Avoided lost wine sales	$126.50	Contaminants in additives; 2 major events (2005 and 2006); in the absence of AWRI problem unlikely to be recognised	$10.20	Applicable; no change in AWRI role; counterfactual or major change in underlying costs/prices
	Other	$7.90			
Brett Taint	Avoided losses (downgraded wine)	$31.90	Aust. Consumers found to not like 'Bretty character'; cost effective management tools re	$0.80	Applicable; no change in AWRI role; counterfactual or major change in underlying costs/prices
	Reduced winery management costs	$11.00			Applicable; no change in AWRI role; counterfactual or major change in underlying costs/prices
Smoke Taint	Avoiding processing of badly affected grapes; salvaging affected grapes through earlier blending	$38.90	Enabled discrimination between 'good and 'bad' grapes before they were harvested	$1.60	Applicable; no change in AWRI role; counterfactual or major change in underlying costs/prices note difference between with and without AWRI 'diminishes rapidly after 2012' (base tools for developing smoke taint would have been developed)
	Other	$3.60			
		$273.10		$16.00	

The Econsearch analysis of AWRI problem solving capability estimated the benefits to the industry of $273m; R&D and implementation costs of $16m, with a resulting $258m net benefit (all in 2011 dollars). The $7m investment in the 2007 to 2013 period was estimated to generate an NPV of $193m (2011 dollars).

Broadly, the Econsearch estimates are in line with the estimated expected benefits and costs resulting from the CRC Impact analysis ($294m benefits against expected costs of $9.45m), although the latter estimates the benefits over a 15 year period against the Econsearch analysis over 30 years.

Two adjustments are required to report the findings in 2015 dollars – an inflation adjustment (to maintain real value) and a present value adjustment. Rebasing the CRC and the Econsearch analysis to 2015 lifts the dollar value by around 25%. (The major effect is through the interest rate or discounting effect of bringing forward the benefits in earlier years).

Adoption and outcomes

Taken together the investment in these flavour and aroma R&D projects can be broadly described as being both of an applied (direct) benefit and strategic benefit.

A prime focus has been upon developing an analytical base for better assessing flavours and aromas. As the CSIRO researchers note, assessing flavours and aromas is of critical importance for the industry but the analysis of them to date has been primarily subjective. Discussions with CSIRO confirmed that the outcome to this point has been the development of strategic capability.

The AWRI R&D has enable growers and more particularly wineries to address specific taint issues through identification of specific taints as well as taking steps to address the issue. This has enabled 'tactical' responses during a vintage, for example to decide to process or not grapes assessed as having smoke taint. Other analytical testing enables winemakers to identify the causes of taint (for example, Halophenol taint management and avoidance). The winery environment has several possible sources of taint, such as painted surfaces in the cellar, sealants, barrels, oak adjuncts, wood ladders, wooden catwalks, wood pallets, plywood, wooden rafters, wood beams, water, water hoses, wine hoses, plastic tank liners, plastics, insulation, filter pads, fining agents, packaging materials (cardboard, adhesives, and paper bags), cleansers, and sanitizers.

The potential industry benefits arising from the better understanding of flavours and aromas are both cost savings (for example, avoiding processing wine that has a significant adverse taint) and potential revenue increases (for example, being able to recover wine that does not have a taint, when it was suspected of having an adverse taint or recovering wine which has a taint using reverse osmosis[11]). As well, albeit it difficult to identify and/or attribute to the specific R&D projects, there are the market opportunities arising from winemakers' being better able to produce wine to meet consumer choices and differentiate between wines produced.

The R&D investment has delivered:

- capability in research and analysis
- analytical tools
- targeted future research directions (ie a focus for future R&D)

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11 Commercial businesses such as Memstar provide a mobile taint removal service for smoke and Brett taint.

- some, but limited, specific management recommendations for grape growers/winemakers.

The AWRI provides a range of analytical services to the industry, including services specifically addressing taint issues (Table 9).

Table 9: AWRI commercial services

4-Ethylphenol and 4-ethylguaiacol		Ochratoxin A in grapes and wine	
Acid analysis		Physical tests	
pH, titratable acidity, volatile acidity, acetic acid, malic acid, lactic acid, citric acid, tartaric acid, organic acid profile		Bottle pressure, extraction force	
Agrochemical residue analysis		Plasticisers	
Alcohol analysis		Preservatives and antioxidants	
Ethanol, methanol		Sulfur dioxide: free and total, ascorbic/erythorbic acids, sorbic acid	
Allergen residue		Problem indicators	
Brettanomyces bruxellensis		Acetaldehyde, ethyl acetate, ID of tartrate by optical rotation	
Rapid method to test for Brettanomyces bruxellensis		Sensory assessment service	
Dissolved Oxygen and Carbon Dioxide		Sensory certification of wine for common faults and Quality sensory assessment	
Ethyl carbamate		Smoke taint	
Grape and colour analysis		Stability analysis and fining trials	
Red grape colour, tannin, brix, pH, TA YAN		Heat stability, cold stability, bentonite fining	
Low molecular weight sulfur compounds		Sugar analysis and hydrometry	
Metal and anion analysis		Glucose/fructose, sucrose, specific gravity and baumé, total sugar content	
Copper, calcium, iron, potassium, sodium, chloride, sulfate, Manganese		TCA analysis	
Methoxypyrazines		Corks, wines, oak wood	
Microbiological stability		Wine colour and tannin	
Microscopic perusal, pre and post bottling sterility		Wine Taint Fault Vials	
Miscellaneous calculations		Yeast assimilable nitrogen	
Total alcohol, total dry extract, approximate calorie value, sugar free extract		Alpha amino nitrogen, ammonia	
Natamycin		Other analyses	
Oak flavour analysis		Diglucosides, laccase activity, pinking susceptibility	
Wine and wood			

Source: AWRI website

There are other organisations which undertake taint testing and specifically in respect of smoke there is the Smoke Taint Risk calculator (known as STAR) which has been developed by researchers at Department of Agriculture and (Western Australia) and The University of Western Australia.

In respect of smoke taint, there have been various information and advisory activities which have focussed informing growers and winemakers of the challenges but also the analytical techniques available, risk management and mitigation strategies. The AWRI and others have, since 2003, published technical and non-technical papers and advisory bulletins, for example the AWRI 2012 Smoke Taint Symposium[12]. Growers are well aware of taint issues and the association Wine Grape Growers Australia website specifically details "Smoke taint and the legal obligations of wine grape growers".[13]

[12] AWRI, see https://www.awri.com.au/industry_support/victorian-node/smoke-taint-symposium-2012/ and see also http://www.awri.com.au/industry_support/winemaking_resources/smoke-taint/smoke-taint-information-and-ordering-page/

[13] WGGA, see http://wgga.com.au/winegrape-sales/smoke-taint-advice

Quantification

Approach

Using the CRC for Viticulture and Econsearch approaches to assessing the benefits of the R&D investment in AWRI, the industry benefits have been estimated given the success of the R&D in delivering analytical techniques and using 2015 data (specifically recent wine grape prices and winemaker costs) (Table 11).

In the absence of follow up surveys of growers or winemakers this approach was the most practical, albeit it has its limitations since estimates of key parameters are still required. Another alternative seeking to measure the additional industry value created through improved flavour management (and apportion the share attributable to the Wine Australia investment) was not practical given measurement issues for the value of improved flavour management and the range of factors which leads to improving flavour (seasons, winemakers, varieties, vineyard and winery management).

This estimate of the benefits is a minimum since a range of other benefits have not been estimated. These other benefits include the following.

- Wine industry benefits from the AWRI R&D but not included in the above analysis and wine industry benefits past 2025. As well as direct cost savings/revenue gains there is capability development to help address future issues.
- Wine industry benefits from the R&D undertaken by the CSIRO which are more strategic and focus on developing capability. In time, payoffs to industry can be expected.
- Wine industry benefits from Project: UWA 04/01: University of Western Australia: "Environment, Management and Compositional Quality of Fruit and Wine of the Grape cv 'Chardonnay'". The project results were inconclusive re site selection, but the project did identify directions for future research.
- Other Australian food industries which might benefit from the better understanding of flavours and the analytical tools developed where this can be applied to other foods and drinks.
- Overseas grape and wine industries which can apply the knowledge developed in the projects either through public domain access, purchase of intellectual property or contracted services.

Analysis

R&D investment costs

- Expressed in 2015 real, present value terms, the Wine Australia R&D investment totalled $17.2m.
- The total investment (ie including co-funded contributions) is estimated at $38.4 m. (real present values derived from financial and timeframe data presented in Table 7).
- The Wine Australia and total investment in the projects where benefits have been measured was $9.1m and $19.2 m, respectively (ie about half the total).

Counterfactual

- In the absence of the Wine Australia funding, it is unlikely that the main organisations involved would have undertaken the R&D. Without industry financial support, internal support for R&D which primarily benefits the industry is difficult to secure.
- Even though AWRI offers additional commercial services as a result of the R&D, it would have had difficulty making the business case for internal funding.
- It is possible that other, perhaps overseas agencies may have funded additional work in the area but the findings would not necessarily be applicable to Australia or cover the Australian situation.
- It is probable that reinvestment will be required in the future given changes in consumer tastes and/or the potential to discern additional flavours and taints. The benefits from the investment to date have been measured out to 2025.
- In summary, in the absence of industry and taxpayer funding through Wine Australia, the R&D would not have been undertaken and it is unlikely that the analytical tools would have been developed by other industries or commercial interests.

Measured benefits

- As summarised above the benefits are estimated, at a minimum, at $370m (2015 real present value).

Timeframe

- The benefits are estimated to have begun to flow from 2011 onwards given the work undertaken from mid-2000. The adoption scenario outlined in Table 11 is limited adoption across the industry (5% of production in 2011 rising to 10% by 2025) noting though that the applicability across the industry is put at `15% of production.

Investment analysis

- The investment returns are summarised in Table 10.

Table 10: Investment in flavour R&D: Investment analysis

	Total investment	Wine Australia investment
Benefits ($m)	$370	$370
Costs ($m)	$38	$17
Net Benefits ($m)	$332	$353
B/C	10	22
IRR	33%	54%

Conclusion

Wine Australia's investment in flavour related R&D has been significant in financial terms and in terms of the benefits it has delivered/is expected to deliver.

Delineating the benefits of the flavour R&D, and assessing their value to the industry, is not without its challenges especially in the absence of industry level data or case studies of use of the R&D findings and adoption across the industry. Nonetheless, the estimated benefits are substantial and indeed a minimum. Further, the measured benefits from a segment of the

R&D investment have more than covered the whole Wine Australia investment in the flavour area (as defined).

Table 11: Estimated minimum benefits from the investment in flavour R&D

	Previous studies		Current analysis Nature of benefits				Estimated potential applicability (broad regions)	Production from applicable areas		Production impacted by the issue (v)	Production impacted by the R&D (IF adoption estimated to address 5% of the problem in 2015)	Value of annual benefit (2015)	PV of benefits (2005 to 2025; adoption rising from 5% (2011) to 10% (2025) Likely conservative)
AWRI	Previous study: CRC for Viticulture (2011 dollars (i))	Previous study Econsearch $m (2011 dollars (ii))	Cost savings: Nature	Cost savings: Wineries $/litre (iii)	Revenue gains: Nature	Revenue gains: $/tonne grapes; $/litre wine (iv)		m l wine	t wine grapes			$ m	$ m
Brettanomyces management and avoidance		$49		$2.04	Improved management strategies enables product recovery (grapes and wine)	Wineries: $2.04/litre	Primarily SA, Vic, WA, TAS and Hunter NSW	905		5%	0.25%	$5	
Smoke Taint management and avoidance	"In 2006 due to limitations of analytical technology 15% wrongly accepted and 15% wrongly rejected = $48m benefit" Est expected PV over 15 years $267m ($ 2012)	$41	Earlier more reliable assessment (to not process further) avoids subsequent wine making and associated costs (when product value would turn out to be very low)	$2.04	Earlier more reliable assessment (to further process) enables otherwise downgraded grapes/juice/wine to be processed to higher value sale (when otherwise discarded/not harvested); additional processing costs may be involved (eg Reverse Osmosis)	Grape growers $463/t	Primarily, SA, Vic, WA	845	1,150,000	5%	0.25%	$1	
Halophenol taint management and avoidance		$124		$2.04		Wineries: $2.04/litre	All wineries	1,231		5%	0.25%	$6	
General help desk		$50		$2.04		Wineries: $2.04/litre	All wineries	1,231		5%	0.25%	$6	
		$264										$19	$323
Eucalyptol	Avoid downgrading of wine due to excessive or too little eucalyptus flavour by managing inputs to optimize this flavour (vi)												$50
Total above													$373

(i) Ex ante NPV, 2011 dollars 15 years time frame of benefits, 5% real discount rate; probabilities of research success and financial gain

(ii) NPV, 2011 dollars, 30 years timeframe of benefits using 5% real discount rate

(iii) Average cost winemaking $1.95/litre (including grape cost of $0.63/l wine) (2012-13; AgEconPlus 2015, pg. 20); Average price of grapes ($/t into winery) 2017 $482; 2016 $472; 2015 $463; 2014 $441; 2013 $499; 2012 $458; (WFA *Vintage report*, various years and ABARES Outlook 2016). ABARES In 2015 dollars (ie adjusted for inflation using the CPI) these prices equate to $3.04 per litre for winemaking costs and an average $463 /t for wine grapes also noting that ABARES (Outlook, 2016) expects that export wine prices will fall in the medium term given the increased

(iv) The gain to growers (profit) equals the revenue gain since at the winery door all growing costs have been incurred. In some situations costs may be saved on farm, eg some harvesting costs

(v) CRC for Viticulture Impact Assessment 2012

(vi) Avoid downgrading of wine due to excessive or too little eucalyptus flavour by managing inputs to optimize this flavour. Assume 5% of crush (80,000t) affected by excessive eucalyptus flavour, potentially downgraded by $200/t = $16m per year. Also, assume one legal case p.a. say single vineyard 40 ha, 10 tonne/ha, $1000/tonne claims $400,000 revenue gain. Est. expected PV $5m (given 10% likelihood of success; with subsequent success PV benefit of around $50m benefit.

4. Refrigeration

Projects

Wine Australia identified two projects for benefit cost analysis:

- AWR 0902: Improving Winery Refrigeration Efficiency
- AWR 1306 : Project 4.3.1: Node project at Griffith

Investment

The investment in the selected refrigeration projects is shown in (Table 12).

Table 12: Investment in selected refrigeration projects (dollars of the day)

Project	Start	Finish	Status	Research agency	Total investment	Wine Australia
AWR 0902	01/03/2010	30/06/2012	Finished	AWRI	$263,000	$212,250
AWR 1306	01/11/2013	30/06/2014	Finished	AWRI	$154,141	$154,141
					$417,141	$366,391

Source: Wine Australia

Project summaries

Project summary: Project: AWR 0902: Australian Wine Research Institute: Improving Winery Refrigeration Efficiency

Aim

Refrigeration is a critical operation for quality Australian wine production. It is also the largest consumer of electricity in many Australian wineries. This project aimed to help wineries decrease electricity use and/or costs associated with refrigeration. A succinct reference guide was produced that provides an overview of winery refrigeration and opportunities for improvement. (The AWRI Refrigeration Demand Calculator is a spreadsheet-based software tool, for analysing and managing winery refrigeration demand.)

Case studies investigating selected opportunities/topics were also completed.

The reference guide and detailed technical reports on the case studies are available for download from the websites of The Grape and Wine Research and Development Corporation and The Australian Wine Research Institute.

Summary

Refrigeration accounts for as much as 50%-70% of winery electricity consumption. Electricity costs are rising and there is considerable interest in decreasing refrigeration-related electricity use and/or costs. Wine Australia funded a project by the Commercial Services group at the Australian Wine Research Institute (AWRI) to investigate how Australian wineries can improve refrigeration efficiency.

This project has successfully produced resources that can be used by wine companies to understand and improve winery refrigeration efficiency. These resources will remain on the Wine Australia and AWRI websites. The reference guide (Appendix 3) should be referred to

by wineries looking to understand and improve winery refrigeration as it provides a succinct coverage of the topic.

Project summary: AWRI 4.3.1: Australian Wine Research Institute: Riverina, Tasmania and Hunter Valley nodes

Abstract

Australia is a geographically large and diverse country, with grape and wine producing regions situated in diverse climatic zones, and consequently, different regions express large differences in their Research, Development and Extension (RD&E) priorities. In addition, the extension and adoption messages for particular research outputs need to be tailored for the region concerned. For this reason, the AWRI established a network of regional nodes in order to address regional RD&E. priorities; the Riverina, Tasmania and Hunter Valley nodes being the subject of this report.

The report covers the period from I November 2013 to 30 June 2014. The work reported, comprising Outputs and Activities largely directed by the Grape and Wine Research and Development Corporation (GWRDC), focuses on extension and facilitated adoption of technologies which had been previously developed, and on extending existing AWRI flavour research projects via the Tasmania node. As such, this period represented a strong opportunity to extend work to a wider Australian wine industry audience, and a total of 30 workshops and seminars were staged across four states, with each event strongly attended by industry personnel.

Summary

Extensive capability building was performed by this project during the period from 1 November 2013 to 30 June 2014.

A large number of industry personnel representing many of Australia's largest wine producers were provided with practical demonstration of two tools which can improve processing efficiency and therefore increase profitability; namely the AWRI Fermentation Simulator and the AWRI Refrigeration Demand Calculator. Seven regional Refrigeration Efficiency workshops were staged and a webinar was presented, which were attended by a total of 116 industry personnel representing 80 wineries. In addition, six regional Fermentation Simulator workshops and a webinar were staged, which were attended by a total of 89 industry personnel. Both the Fermentation Simulator and the A WRI Refrigeration Demand Calculator are available as free downloads from the AWRI website, and recordings of the two webinars are also available from the webinars page of the AWRI website.

With respect to the Fermentation Simulator, the tool was modified in two ways in response to industry feedback; firstly in respect of the ability to model ferments conducted with cool-climate grapes (i.e. low pH and high titratable acidity TA), and fermentations conducted with indigenous yeasts, both of which result in a longer 'lag time' before fermentation becomes fully established. These modifications allow wider applicability of the Ferment Simulator in industry. In addition a simplified 'Lite' version of the Fermentation Simulator was developed in response to feedback received mainly from smaller wineries, and a design brief for a mobile platform App. was developed in response to feedback from potential users that they would prefer a web-based interface. An Industry Adoption Plan to enhance future industry uptake of the Ferment Simulator was also developed.

An article describing use of both versions of the Ferment Simulator was also written and published in the November/December 2013 issue of Wine and Viticulture Journal. In terms of

assessing industry interest in the Ferment Simulator, between 28 October 2013 and 30 June 2014, 956 page-views of the AWRI website section covering the Ferment Simulator homepage, login page and the download page were recorded; including 80 unique page-views of the Ferment Simulator Download page. The AWRI website has recently been modified so that in future it will be possible to track the number of downloads of both the Fermentation Simulator and the Refrigeration Demand Calculator, in addition to the number of page-views.

The working prototype of the AWRI Refrigeration Demand Calculator was developed at the Riverina node using data accessed from three large wineries in the Riverina, and three medium-sized wineries in the Hunter Valley via the Riverina and Hunter Valley nodes.

Refrigeration is by far the largest user of electricity in the majority of wineries, and consequently, improving refrigeration efficiency will result in an immediate improvement to profitability. In response to this opportunity, the Refrigeration Demand Calculator was developed as a practical spreadsheet-based software tool, and was made available to all Australian wine producers as a free download from the AWRI website.

The purpose of the AWRI Refrigeration Demand Calculator is to allow wine producers to analyse, understand, and better manage their refrigeration demand with a view to reducing the amount of electricity used, and thus the amount of money spent on electricity. Wine producers are able to enter grape intake and production data to simulate refrigeration demand across the entire annual production cycle, and assess the impact of factors such as cellar storage, cold stabilisation temperatures, fermentation conditions, climate, brine temperature, tank size and insulation on refrigeration demand and energy costs.

Benefit cost analysis

Project scope

- AWR 0902 Improving Winery Refrigeration Efficiency
- AWR 1306 Project 4.3.1: Node project at Griffith

Other relevant R&D

Prior AWGA projects have included support for the AWRI developed Fermentation Simulator and AGWA support for development of nodes in the Hunter region (NSW) and in Tasmania.

R&D Investment: AGWA and others

AGWA (and co-funder investment - AWR 0902 only) totalled $0.53m (real 2015 present values).

Rationale for AGWA investment

The nodes were established to further dissemination of the calculator technologies, in particular to demonstrate its applicability and to estimate the order of magnitude of cost savings.

Box 1: Refrigeration efficiency workshops

Riverina

a. Winery Refrigeration Efficiency workshops

This project recognises that refrigeration is a major use of electricity in wineries and that many winery refrigeration systems are inefficient and could be improved.

This project sought to provide wine producers with the knowledge and the skills necessary to benchmark and improve their own refrigeration systems, leading to improved energy efficiency and reduced spending on electricity.

Outcome: Improved refrigeration efficiency leading to reduced electricity use.

b. Refrigeration Efficiency – model refrigeration use and develop a monitoring tool

In addition to addressing the need to assist wine producers to improve their refrigeration efficiency described above, the project sought to concurrently develop a practical prototype software tool to assist wine producers to increase their refrigeration efficiency and reduce operating costs.

Outcome: A prototype software tool for analysis of demand-side refrigeration.

c. AWRI Fermentation Simulator – extension and investigate barriers to adoption

The AWRI has developed a workable fermentation simulator in Excel format based on the records of thousands of fermentations of grapes grown in warm to hot grapegrowing regions. The simulator is a powerful and unique tool for optimising fermentation management, avoiding slow and stuck fermentations, and for smoothing electricity use in refrigeration, thus allowing avoidance of punitive electricity tariffs. The simulator was introduced to industry through a variety of extension events, but industry uptake was been slow.

This project sought to investigate barriers to adoption encountered by wine producers in the Riverina and Hunter Valley, and take action to encourage uptake.

Outcome: Improved fermentation management through increased uptake of use of the AWRI Fermentation Simulator.

d. Fermentation simulator expanded to include cool climate (low pH/high TA) and indigenous yeast fermentations

The underlying fermentation simulation model did not accommodate fermentations conducted with fruit grown in cool climates with low pH and high TA, or fermentations conducted with indigenous yeast. This raised a possibility of failure of robustness of the model.

Outcome: Broader applicability and functionality of the fermentation simulator.

Ex ante and other Benefit Cost Analysis (BCA)

No available ex ante BCA analysis

R&D outputs

The R&D outputs comprised the following.

- The calculators developed during the projects
- The nodes established to assist with dissemination of the information (including workshops) and more particularly the application of the calculators within individual wineries.
- Final Reports for the projects.
- Booklets to inform industry.

Benefit (profit change) to winemakers/growers

The potential cost savings to winemakers are 'site specific'. That is, they will depend upon the specific winemaking situation, engineering modifications that may be required and whether they are substantial or marginal.

However, indicative cost savings are illustrated by the case studies developed during the projects (for example, **Error! Reference source not found.**). The case studies are a key g

uide as they are 'real world' examples of both using the calculators and the changes having been adopted.

Box 2: Indicative cost savings: Analysis from case study winery B

Warmer fermentation

Cooling requirements were reduced by between 0 and 8% for fermentations performed at warmer fermentation temperatures (e.g. 20°C instead of 16°C) during the 2011 vintage.
Examination of heat generation and transfer mechanisms supported this result of a small reduction in overall energy use with warmer fermentation temperatures. Across a site fermenting 30,000 kL per annum, it is estimated that the electricity savings from using warmer fermentation temperatures would amount to approximately $4,000 per annum. But there are sensory risks involved; suggesting that the apparent cost savings would not be worthwhile

Tank stratification

There is potential for stratification within tanks to influence wine quality and consistency and possibly waste energy through excessive cooling. Wineries should be aware of the potential for brine-induced stratification and consider auditing the temperatures at different points in tanks at their site to verify that tank temperatures reported on winery monitoring systems are accurate.

Storage temperature

The saving from using a storage temperature of 10°C instead of 5°C would be $0.02/kL/week. If that winery held stocks of 30,000 kL subject to this regime throughout the year, the annual saving would be approximately $31,000 (if this calculation was performed using the experimentally determined overall heat transfer coefficient of 0.76 W/m_2/°C the saving would be $51,000).

Night-time cooling

Shift of refrigeration plant operation from short repeated cycles throughout the day to operation predominantly at night for a sustained period. On the basis of 55% electricity currently used off peak, a shift to 80% was realistic (580,000 kWh annually from peak to off-peak or a saving of $38,000 annually based on their peak/off-peak electricity price differential of $0.065/kWh). However, there is a capital cost involved – for the case study winery it would total $174,000 (a payback period of 4.6 years)
Source: Project report

Adoption pathway

Informing wine makers and seeking to encourage adoption were specific objectives within the projects. This was supported by and specifically pursued by the following.

- A simple to use technology (ie Excel spreadsheets), albeit in a well-developed prototype by the end of the project. Certainly it takes wine makers (and advisors) sometime to fully understand the calculators. Further refinements to the software (which were intended (either with or without AGWA support). In support of further refinements the intellectual property is open access — it can be adapted or further improved without IP constraint.
- Accessible, via the internet (https://www.awri.com.au/industry_support/winemaking_resources/refrigeration-demand-calculator/).
- The spreadsheets were accompanied by user guides, which included the case study summaries.

- The final project report which included detailed case study analysis (based on commercial data), also publicly available (http://research.wineaustralia.com/completed_projects/improving-winery-refrigeration-efficiency/).
- 'Road shows' to inform and explain the use and benefit of the calculators, supported by press coverage and other promotion. Seven regional Refrigeration Efficiency workshops were staged and a webinar was presented, which were attended by a total of 116 industry personnel representing 80 wineries. In addition, six regional Fermentation Simulator workshops and a webinar were staged, which were attended by a total of 89 industry personnel.
- Regional 'nodes' to specifically promote the calculators and provide winemakers with ready local access to technical support, including virtual access to that support on a consultant basis, but at no charge.

The factors influencing adoption appear to have been particularly relevant to the refrigeration technologies (and the ferment calculator technology).

- Where the business stands in terms of size and functionality: growers and winemakers with expanding businesses were more likely to actively seek information and adopt new technologies and had the motivation and resources to do so.
- While many grape growers and winemakers 'intended' to adopt a technology, actual adoption was strongly influenced by the level of contact and support they had from colleagues.
- Typically, "86 per cent of growers and 94 per cent of winemakers said they go online when looking for research or new technologies and product information". Without a specific survey it is not possible to conclude one way or the other the importance of online access. That said, with the refrigeration and ferment calculator both available online, download data for both calculators suggests that the internet was important in access product information.
- "Other growers and winemakers are key sources of credible, experience-based, unbiased information. We found the wine sector network to be in good shape, and a very strong influence on people's decision making". This was an important aspect influencing adoption during the project and would likely have continued to be of importance in the future. The researchers at AWRI intentionally targeted significant winemakers in the respective regions as the strategy to both demonstrate the applicability of the calculators, and the nature and size of the potential benefits. Essentially if it worked for these wine makers it would permeate through to others. In practice, that appeared to be the case. Indeed some winemakers are reported to have offered their essentially commercial data for use by the researchers in demonstrating the applicability of the calculators to other winemakers.
- It is reasonable to conclude that without the access to the highly sensitive technical and commercial data required during the R&D, the project outputs would not have eventuated and more specifically would have lacked credibility with winemakers.

Observed changes in the industry

Adoption and the initial level of use (by the case study wineries) appear significant. Also, there appears to have been some application by other winemakers at the time (following workshop participation and follow up from the node personnel). However, there is little

indication that winemakers have continued to use the calculators or that other winemakers have taken to using the calculators since the project finished. Specifically, there has been no feedback to the researchers that the calculators have continued to be used or that other wine makers have begun using the calculators.

These outcomes could reflect several factors.

- The issue of electricity prices is no longer relevant, although this seems unlikely given the increases in the real (inflation adjusted) cost of electricity and further moves to time of use electricity pricing.
- Limited application given subdued investment in new plant/plant modifications. Equally, the drivers to improve wine quality and reduce costs are strong and investment is encouraged by changes to the deprecation provisions for capital investment, particularly for smaller winemakers.
- Less 'obvious adoption' but possible implicit adoption. The case studies and other information from the project encouraged the participant case study winemakers to make changes in their systems. These included for example, changes which meant that the pattern of electricity demand shifted away from high priced time of use tariffs to lower priced tariffs. That principle could well have been applied to other processes in winemaking without having to use the calculator. Similarly, other winemakers could have adopted ("copied") the same principle (and indeed the same system practice changes) without using the calculator or possibly data analysis.
- The project identified that using the calculators was more involved than either the researchers or winemakers anticipated. In particular, using the calculators requires significant site specific data input (winery and individual tanks/batches within a winery). This data input was undertaken within the scope of the project. Using the calculators subsequent to the project requires additional data which involves winery staff or external contracting.
- Much less access to technical support previously supplied through the nodes. Specifically, application of the calculators in an engineering context.
- Lack of investment to commercialise the calculators and associated consultant support (in turn possibly reflecting factors such as the open access nature of the IP). This could reflect expected demand issues. In particular, limited appreciation by winemakers of possible cost reductions; a concern by winemakers that commercial providers may relay commercially sensitive information to others and cost of services. The AWRI project identified that the technical support requirement is significant (given site specific data collection and the financial and engineering analysis) suggesting a high up-front cost for winemakers.
- Competition from other 'calculator technologies' and advisory providers, including crowding out by government supported energy saving audit/advisory services and grants to improve energy efficiency. That said, the scope and detail required with respect to wineries likely means that general advisory systems are of limited benefit.

Counterfactual: The otherwise case without AGWA investment

It seems likely that in the absence of the AWGA investment the calculators and the nodes in particular would not have been developed. The situation since the project (and stop to AGWA/AWRI funding of the nodes) supports that view.

To the extent that the calculators and nodes would not have otherwise been developed the AGWA investment is additional investment – it did not for example, substitute for investment that would have occurred anyway.

How long will the benefits last (depreciation and obsolescence)

The benefits of the specific electricity savings can be expected to last for at least 5 to 10 years. Real prices for electricity are unlikely to fall and the energy savings will continue, given that wine production systems remain much the same.

The calculator technology is unlikely to become redundant. Rather the analysis using the calculator may become be of less value if the data are not updated. Updating the analysis in the event of engineering/process changes may be required.

Similarly the analysis/savings may fall away significantly in the event of major changes in equipment or processes. However, to the extent that upgrades have been justified on the basis of electricity savings demonstrated using the calculators, the resulting savings can in part be attributed to the AGWA R&D investment.

Benefit quantification: Key parameter values

Approach

- A generally conservative approach has been adopted to the parameter values used.
- In the absence of details of individual wineries that may have applied the calculator technologies and/or benefitted from access to support from the nodes, the benefits have been estimated as the minimum required justifying the AGWA R&D investment.
- AGWA and co-funder contributions of $0.53m (real 2015 prices, 2015 present value)

Research outputs

- The R&D was successful, producing outputs including reports, extending information through the nodes and more particularly providing a technical calculator resource that is readily accessible from the AWRI website.
- Case study estimated benefits
- The source of benefits (cost savings) used in the analysis are summarised in Table 13.

Table 13: AGWA R&D: Refrigeration: Source of cost savings 2015 prices

	Year 1	Year 2 and subsequently
Winery A (small winery, 500 tonnes crush, 90-95% red grapes) Warmer brine temperatures (including fermentation cooling with warmer brine). Unclear whether the rapid drop in ferment temperature was considered desirable by the winery, probable that costs could be saved (net of longer period of pumping). Various strategies, including night time harvesting, some involve additional capital costs. Estimated overall potential for 12% reduction in electricity requirements (on the basis of refrigeration totally 70% of electricity costs) Cooling system operation and control		

Cooling system maintenance (developing a better knowledge of operations, implementation of monitoring systems)		
Plant shutdown/infrequent running (turned off package chiller when no cooling requirements) saving 24% compared to the previous year ($50/day for 4 months)	$6,000	$6,000
Use of external heat exchangers (instead of cooling coils)were investigated; useful but limited in the specific situation		
Total	$6,000	$6,000
Case study Winery B		
Warmer fermentation (lower cooling temperatures eg 20°C instead of 16°C)	$4,000	$4,000
Tank stratification (accuracy of temperature monitoring and avoiding excessive cooling)		
Storage temperature (warmer than otherwise 10°C instead of 5°C $0.02/kL/week on 30,000kL	$31,200	$31,200
Night time cooling (increased the proportion of off peak electricity use - from 55% to 80%, ie 580,000kWh/annum; price differential of $0.065/kWh; but with additional capital cost of $176,000	-$176,000	$37,700
Total	-$140,800	$72,900

- The costs savings to Case Study A (essentially from shutting down the cooling plant for the four months that it was not used) are applied for only 2 years. It is difficult to believe that these costs savings would not have been evident in the near term, only because they seem 'obvious'. Realistically, it does not require the calculator technology to identify or measure the savings. That said, it seems that it was the technology and the associated node/workshop/individual analysis that alerted the winemaker and prompted the change in winery practice. However, it could reasonably be argued that highlighting the costs savings to Winery A will have prompted other wineries to ask the question as to what equipment in their own situation, especially intensive electricity using technology, can be turned off when not in use.
- Other cost savings to Winery A, as they were not quantified in the project report, have not been included in the present analysis.
- At least two winemakers are known to have achieved costs savings of the magnitude demonstrated by Winery B. This is conservative. The researchers report at least three substantial wineries achieving the same broad magnitude of cost savings as Winery B. It is highly probable that still other wineries have made costs savings, given the number attending workshops as part of the R&D project, but these wineries have not been identified. An industry survey would be required to identify such situations.

Time frame

- The benefits are estimated to begin in 2013 and last for two years (winery A type savings) and a decade (winery B type savings – these are likely conservative; while it is possible that major changes in equipment/processes may not occur, there is the possibility that such changes might occur for reasons unrelated to energy costs savings)

Discount rate

- Consistent with the framework proposed by the Council of Rural Research and Development Corporations, a 5% real discount rate has been used. That is, the opportunity cost of investing the AGWA and co-funder monies was 5% real.

Investment performance (measured benefits)

The estimated returns from the AGWA and co-funder investment in the two refrigeration projects are summarised in Table 14. The analysis shows that the investment has returned significant benefits to the wine industry. Further, these benefits are considered conservative since they represent the costs savings to just two (albeit larger) wineries. AWRI data shows that the number of calculators downloaded has been significant, aided by the fact that they are readily accessible. In the July 2014 to October 2015 period 145refrigeration and 19 fermentation calculators were downloaded.[14] Other wineries are likely to have applied the calculator or followed the lead of other wineries (including the case study wineries).

Table 14: AGWA R&D: Refrigeration: Investment returns

Present value of benefits	$m	$0.84
Present value of R&D costs	$m	$0.53
Net Present Value	$m	$0.31
Benefit/cost ratio		1.6
Internal Rate of Return		12%

The Net benefits from the R&D total an estimated $0.31m with the Benefit Cost ratio calculated to be 1.6 and the Internal Rate of Return 12%.

The estimated returns are highly sensitive to the extent of adoption; ie the number of wineries using the calculator to estimate and achieve cost savings. If the number of larger wineries befitting is five (compared to two in the base case), the NPV rises to $1.54m, the B/C ratio to 3.9 and the IRR to 24%.

Attribution to AGWA

AGWA provided around 88% of the total R&D funding. On the basis of cost shares AGWA could claim the majority of the benefits. On the other hand the project concept derived from AWRI's strategic analysis of issues confronting the industry and the importance of developing and using regionally based information and advisory services to support winemakers.

Other benefits to winemakers that have not been quantified

The benefits to winemakers are cost savings as examined above.

Benefits outside of the Australian wine industry

Benefits outside of the wine industry to other were not identified. While businesses in other Australian industries or consumers in general might benefit from cost savings from improved use of refrigeration, those gains are most likely to come from industry specific R&D, general energy advisory services rather than the AGWA refrigeration R&D.

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[14] AWRI, pers. comm.

Overseas winemaking interests could benefit from the R&D findings since the calculator is applicable to any wine making situation.

5. Trunk disease

Projects

Wine Australia listed five trunk disease projects for analysis.

- CRV 99/12 Managing grapevine trunk diseases (Black goo decline, esca, Eutypa dieback and others) that threatens the sustainability of Australian viticulture - continued as CRV 99/12N
- CRV 99/12N Managing grapevine trunk diseases (Petri disease, esca, eutypa dieback and others) that threaten the sustainability of Australian viticulture
- CRV 03/06S Diagnosis and management of Eutypa dieback
- SAR 06/01 Sustaining grapevines infected with eutypa dieback
- GWR IN0905 Eutypa dieback management
- SAR 1001 Optimising management of eutypa dieback

Investment

The trunk disease projects can be broadly grouped into petri disease and eutypa disease. The associated investment is shown in (Table 15).

Table 15: Investment in selected trunk disease projects (dollars of the day)

Project No	Start Date	Complete Date	Research Organisation	Total Project Cost	Wine Australia
Petri disease					
CRV 99/12	01/07/1999	30/06/2004	Cooperative Research Centre for Viticulture	$1,502,434	$683,701
CRV 99/12N	01/07/2003	31/08/2006	The University of Adelaide	$963,776	$470,714
Eutypa disease					
CRV 03/06S	01/07/2003	30/06/2006	The University of Adelaide		$400,582
SAR 06/01	01/07/2006	28/02/2010	South Australian Research and Development Institute	$1,180,239	$315,000
GWR IN0905	01/02/2010	30/06/2010	South Australian Research and Development Institute		$22,727
SAR 1001	01/07/2010	30/06/2013	South Australian Research and Development Institute	$595,191	$240,000
Total				$4,241,640	$2,132,724

Source: Wine Australia

- In real 2015 present value terms the respective investments were $0.96 m in Petri disease (46% AGWA) and $3.7 m in Eutypa disease (47% AGWA).
- Both areas of research had been supported by previous GWRDC, co-investor and agency R&D particularly through the CRC for Viticulture. The prior R&D focussed on the epidemiology of the diseases as well as management and control.
- Significant research continues to be undertaken overseas as Grapevine Trunk Disease (GTD) is of importance in all grape growing areas and, as noted above, of increasing concern. Australia hosted the International Workshop on Grapevine Trunk Diseases, in Adelaide, November 2014 at which a range of papers relevant to the study and management of GTD were presented (see http://www.icgtd.org/Workshops.html).

For analytical purposes these projects have been divided into those primarily focussed on Petri and those focussed on Eutypa, recognising that there is a degree of overlap.

Project summaries

Petri projects: Project CRV 99/12 (continued as CRV 99/12N): Cooperative Research Centre for Viticulture: Managing grapevine trunk diseases (Black goo decline, escaEsca, Eutypa dieback and others) that threatens the sustainability of Australian viticulture

Abstract

Grapevine trunk diseases cause decline and death of vines, thus severely limiting the sustainability of Australian vineyards. Little was known about the contributory factors of these diseases, how to prevent them, or how to minimise their economic impact when this project began. Petri disease, which causes significant losses during the vineyard establishment phase, was shown to be widespread, whereas esca, currently the most serious grapevine disease in Europe, was shown to be rare in Australia. The causal organism, *Phaeomoniella chlamydospora*, is spread from infected mother vines into cuttings, and into newly planted vineyards via infected planting material. Long duration (30 minutes) hot water treatment of dormant cuttings was demonstrated to be an effective method of reducing the risk of producing infected planting material. Best practice protocols for the nursery industry were developed and promoted to encourage production of *P. chlamydospora*-free planting material. Glasshouse studies demonstrated that infected grapevines are more susceptible to water stress. Field trials showed that management practices that reduced stress, such as the use of mulch, reversed the symptoms of decline in infected grapevines. Recently, the number of reports of Petri disease has dropped considerably, suggesting that industry now has the tools both to prevent the spread and to minimise losses attributable to these diseases as a result of this research.

Summary

Grapevine trunk diseases are caused by xylem-inhabiting fungi that cause the slow decline and loss of productivity in vines at all stages of growth. They either infect propagating material and limit the growth of newly planted vines, or they infect established vines through pruning wounds and cause loss of productivity, just as vines are reaching an elite stage of maturity.

Petri disease, formerly known as black goo, is an emerging problem in international grapevine culture. The description of several possible causal organisms, including *Phaeomoniella chlamydospora,* in 1996 led to the realisation that both the pathogens and the

disease are widespread and important. However, there is as yet little understanding of the disease or of its economic effects. The same pathogens are involved in esca, currently the most destructive disease of grapevines in Europe. This project set about to determine which pathogens are the most important, how infection occurs, how it is spread, whether it can be prevented and effective methods of managing infected vineyards.

As a result of this project, it is now known that:

- esca Esca is rare in Australia, whereas Petri disease is widespread;.
- the causal pathogen of both diseases is *Phaeomoniella chlamydospora;*.
- *Pa. chlamydospora* sporulates in cracks on the grapevine trunks associated with machinery damage;
- infection is passed from mother vines into cuttings, resulting in symptomless infected planting material;
- *Pa. chlamydospora* spores can be detected in water used during nursery propagation, indicating there is the potential for further infection;
- Hot water treatment of dormant cuttings is the most effective method of reducing the incidence of infected planting material;
- Best practice nursery protocols were developed and disseminated through Workshops workshops and articles;
- *Pa. chlamydospora* infection in grapevines increases stomatal conductance and reduces xylem function, resulting in reduced capacity to respond to water stress; and
- Vineyards can recover from Petri disease over time with management practices that reduce stress, eg for example, mulch, bunch-thinning.

Eutypa projects: Project CRV 03/06S: Cooperative Research Centre for Viticulture: Diagnosis and management of Eutypa dieback

Abstract

The objectives of this project were to study the epidemiology, management and diagnosis of eutypa dieback to develop integrated management strategies for industry. Growth rate of *Eutypa lata* varied significantly among cultivars. Foliar symptoms of eutypa dieback varied annually and were not a reliable indicator of infection. A strong correlation was observed between symptom severity and yield loss. Analysis of climate data indicated that rainfall and temperature influenced severity and incidence of foliar symptoms. Numerous treatments were evaluated as pruning wound protectants to prevent eutypa dieback. Bavistin was the most suitable replacement for Benlate, which has been withdrawn from the market.

Preliminary studies showed that application using commercial spray equipment may be as effective as applying with a paint brush. Acrylic paints or pastes, with or without fungicides, were also effective wound protectants. Remedial surgery to eliminate *E. lata* from infected vines was effective in the short–term, however, further research is required to assess the long–term success of this technique.

Rapid identification and detection methods for *E. lata* were developed using polymerase chain reaction and Southern hybridisation techniques to generate specific DNA markers. These markers were used to detect the pathogen in infected wood. Specific biochemical markers for *E. lata* were identified, however, these could not be detected in the foliage of infected vines.

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Summary

Obtain enhanced understanding of the interactions between the vine, pathogen and environment to increase knowledge of the epidemiology of eutypa dieback. Develop improved disease management strategies. Develop a rapid means of diagnosis of eutypa dieback, based on the identification and detection of chemical markers in vine foliage.

Project SAR 06/01: Sustaining grapevines infected with eutypa dieback

Abstract

This project developed practical and efficient methods for eutypa dieback control, determined the effect of environmental and production stresses, evaluated remedial surgery treatment for sustaining grapevines and established the presence and extent of eutypa dieback in emerging grapegrowing regions.

Summary

Eutypa dieback is a major disease of grapevines in Australia and worldwide caused by the fungus *Eutypa lata* that infects vines through pruning wounds, colonises wood tissue and causes dieback of cordons, stunting of green shoots and leaf distortion. Eutypa dieback threatens the sustainability of premium vineyards and is becoming a problem in most cool climate growing regions of southern Australia. This disease reduces growth and yield and if unmanaged eventually kills vines.

A number of pruning wound treatments were evaluated and some controlled the disease. Physical barriers such as Gelseal, Greenseal, Garrison, Agseal and an acrylic paint were effective and are recommended for use especially on large wounds, such as those made during remedial surgery. Of the fungicides tested, Bavistin (carbendazim) and Folicur (tebuconazole) were the most effective but Scala (pyrimethanil), Switch (cyprodinil + fludioxonil) and Shirlan (fluazinam) were also effective when applied at rates higher than currently registered for use on other grape diseases. Bavistin, Folicur and Shirlan also controlled Botryosphaeria canker. Further evaluation is required to determine optimal rates

for eutypa dieback control. Garlic and lactoferrin also showed promise as alternatives to fungicide application

Project GWR IN0905: Eutypa dieback management

Industry presentations relating to SAR 06/01.

Project SAR 1001: South Australian R&D Institute: Optimising management of eutypa dieback

Abstract

Management strategies for eutypa dieback have been optimised by identifying new pruning wound treatments that control eutypa dieback, generating efficacy data for fungicide label registration and demonstrating the use of commercial sprayers to apply treatments to pruning wounds effectively.

Summary

Eutypa dieback is a major disease of grapevines worldwide which causes considerable economic loss to the $8.3 billion Australian wine industry and is caused by the fungus *Eutypa lata*. The fungus infects vines through pruning wounds and colonises wood tissue causing dieback of cordons, stunting of green shoots, leaf distortion, poor fruit set, uneven berry ripening and, if not controlled, eventually kills vines. Eutypa dieback is now recognised as a significant problem in most cool climate growing regions of southern Australia where it threatens the sustainability of many vineyards.

Currently, the only method of controlling eutypa dieback, once established in vines, is by removal of all infected wood tissue from the vine using remedial surgery. A more cost effective method of control of the disease is to prevent entry of *E. lata* into the vines by protecting pruning wounds.

A number of pruning wound treatments, including fungicides and alternative products, have been evaluated for efficacy in controlling eutypa dieback. Fungicides from three fungicide activity groups, Folicur (tebuconazole), Shirlan (fluazinam) and Cabrio (pyraclostrobin), provided control of the disease at the label rates currently recommended for control of other grapevine diseases. Permits are being sought for their use as pruning wound protectants during vine dormancy. Use of these products would provide a greater range of options for growers to manage the disease.

The “alternative” products, garlic, lactoferrin and the biocontrol product Serenade, provided some control of eutypa dieback, but less than that of conventional fungicides. These may provide options for organic growers and those wishing to reduce use of synthetic fungicides.

A detached cane assay (DCA) was developed that allows assessment of pruning wound protectants using live single-node cuttings under controlled conditions. This assay can provide efficacy data on wound treatments in as little as 6 six weeks from establishment, compared with up to 18 months for a field trial. The method also allows for evaluation of treatments at decreased disease pressure, more reflective of that occurring naturally. In order to assess the ability of treatments to control eutypa dieback, field trials must be conducted, but the DCA allows for a rapid screening of treatments to support field results and to generate additional data to assist with product registration.

Rationale for AGWA investment

Grapevine trunk disease is recognised as an important disease group. Further there is the concern that its importance is increasing.

> *"Anecdotal evidence (supported by diagnostic service data) from some vineyards suggests that as a result of the combined effects of Eutypa dieback, Petri disease, and possibly esca, whole blocks of premium vines have ceased to be economically viable. The recent discovery of esca (for which Pa. chlamydospora acts as the pioneering infection) increases the urgency with which research must find a way of preventing infection by Pa. chlamydospora. We suggest that an explosion in the incidence and severity of trunk diseases can be expected within 10-15 years (Project report 99-12, pg 7.)*

The increasing importance of GTD and the limits on control options was highlighted at the 2014 International Workshop on Grapevine Trunk Diseases.

> *Grapevine trunk diseases (GTDs) are among the most destructive diseases of vineyards worldwide. Fungicides with the potential to control GTDs have been banned and there are no highly effective treatments available. Developing sustainable alternatives to manage GTDs is therefore required. Currently, there is not a coordinated research approach in Europe, even though a strong demand for innovative disease management strategies is given. The goal of this COST Action FA1303 would be to develop a network of European expertise to improve understanding of GTDs by acquiring knowledge on occurrence of pathogens, vine-pathogen interaction, ecology of wood-inhabiting microorganisms, and to develop new management protocols and biocontrol approaches. (Sustainable control of grapevine trunk diseases (COST Action FA1303). F. Fontaine and J. Armengol, Phytopathologia Mediterranea (2014) 53, 3, pg, 584.)*

The key issue in controlling GTDs is management in respect of planting material and diseased sections of the vine. Researching improved management is a common area of market failure: few individual growers or voluntary groups of growers can justify the level of investment required since they cannot gain enough of the expected benefits of that R&D to justify the investment, especially when it is high risk. Typically, improving management is about information, making it difficult to exclude 'free riders' which in turn makes it challenging to establish voluntary groups. Industry level funding through AGWA enables a contribution from all potential benefitting growers. Further, the management options open to growers are generally specific to the region, thus Australia cannot rely on international R&D. Additionally the diseases having most impact vary between regions (ie Esca and Eutypa in Europe, Eutypa and Botryosphaeria in Australia and USA). Also, international research has now shown that the different environments mean that epidemiology varies, and so management strategies must also be tailored to each country and more specifically, region. Australian researchers work in concert with international researchers.

As well as eutypa dieback, other trunk diseases are important for the industry. In particular, botryosphaeria dieback (formerly known as bot canker). However, the analysis undertaken here focuses on eutypa as the AWGA funded R&D projects selected for the present analysis addressed incidence and management of petri and eutypa.

Ex ante and other Benefit Cost Analysis (BCA)

No previous benefit cost studies have been identified.

Ex post Benefit cost analysis: Petri disease

Outputs

Projects CRV 99/12 and 99/12N documented that the incidence of Petri disease was widespread across Australia. The modes of transmission were identified and Best Practice protocols (Hot Water Treatment) were developed (ensuring clean planting material) and shown to be successful.

Adoption

Prior to the project HWT was not standard practice by nurseries or grape planting material.

Surveys showed that HWT was widely adopted (by2012) "but the reliability of HWT was questioned by most nursery operators" (Waite, 2013)

Noting that Waite et al had only a small number of self-selecting respondents (20) they were confident in concluding that:

> *"Variations in practices both within and between nurseries and confirmed the previous anecdotal evidence that reliability, and efficacy of HWT continues to be questioned by a majority of nursery operators. The literature examining the effects of heat treatment on plant physiology is not large and there is a need for further research on the effects of HWT on the growth and development of cuttings, particularly V. vinifera, before the concerns of the nursery industry can be fully answered. By contrast, the consistent use of treated water and fungicides and other sanitary practices demonstrate a better than expected, although imperfect, understanding of factors that can lead to microbial contamination and consequent loss of quality".*

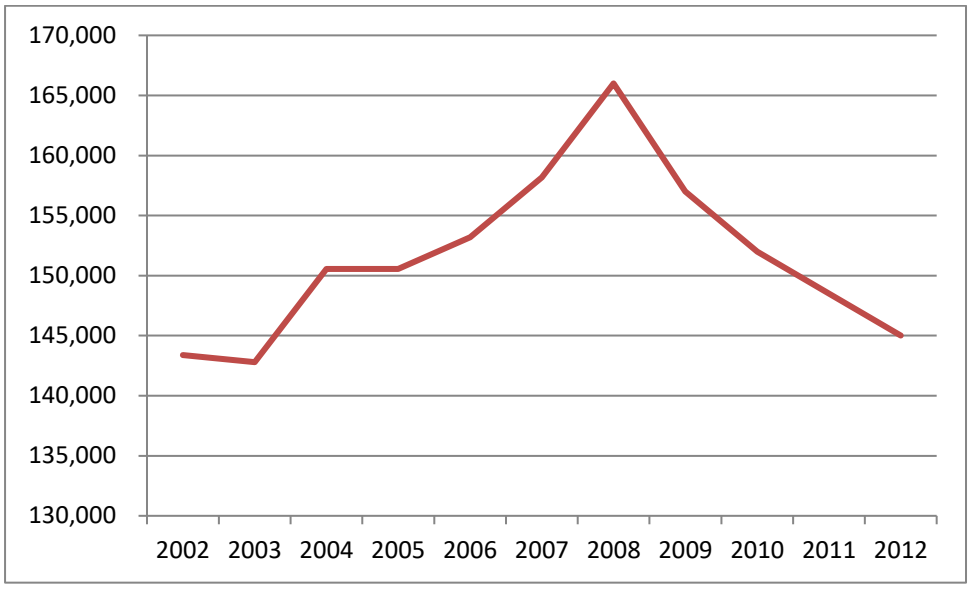
Outcome

The CRV 99/12N Final Report noted that the 'number of reports of Petri disease had dropped substantially' suggesting that best practice was being adopted.

However, as the researchers note, the major increase in demand for rootstock in the 1980s likely led to an expansion of the disease as there was less attention to quality of rootstock (Project report), even though the benefits of good sanitation have been demonstrated since at least the 1950s). The contemporary importance of Petri disease is thus likely to be lower given the marked contraction in new plantings, adoption of best practice management of cuttings and greater use of rooted vines as a means of avoiding weaker vines.

The area of wine grapes has contracted substantially since 2008 (Figure 2). New plantings have also fallen, although data on new plantings is limited. However, in 2011, the total non-bearing area (wine grapes) was now more that 1-1.5% of the total area suggesting that new plantings have been very low, and certainly low by historical standards.

Figure 2: Area of grapes: Wine grapes 2001-12



Source: ABS

The survey results from Waite et al suggest that HWT is being used as a matter of course.

However, Waite et al suggest that there is a way to go in terms of improving the quality of grapevine planting material. They note:

> *"Vine nurseries do not usually belong to the Nursery and Garden Industry Australia association and therefore do not utilize the best practice management guides attached to the accreditation scheme of that organization. They rather belong to the Vine Industry Nursery Association that has not yet completed development of similarly comprehensive guidelines. If the quality and consistency of grapevine planting material is to improve to the standard required for the establishment of healthy, productive, long lived vineyards it is in the interest of all participants in the grape and wine industries to support the development of comprehensive propagation procedures for incorporation into accreditation schemes as a matter of urgency. Until such time, the current ad hoc approaches to nursery practice are likely to persist and the quality of planting material will continue to be erratic.*

No quantification of the benefits from better management of petri arising for the R&D has been undertaken as there is no data available to enable a base assessment of the costs of the disease.

Ex post Benefit cost analysis: Eutypa

Outputs

Project CRV 03/06S "Developed a rapid means of diagnosis of eutypa dieback, based on the identification and detection of chemical markers in vine foliage".

Project: SAR 06/01outlined that Eutypa reduces growth and yield and if unmanaged eventually kills vines. A number of pruning wound treatments were evaluated and some controlled the disease. But, "further evaluation is required to determine optimal rates for eutypa dieback control". Project SAR 06/01 developed practical and efficient methods for eutypa dieback control, determined the effect of environmental and production stresses, evaluated remedial surgery treatment for sustaining grapevines and established the presence and extent of eutypa dieback in emerging grape growing regions. The project included a

decision support tool for growers to enable an assessment of the return from control including the timing of that control in the life of the vine.

In SAR 06/01 removal of infected wood by remedial surgery was shown to be an effective strategy to manage eutypa dieback, but success of this technique relies on removal of all infected wood. This strategy avoids long-term economic losses in affected vineyards and on-going maintenance will ensure good economic returns. Vineyard surveys revealed that eutypa dieback is wide-spread in emerging regions of South Australia, and in Tasmania, but was not detected in Western Australia. The surveys serve as a warning to grape growers to adopt control strategies to avoid production loss and increase the sustainability of grapevines. It is most prevalent in cool climate grape growing/wine regions and much less of an issue in the table grape and dried vine fruit growing areas.

SAR 1001 showed the effectiveness of fungicides in managing eutypa including targeting wounds at/after pruning leading to the registration of specific fungicides for these purposes.

Project SAR 1001 and Project GWR IN0905 reported that management strategies for eutypa dieback have been optimised by identifying new pruning wound treatments that control eutypa dieback, generating efficacy data for fungicide label registration and demonstrating the use of commercial sprayers to apply treatments to pruning wounds effectively. The Project showed this to be more cost effective than removal of all infected wood from the vine using remedial surgery ie what growers need to resort to if they do not protect wounds from infection.

Benefits

Nature of benefits

The AGWA R&D projects, through identifying and promoting better management and control, potentially improves vine vigour, avoids production losses and vine deaths and, reduces control costs.

In describing the importance of Eutypa the project reports outline that:

> *Eutypa dieback is a major disease of grapevines worldwide which causes considerable economic loss to the $8.3 billion Australian wine industry and is caused by the* fungus Eutypa lata. *The fungus infects vines through pruning wounds and colonises wood tissue causing dieback of cordons, stunting of green shoots, leaf distortion, poor fruit set, uneven berry ripening and, if not controlled, eventually kills vines. Eutypa dieback is now recognised as a significant problem in most cool climate growing regions of southern Australia where it threatens the sustainability of many vineyards.*

Value of the benefits

The value ($ benefit) of the AGWA R&D has been estimated as the reduction in costs of trunk disease, measured as disease costs without the R&D less disease costs with the R&D. In turn the reduction in costs comprises savings in treatment costs and reduced production losses.

The disease cost without the R&D has been measured by:

- Updating 2015 a 2009 estimate of the disease costs to reflect industry changes (areas of vines, grape production and grape prices) and more general changes in input prices (labour and materials which impact upon treatment costs)

- Projecting forward this 2015 cost to reflect the likely increase in disease incidence that would have occurred without the R&D.

The disease cost with R&D has been measured as the 2015 cost:

- With additional treatment costs (as growers were more aware of the disease and control options)
- With a lower yield loss (production loss) due to more effective control
- With a lower disease incidence as spread of the disease is projected to be more limited.

2015 disease costs: Updating the 2009 analysis

Scholefield-Robinson in 2009 estimated the costs of trunk diseases (Eutypa and Botryosphaeria) in terms of treatment costs and lost income. That analysis was part of a broader AGWA R&D project (GRW GRR 08/04) which estimated the annual cost of a range of endemic grape diseases to grape growers.[15] The data used relates to 2007-08.[16] Scholefield-Robinson estimated the costs of trunk diseases at $6.2m per annum (2008 dollars) ($2.77m in control costs and $3.47m in lost net income).

The 2009 Scholefield-Robinson cost has been updated to reflect industry changes (areas of vines, grape production and grape prices) and more general changes in prices (labour and materials which impact upon treatment costs). No changes have been made to the control options or extent of yield loss as the Scholefield-Robinson analysis was undertaken prior to the conduct of most the trunk disease R&D project work (SAR 06/01 and SAR 1001) and certainly before its finalization.

The key features of the Scholefield-Robinson analysis are outlined in Box 3.

Box 3: Key features of the Scholefield-Robinson 2009 analysis of trunk disease costs

In the Scholefield-Robinson analysis a baseline farm model was developed using representative farm management data across the grape growing climatic zones. The loss of profit arising from higher costs and/or lower production was estimated over a 15 year period for a range of grape diseases.

In the Scholefield-Robinson analysis, the 'costs associated with prevention and control' (TC_{prev}) for Trunk Diseases were calculated as:

TCprev = (Cahsurg * Aahsurg) + (Cremsurg * Aremsurg) where;

* Cost of ad-hoc surgery (Cahsurg) – is an estimate of the cost per hectare of ad-hoc surgery used to control the disease(s) ($/ha).

* Proportion of area treated annually using ad-hoc surgery (Aahsurg) – is an estimate of the area treated annually in affected vineyards as a proportion of total vineyard area in the zone.

15 Scholefield-Robinson, *Assessment of Economic Cost of Endemic Pests & Diseases on the Australian Grape & Wine Industry*, March 2010

16 The analysis used the initial Australian Bureau of Statistics area and production data for 2007-08 (ABS, 2008 Australian Wine and Grape Industry). Subsequently the ABS revised the data for that year (and reissued the publication). The 2008-09 ABS area and production data closely approximates the 2007-08 data used by Scholefield-Robinson. The 2008-09 and subsequent years is presented on a consistent basis.

* Cost of remedial surgery (Cremsurg) – is an estimate of the cost per hectare of remedial surgery used to control the disease(s) ($/ha).

* Proportion of area treated annually using remedial surgery (Aremsurg) – is an estimate of the area treated annually in affected vineyards as a proportion of total vineyard area in the zone.

The analysis noted that whilst some vineyards use both methods (ad hoc surgery/ remedial surgery) to control trunk diseases, others may use one method only. The assumptions used for the representative vineyard reflect the assumed average response across the particular climatic zone.

In respect of Eutypa and Botryosphaeria Scholefield-Robinson noted the following.

* The diseases cause sectors of cordons and trunks to die and in extreme cases can kill vines. The fungi enter the vine when spores land on fresh pruning wounds in winter. Spread through the vine is slow but generally inevitable.

* Symptoms are usually expressed as distorted shoot growth.

* The only method of control is to prune the cordon or trunk to below the downward front of the disease in the wood. New shoots can burst and a new vine structure can be re-trained.

* The cost of minor "surgery" on the vine is estimated at $50/hectare while remedial surgery can be up to $2,800/hectare (2008 prices)

* Ad hoc surgery - Cutting off symptomatic vine cordons or entire vines - 2 hours/ha at $25/hr (i.e. $2 - $5/vine) (2008 prices)

* Remedial surgery - Cutting off all vines at the same height. Including cutting vines, cordon wire, removal of vines and wire and two training passes ($1.68/vine) (2008 prices)

* Wetter zones have more trunk diseases than drier zones because rain releases spores to the atmosphere from fruiting bodies on infected vines.

* Yield loss varied between 0.5% in Hot-Dry to 10% to 20% in all other climatic zones.

The Scholefield-Robinson analysis highlighted the following.

* The costs of trunk diseases were significant–around $6.2m per annum for the whole industry, based on 2008 areas, treatment costs, yields and average prices for grapes.

* There were significant differences between zones in both the level and source of profit loss (income loss/increased costs), emphasising the need for regional level analysis.

Updating the Scholefield-Robinson cost of trunk disease analysis covered the following.

- Areas of vines in the respective climatic zones
- Treatment costs, primarily reflecting price changes in labour and materials
- Consideration of Table grapes and Dried Vine Fruit
- Average prices for grapes (as these affect the value of lost production).

Area of wine and other grapes

The area of wine grapes in 2008-09 through to 2015 is detailed in **Error! Reference source n ot found.**. (2008-09 has been used as the base as there was a break in the series (method of collection) in 2009. In 2008 the total area bearing and non-bearing was 167,000ha). [17]

Since 2009, the total area of wine grapes has fallen (by around) 17%, while yield has increased resulting in a small (-4%) change in production.

[17] 2008-09 has been used as the base as there was a break in the series (method of collection/reporting) in 2009. In 2008 the total area of bearing and non-bearing grapes used for winemaking was 167,601ha).

While the area of Table Grapes and Dried Vine Fruit (DVF) is significant, area data is not readily available. Both industries are adversely impacted by trunk disease; however, both industries are located in the "Hot-Dry Climatic zone" where the disease incidence is relatively low. Excluding Table Grapes and DVF means that the benefits of the R&D will be underestimated since the grape area affected is smaller (and thus the value of lost production smaller).

Table 16: Winegrape area and production statistics 2009-2015

	2008-09	2009-10	2011-12	2014-15	Change 2015 on 2009
Production for winemaking or distillation (ie harvested) (t)	1683642	1533246	1582049	1608217	-4%
Bearing area (ha)	157290	151789	145382	132436	-16%
Area not yet bearing - Planted or grafted before the harvest (ha)	3,119	3,438	2,187	1507	-52%
Area not yet bearing - Planted or grafted after the harvest (ha)	2,141	1,406	941	1235	-42%
Total area (ha)	162,550	156,633	148,510	135178	-17%
Area of varieties removed (ha)	0	0	3,864	3024	0%
Total area of grapes left on the vine or dropped on the ground (ha)	0	13,147	12,357	5655	0%
Yield (production from bearing ha) (t/ha)	11	10	11	12	13%

Source: IDA Economics, using ABS, Viticulture, Cat. No. 1329.0.55.002, various years

Given both the changes over time in the area of vines and production, and regional differences in the incidence and impact of trunk diseases, a regional approach to analysis has been followed in the present analysis. Further, the 2015 situation re area and production likely provides a reasonable guide to the industry situation for the next few years at least and possibly in the longer term (given that the areas reflect prices over recent years).

Since regional level data is only available for area and production for 2009 and 2015 (and not the intervening years) a 3 or 5 year averages at the regional level was not able to be estimated.

Areas of vines, by climatic region, are detailed in Table 18. The allocation of wine zones to climatic zones (after Scholefield Robinson) is detailed in Table 17.

Table 17: Wine zones allocated to climatic zones

Hot-Wet	Hot-Dry	Warm- Wet	Warm- Dry	Cool
Central Ranges, NSW	Big Rivers, NSW	Northern Slopes, NSW	South West WA	South Coast, NSW
Hunter Valley, NSW	Greater Perth, WA	Central VIC	Fleurieu, SA	Gippsland, VIC
Southern NSW	Central WA	Mt Lofty Ranges, SA	Barossa Valley, SA	Port Phillip, VIC
Northern Rivers, NSW	North West VIC			Western VIC
North East VIC	Lower Murray, SA			Limestone Coast, SA
Queensland	Far North, SA			Tasmania

Source: Scolefield Robinson, pg ix.

2015 treatment costs

The costs involved in control and remediation were indexed to 2015 values (indexing 2008 prices/costs to 2015 prices/costs assuming no fundamental change in labour use or other productivity in control/remediation).

While it is possible that productivity has changed (for example, the level of labour involved) or that relative prices (labour and materials) have changed or that prices have risen faster than the Consumer Price Index, no adjustment has been made for these factors as this level of detail is not readily available.

Using the Consumer Price Index the raising factor used is 1.19 (2015 costs compared to 2008). Further, to simplify the analysis the 'most likely' values have been used (noting that Scholefield-Robinson used minimum, maximum and most likely for each of the parameter sets). The revised parameter values are presented in Table 18.

The overall area of grapes is highest in the Hot-Dry and Warm-Dry climatic zones (83% of the total area). However, the estimated proportion of the areas treated is highest in the Warm-Dry, Warm-Wet and Cool climatic zones (reflecting the higher incidence) with the overall result that the annual costs of treatment are higher in these three zones. The annual cost of treatment for Australia is estimated at $2.46m (2015 prices).

Table 18: Parameter values: Trunk diseases (after Scholefield-Robinson, Most likely) 2008 methods of treatment, proportion of vineyard area treated, frequency, incidence and yield loss (ie prior to the AGWA R&D) indexed to 2015 prices and using 2014-015 vine areas

Climatic Zone	Total area (a)	Incidence	Proportion of total area treated through ad hoc surgery (Most likely) (c)	Cost of ad hoc control (d)	Total cost of ad hoc control	Proportion of total area remedial surgery Most Likely) (c)	Cost of remediation (d)	Total cost of remediation	Total additional costs per annum
	ha	%	%	$/ha	$m	%	$/ha	$m	$m
	(i)	(ii)	(iii)	(iv)	(i)*(ii)*(iii)*(iv)	(v)	(vi)	(i)*(ii)*(v)*(vi)	
Hot-Dry	61,900	1%	0.0%	$60	$0.00	0.0%	$3,332	$0.00	$0.00
Hot-Wet	9,152	5%	1.0%	$60	$0.01	1.0%	$3,332	$0.30	$0.31
Warm-Dry	29,591	10%	5.0%	$60	$0.09	1.0%	$3,332	$0.99	$1.07
Warm-Wet	12,116	10%	5.0%	$60	$0.04	1.0%	$3,332	$0.40	$0.44
Cool	17,460	10%	5.0%	$60	$0.05	1.0%	$3,332	$0.58	$0.63
Australia	130,219	5.4%	2.3%	$60	$0.18	0.5%	$3,332	$2.28	$2.46
(a) ABS survey, 2014-15, Sourced from Wine Australia									
(b) Frequency across climatic zones (Scolefield Robinson)									
(c) Incidence across climatic zones (Scolefield Robinson)									
(d) Costs of treatment (Scolefield Robinson indexed by CPI changes to 2015)									

Source: IDA Economics using Scholefield- Robinson 2009 data and ABS data

The area of grapes is highest in the Hot-Dry and Warm-Dry climatic zones. However, the estimated proportion of the areas treated is highest in the Warm-Dry, Warm-Wet and Cool climatic zones with the overall result that the annual costs of treatment are higher in these three zones. The annual cost of treatment for Australia is estimated at $2.46m (2015 prices)

Grape prices

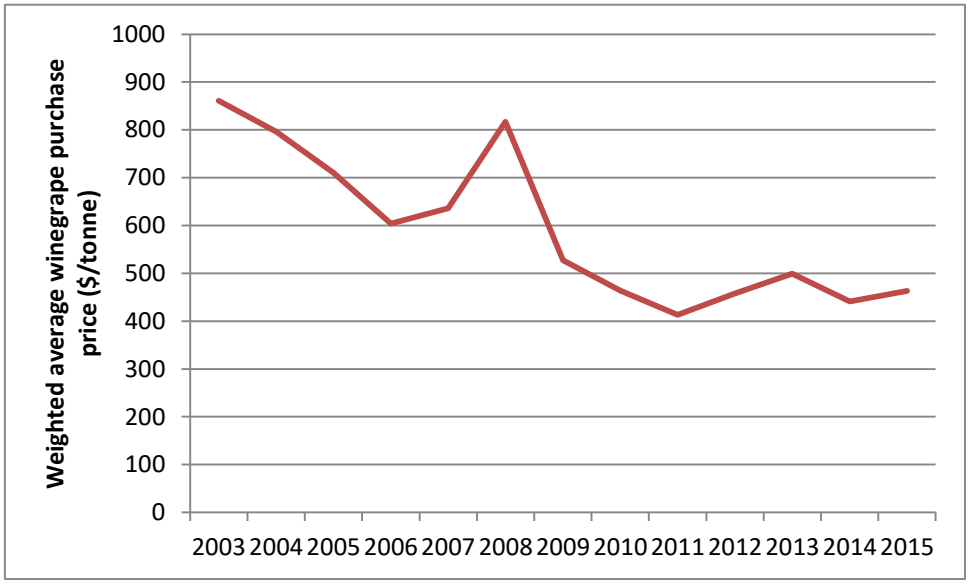
Grape prices are relevant to estimating the value of lost production from trunk diseases.

Scholefield-Robinson used an average price for grapes used for winemaking for the period 2003-04 to 2007-08, reported in 2008 dollars. Prices (nominal, ie current or dollars of the day) from 2003 to 2015 are detailed in Figure 3. The price of grapes used for winemaking has fallen significantly since the 2003 to 2008 period.

However, average prices across the industry mask the significant differences between regions.

The average wine grape price for the 2011-15 period across all growing regions was $467/tonne in nominal terms or $475/tonne in real terms (ie when adjusted for inflation). However, given that the 'Hot-Dry' Climatic zone (inland irrigated) are subject to negligible losses associated with trunk disease, and the average price for wine grapes in the regions is lower, there is a downward bias in using the average grape price.

Figure 3: Wine grape prices: 2003 to 2015 vintage

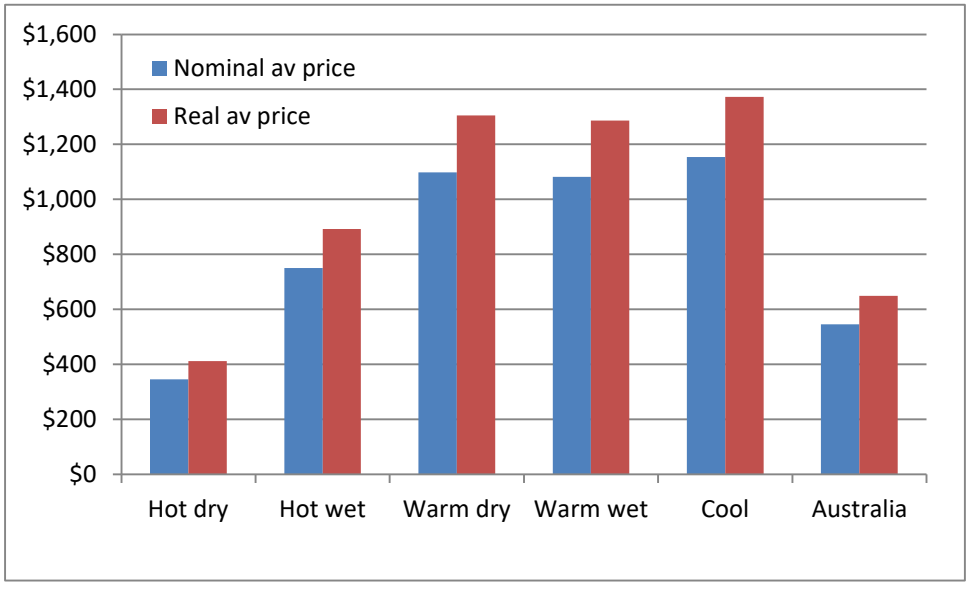


Source: Winemakers' Federation of Australia, Vintage Report 2015

The value of lost production will reflect lost revenue net of any cost savings from a lower yield. However, given that most of the grape growing costs are fixed per hectare there will be little if any cost saving as a result of lower yields. Even harvesting costs (mechanised at least) are set on a per hectare/per hour basis and not per tonne harvested. To that end the value of lost production is the loss in revenue (price times quantity lost).

Grape prices differ substantially between variety and region. On a climatic region basis, (real, 2015) grape prices over the past eight years (2008 to 2015) have averaged (Australia) $650/tonne but ranged from $412/tonne (Hot-Dry) to $1373/tonne (Cool) (Figure 4).

Figure 4: Grape prices: Average 2008-2015, Nominal and Real (2015), $/tonne: By climatic zone



Source: IDA economics analysis using Wine Australia Price Dispersion data, by vintage 2008 to 2015. Real prices calculated using nominal prices and changes in the CPI

Costs of trunk disease in 2015 dollars

The estimated costs of trunk diseases, given no change in the incidence, treatment costs (other than indexing to 2015 prices) and the value of production losses (given no change in percentage yield losses, but using the 2015 production area and average 2008-15 real grape prices) are shown in Table 18 and Table 19. That is, an update of the Scholefield-Robinson estimates to reflect just changes in industry circumstances – with no impact from either disease incidence or approaches to control.

Table 19: Estimated trunk disease yield loss costs: Per annum: Pre R&D projects (real 2015 prices)

Climatic Zone	Total production (a)	Frequency (annual probability) (b)	Incidence (c)	Yield loss (d)	Average price (real 2008-15) (e)	Income loss
	t	%	%	%	$/t	$m
	(i)	(ii)	(iii)	(iv)	(v)	(i)*(ii)*(iii)*(iv)*(v)
Hot-Dry	1,165,660	100%	1%	1%	$412	$0.02
Hot-Wet	50,545	100%	5%	10%	$892	$0.23
Warm-Dry	174,156	100%	10%	10%	$1,306	$2.27
Warm-Wet	80,287	100%	10%	10%	$1,287	$1.03
Cool	137,490	100%	10%	20%	$1,373	$3.77
Australia	1,608,138	100%	3.3%	4.0%	$650	$7.33
(a) ABS survey, 2014-15, Sourced from Wine Australia						
(b) Frequency across climatic zones (Scolefield Robinson)						
(c) Incidence across climatic zones (Scolefield Robinson)						
(d) Yield loss across climatic zones (Scolefield Robinson)						
(e) Average real price by climatic zone (Wine Australia, Price dispersion data), adjusted by CPI changes to 2015						

Source: IDA Economics, using Scholefield- Robinson 2009 data and ABS data

Given these updates, the 2015 costs of trunk disease are estimated at $9.8m per annum ($2.45m in additional treatment costs plus $7.33 m in lost income due to yield loss).

Projecting forward 2015 costs to reflect increasing trunk disease incidence

The current incidence, suggested by the AGWA research, more or less aligns with the 'most likely' estimate used by Scholefield –Robinson (Box 4). In summary, the AWGA R&D projects report the following.

- The incidence is significant in South Australia, of the order of 4% to 4.9% across all vineyards (based on only foliar symptoms – the past approach to assessment). However, assessing vines on dieback (rather than foliar), as is now more usual, better reflects production losses. On this basis the incidence of dieback would be significantly higher. In a Limestone Coast survey in 2012, the overall mean incidence of dieback was put at 41%.[18] Similar numbers could be expected in some of the more established regions like Barossa, McLaren Vale, Clare, Yarra Valley.[19] Further, it is probable that the overall incidence has increased over the past 15-20 years, mainly due to aging of vines over that period.
- Further,

  In SA, research revealed up to 100% of grapevines, in some vineyards, to be affected by eutypa dieback. E. lata appears to be more widespread in NSW than first expected

18 Dr Mark Sosnowski, pers. comm.

19 *ibid.*

and has been isolated, along with other diatrypaceae fungi, from the Central Ranges, southern NSW and Big Rivers districts.[20]

- The disease is likely widespread in Tasmanian vineyards.
- There is little if any incidence in Western Australia.
- The disease is likely to be significant in NSW and Victoria, given earlier studies and the likelihood of infection from co-existing stone fruit in grape growing regions.

Scholefield-Robinson "most likely" estimates of incidence, by climatic zone, are reported in Table 20. When weighted by respective areas of vines (2015) the average incidence across Australia is estimated at 5.4%.

Table 20: Scholefield-Robinson estimates of Eutypa incidence: By climatic zone: 2009

Climatic region	Most likely incidence
Hot-Dry	1%
Hot-Wet	5%
Warm-Dry	10%
Warm-Wet	10%
Cool	10%

Box 4: Incidence and threat of Eutypa dieback

Project SAR 06/01 outlined that:

E. lata is widespread in most areas of the world where grapevines are cultivated. At the beginning of Project SAR06/01, eutypa dieback had been officially reported in South Australia and Victoria (Wicks 1975, Carter 1991, Highet and Wicks 1996) and since then Pitt et al. (2010) have reported *E. lata* in New South Wales. In 1968 and 1997, the extent of eutypa dieback symptoms was documented for established wine regions of South Australia such as Barossa Valley, McLaren Vale, Coonawarra, Langhorne Creek, Riverland and Clare. The incidence of eutypa dieback in emerging wine regions such as the Adelaide Hills, Fleurieu Peninsula and Mt Benson in South Australia has not been determined, so little preventative action is being taken. Determining the presence and extent of the disease in these regions would alert and encourage growers to monitor for disease symptoms and undertake preventative action, if warranted(pg. 37).

Project SAR 06/01, based on extensive field work, reported the incidence of eutypa in South Australia as follows (pg 37). (However, the survey focussed only on the emerging – younger vines - regions: the established regions are likely to have much higher incidence, as noted above in respect of the Limestone Coast).

In Adelaide Hills, foliar symptoms of eutypa dieback were recorded on 4% of all vines and in 90% of all vineyards surveyed. The greatest incidence of symptoms recorded was 27% in 10-year-old Cabernet sauvignon with incidence of above 20% in a further six blocks, including Shiraz, Cabernet Sauvignon and Chardonnay vines between 16 and 25 years old.

In Mt Benson, foliar symptoms of eutypa dieback were recorded on 0.02% of all vines and in 15% of all vineyards surveyed. One vineyard had two vines with symptoms in 12-year-old Cabernet Sauvignon block and a second vineyard had one vine with symptoms in a 14-year-old Cabernet Sauvignon block.

In Southern Fleurieu, foliar symptoms of eutypa dieback were recorded on 2% of all vines and in 15% of all vineyards surveyed. The highest incidences recorded in individual blocks were 34 and 16%, both in 19 yo Cabernet Sauvignon, with all other blocks having less than 10% of vines with symptoms.

[20] National Wine and Grape Industry Centre, *Grapevine Trunk Diseases: Symptoms and distribution*, pg.3.

Significantly, SAR 06/01 reported that the disease incidence in the Adelaide Hills (4%) was similar to the incidence observed in 1998 for all vines surveyed across established South Australian wine regions (4.9%) (Highet and Wicks, 1998) (pg. 40)

For Tasmania, SAR 06/01 noted that although trunk diseases had been reported in stone fruits, "eutypa dieback has not been officially recorded in grapevines in Tasmania, although anecdotal evidence suggested the disease occurs in some vineyards." However, SAR 06/01 field work suggested that the disease was widespread and significant. The project concluded:

Foliar symptoms were recorded in all 5 of the wine regions visited, 10 of the 16 vineyards and 18 of the 44 blocks assessed in Tasmania. Symptoms ranged from very mild, with one or two shoots affected, to severe with the majority of shoots affected … and that it is imperative that growers manage vines to protect from infection by *E. lata* (pg 4).

SAR 06/01 suggested that there were only low levels of infection in Western Australia.

Estimates of eutypa disease incidence in Victorian and NSW vineyards were not presented in SAR 06/01.

The counterfactual

In the absence of the R&D the incidence of trunk disease is likely to have increased and would continue to increase. For example, Smart has suggested that Grape Trunk Disease (GTDs) is becoming more important, even with various management strategies in place.

> *Generally their (GTDs) presence is insidious, as spread, vine decline and death are slower. Even today GTDis are infrequently recognised. Control based on genetic resistance seems remote, and chemical/biological control is not universally proven. Worse, some GTD are being spread much more systematically than phylloxera ever was, because nurserymen unwittingly use GTD infected rootstocks. Paradoxically, it may be the planting of virus-free rootstock mother vines 10-30 years ago, and their subsequent infection by some GTD, which is responsible for the apparent recent rise of GTD in many countries.*[21]

Researchers report that surveying to assess the incidence of GTD has not been easy to get resourced. However, new technologies such as remote sensing technology are being evaluated to provide disease severity across vineyards and regions to provide better figures for levels of disease across the country. [22]

However, care is needed in generalizing GTDs. The predominant trunk disease R&D investment has gone into is Eutypa Dieback. Its spread to new vines occurs 'naturally' with spores landing on open wounds, germinating and beginning to kill woody tissue in the previously healthy vine. In the above quote 'grapevine trunk disease' is used very broadly and includes those which are commonly passed on in the nursery from mothervines to rootlings. This is not likely the case for eutypa dieback as most of the infected vines are mature, bearing vines.

In the absence of a systematic analysis of possible trends in the incidence of trunk diseases, but recognising that the incidence is likely to increase, an indicative rate of increase of has been used. The issue of trend rates of increase is further complicated by the differing views of the start level of existing incidence. While past research and indeed the R&D projects themselves suggest an incidence level of under 10%, other research (as reported above) suggests a markedly higher incidence. Given the easy transmission between vines, a higher

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21 R.E. Smart, and F. Fontaine, Grapevine trunk diseases in 2014. How comparable to phylloxera in 1881? Grapegrower, May-June 2015

22 Dr Mark Sosnowski, pers. comm.

initial incidence suggests that the disease would spread quickly within and between vineyards.

For present purposes the incidence of trunk diseases (in the absence of the R&D) is estimated to increase by 2% per annum (base case) with sensitivity analysis undertaken at 0.5% and 5%. The resulting incidence levels in 2030 by climatic zone are shown in Table 21.

Table 21: Estimated incidence in 2030 given rates of increases in incidence

	2009 incidence	Annual (compound) increase in incidence		
		0.5%	2%	5%
Hot-Dry	1%	1%	2%	3%
Hot-Wet	5%	6%	8%	14%
Warm-Dry	10%	11%	15%	28%
Warm-Wet	10%	11%	15%	28%
Cool	10%	11%	15%	28%
Australia	5.4%	6.0%	8.1%	15.0%

Impacts of R&D projects

The outputs from the R&D projects can be expected to impact disease costs in two main ways.

- Improved information to growers regarding the effectiveness of treatment. Thus growers can be more confident that treatment will be effective. In particular improved techniques for wound protection to avoid infection.
- Decision tools to help growers to decide when and how to treat situations specific to their vineyards. In particular a decision analysis model for the rehabilitation of Shiraz vineyards affected by Eutypa dieback (Box 5).

Box 5: Decision support tool and cost benefit analysis

As part of SAR 06/01a decision tool was built and a cost benefit analysis of remedial surgery undertaken. That analysis noted the following.

Remedial surgery is labour-intensive and the decision on whether to proceed needs to be made on a case by case basis. The benefits of this management strategy may outweigh the costs if the quality and value of the fruit is above average and if the disease has not progressed to ground level in trunks of vines.

This study aimed to conduct a cost-benefit analysis based on data collected during GWRDC and CRCV eutypa dieback projects which would contribute to developing a decision support system to aid growers manage eutypa dieback effectively. In summary, the cost-benefit analysis has provided a preliminary decision support model which is able to: extrapolate and predict economic returns of different decision scenarios in a Shiraz vineyard affected by eutypa dieback.

Maintenance of vineyards in a disease-free condition following remedial surgery by expending approximately $50 per hectare each year to monitor and remove any diseased vines that appear will ensure continued good economic returns for the vineyard.

The cost of retrellising made little difference to the outcome of the model, suggesting it is a small investment for sustainability of vines.

In general, if the incidence of foliar symptoms is below 10%, remedial surgery can be delayed several years without incurring significant losses, however once incidence exceeds 20% it is imperative action is taken to avoid long-term economic losses.

However, the model is limited to Shiraz vines as most data available concerned this cultivar and, due to variable susceptibility to eutypa dieback, further data need to be generated for a range of commonly grown cultivars.

Source: Appendix 1, AGWA Project SAR 06 01.

These developments can be expected to have achieved (or will achieve) the following.

- Better treatment and remediation strategies, leading to some cost savings for growers when treating and investing in remediation.
- Overall, additional treatment and remediation in vineyards given the demonstrated returns from treatment and remediation, resulting in reduced disease incidence and consequent lower yield loss in vineyards and, in turn, net financial gains to growers.
- In the absence of the R&D and subsequent grower response, it is highly probable that the incidence of trunk disease would have increased (as discussed above with the otherwise, counterfactual, cases reported in Table 21).

In the absence of data detailing adoption of treatment and remediation by growers to date or anticipated, possible scenarios have been examined.

- Cost savings for growers for treatment and remediation could be 5-10% as growers change their practices based on the R&D findings.
- The R&D findings will have some impact upon the disease incidence but will not necessarily result in a fall in the overall observed disease incidence. The underlying trend (or otherwise case) is an increase in incidence. The benefit of the R&D is the difference in disease incidence with and without the R&D.
- Some absolute reduction in incidence is possible, especially in the Cool and Warm-Dry and Warm-Wet climatic zones where the financial consequences of lower yields are more significant and hence the returns from remediation higher.

Table 22 summarises the scenarios examined.

These scenarios maybe quite conservative. If, as noted above, the incidence of trunk disease in South Australia is considerable higher (at around 40% compared to 10%) then the consequences of doing nothing (more or less the without R&D scenario) are more substantial (increased incidence) and the impact of the R&D potentially more significant.

Table 22: Impact scenarios

Cost reductions				
	5% on 50% of the area treated/remediated			
Incidence		Otherwise case	Scenario 1	Scenario 2
	2009	No R&D (2% pa increase in incidence)	R&D (Rate of incidence increase held at 1% pa)	R&D (Rate of incidence increase held at 1% pa for Hot zones; 0% pa in other zones)
	2030 incidence	2030 incidence	2030 incidence	2030 incidence
Hot-Dry	1%	2%	1%	1%
Hot-Wet	5%	8%	6%	6%
Warm-Dry	10%	15%	12%	10%
Warm-Wet	10%	15%	12%	10%
Cool	10%	15%	12%	10%
Australia	5.4%	8%	6.6%	5.6%

Benefits from R&D

The estimated benefits for the scenarios outlined are presented in Table 23.

Table 23: Trunk disease: Estimated benefits from R&D: 2009-2030: 2015 real Present Value: $m

		Otherwise case	Scenario 1	Scenario 2
	2009	No R&D (2% pa increase in incidence)	R&D (Rate of incidence increase held at 1% pa)	R&D (Rate of incidence increase held at 1% pa for Hot zones; 0% pa in other zones)
Cost reductions due to R&D adoption				
Ad hoc treatment			$0.2	$0.2
Remediation			$2	$2
Income loss	$134	$160	$147	$135
Avoided yield loss due to R&D adoption			$14	$25
Total gain			$16	$28

Source: IDA estimates

The estimated benefits highlight three issues.

- Most of the estimated benefit derives from the avoided yield loss.
- The estimated losses from trunk diseases are considerable, even with the estimated impact of adoption of the R&D findings on reducing the disease incidence.

- Reducing the level of incidence (and yield loss) in the Warm and Cool climatic zones has high payoffs given the higher value of grapes in these regions. Significantly, the R&D (and in particular the decision making support tools developed in the R&D) has focussed on these zones.

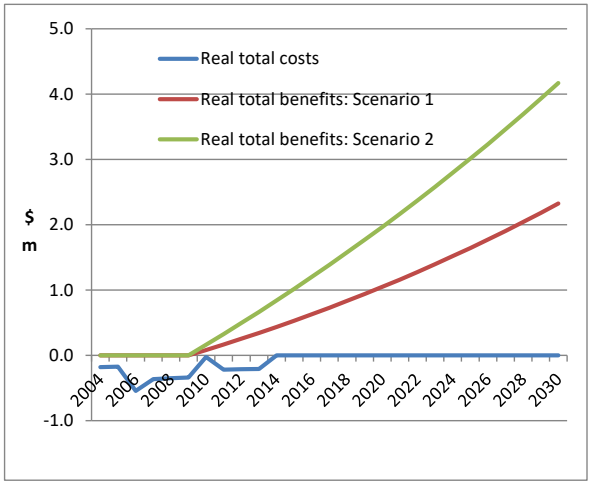
Investment analysis

Rates of return

The time profile of estimated industry net benefits and AGWA and co-investor R&D costs is shown in

Figure 5.

Figure 5: Estimated benefits and R&D costs: Time profile: $m (undiscounted)



Source: IDA estimates

The investment analysis for the AGWA and co-investor investment in projects CRV 03/06S; SAR 06/01; GWR IN0905 and SAR 1001 is summarised in Table 24.

Table 24: Investment analysis: AGWA and co-investor investment in Eutypa R&D projects: 2003-2030: Present real value 2015 (5% discount rate)

		Scenario 1	Scenario 2
Present value of benefits	$m	$15.4	$28.5
Present value of R&D costs	$m	$3.7	$3.7
Net Present Value	$m	$11.7	$24.8
Benefit/cost ratio	ratio	4	8
Internal Rate of Return	%	17%	24%

Source: IDA estimates

Under both scenarios the investment has returned a positive return. The Net Present Value of the investment is between $11m and $25m with an internal rate of return of at least 17%. The Benefit Cost ratio is calculated at 4 (Scenario 1) and 8 (Scenario 2).

While the analysis presents two scenarios, Scenario 2 is quite probable given the higher returns to growers from addressing trunk diseases and it is possible that it is too conservative. The investment return from Scenario 2 is considered an appropriate measure of the returns from the AGWA and co-investor R&D investment in trunk disease.

6. Vine nutrition and management

Projects

Wine Australia identified four projects focussed on vine nutrition for analysis.

- CRV 99/19b: Grapevine nutrition : Research to Practice (4.4.3)
- GWR IN1108: Post-harvest care of vines: irrigation and nutrition
- NWG 0601: Winegrowing Futures - Theme 3 - Multi-seasonal impacts on vine productivity and grape composition
- NWG 0601: Winegrowing Futures - Theme 4 - Optimising resource use and protecting the environment Exp. 4.5 - Grapevine nutrient reserves and their impact on grape yield variability and yield estimation

Investment

The investment in the selected plant nutrition projects is shown in Table 25.

Table 25: R&D investment in selected plant nutrition projects (dollars of the day)

Project	Start	Finish	Status	Research agency/co-investor	Total investment	Wine Australia
CRV 99/19b	01/07/1999	30/06/2002	Finished	Cooperative Research Centre for Viticulture	$124,536	$97,137
GWR IN1108	13/02/2012	31/05/2012	Finished	Charles Sturt University	$3,000	$2,728
NWG 0601 Theme 3	2007	2011	Finished	National Wine and Grape Industry Centre	$1,896,731	$1,896,731
NWG 0601 Theme 4	2007	2011	Finished	National Wine and Grape Industry Centre	$2,276,216	$2,276,216
					$4,300,484	$4,272,813

Source: Wine Australia

Project summaries

CRV 99/19b: Cooperative Research Centre for Viticulture: Grapevine nutrition: Research to Practice (4.4.3)

Summary

The change from routine use of fertilisers to a more strategic or integrated approach to nutrition management in the vineyard impacts on the need to provide grower training and education to ensure ideas of best nutritional practice are adopted. Grapevine nutrition managers need a framework for developing an improved capacity for identifying and implementing strategic decisions. This includes not only the technological competence, but

also developing a positive perspective with the confidence and commitment to implement the changes. Managers need a clear understanding of the options available and the dynamics of their agricultural system with up-to-date information, user-friendly identification and diagnostic tools. Scientific research needs to be translated into information and methodology that works 'on the ground'.

The aim of the project was to develop and maintain a flexible model that brings these various aspects of grapevine nutrition together, while making them accessible to growers and resulting in effective incorporation of research results into nutritional management practices in Australia. The model has been tested over three seasons with more than 500 participants involving growers, vineyard managers, company grower liaison officers/technical officers, researchers, fertiliser company representatives, extension workers and educators. Evaluation of results to date suggests that there have been a number of direct benefits from this program, including important changes in monitoring and testing grapevine health, associated fertiliser practices and improved understanding of industry research priorities. A number of indirect benefits have also resulted from the information being passed on by company grower liaison officers / technical officers and educators to growers who haven't personally attended a workshop.

Project GWR IN1108: Post-harvest care of vines: irrigation and nutrition

A small project involving industry presentations

Project NWG 0601: National Wine & Grape Industry Centre: Winegrowing Futures - Theme 3 – Multi-seasonal impacts on vine productivity and grape composition

The project examined the environmental stresses that influence yield and berry composition over several seasons. Project 3.1 assessed the impacts of heat stress on berry composition and assessed the benefits of hydrocooling on vine and reproductive development. Project 3.2 focused on characterizing seasonal changes in nutrient and carbohydrate partitioning within the vine and assessed the impact of targeted nutrient applications on berry development. Project 3.3 provided fundamental information on how water and nutrients are transported to the berries and the consequences of this on berry size, composition. It also assessed the causes of fruit shriveling and splitting.

Heat stress: project outcomes

- Strategies to help growers better manage the impact of heat stress on grape bunches
- Identified how heat stress impacts on grapevine growth and berry development processes in the Riverina.
- Identified thresholds in temperature stress for Semillon
- Identified protective methods to allow vines to withstand heatwaves including hydrocooling
- Assessed the impact of heat waves on berry sunburn and resultant properties of the wine
- Recommendations:
    - Recommendations on vineyard management to ameliorate heat stress including row orientation (avoiding N-S rows which suffer damage from the westerly afternoon sun), aspect, canopy architecture (adding foliage wires to allows the canopy to sprawl over and shade the fruit) and management (such

as avoiding trimming and leaf plucking), increasing irrigation prior to the heat event, and soil management (avoiding bare soil to minimize heat radiation from the soil).

    - Implementation of hydrocooling system in the Riverina
    - Change in canopy management to encourage shading of fruit

Vascular transport

- Better understanding of environmental and physiological factors impacting on Shiraz berry development, ripening, quality and volume.
- Developed a technique to improve our understanding of functional vascular connections in the grapevine.
- Information on the natural abundance of $^{18}O/^{16}O$ in berries as integrated signal for shoot stomatal conductance and resultant method to assess differences in water-use characteristics amongst varieties
- Demonstrated that splitting is a function of berry ripeness, berry cultivar, air drying potential and berry temperature
- Demonstrated that berry age is a more reliable indicator of susceptibility to berry splitting than sugar 'maturity'.
- Demonstrated that shriveling is a developmental process and can be exacerbated by heat events
- Showed that standard irrigation can ameliorate the extent of shriveling relative to deficit irrigation.
- Recommendations

    - Harvest fruit prior to rain events that are likely to induce splitting. But the decision to harvest is dependent on the risk strategy of the vineyard operator and winemaker.
    - Encourage air movement in the canopy
    - Avoid planting cultivars that are prone to splitting
    - Irrigate during late ripening in Shiraz to ameliorate the level of volume loss from berries if lower alcohol is desired
    - Harvest fruit at an earlier stage of ripening before extensive volume loss
    - Implementation of fruit shading practices during late ripening to decrease shrivelling

Summary

Research in this theme has improved our understanding of seasonal nutrient dynamics in the perennial structure and the allocation to different organs of grapevines. This work showed the seasonal nutrient requirement by the annual growth and the importance of the perennial structure to provide nutrients to the early canopy development and, to a lesser extent to the reproductive development. The intra-seasonal changes have been assessed in two Shiraz trials, indicating the variation of the nutrient reserve pool between years. In addition, the

work suggests that the nutrient reserves differ between rootstocks and can be altered by water and N supply.

The relationship between root dynamics, nutrient accumulation and vine reserves was inconclusive and this requires further research.

Furthermore, findings have identified future research directions and a portion of the data can be utilised for further work. These existing data on nutrient acquisition and reserve mobilisation can be utilised to enhance the timing and amounts of nutrient application, with the potential of integration into a grapevine model. However, the importance of nutrient supply from uptake or storage for early canopy growth and the acquisition of nutrients during berry development on berry composition will require further experimentation.

The project has further determined the importance of the roots as a storage organ, with its accumulated nutrients showing significant seasonal changes and between seasons. These dynamics are driven by the partitioning of the grapevine and the root environment, with factors such as soil temperature, water and nutrient supply. The understanding of the response of grapevines in relation to nutrient acquisition to the range of vine root environments relevant to current and future climatic trends is crucial. The predicted climatic changes will be reflected in the above and below ground environment and is important to understand the nutrition equitation and utilisation under various conditions for sustainable grape production. Future research on nutrition needs to integrate the soil processes, since they strongly contribute to the availability of nutrients for vine development and ultimately for the characteristics of grapes produced from a particular vineyard in a wine region.

Project NWG 0601: National Wine & Grape Industry Centre: Winegrowing Futures - Theme 4 Optimising resource use and protecting the environment Exp. 4.5 - Grapevine nutrient reserves and their impact on grape yield variability and yield estimation

Abstract

Optimising viticultural resource use for economic and environmental sustainability broadly requires knowledge of the impact of resource use practices, and opportunities to improve them. Research in Theme 4 was thus directed along two streams; one which determined the impact of water and nitrogen use in warm, irrigated inland vineyards and the other which revealed opportunities to use new tools, including remote sensing and spatial technologies to understand and optimise the use of those resources for achieving production and environmental goals.

Summary

Knowledge of soil-water movement in vineyards is essential for the management of irrigation, soil nutrition and salinity. This research aimed to determine the extent of water and nutrient losses from vineyards under differing irrigation and fertiliser strategies, the factors that determine those losses and how to measure deep drainage in real-time based on in-situ measurement of water potential gradient as input to general models of soil water movement.

The extent of water and nutrient losses from vineyards was researched in three complementary projects involving:

- The extension of a multi-vineyard study to determine the typical concentrations of nitrogen in the soil-water solution and runoff from vineyards;

- A study of solute movement in soil using bromide as a tracer to simulate nitrate and chloride transport under drip emitters; and
- The use of a dual tube tensiometer and soil hydraulic flow models to determine deep drainage from the rootzone from changes in soil water potential between two points.

The multi-vineyard field study examined soil nitrogen (N) dynamics in both drip and furrow-irrigated vineyards, on three soil types. Nitrogen concentrations combined with the number of days in which drainage below the rootzone was likely indicated that subsurface pathways represent a potential N export risk from vineyards. The risk of leaching N from vineyards was related to its concentration in the soil-water solution, and fertiliser application and irrigation practices. As grapevines in most vineyards had more than adequate N the study revealed a significant opportunity to reduce the risk of environmental impacts and production costs by reducing applications of N. A web-based irrigation scheduling tool which normalised data from a range of different soil water measuring devices was developed to assist grapegrower participants in this study. That tool was successfully tested by farmers and consultants and led to modification of grower practices for greater efficiency of water use in drip irrigated vineyards. The study identified regional differences in irrigation and fertiliser associated with particular production targets and thus highlighted the need for a regional approach to nitrogen and water management in vineyards.

Experiment 4.5 (Grapevine nutrient reserves and their impact on grape yield variability and yield estimation) aimed to:

- Develop guidelines for irrigation and fertiliser management strategies to reduce nutrient loss in drainage water.
- Develop a practical on-farm EMS plan-do-check-act cycle to suit vineyard best management practices (BMPs).
- Stratify vineyard sampling for yield prediction on the basis of remote sensing data and analyse remotely sensed data of individual grapevines at key phenological stages.

The outcomes and conclusions of Experiment 4.5 as outlined in the Final Report can be summarised as follows (Final Report, pgs. 89-90).

Carbohydrate reserve dynamics

- Measurements of carbohydrate reserves at dormancy may provide an indicator of canopy growth in the following spring, and also the capacity of the vine to express full yield potential as determined by the extent of inflorescence initiation and differentiation in the preceding season. To facilitate incorporation of a carbohydrate reserve test into commercial vineyard management practices or future yield forecasting models, a rapid ATR-FT-IR method was developed for starch (and also nitrogen reserves) in root, wood and cane tissue.

Carbohydrate reserves: measurement versus management

- Carbohydrate reserve dynamics are predominantly driven by developmental stage and climatic factors. Carbohydrate reserve mobilisation or restoration can be manipulated in the vineyard, but severe defoliation or crop removal treatments appear to be required to achieve this. For more realistic management practices such as crop thinning or deficit irrigation, there appears to be little scope to deliberately alter carbohydrate reserve status in the shorter term. The rapid method for assessing starch concentrations in perennial tissues (as above) will also be suitable for the free sugar fraction of the non-structural carbohydrate reserves. Measurement of over-wintering

reserves has considerable potential as a predictor of canopy growth and yield potential if a database is compiled over multiple seasons.

Grapevine balance model

- At present there is insufficient knowledge of the physiological processes underlying flowering and berry development for models to make accurate yield or fruit quality predictions. However, with the ability of existing models to accurately simulate photosynthesis (eg. Schultz 2003), and the availability of software to model canopy structure in three dimensions, the ability to estimate the likely effects of weather conditions or water availability on net photosynthetic capacity could in itself be a valuable management tool for growers.
- It is known that reserves can be mobilised to support berry ripening, but the consequence for secondary berry metabolite production is unknown. The challenge also remains to relate the internal carbohydrate availability to berry composition and ripening rate. In the preliminary model output data shown in this report we have presented net canopy photosynthesis in a manner that highlights the differences between seasons. It is proposed that such an approach, whereby seasons are compared and related to fruit composition, may offer grape growers with a chance to predict seasonal variations in fruit composition and provide some advanced warning for management intervention in the vineyard.

Other benefit cost analysis

Other relevant studies have not been identified. There does not appear to have been an individual or overall economic analysis of the CRC for Viticulture nor the National Wine & Grape Industry Centre programs related to vine nutrition. That said, the Review of the Wine Futures Program (November 2009) outlined that the R&D had produced results that had application to the industry (Box 6).

Box 6: Wine Futures Review 2009: Theme 3: Seasonal Impacts on Productivity and Grape Composition

Stream 2: Nutrients, Assimilates and Root Dynamics

A. SCIENTIFIC AND TECHNICAL ACHIEVEMENTS	Rating Mainstream
1. Quality of Research Methodologies and Outputs The quality of research is good. How aligned is the research to industry priorities This research is well aligned with the industry priorities as established at the start of the program. Performance against milestones Performance seems to be well aligned with industry priorities. However, since milestones were not presented performance against milestones was difficult to assess.	

New knowledge generated
Minirhizotron root growth data is novel for Shiraz under Australian conditions
The information provided so far will assist in development of vineyard management strategies to optimise vine nutrient utilization.
Questioning revealed no significant differences between rootstocks in vine vigour, as assessed by weights of pruning wood. This is surprising since in most other trials, vines on Ramsey have higher vigour than vines on own roots. Accordingly, a note of caution should be applied when extending these results.

Scientific Publications
The PowerPoint presentation listed only one publication in peer reviewed journals, this was a CRC for Viticulture PhD student study. The distributed publications list included additional papers, two were on carbohydrate reserves.
Conferences, and technical journal articles, as well as presentations and lectures to CSU students, seem to be satisfactory.

B. IMPACT OF THE WINE FUTURES PROGRAM ON RESEARCH, EDUCATION, AND EXTENSION CAPACITY BUILDING FOR THE INDUSTRY cont.	Rating Mainstream
3. Collaboration and Cooperation with Other Research, Education and Extension Groups Details were not given in the report 3.1 Extent of National and international collaborations (overall) Details were not given in the report. However, it was clear that some interaction had occurred with US researches in relation to the minirhizotron work	
3.2 Relevance to goals, achievements, outputs and outcomes of the program The research seems relevant to the goals of the program. Examples of outputs leading to practice change were not clearly enunciated.	

C. PROPOSED FUTURE DIRECTIONS	
Extended Funding to Address Current Priorities Extending funding is essential for accumulating additional data that will reflect long term root dynamics as well as CHO and N reserve fluctuations during changing climatic conditions. 1.1 Identify any areas in the program that may be adopted by industry and have high impact on the industry if focused on for continued funding. The present study requires collection of data over a few years. Some of the results have potential for an immediate impact on the industry. Continued funding may have a greater impact on the industry. The proposed future research seems to be a logical step forward, however, care will be needed in assessing the effects of soil temperature under field conditions since it may be difficult to map soil temperature in relation to the entire root system.	

There are clear links here to the work proposed in Theme 4. There appears to be interest in using modelling in components of Themes 3 and 4 as a research tool from the perspective of root, soil, nutrient interactions and how this interacts with plant growth and development and then how all of this interacts with climate. There is an opportunity to use this approach as an integrating factor across Themes 3 and 4, provided the planned work is well aligned with industry priorities and planned outputs and industry outcomes are well articulated in terms of potential for adoption and timescales for potential impact are carefully considered and outlined. This would be a two-way interaction with industry and may be assisted by a workshop –based planning approach during the lead up to WF2 proposal.	

R&D outputs

Outputs from the projects comprised workshops, field days, advisory material and reports produced during the projects and on completion (Final Reports) with subsequent material incorporating the R&D findings. As well as output relevant directly to growers the information arising from the R&D has been incorporated in viticulture training and teaching.

The CRC for Viticulture project was primarily concerned with 'extension' in the broad sense of relaying R&D information directly to growers and service groups supporting growers (for example, commercial and government advisors).

National Wine & Grape Industry Centre projects focussed on specific research issues:

- Theme 3: Multi-seasonal impacts on vine productivity and grape composition
- Theme 4: Experiment 4.5 (Grapevine nutrient reserves and their impact on grape yield variability and yield estimation)

CRV 99/19b Grapevine nutrition: Research to Practice workshops

The Grapevine Nutrition: Research to Practice® workshop is a successful continuation of Research to Practice® (Viticulture).

- The Research to Practice® (Viticulture) concept was developed specifically to facilitate the incorporation of research outcomes into practical and economically feasible strategies and practices for vineyard management and grape production in each viticulture region of Australia. The Research to Practice® process is dynamic and workshop programs change rapidly as feedback and participants' needs are analysed. Presentations change from one workshop to the next not only to take into account regional variations, but also in response to evaluation by the participants and speakers
- The Grapevine Nutrition workshop is modeled on the successful IPM and Water Management for Grape Production: Research to Practice® workshops. The training program is a 2 day structured interactive workshop with a third day held after vintage for groups of up to 25 in each region.

National Wine and Grape Industry Centre: NWG 0601

National Wine and Grape Industry Centre: Winegrowing Futures: Theme 3: *Multi-seasonal impacts on vine productivity and grape composition*, Final Report

Grapevine nutrition: Research to Practice workshops

- During the project 26 workshops were delivered across 20 viticultural regions of Australia with 527 participants (Table 26).
- Workshop participants comprised growers, small companies and contract management (76%); corporate employees (17%); and others (agribusiness consultants, TAFE, university and state agriculture departments) (7%).

Table 26: Grapevine Nutrition: Research to Practice® workshops: Number of workshops and participants

State	Region	Number of workshops	Number of participants
South Australia	McLaren Vale	3	60
	South East	1	25
	Adelaide Hills	2	40
	Barossa Valley	1	24
	Riverland	1	26
	Langhorne Creek	1	23
	Clare Valley	1	20
Victoria	Sunraysia	1	17
	Geelong	1	18
	Melbourne	1	10
	Central Victoria	2	38
	Great Western	1	16
New South Wales	Riverina	2	36
	Cowra	1	14
	Hunter Valley	1	24
	Mudgee	1	27
Tasmania	Hobart	1	23
Western Australia	Margaret River	2	44
	Albany	1	19
Queensland	Granite Belt	1	23

Source: Project CRV 99/19b Final Report, pg. 21.

- The workshops were reported as being successful from the viewpoint of information transfer, the opportunity for participants to discuss issues and, a manual for future reference use. Also, the Report noted that it was anticipated that there would be a wider group of growers who would benefit as workshop participants shared their knowledge with other growers.
- The Final Report noted potential and subsequent changes in vineyard practices.

  "Many participants said that they foresaw improvements in their vineyard nutrition management as a result of attending the workshop and comments from the follow up day indicated this occurred. A large number of participants started or increased their frequency of soil and tissue testing with following changes in monitoring observed as a result."

  "Many ultimately saved time and money on streamlining their vineyards nutritional needs by not putting out unrequired fertiliser products and as a result saw improvements in vine health and fruit quality. All these findings indicate that the program was successful at providing a framework for the uptake of new nutritional

management strategies. Many appeared more confident about implementing change at the third day as a result of the framework that was provided to give them support". (Project CRV 99/19b Final Report, pg. 27).

- The Final Report identified changes planned for the Grapevine Nutrition: Research to Practice® program, including improvements to the delivery of information, processes involved in that delivery and other issues such as commercialisation, widening the scope to support growers in assessing changes to profitability.

National Wine and Grape Industry Centre: Winegrowing Futures: Theme 3: Multi-seasonal impacts on vine productivity and grape composition

The Final Report lists the following outputs.

- 10 (plus two in press and two submitted) refereed publications across the lifetime of the theme

11 industry and technical publications on resource allocation, environmental interaction and berry composition

- 18 industry presentations at AWITC in 2007 and 2010; and at the NWGIC Annual Symposiums (2007 to 2010).
- 18 presentations to grower associations in the grape growing regions.
- Five lectures developed and presented (Undergraduate, including Honours programs, training of students enrolled in CSU's viticulture and wine science courses).
- Contributions to lectures relevant to short course and certificate programs as part of training at NWGIC and partner organisations in various wine regions.
- Post graduate training of students enrolled in higher degrees at CSU (coursework Masters and research degrees.
- Two PhD students trained.
- Industry advisory notes, for example, *Vineyard nitrogen management and must and wine composition.* [23]

The Final Report outlines that the communication of the results of this research have been four-fold.

- Several peer-reviewed journal articles and industry articles have been published and several more have either been submitted or are in advanced stages of writing.
- Results have been promulgated at a number of grower and science meetings through oral communication.
- Results are presented to undergraduate student classes at Charles Sturt University.

[23] Bruno Holzapfel1, (NSW DPI, National Wine & Grape Industry Centre) and Michael Treeby (Sunraysia Horticulture Centre), "Vineyard nitrogen management and must and wine composition", *Wine and Viticulture Journal*, March/April 2016.

- Other communication of results to growers has been undertaken through the NSW WIA Grassroots Solutions Implementation Plan ‘Managing heat affected Vineyards”.

National Wine and Grape Industry Centre: Winegrowing Futures: Theme 4: Optimising resource use and protecting the environment

No communications are discussed in the Final Report. However, for Theme 4 overall, the Final Report outlines that the following outputs were achieved.

- Dissemination of results through written publications and extension programs such as On-Farm Trials, RITA demonstration sites, Research to Practice Training and integration into customised MIA EnviroWise® courses in conjunction with Murrumbidgee Irrigation (MI).
- Report outcomes from CRV Theme S2.3.6 (December 2006).
- 13 industry/technical articles across lifetime of theme.
- 14 refereed journal articles across lifetime of theme.
- Presentations at Australian Wine Industry Technical Conferences (2007 and 2010).
- Presentations at the annual NWGIC Industry Symposium (2007 to 2010).
- Presentations to industry associations in the theme regions and at NWGIC Road shows.
- Undergraduate training of students enrolled in CSU wine science and viticulture degree courses: 12 seminars/lectures/workshops.
- Short course and certificate programs offered as part of training programs offered by the NWGIC and its partner organizations in various wine regions.
- Postgraduate training of students enrolled in higher degrees at CSU (coursework Masters and research degrees): One PhD student trained.

Adoption issues: Industry impact

The issues for nutrient application would “seem” to be relatively straightforward from the viewpoint of growers considering the issues and making changes to practices in the vineyard. Specifically, the improved understanding of nutrient requirements for both inter and intra season and a more targeted approach to fertiliser application, in particular enhancing the vine’s capacity to develop in the Spring through improving nutrient uptake and general vine health in the Autumn. However, there are implementation issues including managing other factor that can limit vine performance post-harvest (disease control, water requirements) and harvest recovery especially where mechanical harvesting removes a high proportion of leaves.

With respect to the multiseasonal impacts of heat stress and factors affecting berry development some aspects of adoption (of the recommended strategies) could involve significant investment (eg hydro-cooling, depending upon the system employed) or tradeoff (when other costs are involved or opportunities forgone (eg east west row alignment or early harvest).

The impact of the R&D on nutrition and vine management could be tracked in several ways.

- Analysis of aggregate demand by grape growers for applied nutrients such as commercial fertilisers over time
- Changes in education and training material
- Reviews of advice and information growers/advisors
- Surveys of growers to track actual changes in practices and seeking to attribute the changes to the respective influences (traditional practice of some vineyards; this R&D; other R&D and advisory information).

None of the above approaches are straightforward.

- Aggregate data on fertiliser use by agriculture over time is limited; aggregate use by grape growers is even less accessible. Further, a range of factors impact upon the level of fertiliser use over time, including the financial returns from grape growing. Nonetheless, there is data for 2011-12 which provides a 'snapshot' of nitrogen and other fertiliser use (Application method (Table 27) and fertiliser applied (Table 28), although the ABS caveats re the data reliability need to be noted.
- Changes in the information available to growers/advisors can be identified, but again it does not provide information of the extent of changes in practices by growers. The R&D project outputs detail the 'industry exposure' to the information, but in the absence of tracking references in subsequent advisory notes there is no quantitative data either at a point in time or over time.
- Surveys of growers can be useful; similarly surveys of advisors. There do not appear to be surveys of growers which give an indication of changes in nutrient practices or the basis for any changes if they have occurred.
- The researchers have noted that some vineyards have implemented spraying water on the western edge during heat events to reduce heat stress and some wineries are harvesting earlier, but there does not appear to be significant levels of adoption.

Table 27: Fertiliser use: Grape growing Australia: Method of application 2011-12

Application method		ha	% of total
Broadcast on surface	(x)	59,598	31%
Drilled below surface	(x)	27,428	14%
Fertigation	(x)	70,661	37%
Sprayed on crop	(x)	34,368	18%
Other method	(z)	1,168	1%
All methods		193,222	100%

x: estimate has a relative standard error of 10% to less than 25% and should be used with caution

z: estimate has a relative standard error greater than 50% and is considered too unreliable for general use

Source ABS: Land Management Practices Survey 2011-12, Grape Growing

Table 28: Fertiliser use: Grape growing Australia: Fertiliser applied 2011-12 (x)

Fertiliser	Area applied to (ha)	Weight applied (t)	N%	N applied (t)	N applied (% of total)	N rate /ha (kg)
Urea	28,308	2,513	46%	1,156	33%	41
Ammonium sulphate	5,795	615	21%	126	4%	22
Potassium nitrate	11,688	834	14%	113	3%	10
Ammonium phosphate (a)	35,402	4,043	18%	728	21%	21
Other specialist blends (a)	32,458	5,368	20%	1,074	31%	33
Total	113,650	13,373		3,197	92%	28
		Litres applied (l)				
Urea ammoniam nitrate (b)	28,273	1,806,286	43%	283		10
Total	141,924			3,480	100%	25
(a) Estimated N %						
(b) Estimated N applied 10kg /ha; the lower rate reflecting lower atmospheric losses than broadcast granular N						

x: estimate has a relative standard error of 10% to less than 25% and should be used with caution

Source ABS: Land Management Practices Survey 2011-12, Grape Growing

Quantification

Approach: Nutrients

An approach to measure the financial, on site, potential benefits of the R&D is to work from a conclusion of Project NWG 0601.

> *"As grapevines in most vineyards had more than adequate N the study revealed a significant opportunity to reduce the risk of environmental impacts and production costs by reducing applications of N".*

Discussions with researchers suggest that there are four broad benefit areas arising from implementing the R&D:

- cost savings (more targeted fertiliser and thus reduced overall use)
- improved yields (post-harvest applications from split applications at the start and rthe end of the growing season)
- improved berry composition — amino acid profiles
- environmental benefits (reducing nutrient losses and hence benefits off site).

Further, researchers suggest that the potential gains in each area are significant: 10% cost saving; 10% yield increase and 10% quality improvement.[24]

[24] Bruno Holzapfel, NSW DPI (National Wine & Grape Industry Centre), pers. comm.

Cost savings

Analysis of aggregate industry data implies an average rate of 25kg/ha having been applied in 2011-12 (Table 28). This rate of application is broadly consistent with industry advisory material. For example,

In warm regions apply 50-60 kg of actual N per hectare in spring or split applications between spring and post-harvest is a good starting point. Observe vine vigour to determine an appropriate application rate. In cooler regions the application rate is likely to be approximately 20 kg of actual N per ha applied in spring or post-harvest. In these areas inputs from rainfall, cover crop turnover, contaminated bore water etc. are sufficient to supply the needs of the vines without additional fertiliser. [25]

The ABS survey results could be interpreted as there having been a reduction in N application rates, or that at least in 2011-12 there was a reduction. However, the ABS survey data would appear to be on the low side if advisory recommendations are being followed.

Area fertilised

In terms of the grape area fertilised there are differences in reported areas.

- The ABS survey "Method of application" implies a grape growing area of 193,222 ha in 2011-12
- However, from the ABS survey the area "by type of fertiliser applied" implies an area of 141,924ha in 2011-12
- In contrast the bearing area (*Winefacts*, 2011-12) is reported to be an area of 145,381ha and the total area 148,508ha.
- The more recent ABS survey of vineyards estimates the area in 2014-15 at 130,219ha.[26]

For present purposes the total area in 2014-15 has been used.

Analysis: Nutrients

Cost savings

On the basis of an average rate of 25kg/ha, and 130,200 ha of vineyards implies a total N use of 3.255m tonnes per annum.

If the R&D has delivered average savings of 10% of N use *across the industry* (current use 25kg/ha and no yield or other penalty), the annual benefit would be around $488,000 per annum (using $1500/tonne N, noting that N prices can fluctuate significantly year to year, depending upon word prices and the $A exchange rate).

The potential savings from the R&D can be expected to influence fertiliser use for a number of years, probably at least a decade if not longer. That is, if other R&D funded outside of Wine Australia had not shown the opportunity to reduce N application levels, the costs savings for the next decade can be attributed to the past Wine Australia R&D investment. Further, the low adoption costs (although possibly relevant if a split application is required to

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25 Such as *Grapevine nutrition. Nitrogen fertilization* AWRI ©2010. RTP 0029

26 ABS survey, *Vineyards*, 2014-15, Sourced from Wine Australia

improve effectiveness) means that producers have a strong financial incentive as long as they expect no penalty on yield.

Table 29: Estimated industry level savings from reduced N application: "Full adoption" and No yield penalty: $m per annum

Grape area total	ha	130,200		
Av N application rate	kg/ha	20	25	30
N used	t	2,604	3,255	3,906
Price N (real 2015)	$/t	$1,500		
Savings		$m	$m	$m
	1%	$0.04	$0.05	$0.06
	2.5%	$0.10	$0.12	$0.15
	5%	$0.20	$0.24	$0.29
	7.5%	$0.29	$0.37	$0.44
	10.0%	$0.39	$0.49	$0.59

Source: IDA Economics estimates

Yield

Yield increases translate into higher revenue with the additional net return about the same as the gross return (given production costs per hectare are more or less the same irrespective of yield, although harvesting costs could be a variable cost).

Using a base case of 10% yield increase at average yields (2014-15, by climatic zone) and average prices (real, 2008 to 2015, by climatic zone) implies an annual benefit of $104m across the industry (Table 30).

Table 30: Estimated value of yield increase: By climatic zone: Per annum: $m

Climatic zone	Area	Av yield	Av price	Increase in gross revenue		
	ha	t/ha	$/t	Av yield increase		
			2008-15	2.5%	5%	10%
				$m	$m	$m
Hot-Dry	61,900	18.8	412	12.0	24.0	48.0
Hot-Wet	9,152	5.5	892	1.1	2.3	4.5
Warm-Dry	29,591	5.9	1306	5.7	11.4	22.7
Warm-Wet	12,116	6.6	1287	2.6	5.2	10.3
Cool	17,460	7.9	1373	4.7	9.4	18.9
Australia	130,219	12.3	650	26	52	104

Source: IDA Economics estimates

Grape quality

A gain in grape quality can be expected to be benefit growers/wine makers as a higher grape price or a higher wine price. In practice the benefit will be shared between growers and winemakers, depending upon the market dynamics for specific varieties and associated supply and demand.

Using a base case of a 10% gain in average price (across all regions) the gain would be worth $104 per annum (Table 31).

Table 31: Estimated value of increased grape quality (higher prices): By climatic zone: Per annum: $m

Climatic zone	Production	Av price	Increase in gross revenue		
	m t	$/t	Av price increase		
		2008-15	2.5%	5%	10%
			$m	$m	$m
Hot-Dry	1.17	412	12.0	24.0	48.0
Hot-Wet	0.05	892	1.1	2.3	4.5
Warm-Dry	0.17	1306	5.7	11.4	22.7
Warm-Wet	0.08	1287	2.6	5.2	10.3
Cool	0.14	1373	4.7	9.4	18.9
Australia	1.61	650	26	52	104

Source: IDA Economics estimates

Adoption

The major uncertainty is the number of growers (or more precisely the proportion of production) which the cost savings, yield increase and quality improvement apply. While there is anecdotal comment from individual growers making changes to their fertiliser programs, there is no information on how many growers (and their production area/levels) or the range of factors driving these changes.

While the researchers have pointed to financial gains of 10% for each area of improvement (cost savings, yield gain and quality improvement, ie additive areas of gain), these are sizeable gains from one area of research. Certainly if the gains were of this magnitude, industry comment promoting the gains would be 'common place' and feedback to researchers would be significant. There is little evidence of either and the researchers recognise that they have limited information on adoption. The 2013-14, 2015-16 NSW DPI Grapevine Management Guide makes no mention of nitrogen fertiliser application although the 2011 *Post-harvest Vineyard Management Growers guide for Riverina Vineyards*[27] explicitly discusses the issue of fertiliser quantities and timing of applications.

Further there is the issue of whether grape growers were/are already managing fertiliser use in the ways suggested by the R&D. Some growers are reported to have been using a post-harvest fertilization strategy as standard practice.[28]

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27 *Post-harvest Vineyard Management Growers guide for Riverina Vineyards, March 2011*, edited by Shayne Hackett and Kristy Bartrop, Riverina Wine Grapes Marketing Board, GWRDC and the National Wine and Grape Industry Centre.

28 Bruno Holzapfel, NSW DPI (National Wine & Grape Industry Centre), pers. comm.

In the absence of empirical data on adoption or even probable adoption rates a conservative approach has been used to provide some measure of the quantifiable gains. The key estimates are as follows.

- Conservative benefits: 2.5% nitrogen fertiliser cost saving; 2.5% yield increase a 2.5% quality improvement across the industry (leading to an estimated annual benefit of $52m per annum at 100% adoption).
- No additional costs to adopt the change in fertiliser use; although in practice some (small) additional cost (specifically application costs) may be involved.
- Adoption level of 1% (of the Australian vineyard area) in 2010, rising to 15% by 2030 (implying an annual, constant, increase of 0.7 percentage points per annum). (Other scenarios of a 2030 industry wide adoption level of 10% and 25% are reported).

On the basis of these estimates a conservative estimate of the benefits is around $60m (2015 NPV to 2030) (Table 32). At a lower level of adoption (10% by 2030) the benefits are correspondingly smaller.

Table 32: Estimated benefits: Alternative timing of fertiliser applications: 2010 to 2030: $m

		Annual benefit at 100% adoption	2010 level of adoption	NPV of benefits to 2030 at 100% adoption	2030 level of adoption		
			1.0%		10%	15%	25%
				Implied annual increase in adoption (% points)			
	Change			5%	0.45%	0.7%	1.2%
		$m		$m	NPV $m	NPV $m	NPV $m
Cost savings	-2.5%	$0.12		$0.87	$0.1	$0.1	$0.2
Yield increase	2.5%	$26		$186	$21	$30	$48
Quality improvement	2.5%	$26		$186	$21	$30	$48
Total		$52		$373	$42	$60	$96

Source: IDA Economics estimates

The analysis of potential benefits highlights the implications of achieving a higher level of adoption across the industry. If applied to 25% of the area of vineyards (given the estimated benefits per ha) the benefits (ie profit increases) approach $100m (2015 NPV to 2030).

Environment

In addition to the cost savings, yield benefits and quality improvement to growers benefit, there are potential offsite benefits from improved nitrogen use efficiency. Nitrous oxide (N_2O) is a potent greenhouse gas (GHG) with a 100-year global warming potential 298 times that of carbon dioxide. N_2O emissions from agricultural soils, especially those that receive nitrogen fertiliser, contribute significantly to the total pool of atmospheric GHGs. Grape growing releases N_2O emissions as a result of nitrogen use. However, the emission levels are lower compared to the typical values from other crops such as dairy pasture. Nonetheless, further improvements in nitrogen use efficiency would reduce N_2O levels. [29] The value of these reductions in N_2O levels has not been estimated.

[29] See AWRI "Five on-farm trial sites, in the Hunter Valley, Margaret River, Murray Darling, Eden Valley and McLaren Vale regions, were established in 2012 to evaluate regional differences in N_2O emissions from vineyards. N_2O emissions from the Australian vineyards studied ranged between median values of 0.6 and 9 g N_2O expressed as N per hectare per day. These values are low compared

Analysis: Heat stress and berry development[30]

Heat affected fruit can be expected to return a lower price (25% discount has been suggested) and yields would be lower in affected areas (western sides of vineyards in particular). However, there is a cost to managing heat stress, particularly if specific irrigation is required. There is also the opportunity cost of the water (forgoing watering at another time) or the cash cost of purchasing additional water.

Fruit splitting is estimated by the researchers to affect a vineyard once every five years in the MIA with damage of 10-30% of the fruit. This results in a drop in yield. Moreover, *Botrytis* infection is common and 5% infection results in a complete rejection of the crop by the winery. Losses in sales arising from adverse quality changes could be significant.

Fruit shriveling results is reported to lead to as much as a 30% loss in yield and overly alcoholic, unbalanced wines due to sugar concentrating effects and therefore a loss in consumer confidence. Implementing vineyard management techniques and making appropriate harvest decisions can result in cost savings to the winery and increased sales.

These adverse consequences of heat stress and berry development need to be considered in a net context — the impact on grower profitability. To date there does not appear to be costings available for implementing the recommendations from the project. Combined with, what appears to be very limited (known) adoption, this suggests that the overall net benefit to the industry has been minimal at this stage.

Investment analysis

Given the above time profile of benefits and costs for the nutrient R&D, the project investment is estimated to have delivered (or will deliver) a profitable return. The net benefits are estimated to be around $53m (Table 33). The overall investment analysis is summarised in Table 33.

Table 33: Investment return: Vine nutrition (2000 to 2035, real 2015 values)

	Total investment	Wine Australia investment
Benefits ($m)	$60	$60
Costs ($m)	$7	$7
Net Benefits ($m)	$53	$53
B/C	9.1	9.1
IRR	40%	40%

Conclusion

Wine Australia's investment in vine nutrition R&D has been significant in financial terms and in contributing environmental benefits. The measured benefits have substantially exceeded the project costs. However, the estimated benefits are conservative since they do not reflect benefits such as the additional capacity with the R&D organisations (and thus the ability to respond earlier and more comprehensively to future challenges) and offsite benefits

to the typical values from other crops, such as dairy pasture (22 g N_2O-N/ha/day) or broccoli (72 g N_2O-N/ha/ day), and reflect the efficiency of water and nitrogen use in Australian wine-grape production." http://www.awri.com.au/research_and_development/rde-plan/projects/project-1-1-2/

30 Suzy Rogiers, NSW DPI, pers.comm.

such as reduced greenhouse gas emissions. Further, the estimation of benefits is based on limited analysis given little adoption data, ie how growers have changed their vine nutrition management practices.