# Stabilizing the yields of Pinot Noir grape vines in Tasmania



FINAL REPORT to
**GRAPE AND WINE RESEARCH & DEVELOPMENT**

Project Number: **UT 03/01**

Principal Investigator: **Joanna Heazlewood**

Research Organisation: **Tasmanian Institute of Agricultural Research**

Date: **April 2005**

# Stabilizing the yield of Pinot Noir grape vines in Tasmania

Joanna Heazlewood
Tasmanian Institute of Agricultural Research
University of Tasmania
Private Bag 98
Hobart
Tasmania 7001
jheazlew@utas.edu.au
Telephone 03 62 267460
Facsimile 03 62 262642

## Table of Contents

Stabilizing the yield of Pinot Noir grape vines in Tasmania ..... 1
**Table of Contents** ..... 2
Abstract: ..... 3
Executive Summary: ..... 4
Acknowledgements: ..... 6
Background: ..... 7
Project Aims and Performance targets: ..... 10
Method: ..... 10
Results and Discussion: ..... 11
Concluding remarks: ..... 14
Recommendations: ..... 15
Appendix 1: Communication: ..... 16
Publications resulting from thesis ..... 16
Appendix 2: Intellectual Property ..... 17
Appendix 3: References: ..... 18
Appendix 4: Staff ..... 19
Appendix 5: Other relevant material including raw data ..... 20
Appendix 6: Budget reconciliation ..... 20

## Abstract:

Experiments aimed at identifying influences on yield variability in Pinot Noir in the cool climate wine area of Tasmania are described. Bud number retained at dormant pruning influenced bunch number and bunch size in the form of berry number per bunch, with results varying markedly between seasons. Weather during spring in the current season was identified as a major influence on yield. Aspects of pollination were also studied and results raised some concerns about use of fungicides during anthesis. Berry colour development was inversely related to bunch size.

Results are discussed in terms of the interaction between yield and quality. An investigation of management strategies designed to reduce bunch size and adjust yields according to bunch number after anthesis is recommended.

## Executive Summary:

The issue of yield variability and the physiological factors that determine its severity and patterns of year to year fluctuation remain much of a mystery in the cool climate wine-producing region of Tasmania. Research into causes and management has generally focused on the influence of one specific factor, or issues within any one growing season, with little attention to the full cropping cycle.

Yields of both Pinot Noir and Chardonnay over an eleven-year period were analysed for correlations between vineyards and for responses to seasonal weather. Fluctuations in yield across the industry showed no consistent patterns, possibly because available data corresponded with a period of rapid growth and change throughout the region. However, yields from two vineyards with established and uniform vine age and management, were correlated with each other and with weather events corresponding with previously identified periods of sensitivity in the reproductive growth cycle. At one site a multiple regression model of yield against mean maximum daily temperature and mean sunshine hours at flowering accounted for 90% of the variation in yield. At the second site, sunshine hours and rainfall at flowering accounted for 76%, with sunshine hours alone accounting for 63%.

Due to the effects of weather at flowering on yield and uncertainty surrounding the method of pollen transfer and cross and self-pollination in *Vitis vinifera*, a detailed study into the mode of pollination in Pinot Noir was conducted. The stigmas of both open and closed flowers were examined using scanning electron microscopy and fluorescence microscopy for evidence of anthesis and pollen tube growth, and pollen viability tests were carried out on pollen from both open and closed flowers. Pollen was shown to be present and viable on stigmas prior to cap fall, however pollen tubes did not begin to grow until after cap fall. Bagging of inflorescences throughout flowering in field vines, found that fruitset was not related to cross-pollination.

In view of the effect of cap fall on pollen tube growth, the common commercial practice of fungicide application during flowering was investigated. Dilutions of commercial formulations of three fungicides were added to liquid germination media and pollen germination rates were measured. One of the fungicides was also used in a field study where vines were sprayed during flowering at 5% and 80% cap fall. All three fungicides prevented pollen germination at the recommended concentration for field sprays in the *in vitro* experiment, with pollen tube growth resuming at greater dilutions. In the field, percent fruitset was not affected by fungicide application at either stage of flowering, however average seed number at harvest was affected by fungicide application with the 5% cap fall treatment having a significantly lower seed number.

As recent research suggests that bunch number is the yield component that contributes most to yield variation in cool climate wine producing areas, one option to manage yields from vines subject to variable spring weather, is to dormant prune to a yield target above the desired level, then summer prune or bunch thin to achieve the desired yield after fruit set. Different bud numbers were imposed on field grown vines over three seasons, varying from canopies of ten to forty buds. Yield components were measured at each harvest. Vines with smaller bud numbers had greater over-wintering starch levels, fruit had a lower pH and anthocyanin content, but there was no effect on

sugar content. In a second field trial with the same pruning treatments, bunches were removed (thinned) at veraison, to create fruit loads equivalent to industry levels for small, medium and high yields. There was a reduction in berry number per bunch at the heaviest fruit load, but no treatment effects on bunch weight or berry weight.

In both field trials bunch number per bud decreased with increasing number of buds retained in winter pruning, and berry number per bunch also decreased. Yield the previous season also influenced bunches per bud in the current season. Results are discussed in terms of the influence on yield, of carbohydrate reserves and current photosynthesis in the period from bud burst to flower initiation, and on the potential to manage yield using bunch thinning or summer pruning of vines dormant pruned to bud numbers locally regarded as overcropping. In particular the view that bunch number is the primary yield component is questioned. The results lead to a conclusion that bunch size is a major factor influencing yield variability and, contrary to most published literature, bunch size, rather than yield *per se* may be an important influence on wine quality.

## Acknowledgements:

The author and the Tasmanian Institute of Agricultural Research would like to thank the following organisations whose work enhanced the findings of the project:

Substantial in-kind support was provided by the University of Tasmania's School of Agricultural Science as well as Home Hill Wines, Meadowbank Wines, Bream Creek Vineyard, Pipers Brook Vineyard, and Hardy's in the form of experimental sites, plant material and technical assistance.

Many people have helped make this project a success:

- The Vineyards Association of Tasmania, for their enthusiasm for and endorsement of this project;
- Dr Noel Davies for generous and expert assistance with HPLC and MS analysis;
- Dr David Steele for his expert knowledge and assistance in Scanning Electron Microscopy;
- Dr Cameron Spur for in vitro pollen handling techniques
- Dr Mark Krstic for assistance with carbohydrate extraction techniques;
- Dr Ashley Townsend for leaf nutrition analysis;

## Background:

Although only a small component of the Australian industry, production in Tasmania has increased dramatically in the past 5 years from 3113 tonnes in 1998 to 5198 tonnes in 2003 (Farquhar, 2004) and is continuing to expand. The most important varieties are Riesling, Chardonnay, Sauvignon Blanc and Pinot Noir, with 878 tonnes of the latter produced in 2002, which accounted for 35% of the total (Farquhar, 2004). With most Australian wine regions too warm for production of quality Pinot Noir, the dominance of this variety is apparent only in Tasmania and a few other localised cool climate locations on mainland Australia.

Tasmania is located at latitude 41° - 43º South, corresponding with the northern latitude of the classic cool-climate areas of Burgundy and Bordeaux in France. The local industry has utilised the suitability of the cool temperate climate for Pinot Noir to promote particular wine styles, described, for example, as the "elegant and intensely flavoured wines of today, with rich colour and characteristic varietal aromas" (Johnstone, 1999).

While Pinot Noir wine quality in cool temperate regions can be high, the yield potential of vineyards is generally lower compared with other varieties in warmer regions. Warmer regions of Australia produce commercially acceptable wines well below the cost of Tasmanian production. Local vignerons have been primarily interested in producing premium quality wines for high value niche markets, with little regard to yield. Recent structural changes towards larger scale vineyards with boutique vineyards accounting for a smaller proportion of total production have resulted in a more commercial approach. Vignerons have become increasingly concerned about low yields with a high year to year variability and emphasis is therefore shifting to a balance between yield and quality.

Throughout most wine regions in the world year to year fluctuations in yield can have significant impacts on grower returns and adverse effects on intake scheduling, storage requirements and marketing strategies for domestic or export markets. While growers and wine makers are aware of the problem, solutions have generally targeted yield prediction to improve vintage management (Clingeleffer *et al*., 1997) rather than vineyard management to stabilise yield. There are few research publications reporting management options to reduce yield variability in spite of the fact that early publications (for example Winkler *et al.*, 1974) have identified environmental influences on vine growth likely to impact on critical stages in crop development. Unfavourable weather at critical times in the growing season is often blamed by growers for low yields, but locally there is a lack of evidence showing links with particular weather patterns. In addition growers generally do not adjust management practices in response to "unfavourable" weather. Vineyard factors including biennial bearing (Watson, 2000) and pest and disease influences on yield are also poorly understood.

Certain stages in the flowering and fruiting cycle are more sensitive to detrimental environmental effects than others (Dunn, 2003). The likely magnitude of an environmental effect on final yield will depend on conditions at particular stages in development. Although information on phenology and vine physiology at various stages of development have been published (for example Coombe and Dry, 2000)

there seems to be little recognition by growers of the potential influence of conditions in one season on yield in both the current and subsequent seasons. This difficulty may be due to a lack of information specific to the local industry.

Yield records and growers comments confirm that vines managed to a conservative target yield, produce well below target yields in all but exceptional seasons. Vines pruned to a target based on bunch number, subject to negative influences on bunch emergence, bunch size and berry weight, almost inevitably produce below target yields.

This strategy appears to have given rise to a widespread concern about excess vine vigour. Earlier local work by the present author (Heazlewood, 2000) confirmed that, in Tasmanian Pinot Noir vegetative growth and yield were inversely related, suggesting that conservative yield targets may be contributing to the excess vigour problem rather than the reverse.

Gladstones (1992) suggested that as a result of Tasmania's maritime temperature pattern, vine phenology can be expected to be influenced more strongly by both weather patterns and altitude than in almost any other wine region. Gladstones (1992) used a mean monthly temperature of 19ºC as the cut-off mean temperature above which, on average, there is no further increase in the rate of physiological development, through the growth and ripening period. Australian Bureau of Meteorology records show that long term average mean monthly temperatures in Tasmania are below this temperature throughout the year. Consequently temperature effects on vine phenological development accumulate over the whole season and differences between sites even within the one locality may be dramatic. The temperature difference resulting from a simple altitude difference of 40m would have a dramatic effect on time of ripeness due to the fact that a difference of 0.24ºC (based on the estimated lapse rate) in mean temperature is equivalent to 50 effective day degrees up to ripeness (Gladstones, 1992).

As noted, the issue of yield variability in the Tasmanian wine industry is one of increasing concern as individual vineyards become more commercial, shifting away from lifestyle or hobby based enterprises. Any advance towards more stable yields and more accurate achievement of targets will benefit growers, contract wine makers and planning for improved market development.

This project aimed to identify major sources of variation in yield of Pinot Noir and determine the critical vine growth cycle stages which should be targeted for development of management strategies to reduce yield variability. As there is little published work on management of yield variability the study was developed from recent work on yield prediction and the relative contribution of various yield components to final yield by an Australian study group (Clingeleffer *et al.*, 1997; Martin *et al.*, 2000). These studies concluded that the seasonally variable determinants of yield were, in decreasing order of contribution to variability, bunch number (60%), berry number (30%), and berry weight.

Initially Tasmanian industry yield records were used to study local yield variability in detail, concentrating on inter-site variability and possible influences of seasonal conditions at critical times during development. Critical periods of vine development

were taken as follows: floral initiation and initial floral differentiation, bud burst, fruit set and grape maturation with timing based on Coombe and Dry (2000).

From these results and work by Gladstones (2000) and the yield prediction studies of Martin *et al* (2000) subsequent chapters examined both environmental and selected management effects on the primary yield determinant, number of bunches and the expected secondary influences of fruitset and berry size. Management factors influencing the number of bunches included pruning, crop regulation and canopy structure and the effect of disease control chemicals at flowering on the number of berries. The effect of pruning on stored carbohydrate in the canes over winter was also studied, and the relationship between fruit yield and carbohydrate levels examined.

Overall this study was not primarily concerned with wine quality, however economic viability of local vineyards will remain dependant on maintaining a balance between yield and market value of wine. Consequently, in one of the trials dealing with crop load, relationships between fruit yield and several basic quality parameters were studied.

## Project Aims and Performance targets:

The planned outputs and performance targets as they appeared in the original application are included below.

- To rank the main components of yield according to their overall effect on final yield
- Establish whether there is an intrinsic bearing pattern in Pinot Noir, and identify external factors that may influence any pattern
- Investigate management strategies to improve the higher ranked sources of variation
- Explore the effects of managing to a target yield on aspects of wine quality
- To contribute to the literature on yield variability, underlying causes and external controlling influences

## Method:

The Tasmanian Licensing Board kept an archive of precise records of planted areas and yields for most vineyards in Tasmania, dating from 1990, the data is now held by the Department of Primary Industries Water and Environment. Using these data, an investigation of long term (11y) yield trends in response to seasonal weather patterns was undertaken.

Given the apparent importance of weather at fruitset and literature suggesting that in Pinot Noir, pollination occurs before cap fall, a detailed examination of the pollination/fertilisation process was carried out. Light and scanning electron microscope studies on pollen transfer and germination was followed by field studies examining the effect of the commonly used practise of fungicide application during flowering.

Trials were established to determine the relationship between pruning severity in the current and subsequent seasons in three Tasmanian viticultural areas. Emphasis was on varying bud number whilst retaining the preferred cane pruning system. The various components of fruit yield (bunch number, fruit per bunch, and berry size) were measured at harvest as well as vegetative growth and reserve carbohydrate levels in canes at the end of the growing season. The basic fruit quality measures of pH, Brix and colour were measured at harvest.

An additional trial superimposed fruit thinning (crop regulation) treatments in the pruning experiments observing current and subsequent season yield and quality responses.

## Results and Discussion:

The analysis of commercial yield data confirmed the industry view that yield variability of Pinot Noir grapevines is a major issue in Tasmanian vineyards. Variability was greater than the previously suggested 70 percent figure and in selected vineyards was as high as 150 percent from one year to the next. The lack of any consistent patterns in yield across regions suggested that any weather effect was overridden by local management or climate factors. The rapid development of the industry during this period with a high proportion of young vines in the crop for each year may also have contributed.

In spite of some inconsistencies, results for selected properties showed it is possible that spring weather conditions as either sunshine hours or temperature in the current season and possibly rainfall at fruitset may have a marked impact on final yield. The results of Martin *et al* (2000) in Victoria suggested that the largest source of seasonal variation in yield was bunches/vine, typically accounting for 60% of the variation. Bunches per vine is unlikely to vary after spring budburst. Consequently from these results it appears that, although bunches per vine is regarded as a major yield determinant, the extreme local seasonal variability may be due to variability in other yield components. The same authors noted that berries per bunch accounts for 30% of the variability, and as berries per bunch would be expected to respond to conditions in the current season it appeared from this preliminary study that the high variability in Tasmania may be due to berries per bunch or berry size. That is, under Tasmanian conditions, relative contributions of bunch number and size to yield variability, may be reversed compared with previously published results.

Most vineyards in Tasmania are cane pruned, with a careful selection of the number of fruitful buds retained made at pruning during winter dormancy. This control of potential bunch number is much more precise than in spur, or mechanically pruned vines. Present results have shown that, although bunch number per fruitful node decreases with the number of buds, it did not vary significantly between seasons. Thus with strictly controlled bud number and a predictable and stable relationship between bud number and bunches per bud, the experimental results confirm the interpretation of the yield / climate relationship. That is, in the absence of bunch thinning, bunch number varies little from year to year and extreme variability is almost certainly associated with variability in bunch weight. However, the contribution of bunch number to yield variability should not be underestimated. Results suggest that it probably remains the major management factor (as either dormant pruning or bunch thinning) controlling yield. Further, while a marked decrease in bunch number after the first year in the pruning trial, may be related to the change in vine structure in the preceding winter, the possibility that this was not related to other environmental factors cannot be eliminated. Nevertheless, management induced variability may explain why not all of the vineyards examined closely in the historical yield analysis study demonstrated the postulated effect of weather on yield. Thus, whilst growers use bunch number to manage to a target yield, bunch size will influence actual yields over a broad range around the target.

Changes in bunch number per bud in response to total bud number indicate some control of initiation in response to previous crop probably mediated by carbohydrate levels or associated with endogenous growth substances. Adjustment of bunches per

bud after initiation could only occur as a result of some buds failing to break dormancy, but figures showing no significant treatment or year effects on the number of blind buds suggest control at initiation.

Bunch thinning to a target yield at or near veraison is a common practice in Tasmania, so that variability in yield due to bunch number would be expected to be further limited, emphasising the major role of bunch size as the greatest influence on yield. With bunch weight / berry number identified as a potentially critical yield factor, rather than bunch number, fruitset becomes an important factor in managing yield variability.

Despite this sensitivity of yield to fruitset, the literature contains few studies on the method of pollination in grapevines and, even in recent reviews such as May (2004) there is no clear picture of the flowering to fruitset process. Results presented in this study demonstrate that Pinot Noir is self-fertile and failure of pollen to germinate until after cap fall suggests that conditions that promote cap fall are crucial in achieving successful fertilization and fruitset. These results concur with observations reported in May (2004) that, in cold and rainy weather, flowers may only partially open and irregularly, at temperatures below 15˚C - 17˚C. It was suggested that if unfavourable weather lasts for two or three days flowers do not open completely, and both pollination and fertilisation are poor, resulting in small bunches (May, 2004). Drying conditions such as low humidity and high temperatures and high sunlight incidence are thought to aid cap fall. The sunlight influence appears to be indirect, possibly operating as radiant heating causing a rise in temperature of exposed flowers (May, 2004). These same climatic variables during flowering were shown to explain a significant proportion of the yield variability at three vineyard sites within close proximity to weather stations in the present study. Further work is required to show whether delayed cap fall in fact reduces fruitset or simply delays normal pollination, and hence fertilisation, resulting in uneven berry maturity.

Pollen toxicity to fungicide introduced the possibility of reduced fruitset due to routine fungicide applications. This finding, combined with the suggestion that berries per bunch explains a large proportion of bunch-to-bunch, vine-to-vine and season-to-season yield variation suggests that present fungicide programs could be contributing to yield variability. However, the predominant effect of sunshine and or temperature before cap fall in the initial study suggests that the effect is likely to be related to availability of current photosynthate between budburst and cap fall resulting in reduced fruitset in less favourable years.

Canopy manipulation, by altering the number of potentially fruitful buds, significantly affected the number of bunches per bud as well as vine reserve carbohydrate concentrations. The two higher bud number treatments, with significantly lower stored starch concentrations, also had the lowest number of bunches per bud, thus suggesting these vines might have been overcropped and that resultant low carbohydrate levels were influencing inflorescence initiation. Notably, there were no differences in pruning weight, suggesting that heavy cropping did not influence either total vegetative growth or canopy size.

Results from the fruit thinning trial confirmed that it is possible to achieve a target yield by winter pruning to a bud number higher than desirable and bunch thinning to

reach the target fruit yield. The largest target fruit load of 14 tonnes/ha had a significantly lower number of berries per bunch than the two smaller treatments, thus suggesting that the larger fruit load affected flower differentiation. Importantly however, year to year variations in yield in the two pruning trials were greater than the treatment effects. Further, treatment effects on bunch number and size were consistent across years, with bunch number per viable bud in lightly loaded vines remaining constant across the three years. There was also little change between the second and third years for the other treatments. There are a few reports of adjustments in bunch number per viable bud noted by (May, 2004) with no clear indication on whether changes are induced by conditions in the current or previous seasons. If current season conditions are involved, results of these two trials confirm the inference from the vineyard and climate / growth cycle observation in the historic yield analysis study. That is, variation in bunch size and possibly bunch number in some seasons, in response to weather conditions are the primary causes of highly variable yields in commercial vineyards in Tasmania. This result, particularly the bunch size component, has important ramifications for management to both yield and quality targets.

The strong regression between berries per bunch and anthocyanin concentration, found in this study, suggests that the importance of bunch size in wine quality and yield studies should be re-examined. As berry number per bunch increased, the level of anthocyanin in berry skins decreased. Although there was no significant regression between bunch size and pH, the relatively small change in response to treatment may have been insufficient to demonstrate a more general relationship. Further work is clearly required to clarify links between quality and bunch size. Nevertheless, the clear negative regression relating colour to bunch size, the confusing literature on yield / quality relationships and anecdotal evidence relating yield negatively to colour combined with the marked effect of bunch size on yield suggest a critical review of practical bunch thinning and of some research results. It is notable that a review paper by May (2000) noted that intra-bunch shading is likely to influence quality in tight bunched varieties like Pinot Noir.

Whilst bunch exposure to light has been a dominant theme in canopy structure studies by various authors (Kliewer and Lider, 1970; Smart, 1985; Archer and Strauss, 1989; Jackson and Lombard, 1993; Jeong *et al.*, 2004) the possibility that intra-bunch shading in tightly packed bunches may have an effect on berry exposure has received little attention. Work by Shabala and Wilson (2001) showing that light incident on the berry surface directly influences components of quality emphasises the need to re-examine the current view of fruit exposure. These authors did not, however, consider the potential involvement of intra-bunch shading. Again, the review paper by May (2000) implied that canopy management to increase bunch exposure could have a reduced effect if bunch compactness limits exposure of berries to light under cool climate conditions.

The relationship between yield and vine carbohydrate status also needs to be considered in this context. Leaf plucking to increase fruit exposure may decrease over wintering carbohydrates, and hence yield, in the following year, with few direct advantages in quality. Conversely however, any positive effects may be indirect with reduced carbohydrate status potentially responsible for reduced bunch size in the following season.

Practically, when bunch thinning, growers should selectively remove larger bunches, retaining smaller loose packed ones to maximise quality. Further, whilst bunch thinning to a target yield may be necessary to achieve full fruit maturity, the results suggests that yield effects on quality claimed locally (Farquhar, 2003) and in published literature dating from before Amerine and Winkler (1944) may require some re-examination in their practical application.

Overall, with bunch size apparently having a major influence on both yield and quality, management of bunch size assumes primary importance. Present results indicate bud numbers and spring weather conditions as the main controlling influences. Thus increasing bud numbers during dormant pruning and adjusting bunch thinning regimes to account for spring weather effects on bunch size should be the main components of any revised management strategy. Bunch thinning may also need to be selective, preferentially removing larger tightly packed bunches.

The potential for fungicide application to reduce fruitset also needs further investigation. Whilst avoidance of pollen toxicity will remove a potential contributor to yield variability, timing of sprays to anthesis of early flowers may have the advantage of reducing bunch size, with corresponding increases in quality.

## Concluding remarks:

Yield and weather records, pruning methods and experimental results suggested that bunch size, is a major yield component contributing to uncontrolled yield variability in Tasmanian Pinot Noir. Weather conditions, particularly spring sunlight and temperature in the current season, appeared to have a greater impact on bunch size (as both fruit number and size) than the number of buds left in place during winter pruning. However higher bud numbers did result in consistently smaller bunches across three seasons.

Experimental results also suggested that small bunches develop more intense colour independently of fruit load and that colour development was not inhibited in heavier cropping vines. Although this is only a single marker of quality, it suggests that the current industry view that heavy crops result in poorer quality wine is a reflection of seasonal effects on bunch size. That is, in years with a light crop load, bunch size will be smaller and quality correspondingly higher. Thus, bunch thinning or heavy pruning to obtain a light crop may have either no effect on quality or an effect opposite to that expected, if either activity results in higher average bunch weight. This result may explain the confusion in the literature, with conflicting claims about crop load influences on wine quality. A re-evaluation of published material or experimental approach, is suggested where possible using bunch size rather than total yield as the controlling variable.

## Recommendations:

Application of these results in commercial vineyards will require further work to establish a detailed management approach, but broad guidelines can be drawn as follows:

- Bunch size is of major importance in managing for both quality and yield targets.
- Dormant pruning to a high bud number will reduce average bunch size, relative to lighter cropped vines, but the resultant bunch size will be highly dependent on spring weather.
- Target yields set for wine quality need to take bunch size into account and bunch thinning should target larger bunches for removal.
- Higher yields may not preclude high quality wine, provided the higher yield is as a result of increased bunch number (pruning) and not bunch size (weather).

Further research is required to clarify several of the issues raised here. With yield targets driven by, possibly erroneous, assumptions about yield and quality, it is critically important to confirm the bunch size / colour relationship and establish whether it extends to other quality parameters. Similarly the fungicide toxicity issue needs to be further clarified. While any negative effects on fruitset may be seen as contributing to yield variability, a small reduction in bunch size might be seen as desirable.

A yield management strategy based on pruning to a relatively high bunch number to obtain small bunches, followed by early summer bunch thinning, to obtain a yield target which can reach full maturity requires commercial evaluation.

## Appendix 1: Communication:

Wine producers in Tasmania have been involved in the project process in

- Development of the project
- Managing vineyard operations of the trial sites
- Discussion of significant results as discussion points at the Vineyards Association of Tasmania's Annual General Meetings

### Publications resulting from thesis

Chapter 3:
Heazlewood, J.E., and Wilson, S., 2004, Anthesis, pollination and fruitset in Pinot Noir, *Vitis*, 43, (2), 65-68.

Chapter 3:
Heazlewood, J.E., Wilson, S., Clark, R.J., and Gracie, A., 2005, Pollination of *Vitis vinifera* L. cv. Pinot Noir as influenced by Botrytis fungicides, *Vitis*, accepted February 11th 2005, in press.

Chapter 2:
Heazlewood, J.E., Wilson, S., Clark, R.J., and Gracie, A., 2004, Key climatic effects on the yield of Pinot Noir in Tasmania. Poster presentation at the 12th Australian Wine Industry Technical Conference, Melbourne, July 2004.

## Appendix 2: Intellectual Property

No intellectual property was generated by this project that requires patent protection. To reproduce sections of the report other than for purposes of research and private study please contact the author.

## Appendix 3: References:


Amerine, M. A. and A. J. Winkler (1944). Composition and quality of musts and wines of California grapes. *Hilgardia* 15: 493-675.

Archer, E. and H. C. Strauss (1989). Effect of shading on the performance of *Vitis vinifera* L. cv. Cabernet Sauvignon. *S. Afr. J. Enol. Vitic.* 10: 74-7.

Clingeleffer, P. R., K. J. Sommer, M. Krstic, G. Small and M. Welsh (1997). Winegrape Crop Prediction and Management. *Wine Industry Journal* 12(1): 354-9.

Dunn, G. M. (2003). *Windows of sensitivity in grapevine reproduction*. GWRDC flowering and fruitset workshop, Tatura.

Farquhar, D. (2004). Vintage Reports. Hobart, Department of Primary Industries Water and Environment, Hobart, Tasmania.

Gladstones, J. (1992). Viticulture and Environment. Adelaide, Winetitles.

Gladstones, J. (2000). *Past and Future Climatic Indices For Viticulture*. 5th International Symposium on Cool Climate Viticulture and Oenology, Melbourne.

Heazlewood, J. E. (2000). Responses of major grape vine yield components to vineyard temperatures. School of Agricultural Science. Hobart, University of Tasmania**:** 55.

Jackson, D. I. and P. B. Lombard (1993). Environmental and Management Practices Affecting Grape Composition and Wine Quality- A Review. *Am. J. Enol. Vitic.* 44(4): 409-29.

Jeong, S. T., N. Goto-Yamamoto, S. Kobayashi and M. Esaka (2004). Effects of plant hormones and shading on the accumulation of anthocyanins and the expression of anthocyanin bionthetic genes in grpae berry skins. *Plant Science* 167: 297-52.

Johnstone, D., Wine Lovers Guide to Tasmania, 2000

Kliewer, W. M. and L. A. Lider (1970). Effects of Day Temperature and Light Intensity on Growth and Composition of *Vitis vinifera* L. Fruits. *J. Amer. Soc. Hort. Sci.* 95(6): 766-9.

Martin, S. R., G. M. Dunn, T. Hoogenraad, M. P. Krstic, P. R. Clingeleffer and W. J. Ashcroft (2000). *Crop forecasting in cool climate vineyards*. 5th International Symposium on Cool Climate Viticulture and Oenology, Melbourne.

May, P. (2000). From bud to berry, with special reference to inflorescence and bunch morphology in *Vitis vinifera* L. *Australian Journal of Grape and Wine Research* 6(2): 82-98.

May, P. (2004). Flowering and Fruitset in Grapevines. Adelaide, Lythrum Press.

Shabala, S. and S. Wilson (2001). Fluctuations in light intensity modulate ion fluxes from grape berry mesocarp: direct evidence from microelectrode ion flux estimations. *Australian Journal of Grape and Wine Research* 7(3): 137-43.

Smart, R. E. (1985). Principles of Grapevine Canopy Microclimate Manipulation with Implications for Yield and Quality. A review. *Am. J. Enol. Vitic.* 36(3).

Watson, J. (2000). Alternate bearing in Concord grapes. *Good Fruit Grower*.

Winkler, A. J., J. A. Cook, W. M. Kliewer and L. A. Lider (1974). General Viticulture. Berkeley, Uiniversity of California Press.

## Appendix 4: Staff

List of all staff that have been engaged on the project.

Chief Investigator:
Joanna Heazlewood
PhD Candidate
Tasmanian Institute of Agricultural Research
University of Tasmania
Hobart

Project Supervisor:
Dr Steve Wilson
School of Agricultural Science
University of Tasmania
Hobart

Supervisor:
Dr Alistair Gracie
School of Agricultural Science
University of Tasmania
Hobart

Supervisor:
Professor Rob Clark
Director of the Tasmanian Institute of Agricultural Science
School of Agricultural Science
University of Tasmania
Hobart

Appendix 5: Other relevant material including raw data

Appendix 6: Budget reconciliation