# Crop control for consistent supply of quality winegrapes



***FINAL REPORT to***

**GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION**

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# Final Report to Grape and Wine Research and Development Corporation on:

# Crop control for consistent supply of quality winegrapes

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***Cover Picture***

Post-set crop adjustment with a mechanical harvester.

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**Abstract**

The project aimed to develop and evaluate crop control techniques to stabilise yield from season-to-season and assess their impact on key wine quality indices; facilitate industry adoption of reliable, robust and objective crop forecasting systems and to continue research into the physiological, environmental and cultural determinants of crop yield components. These issues are addressed in the body of research that was undertaken across a number of sites and varieties in both the warm and cooler regions.

The project has developed techniques, supported by software and manuals, whereby vineyard managers can improve their ability to set and consistently hit yield targets based on 'informed pruning', accurate crop forecasting and crop adjustment by shoot thinning or bunch removal, including mechanical thinning. Reponses to imposition of the various crop control techniques on key indices of wine quality varied between seasons and variety. The results indicate that stabilization of wine quality from season to season is much more problematic than achieving yield targets due to the effects of other seasonal factors not related to crop load (eg. temperature during berry development). Adoption of lighter pruning systems, which had high bunch numbers with fewer and smaller berries per bunch enhanced fruit and wine composition provided adequate maturity levels were achieved. In general crop regulation treatments (shoot thinning, bunch removal at veraison, mechanical thinning) advanced maturity, but effects on other indices of fruit quality were small when measured at similar levels of maturity (eg. enhanced berry colour and spectral properties in wine of Shiraz and Cabernet Sauvignon).

Investigations into physiological, environmental and cultural determinants of crop yield components have made significant contributions to enhancement of knowledge in these areas of research. The research has highlighted the importance of both the seasonal and treatment effects on fruitfulness and inflorescence development in spring and subsequent effects on crop development including fruit set and berry development. Seasonal differences in fruit composition (pH, titratable acidity, berry color and phenolics) and wine spectral properties were much larger than effects of pruning or crop thinning when harvested at similar sugar levels. Lighter pruning systems produced higher levels of colour and phenolics in berries and wine, possibly due to differences in canopy structure and fruit exposure as the skin to flesh ratios were similar for all treatments.

**Executive Summary**

The project aimed to develop and evaluate crop control techniques to stabilise yield from season-to-season and assess their impact on key wine quality indices. Furthermore, the project aimed to facilitate industry adoption of reliable, robust and objective crop forecasting systems and to continue research into the physiological, environmental and cultural determinants of crop yield components.

The project showed that it is possible to accurately remove crop by manual shoot and bunch thinning and that it is possible to respond to fluctuations in fertility by adjusting the severity of pruning in hand pruned systems. Irrespective of how one attempts to regulate yield, the results show that accurate regulation demands: (i) an accurate yield forecast, (ii) a quantitative understanding of how the yield components will react to yield regulation (vine compensation) and (iii) a method to accurately remove crop.

Being able to 'hit' target numbers of bunches per vine or unit length of row reliably is a prerequisite for stabilising yield. We have shown that when well developed techniques (eg. microscopic bud dissection, bunch counting, bunch thinning) are properly applied based on the use of sound sampling methods, target numbers of bunches per vine can be hit successfully. It has proved more difficult, however, to predict bunch weight and bunch weight compensation. Further research has shown that the number of branches per bunch is simple to measure and is a good early indicator of bunch weight.

The project has developed techniques, supported by software and manuals, whereby vineyard managers can improve their ability to set and consistently hit yield targets. Future research and development should be directed toward more 'cost-effective' ways to regulate yield. These would necessarily include 'informed mechanised pruning', mechanical shoot thinning and more accurate crop removal through mechanical thinning.

Reponses to imposition of the various crop control techniques on key indices of wine quality varied between seasons and variety. As a general rule, the results indicate that the often reported comment re the negative relationships between yield and quality are at best tenuous and not supported by detailed scientific study. In general, seasonal effects on quality indices were larger than those resulting from the imposed crop control techniques. For example, with Sunraysia Shiraz the lowest and highest yielding seasons (2003 and 2004 respectively) had the lowest and highest levels of colour in fruit and wine. Such results indicate that stabilization of wine quality from season to season is much more problematic than achieving yield targets due to the effects of other seasonal factors not related to crop load (eg. temperature during berry development). This issue warrants further investigation.

The results confirmed benefits from adoption of lighter pruning systems (eg. hedging and minimal pruning), which had high bunch numbers with fewer and smaller berries per bunch and enhanced fruit and wine composition provided adequate maturity levels were achieved. In general crop regulation treatments (shoot thinning, bunch removal at veraison, mechanical thinning) advanced maturity, but effects on other indices of fruit quality were small when measured at similar levels of maturity (eg. enhanced berry colour and spectral properties in wine of Shiraz and Cabernet Sauvignon). Pinot Noir, growing in a cool climate was more sensitive to

crop load than Cabernet Sauvignon and Shiraz, at least for berry colour. Results from the project indicate potential to manipulate wine quality and style through selection of various combinations of pruning and crop regulation (ie. shoot or bunch thinning). For example it was noted that compensatory effects on berry weight were largest for severe pruning treatments, followed by shoot thinning and did not occur with bunch thinning at veraison.

Industry adoption of reliable, robust and objective crop forecasting systems has been a focus for the project. This has involved further development of the crop forecasting system to account for segment length, bunch gain or loss factors, early prediction of harvest bunch weight, allowance for 'hen and chicken' and weight gain from veraison to harvest. Developments have included refinements to methods to analyse sources of inaccuracy and improved crop forecasting formula. Industry adoption has been facilitated by the development of Excel work books (Grape Forecaster *version* 6), manuals and database software; development of training course and trainers guides and delivery of training courses with industry including Grape Cheque groups and major wine companies. A regional crop forecasting approach was also implemented in the Sunraysia region in collaboration with the Murray Valley Winegrowers'. Participants from five pilot industry groups provided favourable reports with respect to the training and crop forecasting package, identified 'barriers to adoption' and areas for further improvement to enhance adoption and provide ongoing technical support.

Investigations into physiological, environmental and cultural determinants of crop yield components have made significant contributions to enhancement of knowledge in these areas of research. Specific outputs from the project in this regard are listed below.

a. application of novel statistical procedures to long term data sets have identified critical periods when climatic variables over the crop two-year development cycle can be linked to yield. In particular, a new critical stage has been identified where high temperatures, 4-6 weeks after fruit-set can be linked to low yields in the following season, presumably due to stress effects on the developing fruit initials in the bud. This warrants further investigation.
b. effects of post-veraison water stress can affect crop development, not only in the current season due to effects on berry size but also in the following season, due to a reduction in bunch numbers associated with reduced budburst attributed to lower vine carbohydrate status.
c. pre- and post-budburst temperature (but not light) can affect the number of flowers per inflorescence, ie. higher temperatures reduce flower numbers.
d. the number of primary branches per inflorescence can be a useful predictor of final bunch weight provided differences between pruning systems are taken into account.
e. there are significant loss of bunches, at least in Chardonnay, between inflorescence counts in spring and final harvest.
f. significant pruning effects on seasonal differences in fruitfulness of Shiraz, ie. 2 fold with severe spur pruning, 3.5 fold with hedging and 7 fold with minimal pruning. These effects may have been exacerbated by RDI stress during the critical post-set period (see a above).

g. inflorescences have fewer branches with fewer flowers and branches in years of low fruitfulness, which may be partly compensated for by higher berry set and development of larger berries leading to very compact bunches.
h. post-set crop thinning had little effect on crop development in the subsequent season, an indication of minimal carryover effects from season to season.
i. increased bunch numbers with lighter pruning systems (ie. mechanical hedging and minimal pruning) were accompanied by significant reductions in length and branches per inflorescence, flower weight and % set leading to development of smaller, less compact bunches with fewer branches and fewer and smaller berries.
j. smaller berries from lighter pruning systems had a similar number of smaller seeds and similar skin to flesh ratios (wet and dry). This indicates that the frequently reported, but generally unsubstantiated comment in relation to berry quality that small berries have higher skin to flesh ratios is incorrect. The results suggest that smaller berries develop thinner skins. It should be noted however that there were differences between seasons in the skin to flesh ratio.
k. pre-harvest berry weight losses were common in all varieties indicating that the phenomena is not just related to Shiraz. The extent of this loss varied from season to season and desired level of maturity.
l. delayed ripening with lighter pruning systems was generally associated with a delay in the commencement of sugar accumulation (ie.veraison?) rather than significant differences in the rate of ripening.
m. seasonal differences in fruit composition (pH, titratable acidity, berry color and phenolics) and wine spectral properties were much larger than effects of pruning or crop thinning when harvested at similar sugar levels. Lighter pruning systems produced higher levels of colour and phenolics in berries and wine, possibly due to differences in canopy structure and fruit exposure as the skin to flesh ratios were similar for all treatments.

Over the course of the project results have been published in scientific and industry journals, presented in major industry forums including ASVO seminars, the 12th Wine Industry Technical Conference and the Viticulture 04 Conference as well as at the regional and local level. There has been significant facilitation and interaction with industry with respect to adoption of improved crop forecasting and techniques for crop regulation, in particular mechanical thinning which was widely used in both the hot and cool regions in recent seasons. Furthermore, data from a number of the detailed studies have been assembled and provided to researchers in the CRCV Viti$ys project to underpin and verify routines in VineLOGIC for sugar accumulation and changes in titratable acidity, colour and phenolics during ripening.

**Project Objectives**

The specific objectives of the project were to:

1. Develop and evaluate crop control techniques to stabilise yield from season-to-season.
2. Evaluate the effects of various crop control techniques on key indices of wine grape quality.
3. Facilitate the industry adoption of reliable, robust and objective crop forecasting systems.
4. Continue the program of research (identified in the position statement produced by phase I of the project) into the physiological, environmental and cultural determinants of crop yield components.
5. Continue to monitor crop development in a selected number of crop forecasting sites.
6. Assemble and make available the data to the industry and the viticultural research community.

# Chapter 1.

# Introduction

# 1. Introduction

***Background***

Unpredictable seasonal variations in yield and composition (quality) of wine grapes continue to cause major economic problems in the Australian wine industry (Clingeleffer et al. 1997). In recognising this, GWRDC, CSIRO and DNRE invested in the collaborative project '*Crop Development, Crop Estimation and Crop Control to Secure Quality and Production of Major Wine Grape Varieties: A National Approach'* from 1997 and until June 2000. This project capitalised on work done in that project. It is the result of extensive consultation with industry, both informally and through planning fora, including Riverlink, VWIA-DNRE and the project Industry Reference Group. Stabilising winegrape yield and quality was considered the highest priority at all of these meetings.

Outcomes from a previous project have led to significant grower/winery adoption of the crop forecasting protocols developed for low input, hedged or minimal pruned vineyards. These have been delivered through linkages with the Victorian and Murray Valley Wine Grape Growers Council Inc. (eg. more than 700 kits were in spring 1999). There is a need to enhance adoption of similar techniques in all major viticultural regions and verify the accuracy and benefits for grower, regional and national crop predictions. The project has also generated considerable interest in application of crop control techniques, particularly in the Sunraysia region in spring 1999. There is a need to develop protocols to optimise such technology, which logically, must be based on both an accurate crop estimate and an accurate estimate of crop removal, for specific varieties and wine styles.

Specifically, the project addressed three key industry needs viz. 1. the need for industry-wide adoption of robust, reliable crop forecasting systems, 2. the need to develop reliable mechanisms to stabilise yield fluctuations from season-to-season and within any given season and 3. the need to develop and evaluate practical techniques to optimise wine grape quality. These priorities result from extensive consultation with industry, both informally and through R&D planning fora, including Riverlink, VWIA-DNRE and the project Industry Reference Group. Stabilising wine grape yield and quality was considered the highest priority at all of these meetings.

*Adoption of robust, reliable crop forecasting systems*

Improving the reliability of grape crop forecasting would improve the quality of planning and the profitability of businesses throughout the grape growing, winemaking and marketing chain. Even a small reduction in forecasting error of say 1% across the whole of industry would deliver benefits in the order of millions of dollars a year (Martin, Urbanski and Dunn, in preparation). Simple, practical methods developed and tested by the project coupled with appropriate sampling (Dunn and Martin, 1998) can reduce forecasting error substantially. By June 2000, a revised protocol suited to the diverse range of management techniques and environments was available to industry. However, realising the potentially large benefits of improved crop forecasting relies on industry-wide adoption of the improved methods. Further benefits are possible through continued improvement to existing techniques.

*Stabilising yield fluctuations*

It is well accepted within industry that much research effort needs to be directed towards stabilising wine grape yields. Typically, there is a seasonal variation of approximately ±20% in the regional production of winegrapes, and wineries are designed to cope with variation in intake of this order. In the wine industry this variation is generally accepted as natural and inevitable. However, in manufacturing industries substantial effort is invested in reducing variation because it is considered to be a source of avoidable costs and the root cause of customer dissatisfaction, interpersonal conflict, poor enterprise performance and waste of all kinds. Examples of this waste include overproduction, waiting, transporting, inappropriate processing, unnecessary inventory, unnecessary motions and defects. A thorough quantification of the cost of variation in winery intake across the entire Australian wine industry would require a project in itself, but it can be shown that the annual opportunity cost (@ 8% p.a.) is in the order of $160 million annually.

*Manipulating crop for quality*

In keeping with the projections of Strategy 2025, there is evidence that the wine industry is entering a period of grape oversupply, falling prices and a shift towards a focus on cost reduction and improvement of grape quality. A recent comment by ABARE (1999) that "one of the easier methods of improving quality is to restrict grape production per vine" expresses a belief that is widely held amongst wine producers. On the basis of this belief, grape purchasers are specifying that growers should restrict their yield to achieve quality targets. In a climate of oversupply, wineries may have the power to insist that growers restrict their yields, but this can generate considerable conflict because grower incomes may be substantially reduced, particularly if prices also fall. Thus, there is an urgent need for objective, scientifically based, techniques that would allow vineyards to manipulate crop development for optimum yield in relation to quality. Crop control technology based on mechanical thinning is applied in the USA to achieve quality specifications for Concord juice (Pool et al. 1989) and has also been used for winegrape varieties in Australia (Clingeleffer et al. 1999)

*Preliminary and previous research*

History of R&D in the area

Large seasonal fluctuations in yield occur across the major winegrape producing areas. Analysis of the long term regional yield data for individual varieties indicates only weak relationships between varietal performance between regions or between varieties in a region (Clingeleffer et al. 1997). The average error in forecasting of grape crops at a block level throughout the industry is in the order of ±25%. Simple, practical methods (modified from May 1971, 1972) for forecasting yield have been developed and tested by the current project Crop Development, Crop Estimation, and Crop Control to Secure Quality and Production of Major Wine Grape Varieties: A National Approach. These methods coupled with appropriate sampling (Dunn and Martin, 1998) could reduce this error to approximately ±15% or less. By June 2000, revised protocols suited to the wide range of Australian environments and management practices were made available to industry to enable it to achieve this target. Industry-wide adoption of the improved methods is necessary, however, if substantial benefits are to be realised. The aim of this was to drive industry-wide adoption through closely working with technical officers from wine companies (linkages already established), procedures for disseminating information and skills

through grapecheque groups in Victoria and liaison with appropriate technical personnel in other states (eg. The Winegrapes Marketing Board in NSW).

Unpredictable seasonal variations in yield and composition (quality) of wine grapes continue to cause major economic problems in the Australian wine industry. Being able to forecast this variation is an important first step in addressing the 'variation' problem. However, it is clear that industry also requires greater control, at the vineyard level, over variations in yield and composition. There is a good knowledge of the sequence, timing and phenology of the bunch and flower development in grapevines (Srinivasan and Mullins 1981, May 1987, Mullins et al. 1992). However, an incomplete 'mechanistic' understanding of causal relationships between environmental variables, cultural factors (eg. pruning, irrigation etc.) and the development of yield hinders our ability to manage variation in the vineyard. Detailed studies undertaken in the previous project with regard to the timing of bunch primordia development under field conditions has enhanced the knowledge base. It also identified the need for more research into the interaction between environmental conditions and fruitfulness, particularly at the axillary bud level under field conditions.

In Sultana, arguably the most-studied of all *Vitis vinifera* cultivars, seasonal variations in yield were strongly linked to cane fruitfulness (bunch numbers per shoot). A set of studies elucidated the importance of light and temperature during critical stages of reproductive development in the previous season (Baldwin 1964, May and Antcliff 1963, May 1965). More recently, Martin and Dunn (in preparation) analysed a comprehensive collection of yield data sets for a range of wine grape varieties grown in range of climates. Of the yield components assessed, bunch number was the largest contributor to season-to-season variation followed, in turn, by bunch size and then berry size. Similar results have been obtained across the crop forecasting sites for the 3 main wine varieties (Krstic et al., in press). This is important as it further underlines the importance of the developmental stages (in the previous season) that culminate in bunch formation along with the events at budburst that act to moderate bunch numbers in the vineyard. A recent review of the effects of the environment and physiology on bunch characteristics (Dunn and Martin, in preparation) identified a set of critical control points for managing yield development in grapevines. Thus, a program of physiological studies commencing under the existing project (eg. Martin and Dunn 2000, Dunn and Martin 2000) along with the development of in-season mechanical and chemical crop control techniques (Clingeleffer, Sommer and Walker 1999) has identified some promising methods for reducing the year-to-year fluctuations in wine grape yields.

It is well understood that overcropping reduces wine quality (Winkler 1954), particularly in cooler areas where overcropping can delay maturation and increase the risk of disease. On the other hand, studies have shown little apparent response of wine quality to increasing yields (Ewart et al. 1985, Clingeleffer 1993, Johnstone et al. 1996, Gray et al. 1998, and Clingeleffer et al. 1999). Although there has been a great deal of speculation and much written and experimental effort expended on understanding the physiological, environmental and cultural determinants of grape composition (quality), our understanding remains superficial in comparison to other fields. In fact, there is evidence that we have yet to describe adequately vineyard variability for some of the more commonly assessed indicators of compositional quality (Johnstone 1999).

One difficulty in assessing the impact of yield on quality specifically is that the methods of adjusting yield also change the balance with other components, eg. leaf area. However, for any give site, the optimum yields are likely to vary with canopy management system, climatic conditions, amount of irrigation, pruning level, variety and planting density (Jackson and Lombard 1993, Clingeleffer et al. 1999). Clearly, much depends on the particular circumstance and the method by which yield is manipulated. The approach advocated by this proposal is one that combines regional trials testing the effects of practical crop control techniques on wine grape 'quality', with detailed physiological studies seeking to better understand the environmental and physiological controls of berry composition.

Seasonal influences on budburst, shoot fruitfulness, bunch development and fruit set limit grower capability to control crop levels by winter pruning (Clingeleffer 1993). Strategies for the control of cropping level after fruit set, indicate that there is potential to compensate for seasonal influences on yield potential and to promote consistent production from season to season., manipulate canopy to fruit ratios and provide the winemaker with a consistent supply of fruit, produced to specifications of a given wine style. The current development of accurate yield prediction techniques will be very important to facilitate accurate control of cropping levels for specified wine styles (Clingeleffer et al. 1997).

Crop adjustment after fruit set of minimal pruned Cabernet Sauvignon and Shiraz either by mechanical thinning using mechanical harvesters or skirting has been successfully applied in Coonawarra (Clingeleffer 1993). Mechanical thinning, compared with the untreated control treatment, promoted higher sugar levels and produced desirable changes in wine quality parameters, ie., improved organic acid composition, in particular the tartrate to malate ratio, higher levels of titratable acidity, improved spectral qualities and higher levels of phenolics (Clingeleffer 1992, 1993, Clingeleffer and Sommer 1995). Unpublished results and commercial experiences in the Riverland and Griffith regions indicate that crop control by thinning may also be beneficial in warmer climates when applied to high yielding, vigorous, grafted vines. The benefits of crop adjustment of mechanical and minimal pruned vines by mechanical thinning have also been demonstrated for Concord and a range of French hybrids in the USA and Canada where it is now applied commercially (Pool et al. 1989, Fendinger et al. 1997, and Fisher et al. 1997). Simple tractor mounted equipment is being developed for mechanical thinning (Morris 1997). Chemical thinning treatments also have been successfully applied to Concord vines (Zabadal et al. 1997).

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# Chapter 2.

# Develop and evaluate crop control techniques

## 2a. Stabilisation of yield from season to season

***Introduction***

Unpredictable variations in wine grape yield and composition (quality) continue to represent a major threat to the Australian wine industry. They make it difficult for viticulturists and winemakers to plan for vintage and reduce the ability of marketing professionals to match supply to demand. The impacts of yield instability were evident in the low crops of the 2003 vintage being followed by the large crops seen in 2004. These yield fluctuations are mainly driven by the weather but can also be exacerbated by changes to vine management in response to the season. They lead to an inconsistent supply of fruit to wineries and variations in fruit composition and wine quality (Table 2.1).

Variations in grape yield and composition also occur from vine to vine, across sites and between regions. Spatial yield variation is very much a function of the environment that individual plants experience (ie. soil factors, aspect, meso-climate, interaction with neighbouring plants etc.). Like annual variation, spatial variation has implications for fruit composition and wine quality. It can pose problems for managing both inputs as well as outputs of the production system. The high level of spatial variability in vineyards often dictates high sampling intensities to make representative and accurate vineyard estimates (eg. bunches per vine, grape maturity). In the near future a geo-referenced understanding of spatial variability may instruct the location of sampling and facilitate more precise management of inputs and outputs (eg. differential harvesting).

Notwithstanding any benefits of more precise management of spatial variation, there are compelling reasons to regulate yield from season to season. These relate to economic benefits that flow from a more consistent fruit supply and a need to meet winery yield targets based on reputed quality benefits. This chapter first explores some of the options available for managing temporal (annual) yield variations. It then reports on a set of large experiments that attempted to regulate yield with interventions during dormancy and during the season. Finally, the requirements for successful yield regulation are outlined.

Table 2.1 Causes and implications of temporal (annual) and spatial variation in vineyards.

| | Type of variation | |
|---|---|---|
| | Annual (temporal) | Spatial |
| Causes | • weather<br>• vine management | • environment of the plant<br>• planting stock |
| Issues | • consistency of supply<br>• seasonal variation in fruit composition and wine quality<br>• yield forecasting & yield management | • management of inputs<br>• variable fruit composition<br>• -sampling to estimate yield & maturity<br>• -experimental design and interpretation |

*Annual (Temporal) Variation*

Season-to-season fluctuations in grapevine yields may be considerable. Generally, individual vineyard blocks form management units to which many management actions (eg. pruning, weed control, harvesting) are homogenously applied. Figure 2.1 presents examples of annual variation for three such blocks *viz.* a Cabernet Sauvignon block in Coonawarra, a Shiraz block in the Barossa Valley and a Shiraz block near Mildura (Sunraysia). Coonawarra experiences a cool to warm climate compared with the hot climate of Sunraysia. The Barossa Valley is intermediate between the two.

A simple measure of yield variability is the coefficient of variation (CV). For distributions of yield the CV equals the standard deviation (SD) divided by the mean, and is often expressed as a percentage. High CVs indicate a wide distribution of yields relative to the mean while low CVs describe a more stable system where the distribution of yields around the mean is narrow. The CVs for the blocks in Figure 1 are 49%, 38% and 34% for the 'Coonawarra Cabernet', 'Barossa Shiraz' and 'Sunraysia Shiraz' blocks, respectively. This level of variation is fairly typical across the industry but large in comparison with many other agricultural systems. It is important to note that variation can be substantial even in climates like Sunraysia where conditions during cardinal events of grapevine reproduction (ie. initiation, differentiation, budburst and flowering) are less variable in comparison with cooler climates.

Data presented in Figure 2.1 illustrate another important point about fluctuations in grapevine yields. There are no obvious underlying patterns or cycles, unlike some biennial-bearing horticultural tree crops for instance. This makes predicting yields based on yields in previous seasons a risky proposition. Being able to forecast yield variation is an important first step in addressing the problem but the industry would also benefit if greater control, at the vineyard level, could be achieved over variation in yield and composition. At present an incomplete 'mechanistic' understanding of causal relationships between environmental variables, cultural factors (eg. pruning, irrigation etc.) and the development of yield is hindering our ability to manage variation in the vineyard.

We can move down a level from the vineyard block to considering individual vines, which in many ways represent the smallest conceivable management unit. For individual vines, harvest yield can be simply described as:

*weight/vine = bunches/vine x berries/bunch x berry weight*

The first step in understanding the causes of variation is to quantify its sources. In general terms, recent statistical studies have analysed the comparative importance of yield components such as bunches per vine, berries per bunch and weight per berry as factors contributing to variation in vineyard productivity (see chapters by Martin and Clingeleffer in Clingeleffer, 2001). These studies consistently show that bunches per shoot (or vine) is the major contributor to fluctuating (both high and low) yields, explaining 60% – 80% of season-to-season yield variation for the cultivars Cabernet Sauvignon, Chardonnay and Shiraz. A graphic illustration of this can be seen in Figure 2.2 where the average number of bunches per vine overlays the Figure 2.1 yield traces for 'Coonawarra Cabernet' and 'Barossa Shiraz'.

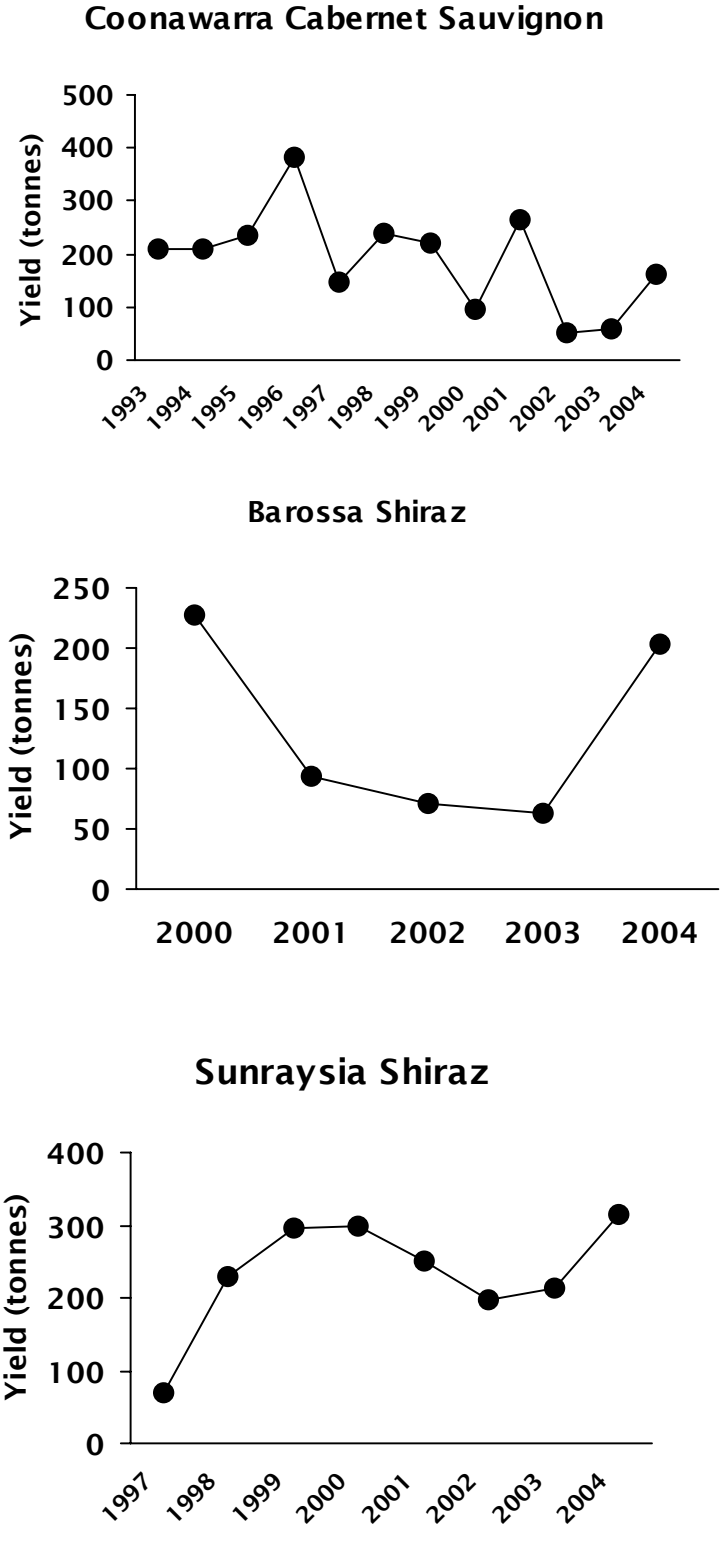



Figure 2.1. Annual yield over time for three irrigated vineyard blocks: Cabernet Sauvignon in Coonawarra, Shiraz in the Barossa Valley and Shiraz near Mildura (Sunraysia).

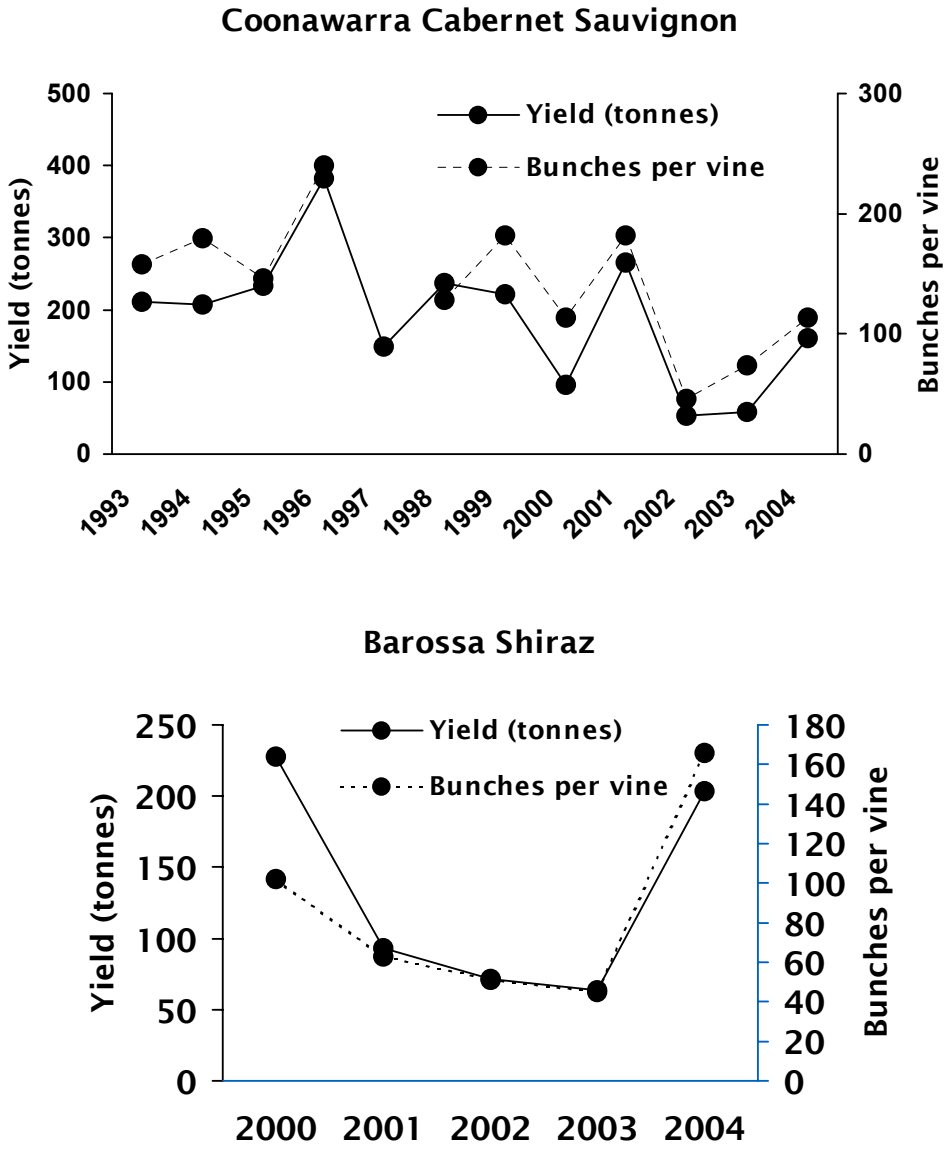



Figure 2.2. Association between the average number of bunches per vine and annual yield for two irrigated vineyard blocks: Cabernet Sauvignon in Coonawarra and Shiraz in the Barossa Valley.

While problems of fruit set are important, at least in some regions and some seasons' these results suggest that, in the main, stabilising yield hinges upon understanding and being able to manipulate the determinants of bunch number in grapevines. It is important to note here that there is likely to be a positive interaction between bunch number and bunch size from one season to the next. Thus some caution needs to be exercised when investigating those seasons when bunches are small. Without assessing the ratio of set berries per bunch to flowers per inflorescence it is not possible to determine to what extent small bunch size was a function of

poor fruit set or the low number of flowers to begin with. Care needs to be taken when estimating both of these variables. First in the techniques used and secondly ensuring that enough inflorescences and bunches are sampled to ensure a representative sample.

What then do we know about the control of bunch numbers? Grapevines begin forming their flower buds during the preceding season. Flower buds begin to develop in axils of leaf primordia of primary latent buds during late spring and summer before entering a period of dormancy. In the following season, flowers form during a short period spanning budburst. Bunch numbers per vine are the product of bunches per shoot and shoots per vine. Hence, they are controlled by processes that determine bud fruitfulness as well as processes that determine the extent (%) and nature (which buds burst) of budburst. Thus, potential bunch numbers are largely determined by what goes on within latent buds in the previous season and this potential is moderated by events during budburst.

*Spatial Yield Variation*

Graphic illustration for the extent of small-scale variation in vine yields comes from the use of yield mapping, where maps are generated by linking harvest-monitoring systems to GPS devices. For instance, in a Cabernet Sauvignon block at Coonawarra, yields in the 1999 vintage varied from little more than zero to 16 t/Ha across very small distances (Bramley and Proffitt 1999). To put the costs of this variation into perspective, Bramley and Proffitt (1999) applied a yield-quality relationship to their data. Yields between 5 and 10 t/Ha attracted premium prices and all other yields attracted lower prices. While recognising the uncertainty of applying such relationships, they generated a gross margin response surface for the block where gross margins varied from losses through to >$12,000/Ha.

Whilst noting the importance of spatial variation, this chapter concentrates mainly on controlling annual variations in yield. However, we would like to make one important point about the yield component sources of spatial yield variation. Figure 2.3a presents yields for each vine in a 130m long vineyard row. Despite the row being flat and apparently uniform, large variations in vine yields are evident (CV = 35%). It may be that differences in the early performance of vines due to variable stock quality or small-scale variations in soil conditions persist throughout the life of the vineyard. These differences may even be intensified by the effects of vine-to-vine competition or seasonal interventions, such as the common practice of ‘pruning to vigour’. However, as with temporal variation, bunch numbers per vine explains much of the variation in yield (Figure 2.3b).

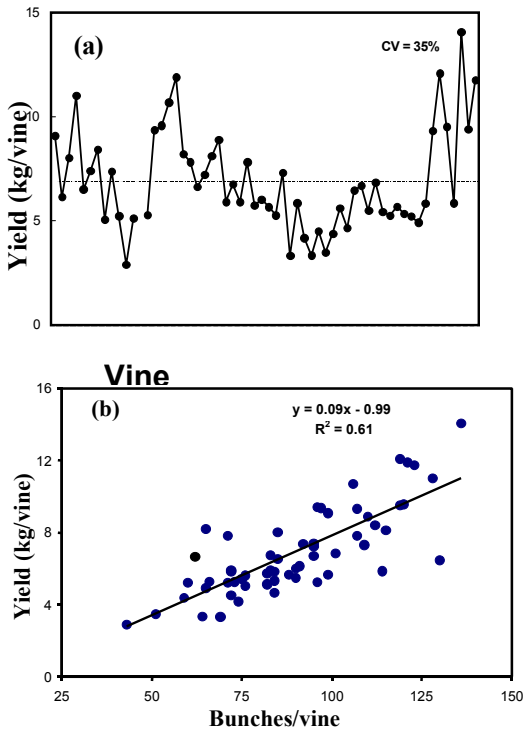



Figure 2.3. Harvested yields from a row of 13-year-old spur-pruned Cabernet Sauvignon vines at Dookie in Northeast Victoria in 1999. (a) sequence of individual vine yields along the row relative to the mean (b) relationship of yields to bunches per vine.

### *Options for yield regulation*

Various options for yield regulation become available as the season progresses.

*Informed Pruning*

Pruning during winter is the earliest, most commonly used and cheapest technique available to the vineyard manager for stabilising yield. It is also used to control the structure of the vine, to ensure an even distribution of shoots and fruit and to facilitate a whole range of vineyard operations including harvesting and disease and pest control. Because bunches per shoot varies substantially from year to year in a way that we are unable at present to predict reliably from the weather, any attempt to stabilise yield by altering the severity of pruning needs to be based on an assessment of node fertility. Most notably this was practised with Australia's sultana crop in the 1960s and 1970s. To regulate yield through informed pruning one also needs to be able predict the extent (%) and nature (which type of buds burst) of budburst and factor in yield compensation that will occur in response to leaving more or fewer buds. It may also be important to consider effects on canopy during the following season and future vine structure.

*Shoot Thinning*

Shoot thinning to regulate yield is not commonly practised in vineyards. It is potentially cheaper than bunch thinning and easy while shoots are young and tender. It offers scope for future mechanisation with commercial systems becoming available (eg. http://www.uark.edu/depts/ifse/major8a.html). In the experiments reported here shoot thinning followed a yield forecast made 6 to 8 weeks after budburst (usually a week or two before flowering). Because thinning preceded flowering and fruit set we had to factor in compensation in bunch size in response to bunch removal (increased set as well as increased berry size).

*Bunch Thinning*

Bunch thinning or cluster thinning can also be used to stabilise yields. Its main advantage is that it can be carried out after the crop is visible and a better yield forecast is possible. Bunches can be selectively removed to improve overall quality and control the distribution of fruit. The timing of thinning is important. For instance thinning inflorescences (flower clusters) will affect fruit set. Leaving thinning until later (eg. veraison) will lead to less 'yield compensation'. The bunch thinning reported here took place at veraison and was based on random bunch removal (i.e. every bunch was given the same chance of being removed). Although selective bunch thinning has the potential to improve overall fruit composition, it makes accurate crop thinning to hit a yield target much more difficult and harder to mechanise. We assumed that from veraison onward there would be little compensation in berry size in response to bunch removal, and indeed we found this to be generally true.

*Mechanical Thinning*

Mechanical thinning through either the use of mechanical harvesters (berry thinning) or mechanical skirting (bunch removal) is cheaper than hand thinning and suited to minimally and mechanically pruned systems. However, it is difficult to precisely control the amount of fruit removed, particularly in canopy management systems that are characterised by a restricted fruiting zone. It can be a very cost-effective way to manage the risk of fruit not reaching a Baumé target or ripening at a time that increases chances of disease in seasons when crop loads are excessive.

***Materials and Methods***

The yield regulation experiments that are discussed in this chapter were established in the 2000/01 season and included: informed pruning, shoot thinning, bunch thinning and mechanical thinning. For most of the experiments three levels of intervention at 3 stages of crop development were compared. At each stage potential yield was estimated, based on measurement of crop components. Then bunch numbers were adjusted (through retained buds, shoot thinning or bunch thinning) in an attempt to achieve the desired target yields. The 3 yield targets were low, medium and high with ratios of 1:2:3 (eg. 5, 10, 15, t/ha). Very light pruning with no subsequent intervention was the control, which aimed to deliver a very high yield. Light, moderate or severe levels of pruning during dormancy, shoot thinning before flowering or bunch thinning at veraison targeted high, medium and low yields (Figure 2.4).

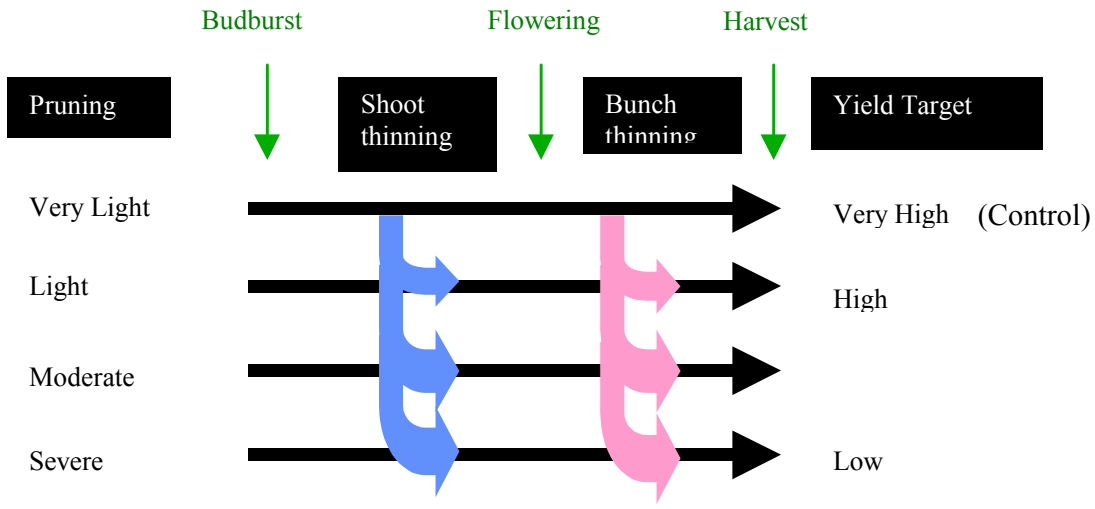



Figure 2.4. A schematic diagram of yield regulation experiments which attempt to hit 3 yield targets using 3 methods *viz*. Pruning during dormancy, shoot thinning before flowering or bunch thinning at veraison.

*Pruning*
During dormancy buds were collected, dissected and their fertility analysed microscopically. This information along with an estimate of budburst was used to make a forecast of potential yield. Predictions of bunch weight were based on historical means. Vines were then pruned to four levels of retained buds taking into account any bunch weight compensation, based on best available knowledge.

*Shoot Thinning*
Six weeks after budburst bunches and shoots were counted. These counts were then used to evaluate the bud dissections made during dormancy. The counts were also used to determine 3 levels of shoot removal (from 'control' vines that were initially lightly pruned) that would deliver high, medium and low yields. Again, any bunch weight compensation was taken into account based on our best available knowledge

*Bunch Thinning*
At the onset of veraison bunches were collected from lightly pruned vines and their weight and berry numbers measured. This information was used to predict potential yield and 3 levels of bunch thinning estimated to deliver high, medium and low yields are invoked. Veraison was chosen for this intervention because it seemed the best bet for reliably regulating yield. Bunch thinning before veraison can lead to substantial yield compensation (eg. increased berry size, improved fruit set). No yield compensation in the form of increased berry size was expected.

Identical experiments were conducted at the following sites. Two hot sites (Barooga, mean January temperature (MJT) 23.7°C [Chardonnay] and Dookie MJT 22.4°C [Cabernet Sauvignon]) were contrasted with Chardonnay and Cabernet Sauvignon at Whitlands, a cool site at an elevation of 800m (Figure 2.5). These experiments complemented crop regulation experiments at Mildura (very hot). Pinot Noir at Whitlands was added because there is localised

interest in this cultivar, which is considered to be very sensitive to crop load. The yield targets were designed to cover a wide range and were set taking into consideration the climate and vine management at each site. The intention was to reflect typical yields in hot and cool regions in south-eastern Australia.

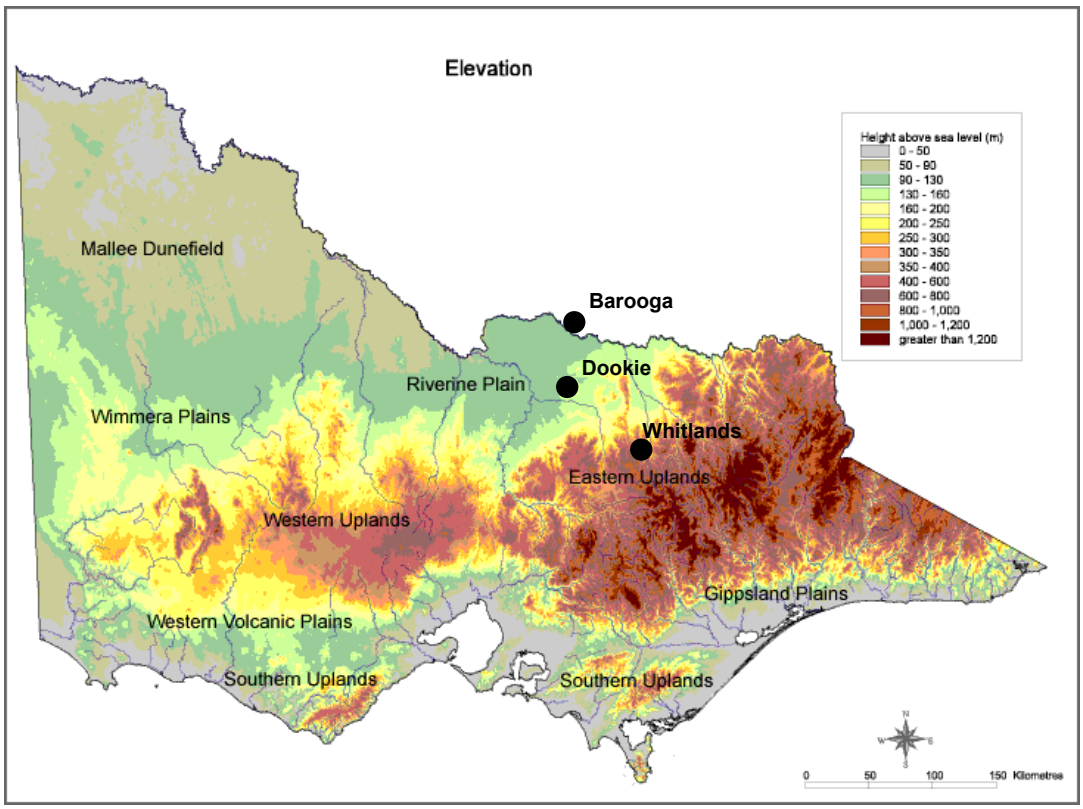



Figure 2.5. Location of crop regulation experimental sites (Barooga, Dookie and Whitlands). Map source: Victoria Online

At four of the five sites each treatment was replicated 16 times in a randomised block design. The 10 treatment plots were nested in each block with neighbour balance to facilitate spatial analysis. Each plot consists of 4 contiguous vines in the same row with the 2 outer vines being guard vines. Thus, 640 contiguous vines are included in each experiment. The block of Cabernet at Dookie had less available vines and, therefore, each pruning treatment was replicated 13 times and the shoot thinning and bunch thinning treatments were replicated 14 times.

*Measurements of yield and its components*

Yield components were measured as follows:

- Bunches/bud during dormancy (using light microscopy)
- Shoots and bunches per unit length of row approximately 6 weeks after budburst
- Berries per bunch, bunches per unit length of row and bunch weight at the onset of veraison

- Weight/vine, bunches/vine, weight/bunch, berries/bunch, weight/berry at harvest
- Leading up to vintage, weekly measurements berry size were made after veraison until harvest. Thirty-two berries were collected from each experimental plot. . In total 160 samples were collected and analysed weekly from each experimental site.

*Statistical Analyses*
Residual Maximum Likelihood (REML) analysis was used to test the effect of treatments. Treatment means were compared using Fisher's unrestricted least significant difference ($LSD_{5\%}$). Other relationships were assessed by regression analysis. Statistical analyses were performed using Genstat© 5 Release 4.1 (Lawes Agricultural Trust, 1997).

***Results and Discussion***
Figure 2.6 summarises the results (Appendix) showing how close we came to hitting our yield targets over two and sometimes three seasons for Cabernet Sauvignon and Chardonnay in hot and cool climates and Pinot Noir in a cool climate. Unfortunately, three experimental sites (Cabernet Sauvignon, Pinot Noir and Chardonnay at Whitlands) were destroyed by a severe hailstorm in November 2002. Because of this, no results are available for the third season of the cool climate experiments. Nevertheless, results show that the later one leaves crop removal the easier it is to hit yield targets. This is in part due to an improved ability to forecast yield as the season progresses. In some ways the results presented in Figure 2.6 understate our ability to regulate yield. This is because we attempted to hit a wide range of targets between 5 t/ha and 30 t/Ha, many of which would not be contemplated commercially. In attempting to hit some of the lower targets at some sites we did not predict the extent of yield compensation that we observed at harvest.

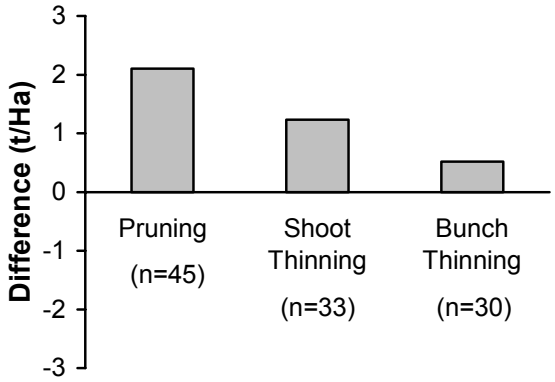



Figure 2.6. The average difference between actual yield and target yield for Cabernet Sauvignon and Chardonnay in a hot and cool climate and Pinot Noir in a cool climate over two, and sometimes three, consecutive seasons. Yield targets ranged from 5 t/Ha to 30 t/Ha.

Being able to accurately hit bunch number targets for the winter pruning intervention (Figure 2.7, Pruning) was due, in part, to our estimates of node fertility made during dormancy (eg. see

Figure 2.11). However, despite being able to consistently hit bunch number targets at each intervention (Figure 2.7), our ability to predict bunch weight and model bunch weight compensation relationships was poor (Figure 2.7). A major source of error in our bunch weight predictions was the use of historical bunch weights as a guide for forecasting. Industry clearly needs a more reliable method to predict bunch weight. The other major source of error was related to the equations used to predict bunch weight compensation due to pruning and shoot thinning. Slopes (g/bunch) were either too shallow (Dookie Cabernet Sauvignon) or too steep (eg. Barooga Chardonnay). Using yield compensation data from other sites in the absence of local information contributed to this source of error. In the some instances (eg. Chardonnay and Pinot Noir at Whitlands) average bunch weight decreased with pruning severity, despite the vines carrying far fewer bunches. This may have been because a greater proportion of more distal buds was retained in the lightly pruned treatments. Bunch size (weight) often increases on more distal node positions.

Whilst presenting a promising outlook, figures 2.8 and 2.9 demonstrate that further improvement in crop regulation relies on better early prediction of final bunch weight. This continues to represent a substantial source of error. At present many growers use historical averages. One method for assessing potential bunch size after budburst is to count flowers but this is time consuming and impractical for most growers. With this in mind the project team researched and developed improved methods for the early prediction of bunch weight (see Chapter 5 of this report).

Pruning

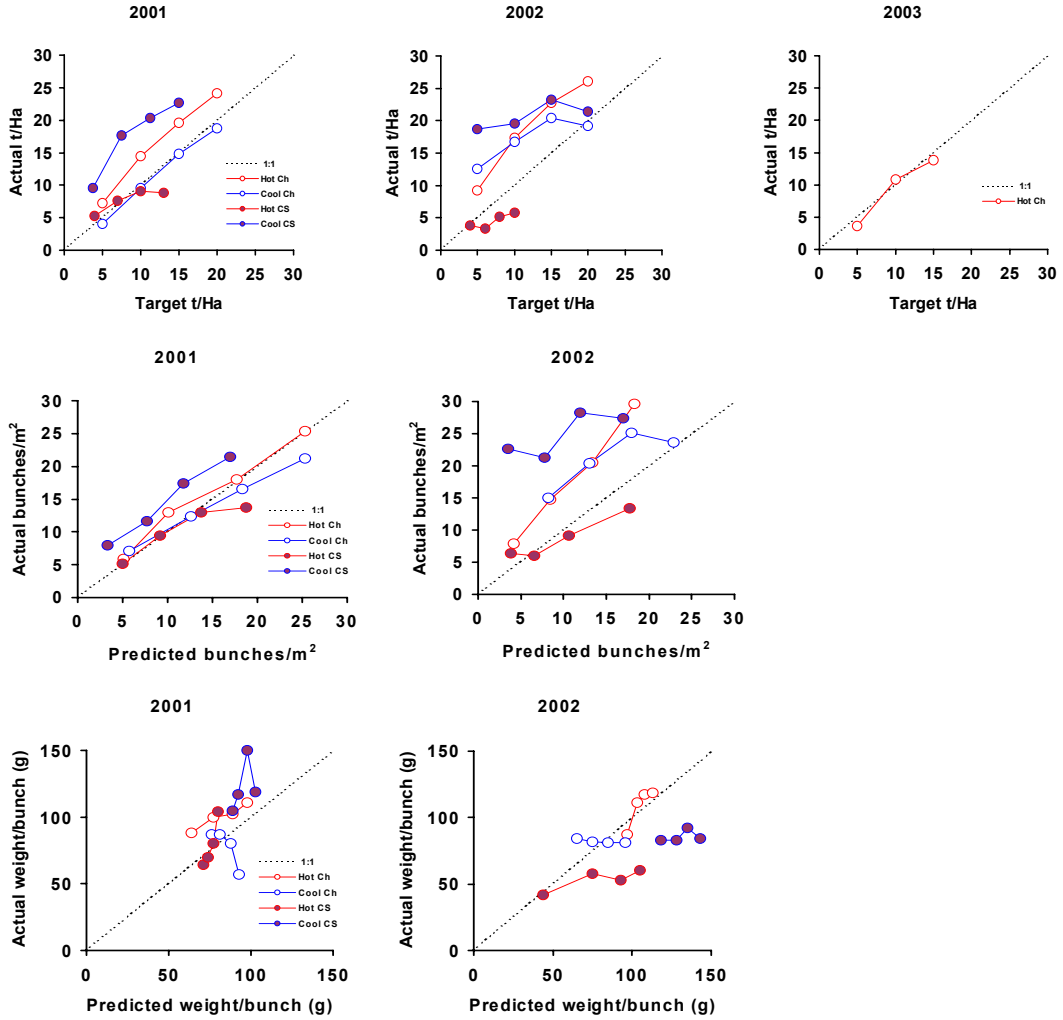



Figure 2.7. Comparisons of actual and target yield, bunches per vine and bunch weight across 5 sites for winter pruning to hit yield targets in the 20001, 2002 and 2003 seasons. The dashed line represents a 1:1 relationship.

Shoot Thinning

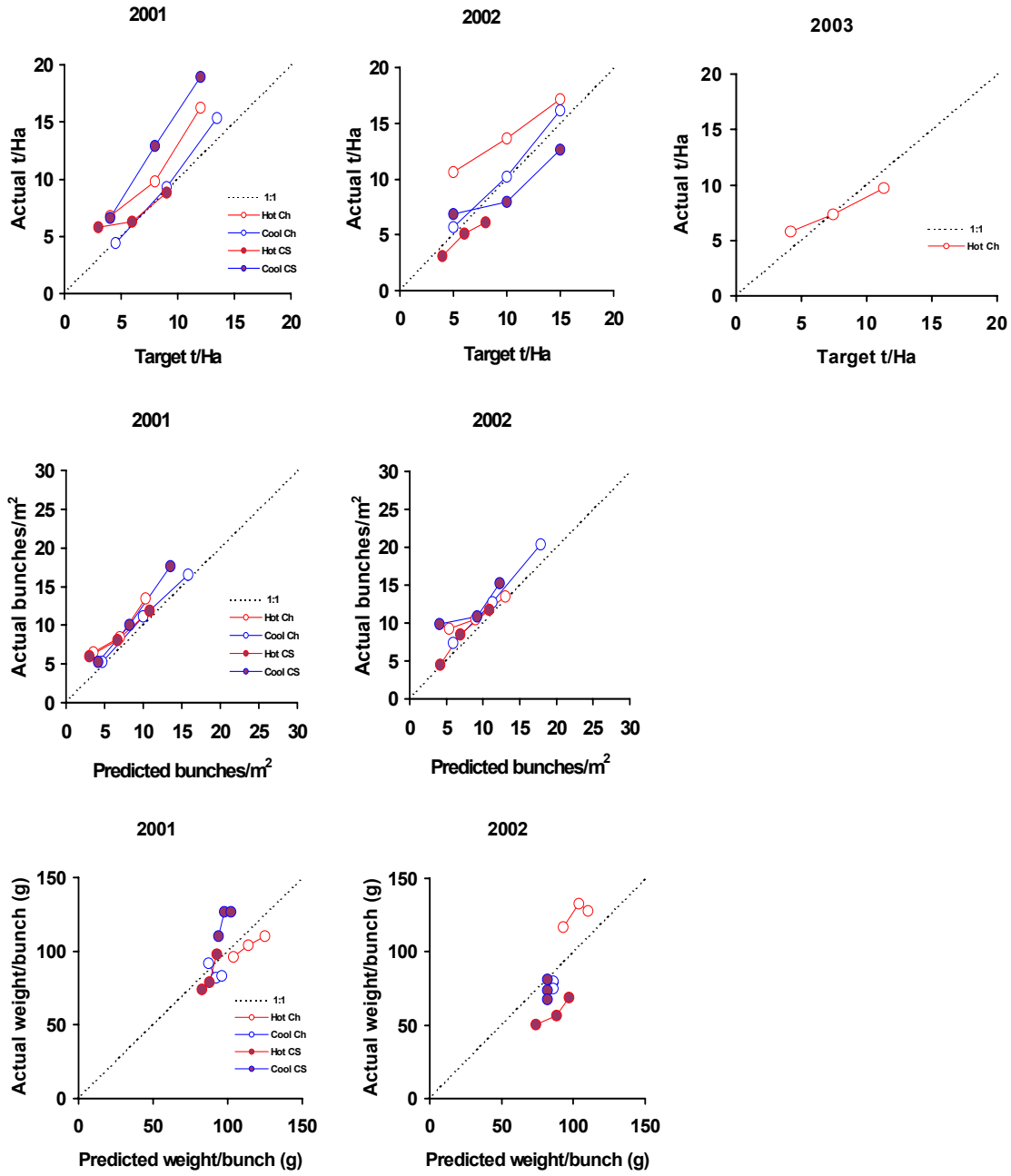



Figure 2.8. Comparisons of actual and target yield, bunches per vine and bunch weight across 5 sites for shoot thinning to hit yield targets in the 20001, 2002 and 2003 seasons. The dashed line represents a 1:1 relationship.

Bunch Thinning

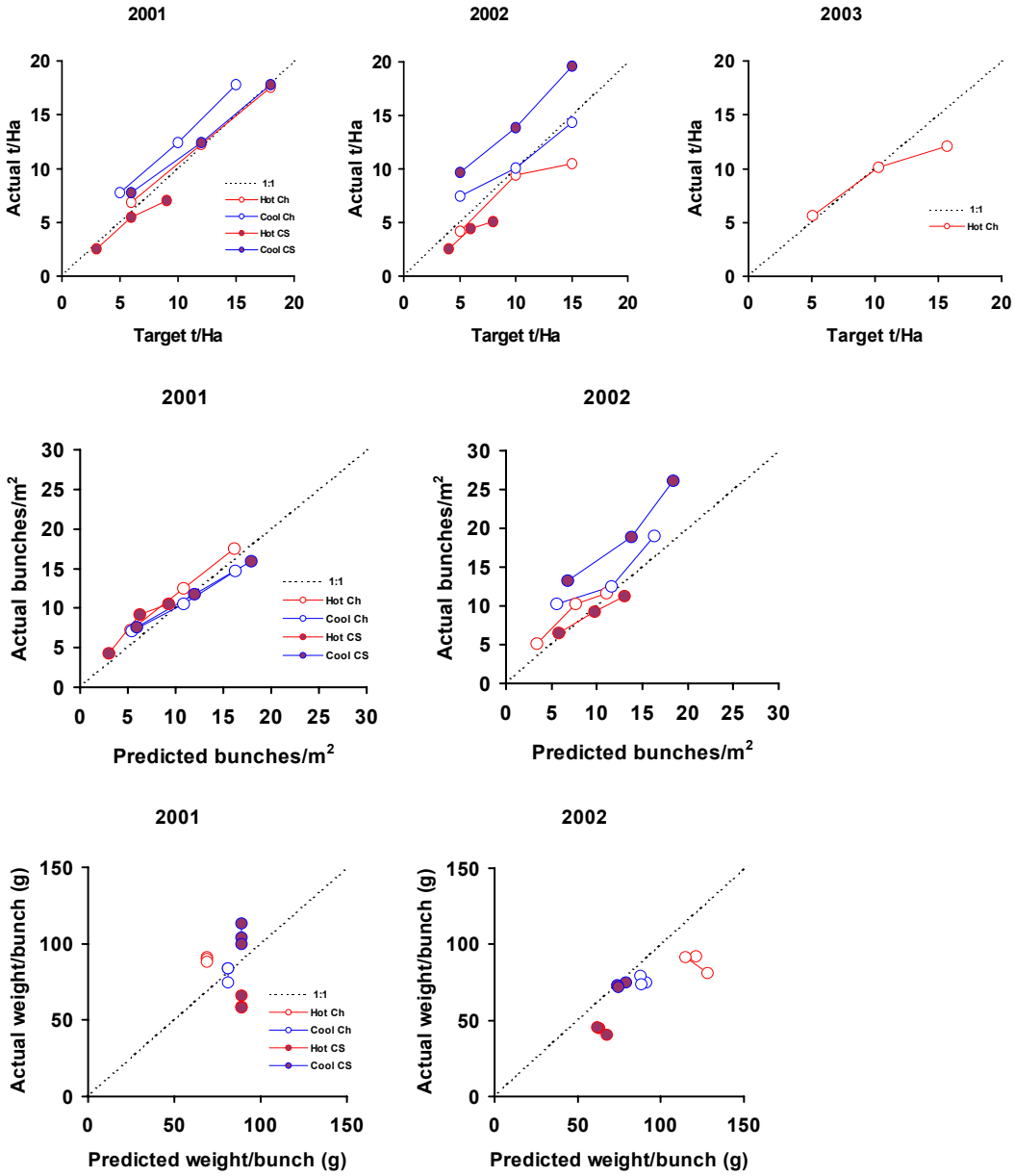



Figure 2.9. Comparisons of actual and target yield, bunches per vine and bunch weight across 5 sites for bunch thinning to hit yield targets in the 20001, 2002 and 2003 seasons. The dashed line represents a 1:1 relationship.

The intermediate yield target of 10 t/Ha was also the nominal target vineyard managers were attempting to hit with their own pruning regimes in most of our collaborating vineyards. Hence, we have compared our shoot thinning and bunch thinning attempts to hit 10 t/Ha to operational practice in four out of our five sites (Figure 2.10) believing this to be a valid comparison. Results from Dookie (Cabernet Sauvignon) have not been included because the experiment took up most of the vineyard block. The results show that it is possible to improve our performance significantly. One can also contend that during the first season, knowledge about the sites was being assembled and that our performance would have continued to improve over time. This once again underlines the extreme disappointment felt by all concerned after the devastating hail storm in November 2002 at Whitlands.

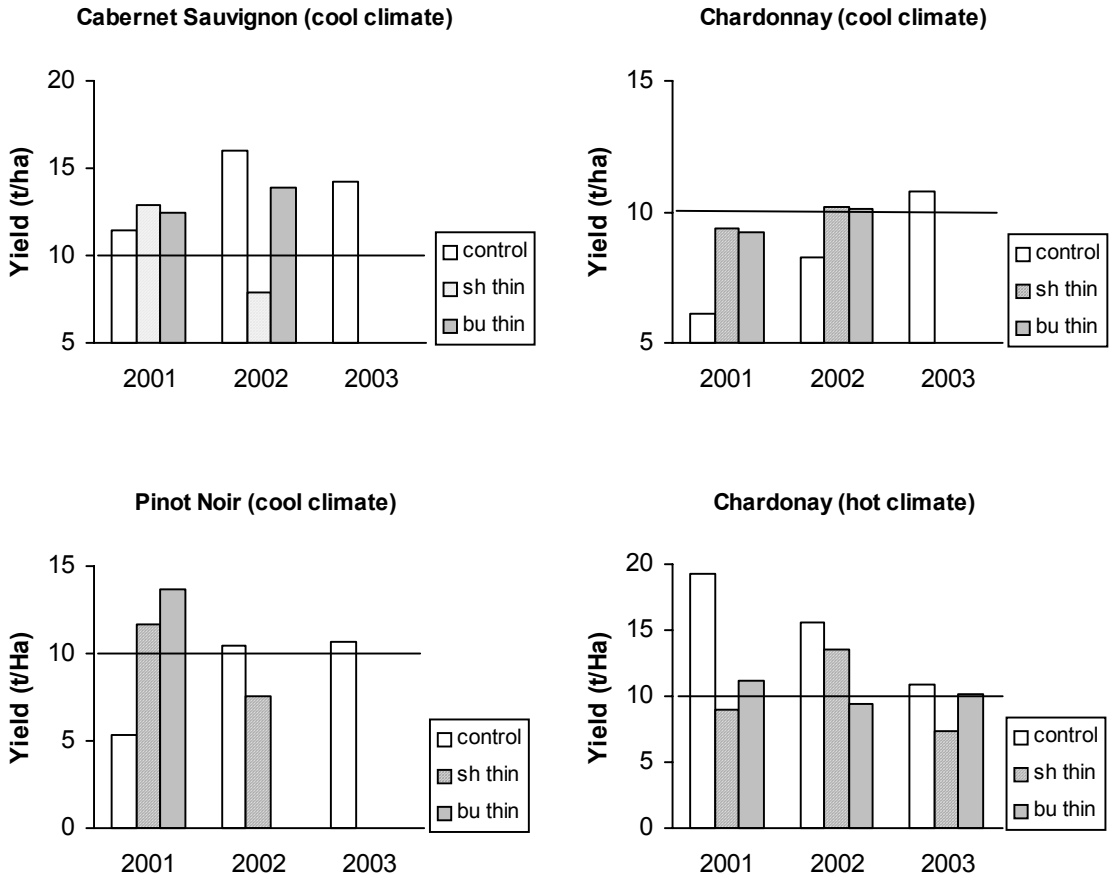



Figure 2.10. Comparisons between shoot thinning (prior to flowering) and bunch thinning (at veraison) attempts to hit a yield target of 10 t/Ha with operational pruning practices (control) that also targeted 10 t $Ha^{-1}$.

*Predicting Fertility*

As previously discussed, being able to accurately hit bunch number targets for the winter pruning intervention (Figure 2.7, Pruning) was due, in part, to our estimates of node fertility made during

dormancy which were generally very good (see Figure 2.11 for typical examples). There were, however, instances where predictions were poor (eg. Figure 2.12). These poor predictions were most often for vines that had been severely pruned during dormancy. The observed differences were not entirely explained by differences in budburst (more shoots/node or an increased number of water shoots). There is some evidence to suggest that some of the buds that we dissected and assumed to be dead based on slight browning of mersitematic tissue may have indeed burst and given rise to functional shoots in Spring.




Figure 2.11. A comparison of estimates of fertility based on dissecting dormant latent buds during winter (❍) with observed node fertility measured 6 weeks after budburst (●) for Cabernet Sauvignon at Dookie and at Whitlands. Vines at Dookie were pruned to 3 bud spurs while those at Whitlands were cane-pruned.

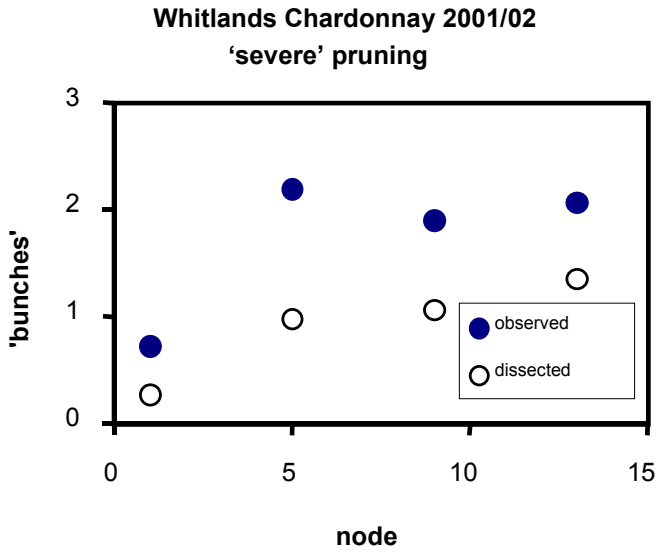



Figure 2.12. A comparison of estimates of fertility based on dissecting dormant latent buds during winter (❍) with observed node fertility measured 6 weeks after budburst (●) for Chardonnay at Whitlands that had been severely pruned during dormancy in 2001.

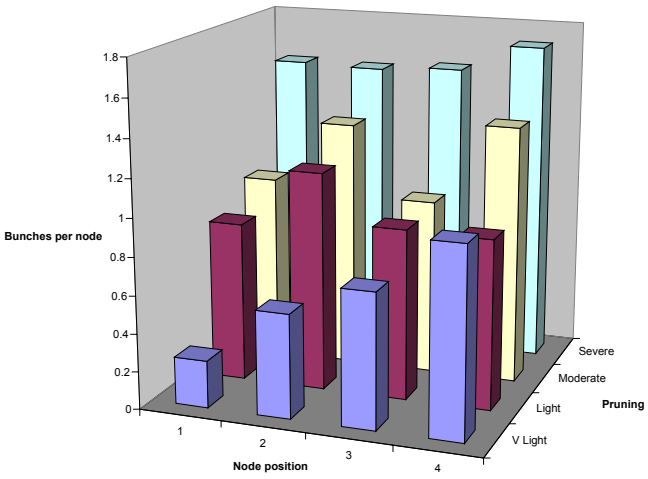



Figure 2.13

*Effect of yield regulation on yield components*
Methods aimed at reducing bunch numbers can lead to compensation in other yield components. The timing and severity of crop removal are both important. More severe pruning might be expected to increase both berries per bunch and berry weight. However, bunch thinning after veraison should have less effect on bunch weight or berry weight. In most cases pruning increased both bunch weight and berry weight. Shoot thinning had very variable effects depending on the site. In some cases the effects of shoot thinning were difficult to assess as severe shoot thinning led to an increased number of bunches being formed on lateral shoots (second crop) when vines were trimmed. These bunches were smaller with smaller berries (personal observation). Bunch thinning at veraison had no effect on either bunch weight or berry weight. By this time not only had fruit set occurred but also the cell division phase of berry development had finished.

Variable responses of yield components to the type of regulation are seen in the response of berry size. For hot climate Cabernet Sauvignon and Chardonnay trained to permanent cordons our results are fairly consistent across years and yield potential (Figure 7). Bunch thinning at veraison had no effect on berry size. Shoot thinning had a slight effect in Chardonnay and an effect similar to pruning in Cabernet Sauvignon. Pruning had the biggest effect with harder pruning increasing berry size. Generally, the earlier the yield reduction measure, the greater the opportunity for compensation in berry weight.

The results for cool climate Cabernet Sauvignon and Chardonnay that were cane-pruned were less consistent when compared with those from hot climates (Figure 8). In the first year of the experiments there was no significant effect of any treatment on berry size in Chardonnay, and in Cabernet Sauvignon, the only significant effects were due to the most severe pruning and all levels of bunch thinning. Curiously, these all significantly decreased berry size. In the second year, pruning Chardonnay had no effect on berry size. The only treatment to affect berry size significantly ($P < 0.05$) was severe shoot thinning. In Cabernet Sauvignon only pruning affected berry size, with harder pruning increasing berry size.

For vines trained to a permanent cordon in hot climates we can give some fairly reliable guidance when it comes to manipulating berry size. If you want smaller berries, prune lighter, but this is likely to give you a higher yield, which could affect other aspects of composition adversely. Shoot thinning before flowering is likely, if anything, to increase berry size, so it would be prudent to avoid it if you don't want bigger berries. If you want smaller berries and you think there is likely to be some benefit in a lower crop load, this can best be achieved by pruning lightly and then bunch thinning at veraison.

However, for vines that are set up for cane pruning in a cool climate, the story isn't so clear. We observed some unexpected responses, particularly in the first year. It could be that this sort of system takes a while to settle down. Much could depend, too, on selection of cane lengths - some of our treatments included some odd cane lengths to try to hit yield targets (eg. half canes with 5 to 7 buds).

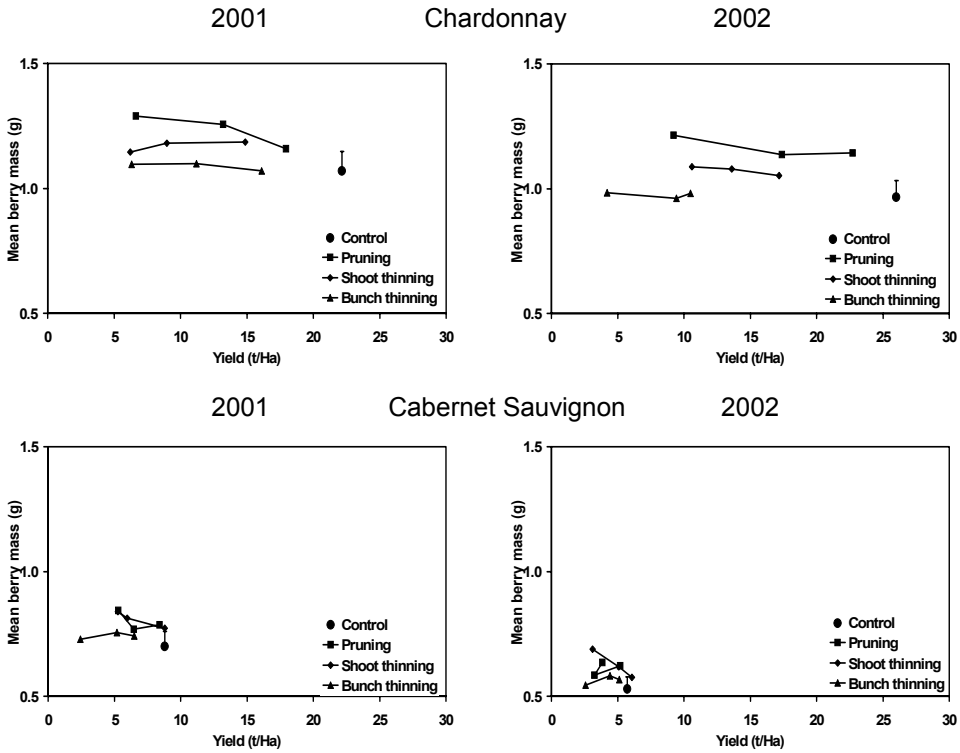



Figure 2.14. Effect of yield regulation on berry mass at harvest in hot climates - permanent cordon, mechanical or spur pruning. The points represent treatment means and the bar above the control symbol represents the $LSD_{5\%}$.

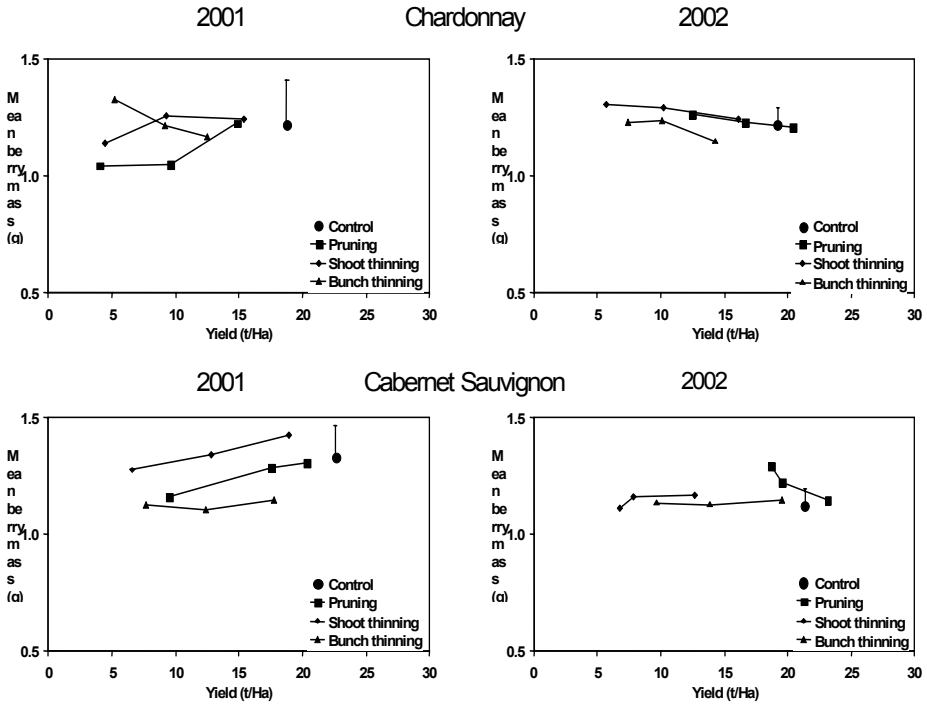



Figure 2.15. Effect of yield regulation on berry mass at harvest in a cool climate - cane pruning. The points represent treatment means and the bar above the control symbol represents the $LSD_{5\%}$.

### *Conclusions*

Irrespective of how one attempts to regulate yield, our results show that accurate regulation demands: (i) an accurate yield forecast, (ii) a quantitative understanding of how the yield components will react to yield regulation (vine compensation) and (iii) a method to accurately remove crop. We have shown that is possible to accurately remove crop by manual shoot and bunch thinning and that it is possible to respond to fluctuations in fertility by adjusting the severity of pruning in hand pruned systems. Taken overall, the results show that it is possible to move closer toward the situation described in Figure 2.16. Furthermore, the project has developed techniques, supported by software and manuals, whereby vineyard managers can improve their ability to set and consistently hit yield targets

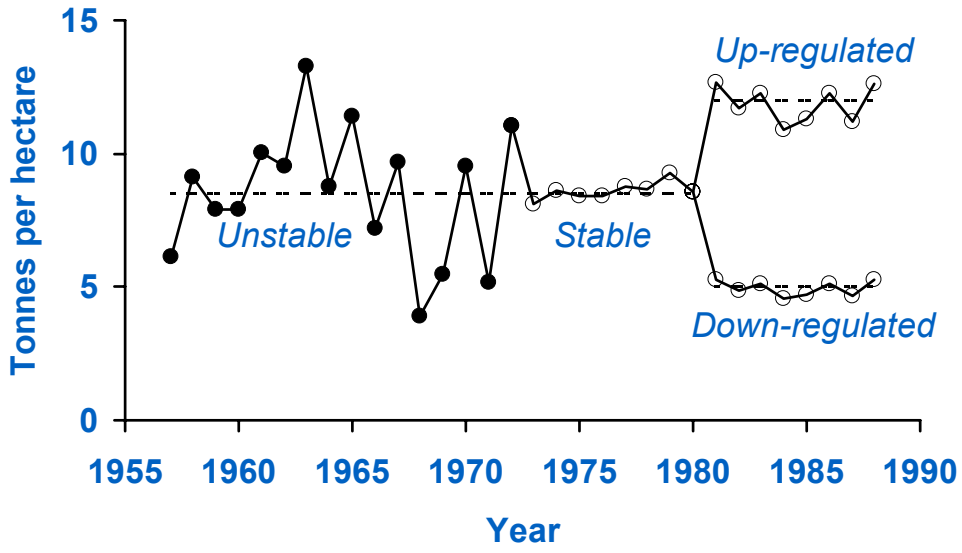



Figure 2.16 A hypothetical yield tracing demonstrating a stabilisation of yield followed by the capacity to regulate yield.

However, these techniques rely on accurate crop forecasting. Crop forecasting can be accurate if objective methods are used that employ adequate sampling techniques and are based on using correct formulae (Dunn and Martin 2003). Current research is directed toward better prediction of 'unknowns' (eg. Bunch size at harvest, see Dunn and Martin 2003) and more rapid techniques to assess crop load (e.g. Dunn and Martin 2004). However, many growers and vineyard mangers are unwilling to commit sufficient resources for statistically adequate sampling and data interpretation. Such unwillingness continues to be a major impediment to adoption of demonstrably better methods for crop forecasting and, therefore, crop regulation. It will continue to prevail unless the benefits of better measurement and prediction are appreciated and incentives are provided to do them.

The results from the shoot thinning treatments were extremely promising. Also, there may be other unforseen benefits related to shoot thinning. We noticed that shoot thinned vines were much quicker to prune during dormancy. This may translate to substantial savings in pruning costs. However, manual shoot thinning is an expensive and time-consuming operation. We believe there is great potential for future mechanisation of this technique. Notwithstanding this, there are commercial systems currently available overseas that may be worth testing.

***Recommendations***

There are good reasons to improve our ability to stabilise seasonal yield fluctuations. These are based on economic imperatives and wine quality benefits. However, successful yield regulation depends, in the first place, on being able to accurately forecast yield or yield potential. This cannot be stressed strongly enough.

Being able to 'hit' target numbers of bunches per vine or unit length of row reliably is a prerequisite for stabilising yield. We have shown that when well developed techniques (eg. microscopic bud dissection, bunch counting, bunch thinning) are properly applied based on the use of sound sampling methods, target numbers of bunches per vine can be hit successfully. It has proved more difficult, however, to predict bunch weight and bunch weight compensation. Further research has shown that the number of branches per bunch is simple to measure and is a good early indicator of bunch weight.

Better yield regulation also relies on a quantitative understanding of yield compensation in response to regulation at different times throughout the season and accurate methods to thin crops. Of these two, more work is needed to develop methods of crop removal that are both accurate and cost-effective. Manually removing bunches and shoots is extremely expensive and, furthermore, much of Australian viticulture is mechanically pruned. Therefore, future research and development should directed toward more 'cost-effective' ways to regulate yield. These would necessarily include 'informed mechanised pruning', mechanical shoot thinning and more accurate crop removal through mechanical thinning.

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## Appendix 2.1. Crop control experiment, Southcorp Barooga Chardonnay

Situated in Block N1 on the Southcorp 'Tarn Pirr' vineyard at Barooga, NSW
Rows oriented East-West are numbered south to north
Included:
150 plots = 10 treatments x 15 replicates
4 of these plots would have a replanted measurement vine
Block name Barooga Chardonnay
Row spacing 2.75 metres
Vine spacing 2 metres

Vines/Ha 1818

Barooga Chardonnay 2000/01

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Target yield (t/Ha) | 20 | 15 | 10 | 5 | 15 | 10 | 5 | 15 | 10 | 5 |
| Actual yield (t/Ha) | 22.16 | 17.96 | 13.20 | 6.63 | 14.88 | 8.96 | 6.24 | 16.11 | 11.19 | 6.32 |

| | bu_thin | sh_thin | pruning | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-N | | | | | | | 1-L | 2-M | 3-S | Grand Total |
| | 0-N | | | | 1-L | 2-M | 3-S | 0-N | 0-N | 0-N | |
| Data | 0-VL | 1-L | 2-M | 3-S | 0-VL | 0-VL | 0-VL | 0-VL | 0-VL | 0-VL | |
| Average of Brix | 21.46 | 22.16 | 22.63 | 22.78 | 22.80 | 23.15 | 22.92 | 22.68 | 23.56 | 23.89 | 22.80 |
| Average of pH | 3.86 | 3.89 | 3.96 | 3.99 | 4.00 | 3.97 | 3.93 | 3.99 | 4.00 | 4.04 | 3.96 |
| Average of TA | 5.72 | 5.76 | 5.63 | 5.67 | 5.64 | 5.86 | 6.13 | 5.48 | 5.62 | 5.26 | 5.68 |
| Average of kg.p.vi | 13.30 | 10.78 | 7.92 | 3.98 | 8.93 | 5.37 | 3.74 | 9.66 | 6.72 | 3.79 | 7.42 |
| Average of bu.p.vi | 152 | 108 | 78 | 35 | 81 | 51 | 39 | 105 | 75 | 43 | 77 |
| Average of g.p.bu1 | 88 | 100 | 102 | 111 | 110 | 104 | 96 | 91 | 90 | 88 | 98 |
| Average of g.p.bu2 | 91 | 106 | 115 | 121 | 116 | 108 | 96 | 99 | 98 | 94 | 104 |
| Average of be.p.bu | 81 | 87 | 87 | 88 | 92 | 84 | 77 | 82 | 83 | 80 | 84 |
| Average of bug.p.be | 1.14 | 1.22 | 1.33 | 1.35 | 1.25 | 1.24 | 1.21 | 1.20 | 1.16 | 1.17 | 1.23 |
| Average of beg.p.be | 1.07 | 1.16 | 1.26 | 1.29 | 1.19 | 1.18 | 1.15 | 1.07 | 1.10 | 1.10 | 1.15 |

Barooga Chardonnay 2001/02

Yield (t/Ha) 26.01 22.73 17.39 9.21 17.16 13.60 10.61 10.49 9.43 4.19

| | thinned | method | cropload | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-nothin | 1-thinned | | | | | | | | | Grand Total |
| | 0-none | 1-prune | | | 2-shthin | | | 3-buthin | | | |
| Data | 4-VH | 3-H | 2-M | 1-L | 3-H | 2-M | 1-L | 3-H | 2-M | 1-L | |
| Average of Brix | 20.06 | 21.18 | 21.75 | 22.59 | 21.31 | 22.15 | 23.26 | 23.53 | 23.97 | 24.13 | 22.38 |
| Average of pH | 3.42 | 3.56 | 3.57 | 3.60 | 3.54 | 3.56 | 3.57 | 3.66 | 3.68 | 3.70 | 3.59 |
| Average of TA | 5.23 | 4.96 | 5.00 | 5.42 | 5.04 | 5.00 | 5.32 | 4.74 | 4.91 | 4.58 | 5.02 |
| Average of kg.p.vi | 15.61 | 13.64 | 10.43 | 5.53 | 10.30 | 8.16 | 6.37 | 6.29 | 5.66 | 2.52 | 8.49 |
| Average of bu.p.vi | 177 | 123 | 88 | 47 | 81 | 63 | 56 | 70 | 62 | 31 | 80 |
| Average of g.p.bu1 | 87 | 111 | 118 | 119 | 128 | 133 | 117 | 92 | 92 | 81 | 108 |
| Average of g.p.bu2 | 92 | 127 | 128 | 148 | 133 | 144 | 129 | 94 | 105 | 98 | 120 |
| Average of be.p.bu | 88 | 103 | 106 | 114 | 116 | 121 | 111 | 89 | 100 | 91 | 104 |
| Average of bug.p.be | 1.02 | 1.22 | 1.20 | 1.30 | 1.12 | 1.16 | 1.11 | 1.05 | 1.03 | 1.06 | 1.13 |

Barooga Chardonnay 2002/03

Yield (t/Ha) 13.07 13.84 10.78 3.66 9.73 7.31 5.79 12.11 10.10 5.61

| | thinned | method | cropload | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-nothin | 1-thinned | | | | | | | | | Grand Total |
| | 0-none | 1-prune | | | 2-shthin | | | 3-buthin | | | |
| Data | 4-VH | 3-H | 2-M | 1-L | 3-H | 2-M | 1-L | 3-H | 2-M | 1-L | |
| Average of Brix | 22.72 | 22.25 | 22.38 | 22.69 | 22.25 | 22.87 | 23.14 | 22.97 | 22.00 | 23.86 | 22.69 |
| Average of pH | 3.69 | 3.66 | 3.67 | 3.62 | 3.64 | 3.62 | 3.62 | 3.78 | 3.64 | 3.75 | 3.67 |
| Average of TA | 4.61 | 4.90 | 4.67 | 5.20 | 4.99 | 4.72 | 4.76 | 4.28 | 4.77 | 4.30 | 4.73 |
| Average of kg.p.vi | 7.84 | 8.30 | 6.47 | 2.20 | 5.84 | 4.39 | 3.48 | 7.27 | 6.06 | 3.37 | 5.57 |
| Average of bu.p.vi | 146 | 130 | 97 | 35 | 95 | 64 | 47 | 120 | 111 | 62 | 91 |
| Average of g.p.bu1 | 54 | 64 | 67 | 63 | 60 | 69 | 72 | 59 | 54 | 53 | 62 |
| Average of g.p.bu2 | 53 | 69 | 70 | 70 | 61 | 70 | 68 | 68 | 60 | 56 | 65 |
| Average of be.p.bu | 62 | 73 | 76 | 63 | 63 | 69 | 68 | 72 | 67 | 56 | 67 |
| Average of bug.p.be | 0.86 | 0.94 | 0.93 | 1.10 | 0.96 | 1.04 | 1.01 | 0.96 | 0.91 | 1.01 | 0.97 |

**Appendix 2.2. Average bunches per bud for buds dissected during dormancy**

Fruitfulness Data
Dookie Cabernet Sauvignon

| Bud | Primary | Acc. 1 | Acc. 2 |
|---|---|---|---|
| 00/01 | 1.45 | 1.09 | 0.42 |
| 01/02 | 1.15 | 0.90 | 0.52 |
| 02/03 | 0.90 | 0.61 | 0.31 |
| 03/04 | 1.63 | 1.05 | 0.95 |

Barooga Chardonnay

| Bud | Primary | Acc. 1 | Acc. 2 |
|---|---|---|---|
| 00/01 | 1.64 | 1.43 | 0.62 |
| 01/02 | 1.23 | 0.89 | 0.59 |
| 02/03 | 0.79 | 0.40 | 0.19 |

Whitlands Cabernet Sauvignon

| Bud | Primary | Acc. 1 | Acc. 2 |
|---|---|---|---|
| 00/01 | 1.64 | 0.80 | 0.82 |
| 01/02 | 1.27 | 0.17 | 0.36 |
| 02/03 | 1.07 | 0.55 | 0.26 |

Whitlands Chardonnay

| Bud | Primary | Acc. 1 | Acc. 2 |
|---|---|---|---|
| 00/01 | 1.83 | 1.27 | 0.83 |
| 01/02 | 1.48 | 0.67 | 0.33 |
| 02/03 | 0.94 | 0.26 | 0.07 |

Whitlands Pinot Noir

| Bud | Primary | Acc. 1 | Acc. 2 |
|---|---|---|---|
| 00/01 | 1.75 | 1.33 | 0.77 |
| 01/02 | 1.45 | 0.43 | 0.43 |

## Appendix 2.3. Dookie Cabernet Sauvignon

13-14 reps of 10 treatments are to be allocated to 8 rows of vines at Dookie. The experimental unit was 4 contiguous vines. There were 136 plots including ten, 3 vine plots. There were 13 reps allocated to the very light, light, moderate and severe winter pruning treatments that had no shoot or bunch thinning. All the shoot or bunch thinning treatments had 14 reps.

| | | |
|---|---|---|
| Block name | Dookie Cabernet | |
| Row spacing | 3.4 | metres |
| Vine spacing | 2.4 | metres |
| | | |
| Vines/Ha | 1225 | |

### Tags and Tape

| Tmt | Tag | Code | Tape | Pruning during dormancy | Shoot thinning after bud burst | Bunch thinning after fruit set |
|---|---|---|---|---|---|---|
| **1** | **Green** | **VL/N/N - VH** | Green | Very light | Nil | Nil |
| **2** | **Orange** | **L/N/N - H** | Orange | Light | Nil | Nil |
| **3** | **Yellow** | **M/N/N - M** | Yellow | Moderate | Nil | Nil |
| **4** | **White** | **S/N/N - L** | White | Severe | Nil | Nil |
| **5** | **Orange** | **VL/L/N - H** | Orange+Blue | Very light | Light | Nil |
| **6** | **Yellow** | **VL/M/N - M** | Yellow+Blue | Very light | Moderate | Nil |
| **7** | **White** | **VL/S/N - L** | White+Blue | Very light | Severe | Nil |
| **8** | **Orange** | **VL/N/L - H** | Orange+Pink | Very light | Nil | Light |
| **9** | **Yellow** | **VL/N/M - M** | Yellow+Pink | Very light | Nil | Moderate |
| **10** | **White** | **VL/N/S - L** | White+Pink | Very light | Nil | Severe |

Weight gain factors

Weights of individually sampled bunches (g)

| | | 2002 | | |
|---|---|---|---|---|
| | 2001 | 5 T/Ha | 4 T/Ha | 3 T/Ha |
| Veraison | 33 | 31 | 31 | 32 |
| Harvest | 72 | 54 | 57 | 45 |
| Weight gain | 2.19 | 1.73 | 1.82 | 1.40 |

Summary of weight gain factors over two years

| | |
|---|---|
| Mean | 1.96 |
| Variation | 12% |
| Doubt | 23% |

Veraison 2000-01

| | |
|---|---|
| Average of score(1-5) | 0.9 |
| Average of Bunch wt. | 32.61 |
| StdDev of Bunch wt. | 21.96 |
| Average of Big Berries | 89.30 |
| StdDev of Big Berries | 54.74 |
| Average of Berry Wt. | 27.93 |
| StdDev of Berry Wt. | 19.14 |
| Average of Branch No. | 16.61 |

Harvest 2000-01

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Actual yield (t/Ha) | 8.80 | 8.42 | 6.48 | 5.30 | 8.78 | 5.99 | 5.27 | 6.51 | 5.19 | 2.43 |

| | bu_thin | sh_thin | pruning | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0-N | | | | | | | 1-L | 2-M | 3-S |
| | 0-N | | | | 1-L | 2-M | 3-S | 0-N | 0-N | 0-N |
| Data | 0-VL | 1-L | 2-M | 3-S | 0-VL | 0-VL | 0-VL | 0-VL | 0-VL | 0-VL |
| Average of Brix | 25.01 | 24.68 | 24.59 | 24.44 | 24.92 | 24.59 | 24.78 | 24.66 | 24.58 | 25.04 |
| Average of pH | 3.70 | 3.68 | 3.73 | 3.77 | 3.75 | 3.69 | 3.62 | 3.75 | 3.78 | 3.79 |
| Average of TA | 6.20 | 6.33 | 6.17 | 6.33 | 6.37 | 6.70 | 6.65 | 6.26 | 6.35 | 6.12 |
| Average of kg.p.vi | 7.18 | 6.87 | 5.29 | 4.33 | 7.17 | 4.88 | 4.30 | 5.31 | 4.23 | 1.98 |
| Average of bu.p.vi | 112.19 | 101.00 | 65.08 | 41.58 | 96.64 | 61.75 | 43.68 | 79.11 | 71.46 | 34.29 |
| Average of g.p.bu1 | 63.55 | 69.60 | 79.73 | 104.21 | 73.88 | 78.51 | 97.08 | 66.28 | 58.76 | 58.17 |
| Average of g.p.bu2 | 71.50 | 79.37 | 96.05 | 110.95 | 87.22 | 94.24 | 117.37 | 66.90 | 68.94 | 66.36 |
| Average of be.p.bu | 93.43 | 93.49 | 114.38 | 121.27 | 102.48 | 106.98 | 126.01 | 79.90 | 83.56 | 81.21 |
| Average of bug.p.be | 0.75 | 0.84 | 0.82 | 0.90 | 0.89 | 0.87 | 0.89 | 0.80 | 0.80 | 0.78 |

Veraison 2001-02

| | cropload | | | |
|---|---|---|---|---|
| Data | 3-high | 2-med | 1-low | Grand Total |
| Average of Score | 0.88 | 0.82 | 0.92 | 0.87 |
| Average of BunchWt | 30.99 | 31.45 | 32.37 | 31.60 |
| Average of BunchBiBe | 87.65 | 86.26 | 93.56 | 89.09 |
| StdDev of Score | 0.46 | 0.54 | 0.42 | 0.48 |
| StdDev of BunchWt | 18.99 | 18.43 | 19.65 | 18.94 |
| StdDev of BunchBiBe | 42.97 | 44.08 | 53.26 | 46.83 |
| Count of Score | 78 | 83 | 77 | 238 |
| Count of BunchWt | 78 | 84 | 78 | 240 |
| Count of BunchBiBe | 78 | 84 | 78 | 240 |

Harvest 2001-02

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Yield (t/Ha) | 5.73 | 5.20 | 3.26 | 3.86 | 6.09 | 5.09 | 3.10 | 5.11 | 4.41 | 2.58 |

| | thinned 0-nothin 0-none | method 1-thinned 1-prune | cropload | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2-shthin | | | 3-buthin | | |
| Data | 4-VH | 3-H | 2-M | 1-L | 3-H | 2-M | 1-L | 3-H | 2-M | 1-L |
| Average of Brix | 23.07 | 23.25 | 23.98 | 23.79 | 23.19 | 23.14 | 23.92 | 23.21 | 23.87 | 23.79 |
| Average of pH | 3.52 | 3.43 | 3.49 | 3.49 | 3.48 | 3.42 | 3.39 | 3.49 | 3.45 | 3.51 |
| Average of TA | 6.87 | 7.22 | 7.21 | 7.14 | 7.00 | 7.27 | 7.44 | 7.00 | 7.01 | 7.17 |
| Average of kg.p.vi | 4.68 | 4.24 | 2.66 | 3.15 | 4.97 | 4.16 | 2.53 | 4.17 | 3.59 | 2.11 |
| Average of bu.p.vi | 108.88 | 74.08 | 49.19 | 51.58 | 96.25 | 69.43 | 37.04 | 91.46 | 75.32 | 52.82 |
| Average of g.p.bu1 | 42.35 | 57.53 | 53.22 | 59.96 | 50.44 | 56.73 | 68.87 | 45.14 | 45.19 | 40.49 |
| Average of g.p.bu2 | 48.74 | 65.98 | 66.41 | 74.73 | 52.98 | 58.91 | 79.08 | 53.74 | 57.16 | 45.22 |
| Average of be.p.bu | 77.86 | 91.83 | 98.44 | 99.89 | 80.13 | 84.59 | 101.64 | 79.80 | 82.98 | 70.32 |
| Average of bug.p.be | 0.59 | 0.68 | 0.64 | 0.70 | 0.64 | 0.68 | 0.75 | 0.62 | 0.64 | 0.61 |

Dookie Cabernet 2002-03

Yield (t/Ha) 4.15 5.41 4.62 4.33

| | thinned | method | cropload | |
|---|---|---|---|---|
| | 0-nothin | 1-thinned | | |
| | 0-none | 1-prune | | |
| Data | 4-VH | 3-H | 2-M | 1-L |
| Average of Brix | 22.31 | 22.05 | 22.88 | 23.18 |
| Average of pH | 3.50 | 3.43 | 3.47 | 3.45 |
| Average of TA | 6.28 | 7.02 | 6.88 | 6.96 |
| Average of kg.p.vi | 3.39 | 4.41 | 3.77 | 3.53 |
| Average of bu.p.vi | 131 | 121 | 112 | 68 |
| Average of g.p.bu1 | 23 | 34 | 32 | 51 |
| Average of g.p.bu2 | 0 | 0 | 0 | 9 |
| Average of be.p.bu | 0 | 0 | 0 | 11 |

**Appendix 2.4. Crop control experiment, Whitlands**
**Chardonnay 2000/01**

Situated in Block E3 in the Brown Brothers vineyard at Whitlands
Rows oriented North-South are numbered west to east
Included:
160 plots = 10 treatments x 16 replicates
4 of these plots would have a replanted measurement vine
1 plot would have a missing guard vine
so 5 plots with 1 measurement vine rather than 2

| | | |
|---|---|---|
| Block | Whitlands Chardonnay | |
| Row spacing | 1.7 | metres |
| Vine spacing | 1 | metres |
| Vines/Ha | 5882 | |

| Tmt | Tag | Code | Tape | Pruning | Shoot Thin | Bunch Thin |
|---|---|---|---|---|---|---|
| 1 | Green | VL/N/N - VH | Green | VL | Nil | Nil |
| 2 | Orange | L/N/N - H | Orange | L | Nil | Nil |
| 3 | Yellow | M/N/N - M | Yellow | M | Nil | Nil |
| 4 | White | S/N/N - L | White | S | Nil | Nil |
| 5 | Orange | VL/L/N - H | Orange+Blue | VL | L | Nil |
| 6 | Yellow | VL/M/N - M | Yellow+Blue | VL | M | Nil |
| 7 | White | VL/S/N - L | White+Blue | VL | S | Nil |
| 8 | Orange | VL/N/L - H | Orange+Pink | VL | Nil | L |
| 9 | Yellow | VL/N/M - M | Yellow+Pink | VL | Nil | M |
| 10 | White | VL/N/S - L | White+Pink | VL | Nil | S |

Whitlands Chardonnay 2000-01

| Treatments | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Target t/Ha | 20 | 15 | 10 | 5 | 15 | 10 | 5 | 15 | 10 | 5 |
| Mean t/Ha | 18.77 | 14.85 | 9.58 | 4.07 | 15.37 | 9.34 | 4.44 | 12.51 | 9.19 | 5.18 |
| Difference % | -6 | -1 | -4 | -19 | 2 | -7 | -11 | -17 | -8 | 4 |

| | bu_thin | sh_thin | pruning | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-N | | | | | | | 1-L | 2-M | 3-S | Grand Total |
| | 0-N | | | | 1-L | 2-M | 3-S | 0-N | 0-N | 0-N | |
| Data | 0-VL | 1-L | 2-M | 3-S | 0-VL | 0-VL | 0-VL | 0-VL | 0-VL | 0-VL | |
| Average of Brix | 21.89 | 21.92 | 22.84 | 22.31 | 21.97 | 22.71 | 22.89 | 22.53 | 22.50 | 22.53 | 22.41 |
| Average of pH | 3.09 | 3.10 | 3.10 | 3.08 | 3.09 | 3.06 | 3.07 | 3.13 | 3.11 | 3.09 | 3.09 |
| Average of TA | 9.05 | 9.53 | 9.87 | 10.35 | 9.45 | 9.72 | 9.49 | 9.30 | 9.27 | 9.39 | 9.55 |
| Average of kg.p.vi | 3.192 | 2.524 | 1.628 | 0.692 | 2.612 | 1.588 | 0.755 | 2.127 | 1.562 | 0.880 | 1.751 |
| Average of bu.p.vi | 36 | 28 | 21 | 12 | 28 | 19 | 9 | 25 | 18 | 12 | 21 |
| Average of g.p.bu1 | 87 | 87 | 80 | 57 | 92 | 82 | 83 | 84 | 85 | 75 | 81 |
| Average of g.p.bu2 | 89 | 88 | 69 | 65 | 89 | 80 | 90 | 93 | 93 | 83 | 84 |
| Average of be.p.bu | 68 | 72 | 64 | 59 | 69 | 62 | 73 | 77 | 74 | 67 | 68 |
| Average of bug.p.be | 1.28 | 1.29 | 1.09 | 1.11 | 1.30 | 1.33 | 1.20 | 1.21 | 1.27 | 1.37 | 1.24 |
| Average of beg.p.be | 1.22 | 1.22 | 1.04 | 1.04 | 1.24 | 1.26 | 1.14 | 1.16 | 1.22 | 1.32 | 1.19 |

Whitlands Chardonnay 2001-02

| Treatments | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Target t/Ha | 20 | 15 | 10 | 5 | 15 | 10 | 5 | 15 | 10 | 5 |
| Mean t/Ha | 19.17 | 20.46 | 16.67 | 12.52 | 16.15 | 10.19 | 5.71 | 14.33 | 10.09 | 7.43 |
| Difference % | -4 | 36 | 67 | 150 | 8 | 2 | 14 | -4 | 1 | 49 |

| | Treated | Method | Cropload | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-no | 1-yes | | | | | | | | | Grand Total |
| | 0-none | 1-pruning | | | 2-sh_thin | | | 3-bu_thin | | | |
| Data | 4-max | 3-high | 2-med | 1-low | 3-high | 2-med | 1-low | 3-high | 2-med | 1-low | |
| Average of Brix | 22.31 | 21.98 | 21.96 | 22.18 | 22.83 | 23.03 | 23.15 | 22.46 | 22.19 | 22.20 | 22.42 |
| Average of pH | 3.23 | 3.27 | 3.18 | 3.19 | 3.26 | 3.21 | 3.22 | 3.27 | 3.20 | 3.19 | 3.22 |
| Average of TA | 10.07 | 9.99 | 10.54 | 10.70 | 10.13 | 10.62 | 9.93 | 9.89 | 10.39 | 10.37 | 10.26 |
| Average of kg.p.vi | 3.259 | 3.479 | 2.834 | 2.129 | 2.745 | 1.732 | 0.970 | 2.435 | 1.715 | 1.263 | 2.256 |
| Average of bu.p.vi | 40 | 43 | 35 | 26 | 35 | 22 | 13 | 32 | 21 | 17 | 28 |
| Average of g.p.bu1 | 81 | 81 | 82 | 84 | 80 | 80 | 75 | 75 | 80 | 74 | 79 |
| Average of g.p.bu2 | 84 | 89 | 92 | 91 | 80 | 81 | 78 | 81 | 85 | 83 | 85 |
| Average of be.p.bu | 66 | 72 | 75 | 72 | 62 | 62 | 59 | 67 | 69 | 67 | 67 |
| Average of bug.p.be | 1.27 | 1.24 | 1.24 | 1.28 | 1.30 | 1.31 | 1.25 | 1.21 | 1.25 | 1.24 | 1.26 |
| Average of beg.p.be | 1.22 | 1.20 | 1.23 | 1.26 | 1.24 | 1.29 | 1.30 | 1.15 | 1.24 | 1.23 | 1.24 |

**Appendix 2.5. Crop control experiment, Whitlands**
**Cabernet Sauvignon**

Situated in Block J1 in the Brown Brothers vineyard at Whitlands
Rows oriented North-South are numbered west to east
All of Rows 370-373 were allocated after discussion with vineyard manager and staff
Each row contains 182-183 vines
Included:
160 plots = 10 treatments x 16 replicates
12 plots with only one measurement vine

Row spacing 1.7 metres
Vine spacing 1 metres
Vines/Ha 5882

| Tmt | Tag | Code | Tape | Pruning | Shoot Thin | Bunch Thin |
|---|---|---|---|---|---|---|
| 1 | Green | VL/N/N - VH | Green | VL | Nil | Nil |
| 2 | Orange | L/N/N - H | Orange | L | Nil | Nil |
| 3 | Yellow | M/N/N - M | Yellow | M | Nil | Nil |
| 4 | White | S/N/N - L | White | S | Nil | Nil |
| 5 | Orange | VL/L/N - H | Orange+Blue | VL | L | Nil |
| 6 | Yellow | VL/M/N - M | Yellow+Blue | VL | M | Nil |
| 7 | White | VL/S/N - L | White+Blue | VL | S | Nil |
| 8 | Orange | VL/N/L - H | Orange+Pink | VL | Nil | L |
| 9 | Yellow | VL/N/M - M | Yellow+Pink | VL | Nil | M |
| 10 | White | VL/N/S - L | White+Pink | VL | Nil | S |

Weight gain factors

Weights of individually sampled bunches (g)

| | 2001 | 2002 20 t/Ha | 14 T/Ha | 10 T/Ha |
|---|---|---|---|---|
| Veraison | 79 | 46 | 47 | 49 |
| Harvest | 118 | 93 | 90 | 86 |
| Weight gain | 1.49 | 2.02 | 1.90 | 1.77 |

Summary of weight gain factors over two years

| | |
|---|---|
| Mean | 1.75 |
| Variation | 15% |
| Doubt | 30% |

Veraison 2000-01

| Data | Total |
|---|---|
| Average of Score | 0.53 |
| Average of Bunch wt. | 79.47 |
| Average of Big Berries | 113.73 |
| StdDev of Score | 0.70 |
| StdDev of Bunch wt. | 49.04 |
| StdDev of Big Berries | 64.81 |
| Count of Score | 93 |
| Count of Bunch wt. | 93 |
| Count of Big Berries | 93 |

Harvest 2000-01

| Treatments | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Yield (t/Ha) | 22.63 | 20.38 | 17.61 | 9.51 | 18.91 | 12.87 | 6.60 | 17.78 | 12.44 | 7.73 |

| | thinned 0-nothin 0-none | method 1-thinned 1-prune | cropload | | 2-shthin | | | 3-buthin | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Data | 4-VH | 3-H | 2-M | 1-L | 3-H | 2-M | 1-L | 3-H | 2-M | 1-L |
| Average of Brix | 22.54 | 22.91 | 22.02 | 23.24 | 22.37 | 23.41 | 24.11 | 22.41 | 23.34 | 23.07 |
| Average of pH | 3.36 | 3.37 | 3.28 | 3.34 | 3.35 | 3.33 | 3.40 | 3.30 | 3.28 | 3.24 |
| Average of TA | 10.42 | 10.35 | 10.70 | 10.24 | 10.44 | 10.19 | 10.16 | 10.52 | 10.17 | 9.35 |
| Average of bu.p.vi | 36.46 | 29.50 | 19.79 | 13.61 | 29.63 | 17.04 | 8.50 | 26.72 | 20.32 | 13.34 |
| Average of kg.p.vi | 3.85 | 3.46 | 2.99 | 1.62 | 3.22 | 2.19 | 1.12 | 3.02 | 2.12 | 1.31 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Average of g.p.bu1 | 105.17 | 116.53 | 151.55 | 119.12 | 109.75 | 127.50 | 126.90 | 113.20 | 104.23 | 99.64 |
| Average of g.p.bu2 | 118.10 | 129.66 | 151.72 | 99.51 | 160.11 | 139.83 | 135.23 | 129.05 | 100.92 | 108.97 |
| Average of be.p.bu | 86.77 | 96.67 | 111.89 | 74.48 | 112.38 | 101.70 | 98.16 | 106.04 | 83.63 | 87.36 |
| Average of bug.p.be | 1.40 | 1.38 | 1.37 | 1.23 | 1.51 | 1.42 | 1.38 | 1.22 | 1.17 | 1.22 |
| Average of beg.p.be | 1.33 | 1.30 | 1.28 | 1.16 | 1.42 | 1.34 | 1.27 | 1.15 | 1.10 | 1.12 |
| Average of NIRColour | 12.89 | 13.35 | 13.04 | 13.44 | 13.04 | 13.64 | 14.24 | 14.56 | 15.69 | 15.65 |

Veraison 2001-02

| | cropload | | | |
|---|---|---|---|---|
| Data | 3-high | 2-med | 1-low | Grand Total |
| Average of Score | 1 | 0.90 | 0.79 | 0.90 |
| Average of BunchWt | 46.26 | 47.41 | 48.71 | 47.46 |
| Average of BunchBiBe | 76.56 | 71.69 | 72.27 | 73.59 |
| StdDev of Score | 0.68 | 0.79 | 0.82 | 0.77 |
| StdDev of BunchWt | 22.75 | 26.09 | 30.11 | 26.33 |
| StdDev of BunchBiBe | 38.73 | 39.87 | 37.43 | 38.42 |
| Count of Score | 48 | 42 | 48 | 138 |
| Count of BunchWt | 48 | 42 | 48 | 138 |
| Count of BunchBiBe | 48 | 42 | 48 | 138 |

Harvest 2001-02

| Treatments | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Yield (t/Ha) | 21.39 | 23.18 | 19.54 | 18.73 | 12.65 | 7.92 | 6.82 | 19.59 | 13.87 | 9.68 |

| | Treated 0-no 0-none | Method 1-yes 1-pruning | Cropload | | 2-sh_thin | | | 3-bu_thin | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Data | 4-max | 3-high | 2-med | 1-low | 3-high | 2-med | 1-low | 3-high | 2-med | 1-low |
| Average of Brix | 20.89 | 20.81 | 21.61 | 21.37 | 21.51 | 21.62 | 21.82 | 21.74 | 21.85 | 21.71 |
| Average of pH | 3.34 | 3.34 | 3.24 | 3.32 | 3.30 | 3.37 | 3.36 | 3.21 | 3.27 | 3.33 |
| Average of TA | 10.01 | 10.09 | 11.04 | 11.28 | 11.60 | 11.07 | 10.59 | 11.03 | 10.67 | 10.68 |
| Average of bu.p.vi | 46.63 | 47.94 | 36.18 | 38.46 | 26.00 | 18.39 | 16.72 | 44.34 | 32.04 | 22.53 |
| Average of kg.p.vi | 3.64 | 3.94 | 3.32 | 3.18 | 2.15 | 1.35 | 1.16 | 3.33 | 2.36 | 1.65 |
| Average of g.p.bu1 | 82.58 | 82.58 | 92.12 | 83.97 | 81.00 | 73.55 | 67.70 | 75.04 | 73.45 | 72.22 |
| Average of g.p.bu2 | 87.79 | 90.35 | 107.14 | 105.63 | 94.41 | 89.44 | 78.07 | 93.44 | 89.97 | 86.33 |
| Average of be.p.bu | 72.73 | 73.31 | 81.59 | 75.64 | 75.07 | 71.54 | 63.90 | 74.94 | 75.40 | 69.38 |
| Average of | 1.21 | 1.23 | 1.32 | 1.41 | 1.25 | 1.26 | 1.22 | 1.25 | 1.22 | 1.25 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| bug.p.be<br>Average of beg.p.be | 1.12 | 1.14 | 1.22 | 1.29 | 1.17 | 1.16 | 1.11 | 1.15 | 1.13 | 1.13 |

Comparison of yield components measured at veraison, 2002 v 2001

Bunches per segment

| Treatment | 8 | 9 | 10 | Mean |
|---|---|---|---|---|
| 2001 | 33.73 | 33.73 | 33.73 | 33.73 |
| 2002 | 40.56 | 40.73 | 42.00 | 41.10 |
| Change | 0.20 | 0.21 | 0.25 | 0.22 |

Normal berries per bunch

| Treatment | 8 | 9 | 10 | Mean |
|---|---|---|---|---|
| 2001 | 113.73 | 113.73 | 113.73 | 113.73 |
| 2002 | 76.56 | 71.69 | 72.27 | 73.51 |
| Change | -0.33 | -0.37 | -0.36 | -0.35 |

Normal berries per segment

| Treatment | 8 | 9 | 10 | Mean |
|---|---|---|---|---|
| 2001 | 3836.53 | 3836.53 | 3836.53 | 3836.53 |
| 2002 | 3105.57 | 2920.19 | 3035.38 | 3021.07 |
| Change | -0.19 | -0.24 | -0.21 | -0.21 |

Weight per bunch at onset of veraison

| Treatment | 8 | 9 | 10 | Mean |
|---|---|---|---|---|
| 2001 | 79.47 | 79.47 | 79.47 | 79.47 |
| 2002 | 46.26 | 47.41 | 48.71 | 47.46 |
| Change | -0.42 | -0.40 | -0.39 | -0.40 |

Weight per segment at veraison

| Treatment | 8 | 9 | 10 | Mean |
|---|---|---|---|---|
| 2001 | 2680.84 | 2680.84 | 2680.84 | 2680.84 |
| 2002 | 1876.41 | 1931.14 | 2045.96 | 1950.57 |
| Change | -0.30 | -0.28 | -0.24 | -0.27 |

**Appendix 2.6. Crop control experiment, Whitlands Pinot Noir**

Situated in Block I1 in the Brown Brothers vineyard at Whitlands
Rows oriented North-South are numbered west to east
All of Rows 297-300 were allocated after discussion with vineyard manager and staff
Each row contains 212 vines, numbered North to South
Included:
160 plots = 10 treatments x 16 replicates
14 plots with only one measurement vine

| | | |
|---|---|---|
| Row spacing | 1.7 | metres |
| Vine spacing | 1 | metres |
| Vines/Ha | 5882 | |

| Tmt | Tag | Code | Tape | Pruning | Shoot Thin | Bunch Thin |
|---|---|---|---|---|---|---|
| 1 | Green | VL/N/N - VH | Green | VL | Nil | Nil |
| 2 | Orange | L/N/N - H | Orange | L | Nil | Nil |
| 3 | Yellow | M/N/N - M | Yellow | M | Nil | Nil |
| 4 | White | S/N/N - L | White | S | Nil | Nil |
| 5 | Orange | VL/L/N - H | Orange+Blue | VL | L | Nil |
| 6 | Yellow | VL/M/N - M | Yellow+Blue | VL | M | Nil |
| 7 | White | VL/S/N - L | White+Blue | VL | S | Nil |
| 8 | Orange | VL/N/L - H | Orange+Pink | VL | Nil | L |
| 9 | Yellow | VL/N/M - M | Yellow+Pink | VL | Nil | M |
| 10 | White | VL/N/S - L | White+Pink | VL | Nil | S |

**Whitlands Pinot Noir**

Weight gain factors

Weights of individually sampled bunches (g)

| | 2001 | 2002 |
|---|---|---|
| Veraison | 72.73 | 32.13 |
| Harvest | 78.01 | 45.12 |
| Weight gain | 1.07 | 1.40 |

Summary of weight gain factors over two years

| | |
|---|---|
| Mean | 1.24 |
| Variation | 13% |
| Doubt | 27% |

Whitlands Pinot Noir

2000-01 veraison data

| Data | Total |
|---|---|
| Average of Score | 0.02 |
| Average of Bunch wt. | 72.73 |
| Average of Big Berries | 103.73 |
| StdDev of Score | 0.15 |
| StdDev of Bunch wt. | 36.08 |
| StdDev of Big Berries | 49.14 |
| Count of Score | 92 |
| Count of Bunch wt. | 92 |
| Count of Big Berries | 92 |

| | |
|---|---|
| Verasion berry weight | 0.70 |

2000-01 harvest data

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Yield (t/Ha) | 20.17 | 19.49 | 14.70 | 7.23 | 14.49 | 11.66 | 7.03 | 18.27 | 13.64 | 5.91 |

| | Treated 0_no 0_none | Method 1_yes 1_prune | Cropload | | 2_shthin | | | 3_buthin | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Data | 4_Max | 3_H | 2_M | 1_L | 3_H | 2_M | 1_L | 3_H | 2_M | 1_L |
| Average of Brix | 23.89 | 23.96 | 23.66 | 24.39 | 23.83 | 23.87 | 23.89 | 23.80 | 23.50 | 24.67 |
| Average of pH | 3.31 | 3.31 | 3.28 | 3.26 | 3.28 | 3.30 | 3.31 | 3.29 | 3.36 | 3.31 |
| Average of TA | 7.92 | 8.44 | 8.06 | 10.20 | 7.71 | 8.39 | 9.07 | 8.29 | 7.87 | 9.24 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Average of bu.p.vi | 41.25 | 34.97 | 29.50 | 15.91 | 29.18 | 20.53 | 11.97 | 33.94 | 25.00 | 11.93 |
| Average of kg.p.vi | 3.43 | 3.31 | 2.50 | 1.23 | 2.46 | 1.98 | 1.20 | 3.11 | 2.32 | 1.00 |
| Average of g.p.bu1 | 82.83 | 91.34 | 84.91 | 77.28 | 85.04 | 97.22 | 97.40 | 93.33 | 93.43 | 84.37 |
| Average of g.p.bu2 | 78.01 | 104.24 | 94.98 | 70.09 | 91.57 | 97.04 | 99.19 | 99.38 | 91.08 | 88.23 |
| Average of be.p.bu | 79.52 | 90.73 | 83.47 | 59.67 | 85.69 | 85.53 | 83.32 | 93.34 | 79.60 | 79.53 |
| Average of beg.p.be | 0.93 | 1.10 | 1.08 | 1.09 | 0.99 | 1.08 | 1.13 | 1.01 | 1.07 | 1.03 |
| Average of NIRColour | 6.60 | 5.89 | 7.00 | 8.88 | 7.20 | 8.59 | 9.03 | 5.89 | 8.45 | 9.27 |

| | |
|---|---|
| Berry loss | 0.77 |
| Berry weight gain | 1.40 |
| | 1.07 |

2001-02 veraison data

| Data | cropload 3-high | 2-med | 1-low | Grand Total |
|---|---|---|---|---|
| Average of Score | 0.83 | 0.85 | 1.04 | 0.91 |
| Average of BunchWt | 32.13 | 35.35 | 36.77 | 34.71 |
| Average of BunchBiBe | 51.35 | 43.96 | 53.56 | 49.54 |
| StdDev of Score | 0.92 | 0.93 | 0.95 | 0.93 |
| StdDev of BunchWt | 15.62 | 15.47 | 15.19 | 15.45 |
| StdDev of BunchBiBe | 28.09 | 26.17 | 29.89 | 28.15 |
| Count of Score | 47 | 47 | 45 | 139 |
| Count of BunchWt | 48 | 48 | 45 | 141 |
| Count of BunchBiBe | 48 | 48 | 45 | 141 |

2001-02 harvest data

| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Yield (t/Ha) | 11.90 | 11.81 | 10.53 | 7.92 | 10.45 | 7.54 | 5.89 |

| | Treated 0-no 1-yes | Method 0-none 1-pruning | Cropload | | 2-sh_thin | | | 3-bu_thin | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Data | 4-max | 3-high | 2-med | 1-low | 3-high | 2-med | 1-low | 3-high | 2-med | 1-low |
| Average of Brix | 21.79 | 22.29 | 21.75 | 22.36 | 23.39 | 22.35 | 22.17 | | | |
| Average of pH | 3.32 | 3.30 | 3.31 | 3.31 | 3.41 | 3.29 | 3.26 | | | |
| Average of TA | 9.20 | 9.27 | 8.63 | 9.07 | 8.47 | 8.52 | 8.90 | | | |
| Average of bu.p.vi | 50.41 | 46.77 | 37.50 | 28.94 | 38.73 | 28.20 | 16.10 | | | |
| Average of kg.p.vi | 2.02 | 2.01 | 1.79 | 1.35 | 1.78 | 1.28 | 1.00 | | | |
| Average of g.p.bu1 | 39.87 | 42.56 | 48.40 | 47.72 | 45.22 | 46.61 | 63.17 | | | |
| Average of g.p.bu2 | 45.12 | 48.70 | 53.37 | 58.12 | 47.79 | 56.44 | 58.40 | | | |
| Average of be.p.bu | 43.21 | 45.28 | 46.35 | 74.96 | 47.42 | 48.57 | 51.45 | | | |
| Average of bug.p.be | 1.06 | 1.09 | 1.15 | 1.12 | 1.01 | 1.17 | 1.15 | | | |
| Average of beg.p.be | 0.95 | 0.99 | 1.03 | 1.00 | 0.91 | 1.06 | 1.05 | | | |

| | |
|---|---|
| Berry loss | 0.84 |
| Berry weight gain | 1.67 |
| | 1.40 |

comparison at veraison between 2001 and 2002
Weight per bunch at onset of veraison

| Treatment | 8 | 9 | 10 | Mean |
|---|---|---|---|---|
| 2001 | 72.73 | 72.73 | 72.73 | 72.73 |
| 2002 | 32.13 | 35.35 | 36.77 | 34.75 |
| Change | -0.56 | -0.51 | -0.49 | -0.52 |

# Chapter 3.

# Effects of crop control techniques on key indices of wine grape quality

## 3a. Effects of crop control techniques on wine grape quality

### *Introduction*

Grape producers strive to manipulate the composition of their grapes to match desired wine styles. This coupled with the belief that meeting pre-determined yield targets will improve and maintain wine quality ensures that there is a demand for crop regulation guidelines and cost-effective techniques. However, defining the relationship between grape yield and wine quality is one of the most controversial issues in the wine industry. On one hand, grape growers are paid per tonne. Although they are paid bonuses for meeting certain composition targets, these bonuses often fail to outweigh any penalties associated with reducing yields to meet specifications. Winemakers, on the other hand, require a reliable (predictable) supply of consistent 'quality' fruit. The situation is complicated by many apparently contradictory examples of the effect of yield on quality. Clearly overcropped vines, where fruit maturation is delayed, produce lower quality fruit and there are many examples that demonstrate benefits of reducing yield. However, there are just as many instances where there seems to be little or no benefit in reducing yield. A level of confusion about which vineyard standards are appropriate and objective makes the issue more difficult for both grape growers and wine makers. Different methods to regulate yield may lead to differences in berry composition, even at similar yield levels making attempts to derive optimum yield for any given variety in any given climate doubly complex.

This chapter seeks to investigate relationships and interactions between temperature, crop load and aspects of berry development and composition within the season and from season-to-season over three consecutive seasons for the major varieties Cabernet Sauvignon, Chardonnay and Shiraz across a wide range of climates. Furthermore, different yield regulation techniques applied at different times during the season are evaluated.

### *Materials and methods*

The yield regulation experiments that are discussed in this chapter were established in the 2000/01 season and included: informed pruning, shoot thinning, bunch thinning and mechanical thinning. For most of the experiments three levels of intervention at 3 stages of crop development were compared. At each stage potential yield was estimated, based on measurement of crop components. Then bunch numbers were adjusted (through retained buds, shoot thinning or bunch thinning) in an attempt to achieve the desired target yields. The 3 yield targets were low, medium and high with ratios of 1:2:3 (eg. 5, 10, 15, t/ha). Very light pruning with no subsequent intervention was the control, which aimed to deliver a very high yield. Light, moderate or severe levels of pruning during dormancy, shoot thinning before flowering or bunch thinning at veraison targeted high, medium and low yields. The full experimental details are described in Chapter 2.

*Weekly Measurements*

Leading up to the harvest, weekly measurements of °Brix, pH and berry size were made after veraison until harvest. Thirty-two berries were collected from each experimental plot. In total 160 samples were collected and analysed weekly from each experimental site.

*Harvest Measurements*
Fruit composition was measured at normal commercial harvest (ie. 23°Brix). Measurements included soluble solid concentration, pH and titratable acidity. Colour/phenolics and concentrations of K, tartaric acid and malic acid were also measured on reserved samples. colour of skin discs was assessed after Holgate (2000) in 2001 and colour of homogenised berries that had been frozen was assessed after Iland et al. (2000) in 2001, 2002 and 2003.

*Small scale winemaking*
Small-scale wines were made from Cabernet Sauvignon fruit collected from Dookie and Whitlands in 2002 and Chardonnay fruit collected from Barooga in 2003. Three field replicates of grapes (20 to 25kg) were collected from each experimental treatment and crushed within a day of harvest in a crusher/destemmer. Fruit temperature was at about 15$^{o}$C before crushing to ensure gradual start to fermentation. Each ferment had approximately the same volume to start with (20 L to 22L). Open fermentation was in 25L plastic fermenters. After crusing 30 mg/L $SO_2$, 300 mg/L DAP and yeast @ 250mg/L was added to each ferment.

Ferments were acid adjusted to pH 3.4 with tartaric acid. Temperature was maintained at 25$^{o}$C. Caps were plunged twice per day. Ferments were pressed off at appropriate dryness (usually after 7 days on skins) into 10L demijohns with any excess put into labelled flagons for topping up). At this time ferments were inoculated for MaloLactic Fermentation and maintained at 20$^{o}$C. Ferment condition was monitored through airlocks and racked after 3-4 weeks (10mg/L $SO_2$). Some analysis of these wines has been done (Appendix) and a complete analysis will be done during the next 12 months.

*Statistical Analyses*
ANOVA and Residual Maximum Likelihood (REML) analysis were used to test the effect of treatment on ripening, pH and other compositional characters. Treatment means were compared using Fisher's unrestricted least significant difference ($LSD_{5\%}$). Other relationships were assessed by regression analysis. Statistical analyses were performed using Genstat© 5 Release 4.1 (Lawes Agricultural Trust, 1997).

***Results and Discussion***
The summary of responses to yield regulation of Cabernet Sauvignon and Chardonnay in hot and cool climates (Table 2) demonstrates some important points. First, responses to regulation will differ with cultivar. In this instance the later season Cabernet Sauvignon is far more responsive to yield regulation than is Chardonnay in both hot and cool climates. It is worth noting that to achieve the advanced ripening reported in the table (two to three weeks) for Cabernet we needed to remove more than 50% of the crop. This obviously represents a severe yield penalty. In the seasons in which we conducted experiments we encountered few difficulties adequately ripening Cabernet Sauvignon at our sites. However, such severe reductions in yield may need to be contemplated at some sites and in certain seasons when yields are excessive and the risks of not being able to ripen the crop or harvesting in unfavourable weather need to be managed.

In contrast to Chardonnay, Pinot noir was extremely sensitive to crop load in a cool climate. Crop removal substantially advanced ripening and increased TA, colour and berry size at the same °Brix. Reducing yield increased colour irrespective of how yield was regulated whether

through more severe pruning, shoot thinning (which removes fruit and foliage) or bunch thinning at veraison (which removes fruit but not foliage) (Figure 3.1). Thus, it seems that it is yield per se that exerts a dominant influence over colour for Pinot Noir in this production system.

Table 3.1. Responses of Cabernet Sauvignon and Chardonnay to crop thinning in hot and cool climates. These responses are summarised from the results presented in Appendix.

| | Hot climate | Cool climate |
|---|---|---|
| Cabernet Sauvignon | | |
| Ripening | lower yields advanced harvest (1 - 2 weeks) | lower yields advanced harvest by up to 25 days |
| fruit composition | no effect on pH and TA | 2001<br>no effect on pH and TA<br><br>2002<br>no effect on pH<br>harder pruning ↑ TA<br>harder shoot thinning ↓ TA |
| berry colour | not reported<br><br>Increased colour density and ↑ anthocyanin concentration of wines (but lower yield treatment harvested at higher TSS: 24<br>versus 21.4<br>Brix) | 2001<br>lower crops ↑ colour at same soluble solids (particularly bunch thinning)<br><br>2002<br>lower crops ↓ colour at same soluble solids |
| Chardonnay | | |
| Ripening | decreasing yields (from 30 to 5 t/Ha) advanced harvest < 1 week | decreasing yield (from 30 to 5 t/Ha) advanced harvest < 1 week |
| fruit composition | negligible effects on pH and TA | negligible effects on pH and TA<br>increased flavanols of juice<br>improved fruit aromas of juice |

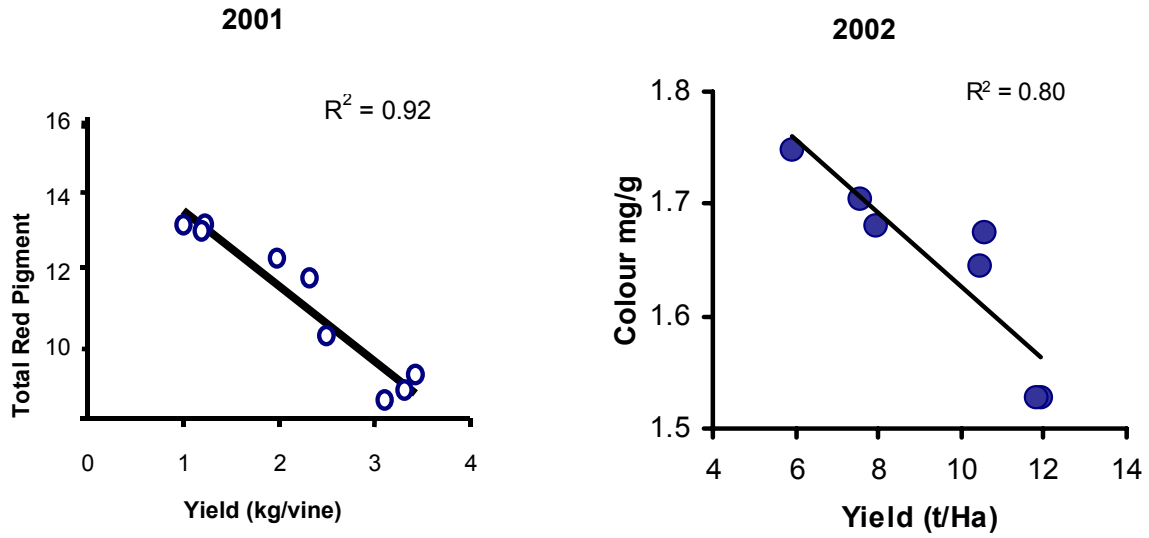



Figure 3.1. Effect of regulating Pinot Noir (MV6) yields in a cool climate at Whitlands on colour of skin discs (after Holgate, 2000) in 2001 and colour of homogenised berries (after Iland et al. 2000) in 2002. Yield was regulated either through winter pruning, shoot thinning or bunch thinning. All vines were harvested when soluble solids reached 23° Brix.

Responses to the type of regulation may also differ. Taking berry size as an example, smaller berries may be preferred for making red wines because of higher skin to juice ratios leading to better colours. On the other hand, larger berries may be preferred for making white wines because there is higher wine yield per tonne of grapes and less skin contact in processing. For hot climate Cabernet Sauvignon and Chardonnay trained to permanent cordons our results are fairly consistent across years and yield potential (Figure 3.2). Bunch thinning at veraison had no effect on berry size. Shoot thinning had a slight effect in Chardonnay and an effect similar to pruning in Cabernet Sauvignon. Pruning had the biggest effect with harder pruning increasing berry size. Generally, the earlier the yield reduction measure, the greater the opportunity for compensation in berry weight.

The results for cool climate Cabernet Sauvignon and Chardonnay that were cane-pruned were less consistent when compared with those from hot climates (Figure 3.3). In the first year of the experiments there was no significant effect of any treatment on berry size in Chardonnay, and in Cabernet Sauvignon, the only significant effects were due to the most severe pruning and all levels of bunch thinning. Curiously, these all significantly decreased berry size. In the second year, pruning Chardonnay had no effect on berry size. The only treatment to affect berry size significantly ($P < 0.05$) was severe shoot thinning. In Cabernet Sauvignon only pruning affected berry size, with harder pruning increasing berry size.

For vines trained to a permanent cordon in hot climates we can give some fairly reliable guidance when it comes to manipulating berry size. If you want smaller berries, prune lighter, but this is likely to give you a higher yield, which could affect other aspects of composition adversely. Shoot thinning before flowering is likely, if anything, to increase berry size, so it would be prudent to avoid it if you don't want bigger berries. If you want smaller berries and you

think there is likely to be some benefit in a lower crop load, this can best be achieved by pruning lightly and then bunch thinning at veraison. However, for vines that are set up for cane pruning in a cool climate, the story isn't so clear. We observed some unexpected responses, particularly in the first year. It could be that this sort of system takes a while to settle down. Much could depend, too, on selection of cane lengths - some of our treatments included some odd cane lengths to try to hit yield targets (eg. half canes with 5 to 7 buds). These results for the cane-pruned, cool-climate vines reinforce the caution that simply reducing yield may not achieve the result you desire. A decision will be based on what sort of wine you want to make and how and when you choose to regulate crop load.

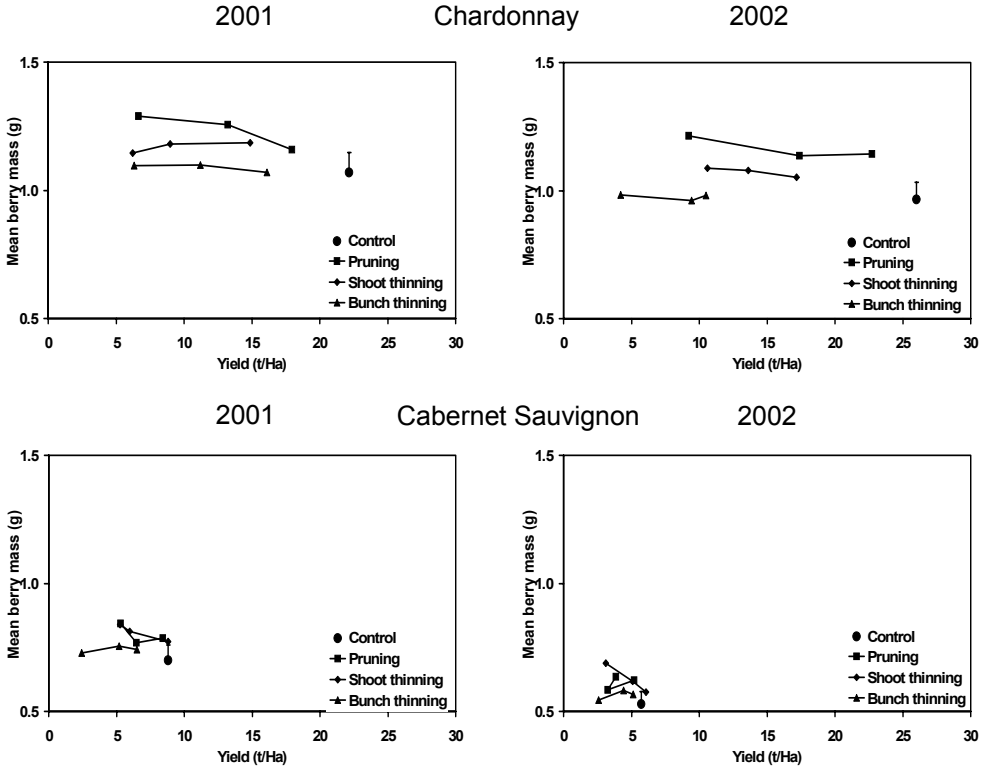



Figure 3.2. Effect of yield regulation on berry mass at harvest in hot climates - permanent cordon, mechanical or spur pruning. The points represent treatment means and the bar above the control symbol represents the $LSD_{5\%}$.

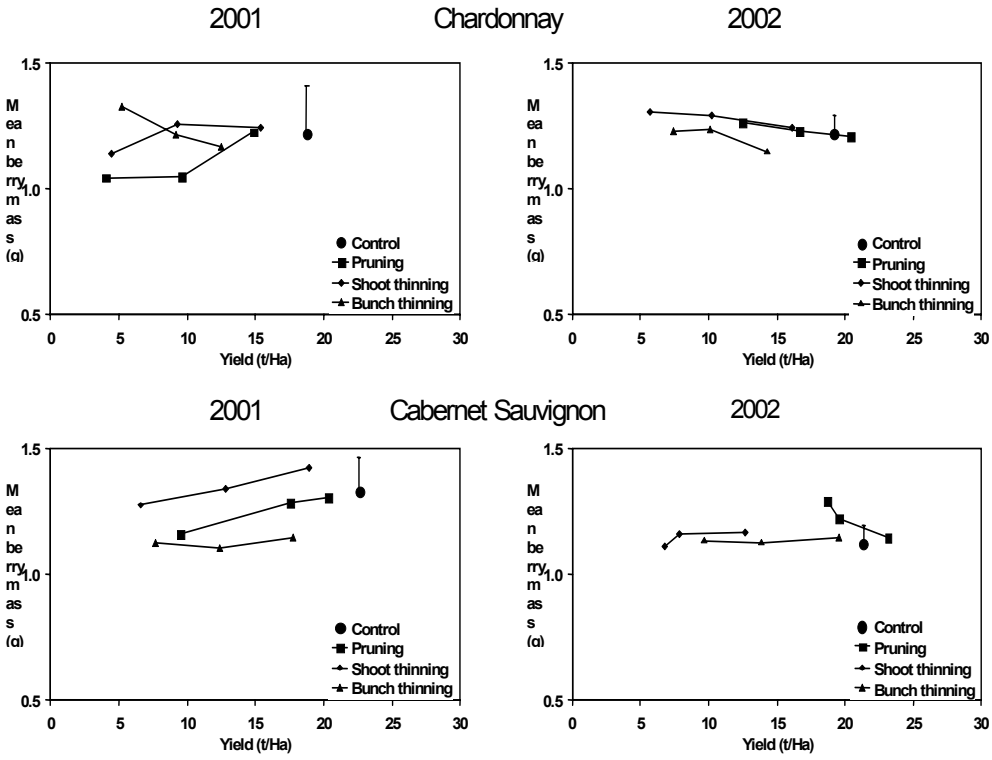



Figure 3.3. Effect of yield regulation on berry mass at harvest in a cool climate - cane pruning. The points represent treatment means and the bar above the control symbol represents the $LSD_{5\%}$.

***References***

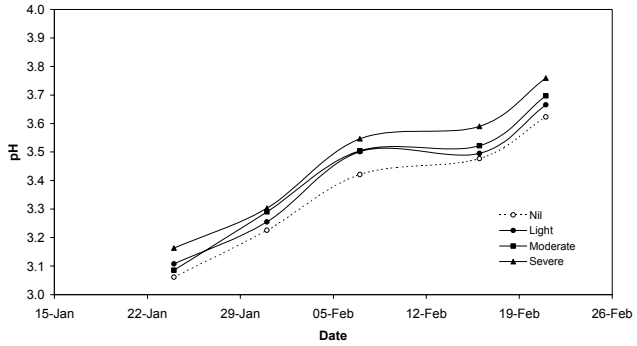
Holgate, A. (2000) Berry colour index assay – application and interpretation of the assay as a measure of red wine grape quality in a commercial vineyard. Paper presented to 5th International Symposium on Cool Climate Viticulture and Oenology, Melbourne, 16-20th January 2000 (4 pp.).

Iland, P.; Ewart, A.; Sitters, j.; Markides, A; Bruer, N.; (Eds.) (2000) Techniques for chemical analysis and quality monitoring during winemaking. Partick Iland Promotions.

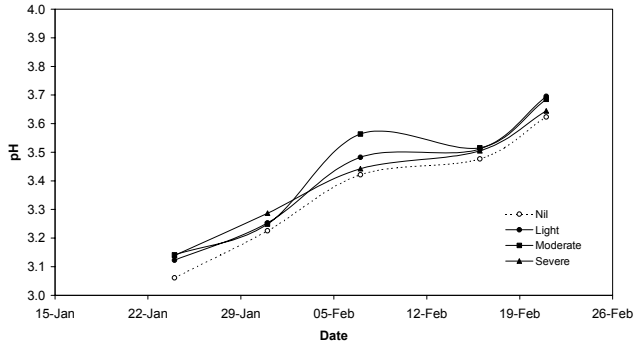
Lawes Agricultural Trust (1997) Genstat 5 Release 4.1. 3rd edition, IACR - Rothamsted.

# Appendix 3a.1. Berry pH from Veraison to Harvest

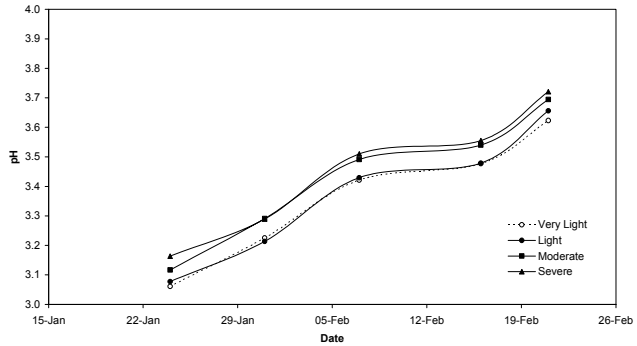
**Barooga Chardonnay 2001 - bunch thinning treatments**



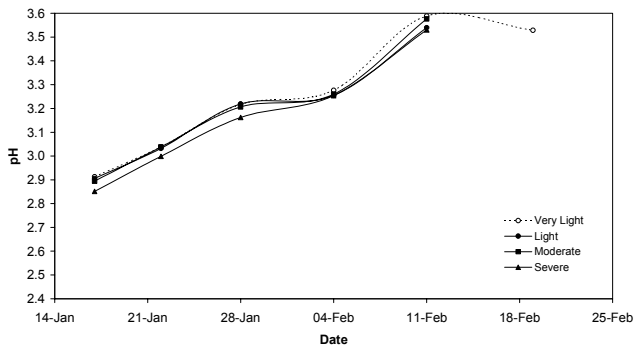

**Barooga Chardonnay 2001 - shoot thinning treatments**



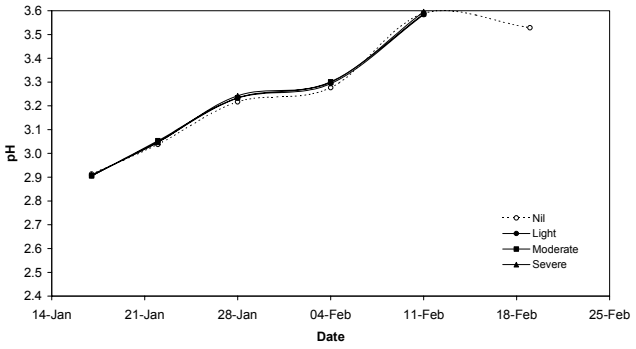

**Barooga Chardonnay 2001 - pruning treatments**



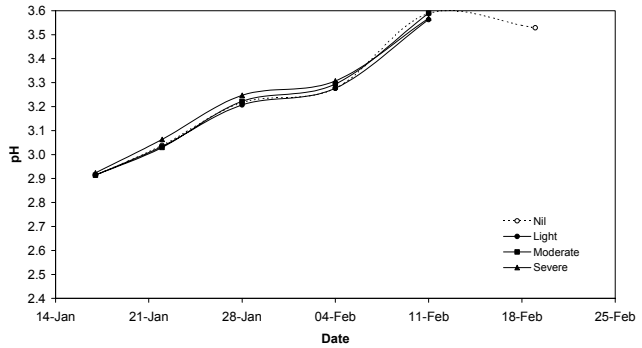

**Barooga Chardonnay 2003 - pruning treatments**



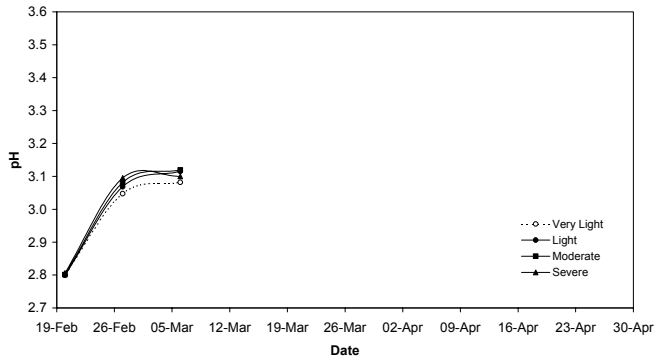
**Barooga Chardonnay 2003 - shoot thinning treatments**



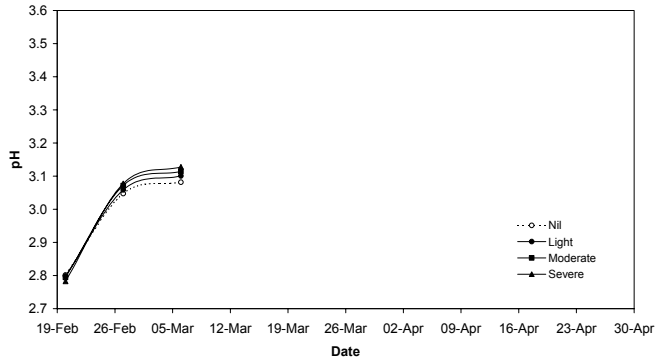

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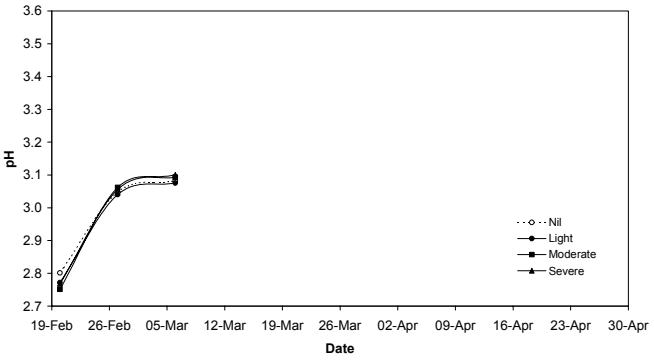

**Whitlands Chardonnay - pruning treatments 2001**



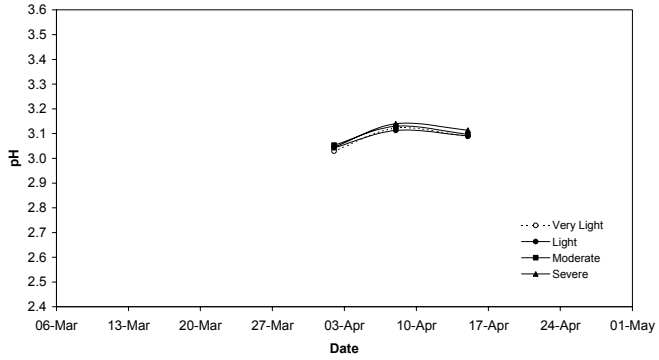
**Whitlands Chardonnay - bunch thinning treatments 2001**



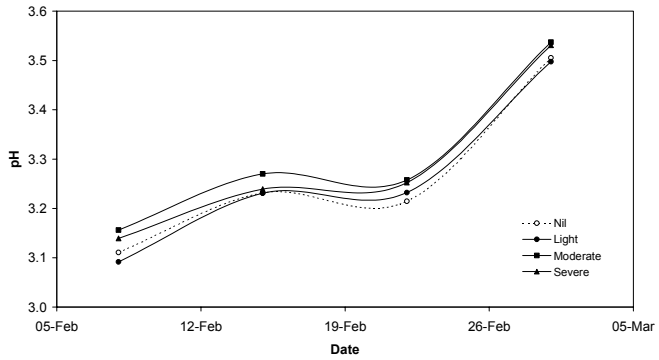

**Whitlands Chardonnay - shoot thinning treatments 2001**



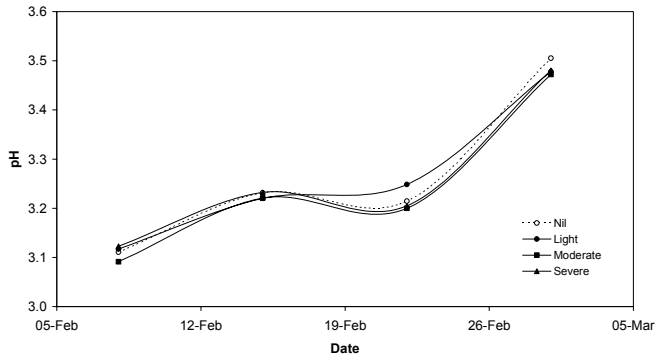

**Whitlands Chardonnay - pruning treatments 2002**



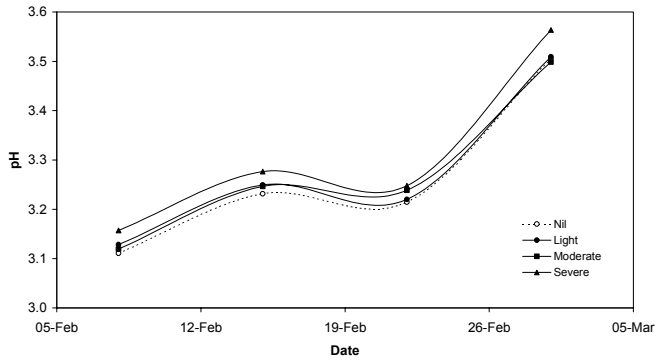
**Dookie Cabernet - pruning treatments 2001**



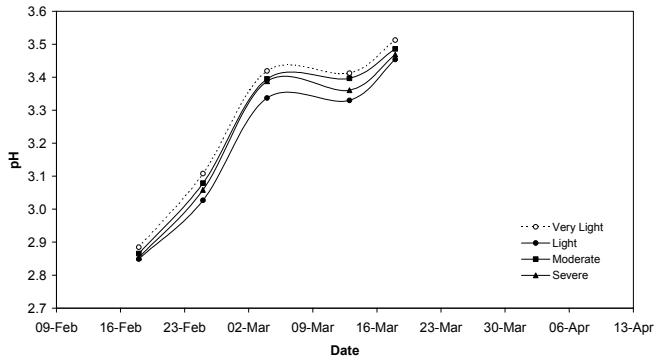

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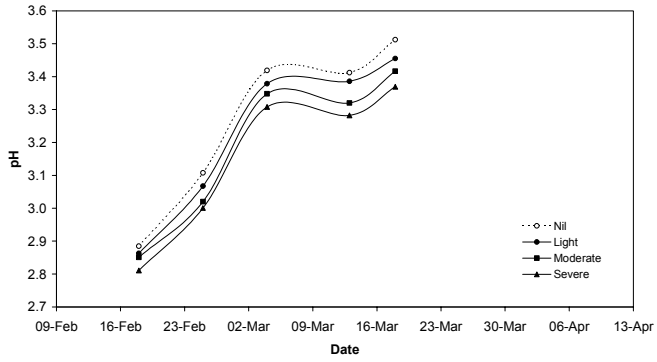

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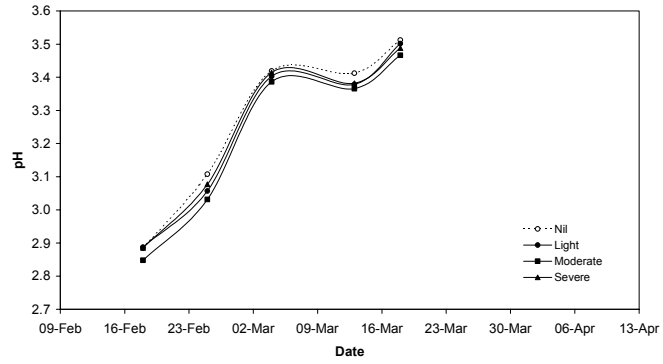
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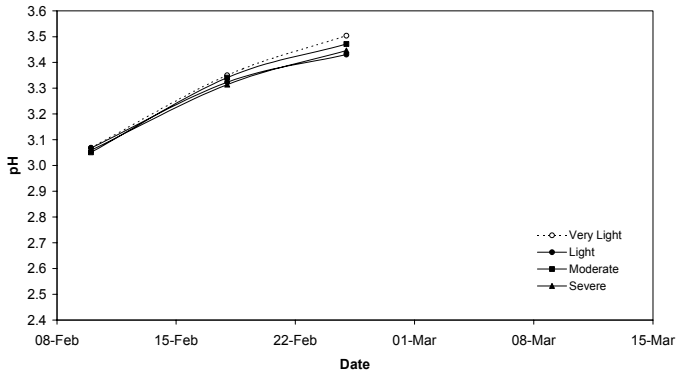

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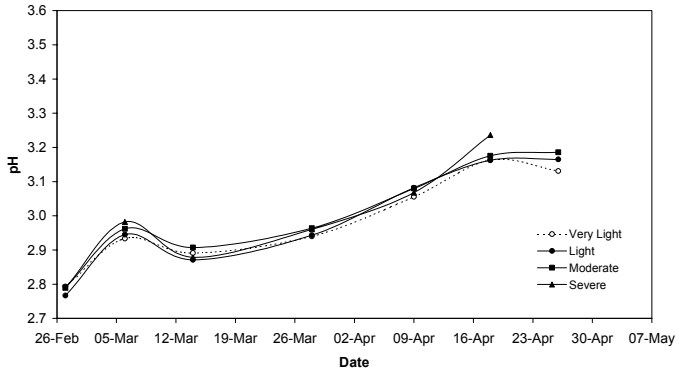

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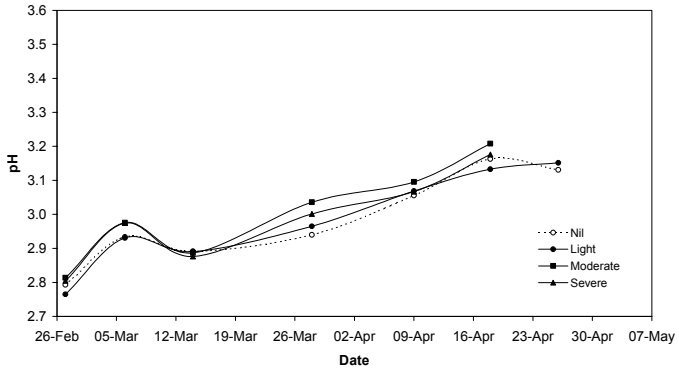
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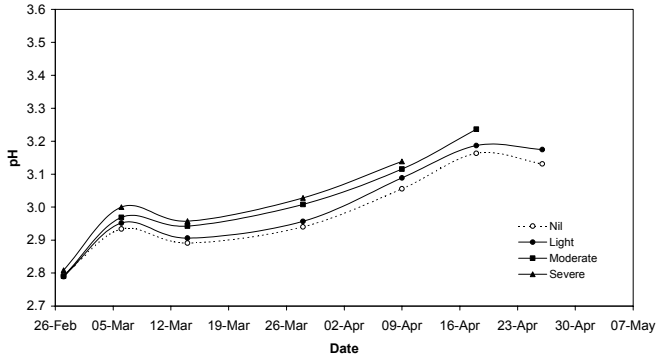

**Whitlands Cabernet Sauvignon - pruning treatments 2001**



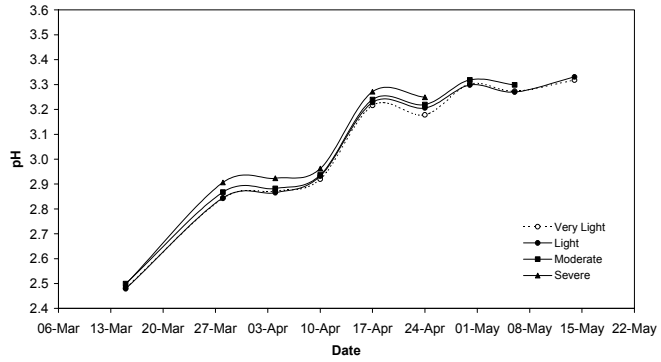

**Whitlands Cabernet Sauvignon - shoot thinning treatments 2001**



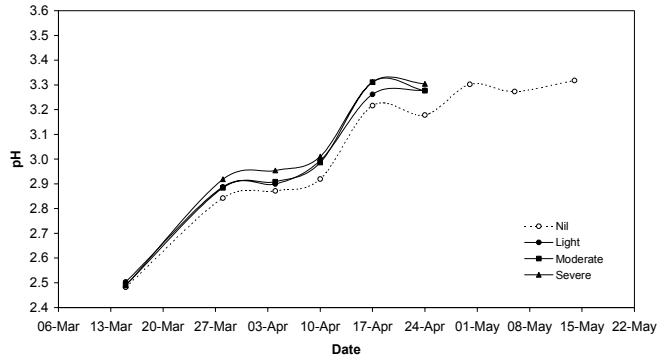
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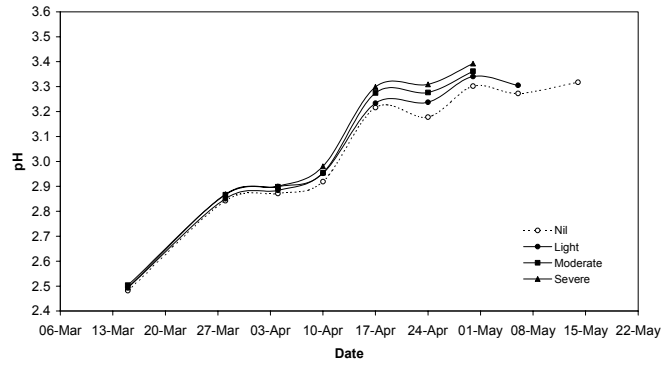

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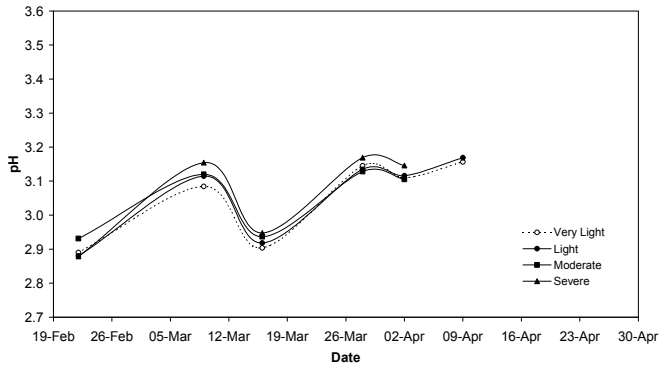

**Whitlands Cabernet Sauvignon - shoot thinning treatments 2002**



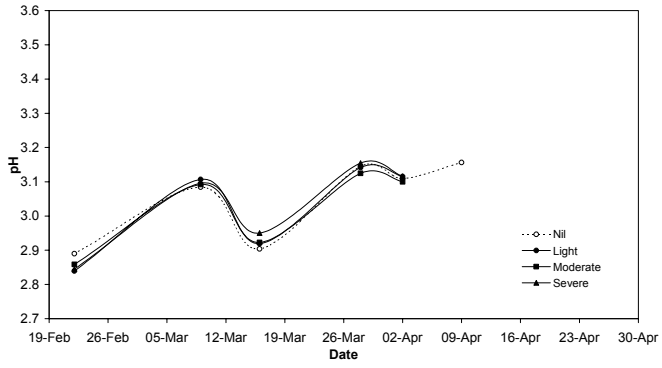
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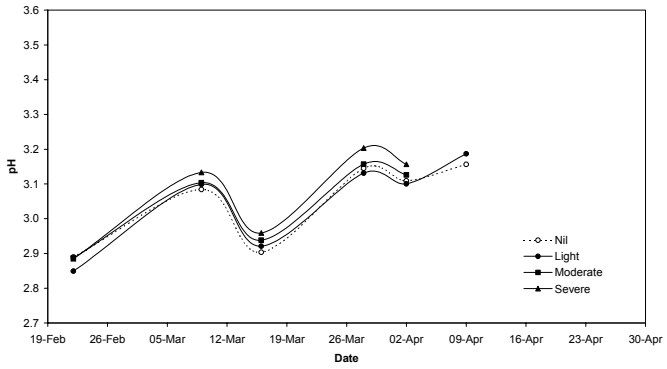

**Whitlands Pinot Noir - pruning treatments 2001**



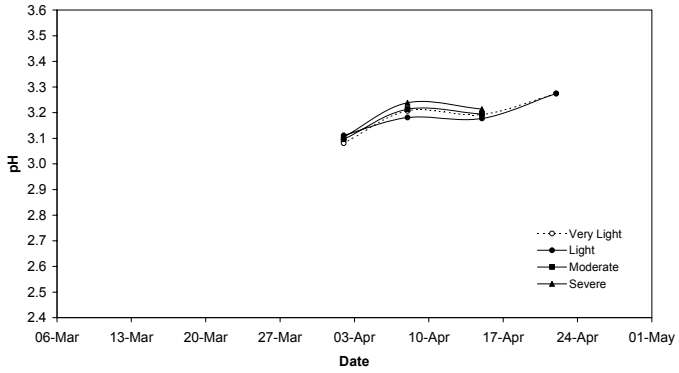

**Whitlands Pinot Noir - shoot thinning treatments 2001**



**Whitlands Pinot Noir - bunch thinning treatments 2001**




**Whitlands Pinot Noir - pruning treatments 2002**



**Appendix 3a.2. Harvest Composition**

| ***Barooga Chardonnay 2001*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Actual yield (t/Ha) | 22.16 | 17.96 | 13.20 | 6.63 | 14.88 | 8.96 | 6.24 | 16.11 | 11.19 | 6.32 |
| | | | | | | | | | | |
| Average of Brix | 21.46 | 22.16 | 22.63 | 22.78 | 22.80 | 23.15 | 22.92 | 22.68 | 23.56 | 23.89 |
| Average of pH | 3.86 | 3.89 | 3.96 | 3.99 | 4.00 | 3.97 | 3.93 | 3.99 | 4.00 | 4.04 |
| Average of TA | 5.72 | 5.76 | 5.63 | 5.67 | 5.64 | 5.86 | 6.13 | 5.48 | 5.62 | 5.26 |

| ***Barooga Chardonnay 2002*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Yield (t/Ha) | 26.01 | 22.73 | 17.39 | 9.21 | 17.16 | 13.60 | 10.61 | 10.49 | 9.43 | 4.19 |
| | | | | | | | | | | |
| Average of Brix | 20.06 | 21.18 | 21.75 | 22.59 | 21.31 | 22.15 | 23.26 | 23.53 | 23.97 | 24.13 |
| Average of pH | 3.42 | 3.56 | 3.57 | 3.60 | 3.54 | 3.56 | 3.57 | 3.66 | 3.68 | 3.70 |
| Average of TA | 5.23 | 4.96 | 5.00 | 5.42 | 5.04 | 5.00 | 5.32 | 4.74 | 4.91 | 4.58 |

| ***Barooga Chardonnay 2003*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Yield (t/Ha) | 13.07 | 13.84 | 10.78 | 3.66 | 9.73 | 7.31 | 5.79 | 12.11 | 10.10 | 5.61 |
| | | | | | | | | | | |
| Average of Brix | 22.72 | 22.25 | 22.38 | 22.69 | 22.25 | 22.87 | 23.14 | 22.97 | 22.00 | 23.86 |
| Average of pH | 3.69 | 3.66 | 3.67 | 3.62 | 3.64 | 3.62 | 3.62 | 3.78 | 3.64 | 3.75 |
| Average of TA | 4.61 | 4.90 | 4.67 | 5.20 | 4.99 | 4.72 | 4.76 | 4.28 | 4.77 | 4.30 |

| ***Whitlands Chardonnay 2001*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Mean t/Ha | 18.77 | 14.85 | 9.58 | 4.07 | 15.37 | 9.34 | 4.44 | 12.51 | 9.19 | 5.18 |
| | | | | | | | | | | |
| Average of Brix | 21.89 | 21.92 | 22.84 | 22.31 | 21.97 | 22.71 | 22.89 | 22.53 | 22.50 | 22.53 |
| Average of pH | 3.09 | 3.10 | 3.10 | 3.08 | 3.09 | 3.06 | 3.07 | 3.13 | 3.11 | 3.09 |
| Average of TA | 9.05 | 9.53 | 9.87 | 10.35 | 9.45 | 9.72 | 9.49 | 9.30 | 9.27 | 9.39 |

| ***Whitlands Chardonnay 2002*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Mean t/Ha | 19.17 | 20.46 | 16.67 | 12.52 | 16.15 | 10.19 | 5.71 | 14.33 | 10.09 | 7.43 |
| | | | | | | | | | | |
| Average of Brix | 22.31 | 21.98 | 21.96 | 22.18 | 22.83 | 23.03 | 23.15 | 22.46 | 22.19 | 22.20 |
| Average of pH | 3.23 | 3.27 | 3.18 | 3.19 | 3.26 | 3.21 | 3.22 | 3.27 | 3.20 | 3.19 |
| Average of TA | 10.07 | 9.99 | 10.54 | 10.70 | 10.13 | 10.62 | 9.93 | 9.89 | 10.39 | 10.37 |

| ***Dookie Cabernet, 2001*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Actual yield (t/Ha) | 8.80 | 8.42 | 6.48 | 5.30 | 8.78 | 5.99 | 5.27 | 6.51 | 5.19 | 2.43 |
| | | | | | | | | | | |
| Average of Brix | 25.01 | 24.68 | 24.59 | 24.44 | 24.92 | 24.59 | 24.78 | 24.66 | 24.58 | 25.04 |
| Average of pH | 3.70 | 3.68 | 3.73 | 3.77 | 3.75 | 3.69 | 3.62 | 3.75 | 3.78 | 3.79 |
| Average of TA | 6.20 | 6.33 | 6.17 | 6.33 | 6.37 | 6.70 | 6.65 | 6.26 | 6.35 | 6.12 |

| ***Dookie Cabernet 2002*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Yield (t/Ha) | 5.73 | 5.20 | 3.26 | 3.86 | 6.09 | 5.09 | 3.10 | 5.11 | 4.41 | 2.58 |
| | | | | | | | | | | |
| Average of Brix | 23.07 | 23.25 | 23.98 | 23.79 | 23.19 | 23.14 | 23.92 | 23.21 | 23.87 | 23.79 |
| Average of pH | 3.52 | 3.43 | 3.49 | 3.49 | 3.48 | 3.42 | 3.39 | 3.49 | 3.45 | 3.51 |
| Average of TA | 6.87 | 7.22 | 7.21 | 7.14 | 7.00 | 7.27 | 7.44 | 7.00 | 7.01 | 7.17 |

| ***Dookie Cabernet 2003*** | | | | |
|---|---|---|---|---|
| | | | | |
| Treatment | 1 | 2 | 3 | 4 |
| Yield (t/Ha) | 4.15 | 5.41 | 4.62 | 4.33 |
| | | | | |
| Average of Brix | 22.31 | 22.05 | 22.88 | 23.18 |
| Average of pH | 3.50 | 3.43 | 3.47 | 3.45 |
| Average of TA | 6.28 | 7.02 | 6.88 | 6.96 |

| ***Whitlands Cabernet 2001*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Mean t/Ha | 22.63 | 20.38 | 17.61 | 9.51 | 18.91 | 12.87 | 6.60 | 17.78 | 12.44 | 7.73 |
| | | | | | | | | | | |
| Average of Brix | 22.54 | 22.91 | 22.02 | 23.24 | 22.37 | 23.41 | 24.11 | 22.41 | 23.34 | 23.07 |
| Average of pH | 3.36 | 3.37 | 3.28 | 3.34 | 3.35 | 3.33 | 3.40 | 3.30 | 3.28 | 3.24 |
| Average of TA | 10.42 | 10.35 | 10.70 | 10.24 | 10.44 | 10.19 | 10.16 | 10.52 | 10.17 | 9.35 |

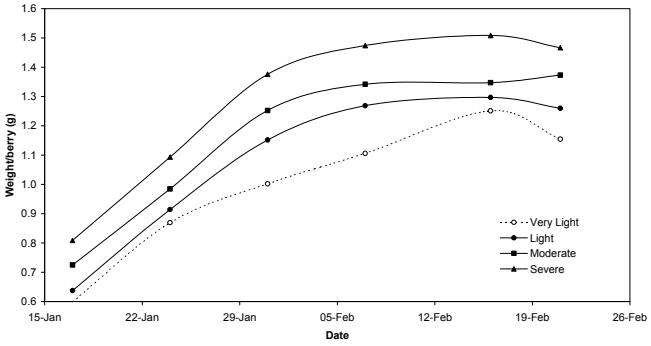
| ***Whitlands Cabernet 2002*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Mean t/Ha | 21.39 | 23.18 | 19.54 | 18.73 | 12.65 | 7.92 | 6.82 | 19.59 | 13.87 | 9.68 |
| | | | | | | | | | | |
| Average of Brix | 20.89 | 20.81 | 21.61 | 21.37 | 21.51 | 21.62 | 21.82 | 21.74 | 21.85 | 21.71 |
| Average of pH | 3.34 | 3.34 | 3.24 | 3.32 | 3.30 | 3.37 | 3.36 | 3.21 | 3.27 | 3.33 |
| Average of TA | 10.01 | 10.09 | 11.04 | 11.28 | 11.60 | 11.07 | 10.59 | 11.03 | 10.67 | 10.68 |

| ***Whitlands Pinot Noir 2001*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Mean t/Ha | 20.17 | 19.49 | 14.70 | 7.23 | 14.49 | 11.66 | 7.03 | 18.27 | 13.64 | 5.91 |
| | | | | | | | | | | |
| Average of Brix | 23.89 | 23.96 | 23.66 | 24.39 | 23.83 | 23.87 | 23.89 | 23.80 | 23.50 | 24.67 |
| Average of pH | 3.31 | 3.31 | 3.28 | 3.26 | 3.28 | 3.30 | 3.31 | 3.29 | 3.36 | 3.31 |
| Average of TA | 7.92 | 8.44 | 8.06 | 10.20 | 7.71 | 8.39 | 9.07 | 8.29 | 7.87 | 9.24 |

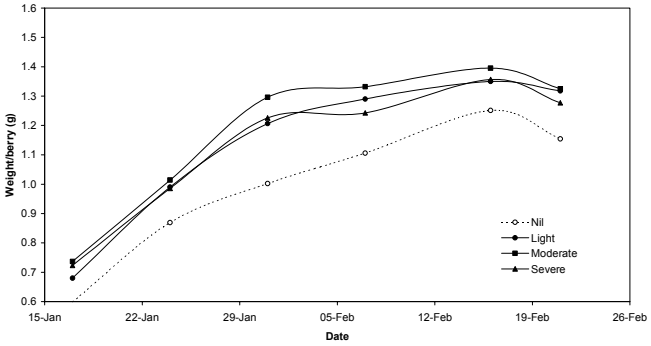
| ***Whitlands Pinot Noir 2002*** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Treatment | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Mean t/Ha | 11.90 | 11.81 | 10.53 | 7.92 | 10.45 | 7.54 | 5.89 |
| | | | | | | | |
| Average of Brix | 21.79 | 22.29 | 21.75 | 22.36 | 23.39 | 22.35 | 22.17 |
| Average of pH | 3.32 | 3.30 | 3.31 | 3.31 | 3.41 | 3.29 | 3.26 |
| Average of TA | 9.20 | 9.27 | 8.63 | 9.07 | 8.47 | 8.52 | 8.90 |

# Appendix 3a.3. Berry Weight Curves –Veraison to Harvest

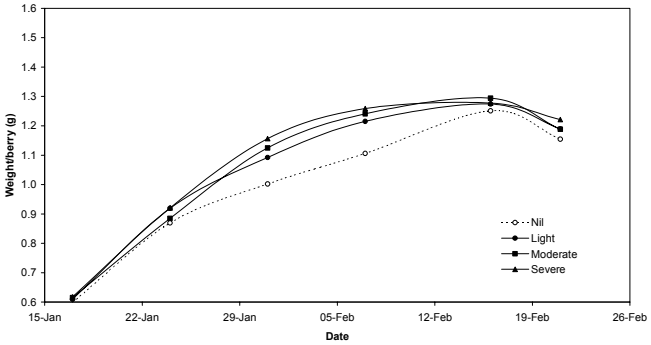
**Barooga Chardonnay 2001 - pruning treatments**



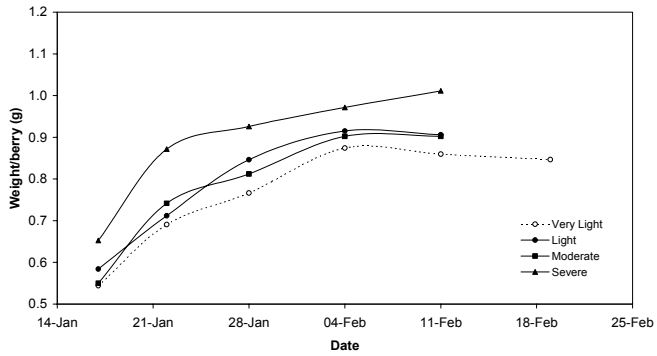

**Barooga Chardonnay 2001 - shoot thinning treatments**



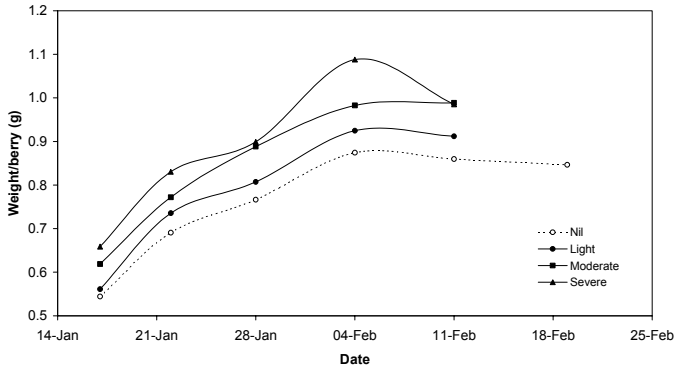

**Barooga Chardonnay 2001 - bunch thinning treatments**



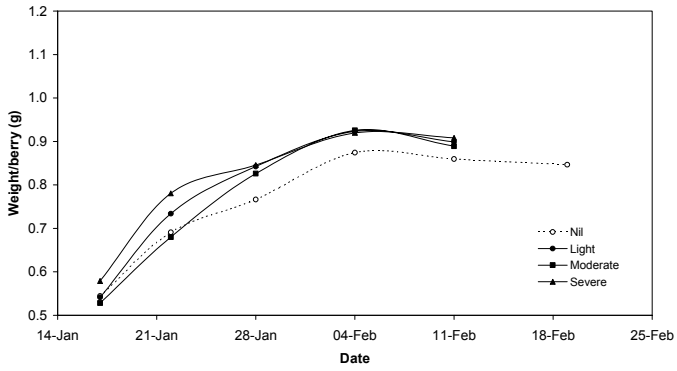
**Barooga Chardonnay 2003 - pruning treatments**



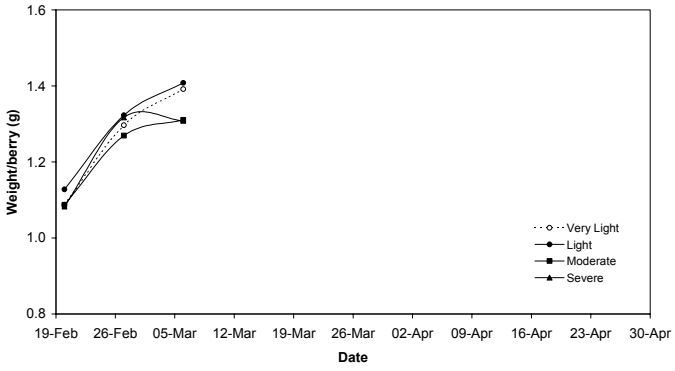

**Barooga Chardonnay 2003 - shoot thinning treatments**



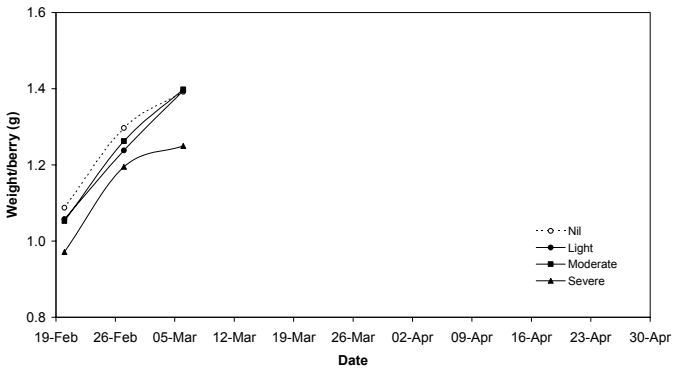

**Barooga Chardonnay 2003 - bunch thinning treatments**



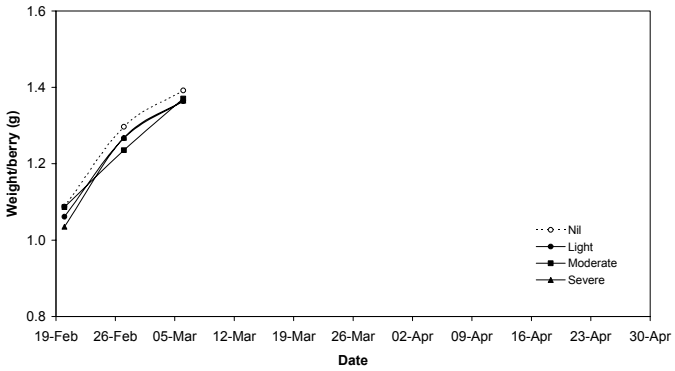
**Whitlands Chardonnay - pruning treatments 2001**



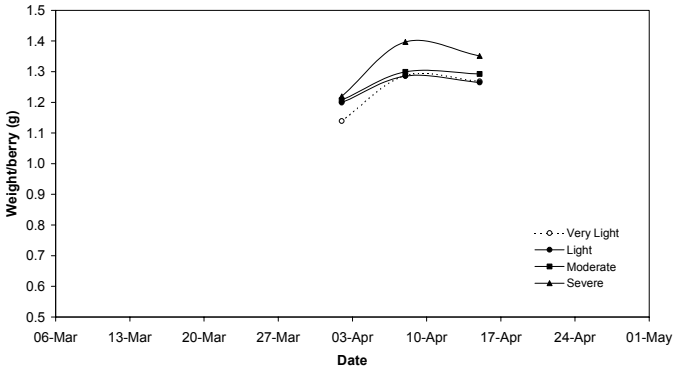

**Whitlands Chardonnay - shoot thinning treatments 2001**



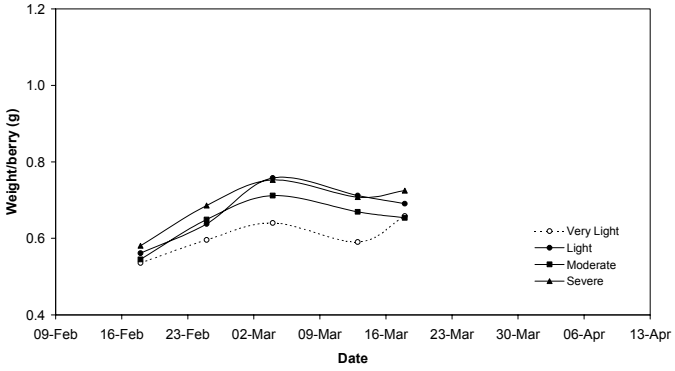

**Whitlands Chardonnay - bunch thinning treatments 2001**



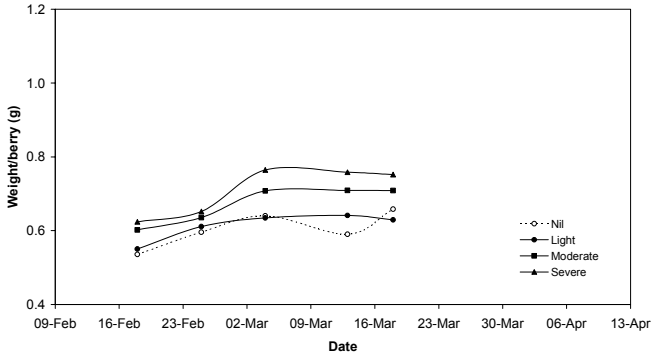
**Whitlands Chardonnay - pruning treatments 2002**



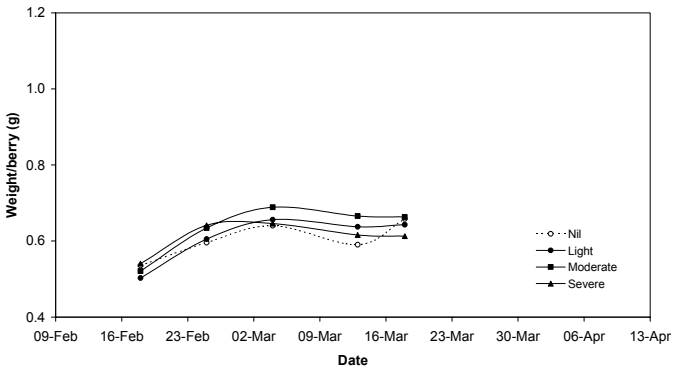

**Dookie Cabernet Sauvignon - pruning treatments 2002**



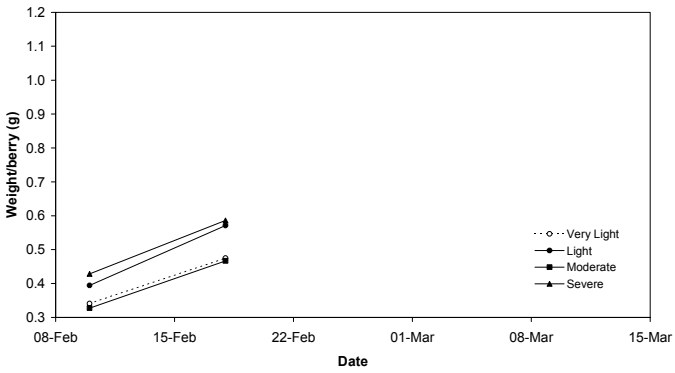

**Dookie Cabernet Sauvignon - shoot thinning treatments 2002**



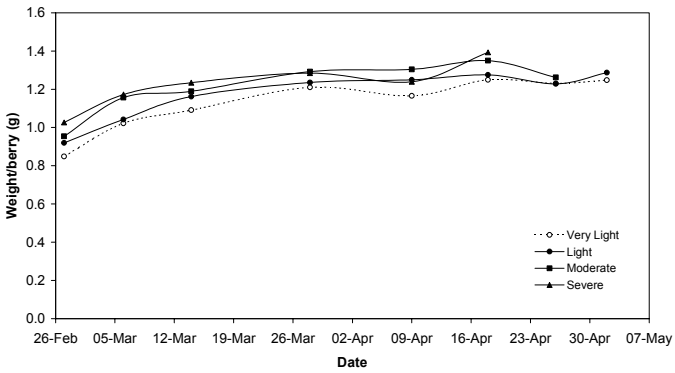
**Dookie Cabernet Sauvignon - bunch thinning treatments 2002**



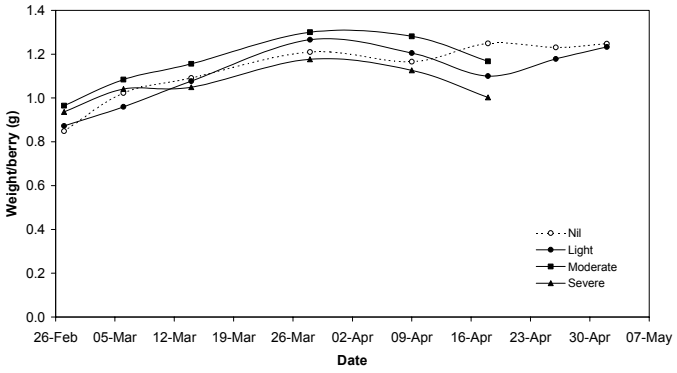

**Dookie Cabernet Sauvignon 2003 - pruning treatments**



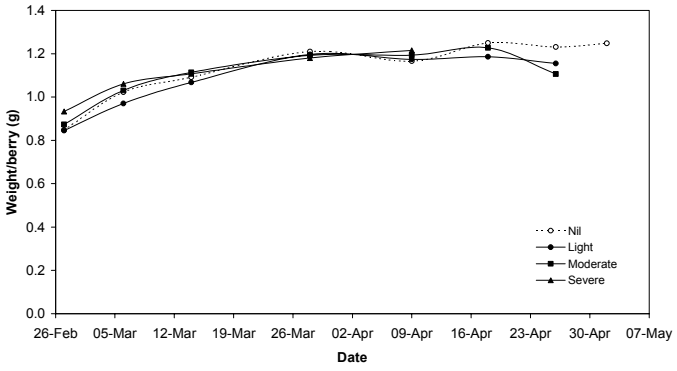

**Whitlands Cabernet Sauvignon - pruning treatments 2001**



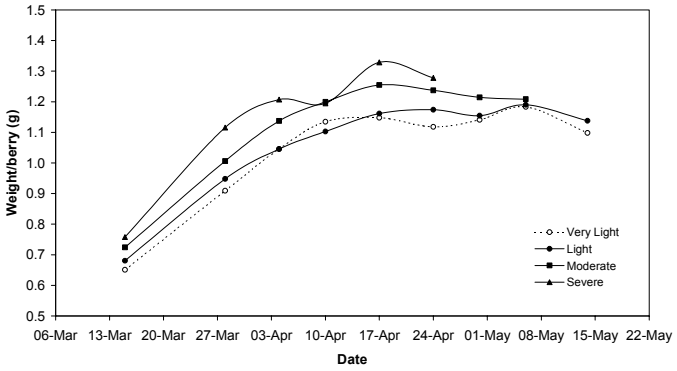
**Whitlands Cabernet Sauvignon - shoot thinning treatments 2001**



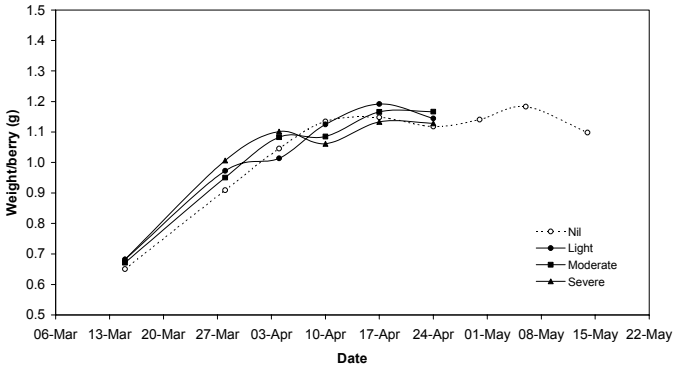

**Whitlands Cabernet Sauvignon - bunch thinning treatments 2001**



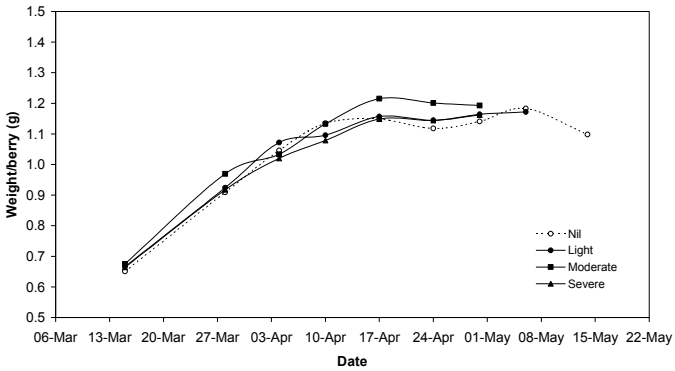

**Whitlands Cabernet Sauvignon - pruning treatments 2002**



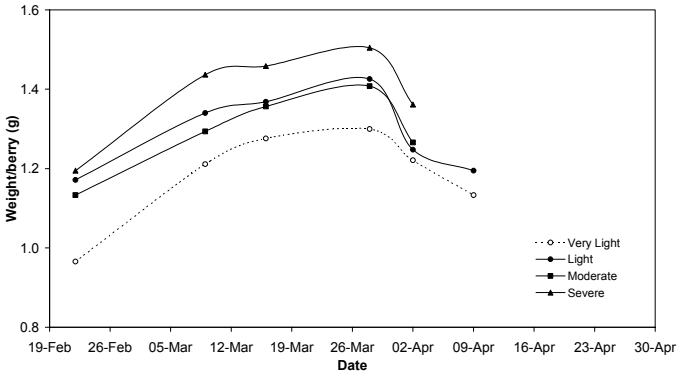
**Whitlands Cabernet Sauvignon - shoot thinning treatments 2002**



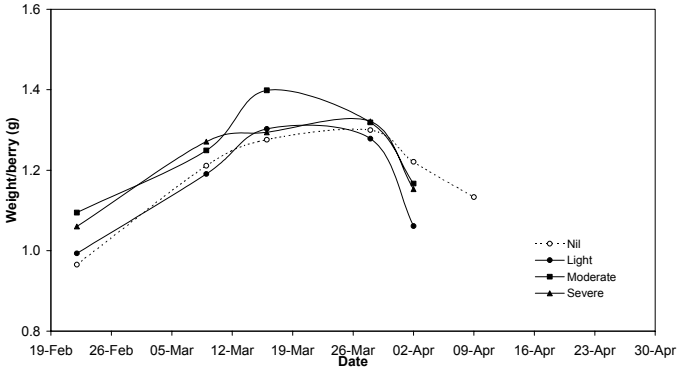

**Whitlands Cabernet Sauvignon - bunch thinning treatments 2002**



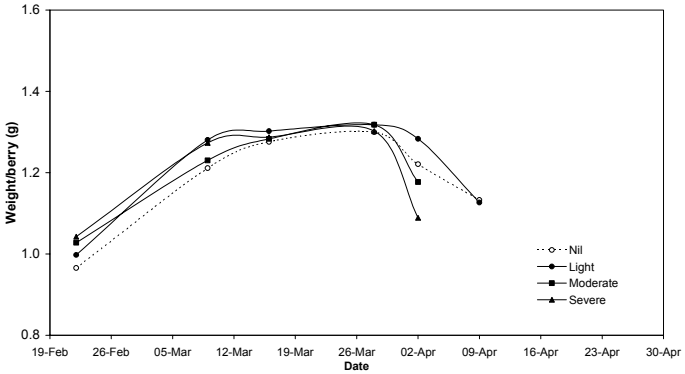
**Whitlands Pinot Noir - pruning treatments 2001**



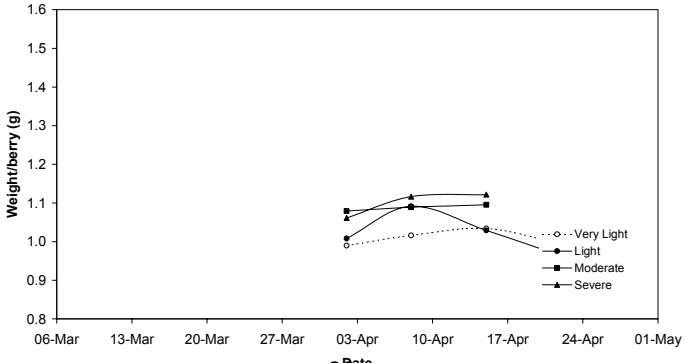

**Whitlands Pinot Noir - shoot thinning treatments 2001**




**Whitlands Pinot Noir - bunch thinning treatments 2001**

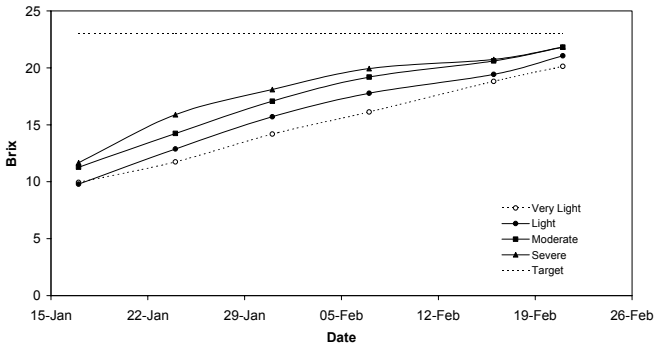



**Whitlands Pinot Noir - pruning treatments 2002**

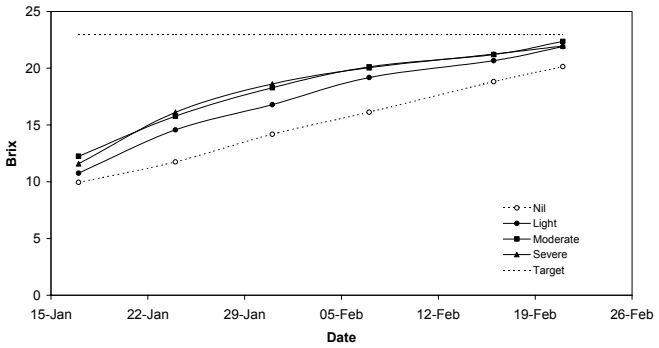


# Appendix 3a.4. Ripening Curves

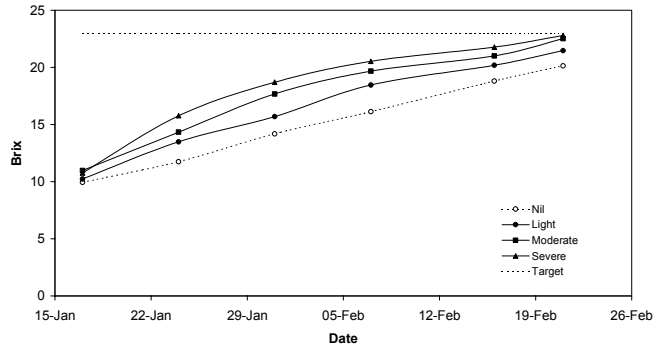
**Barooga Chardonnay 2001 - pruning treatments**



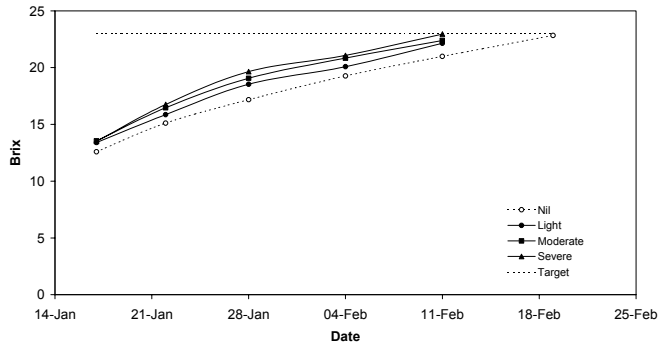

**Barooga Chardonnay 2001 - shoot thinning treatments**



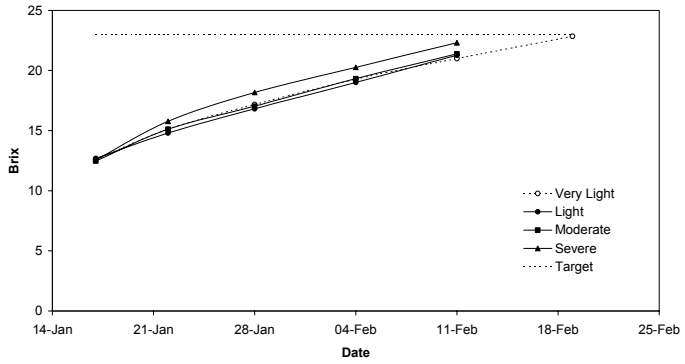
**Barooga Chardonnay 2001 - bunch thinning treatments**



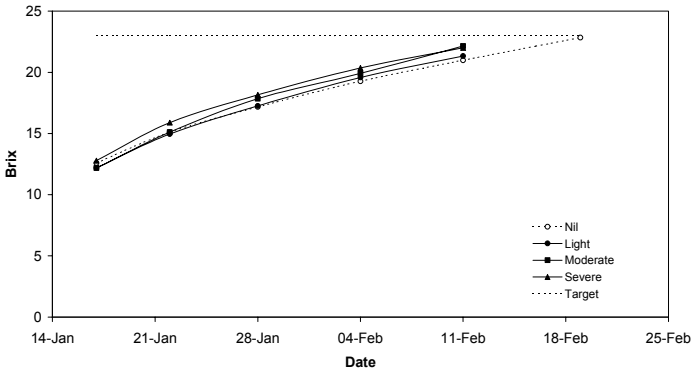

**Barooga Chardonnay 2003 - shoot thinning treatments**



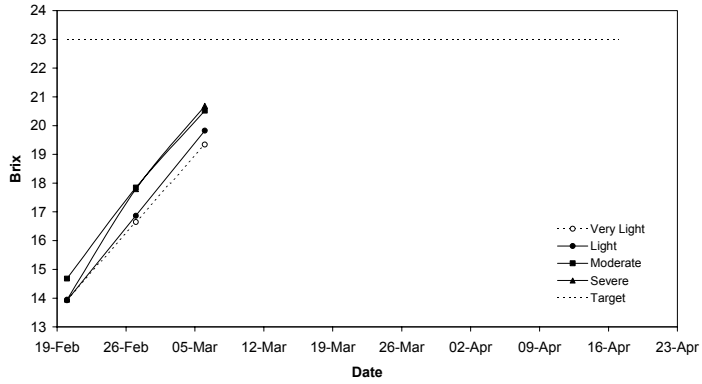

**Barooga Chardonnay 2003 - pruning treatments**



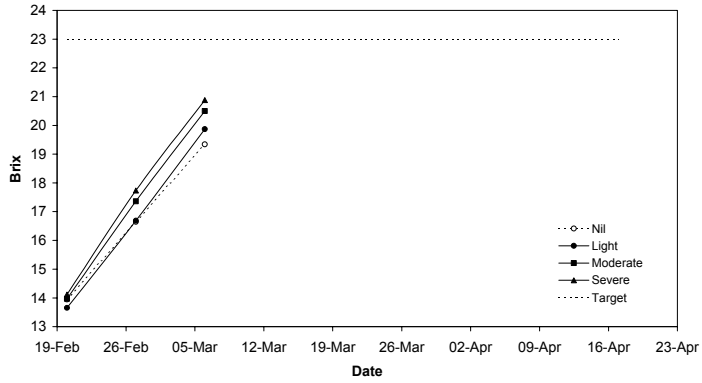

**Barooga Chardonnay 2003 - bunch thinning treatments**



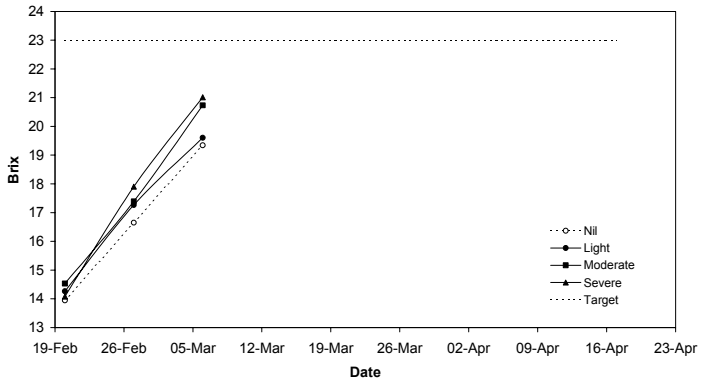
**Whitlands Chardonnay - pruning treatments 2001**



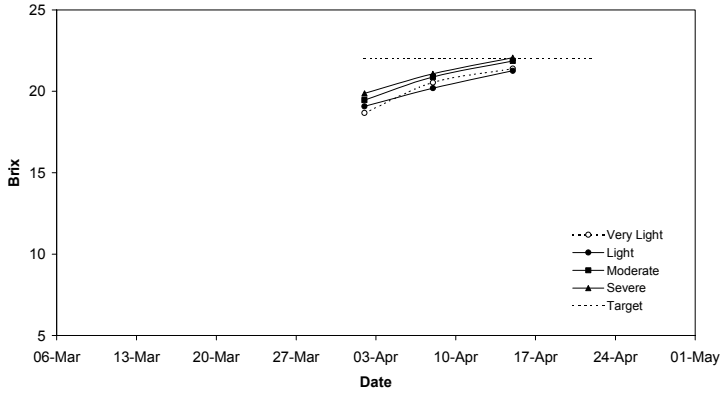

**Whitlands Chardonnay - shoot thinning treatments 2001**



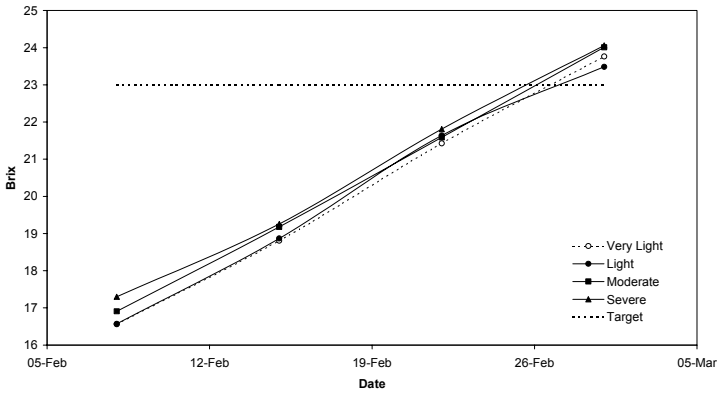
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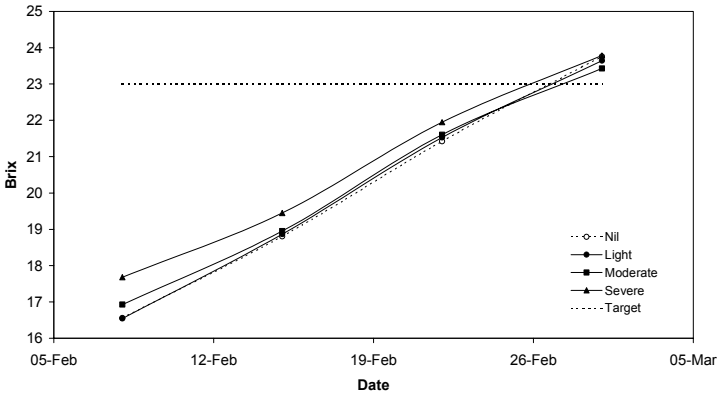

**Whitlands Chardonnay - pruning treatments 2002**



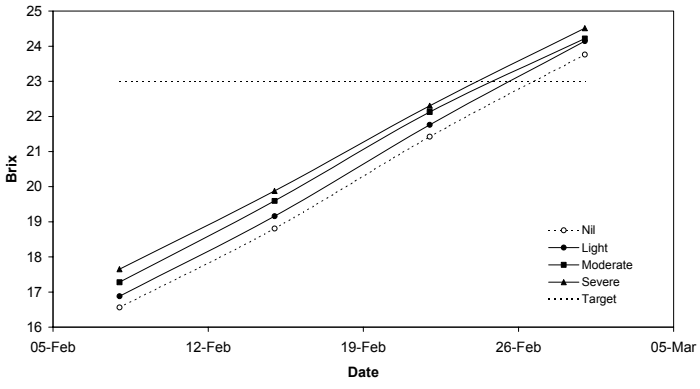
**Dookie Cabernet - pruning treatments 2001**



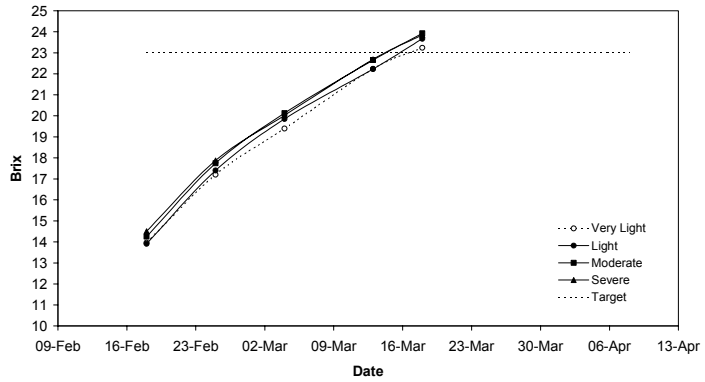

**Dookie Cabernet - shoot thinning treatments 2001**



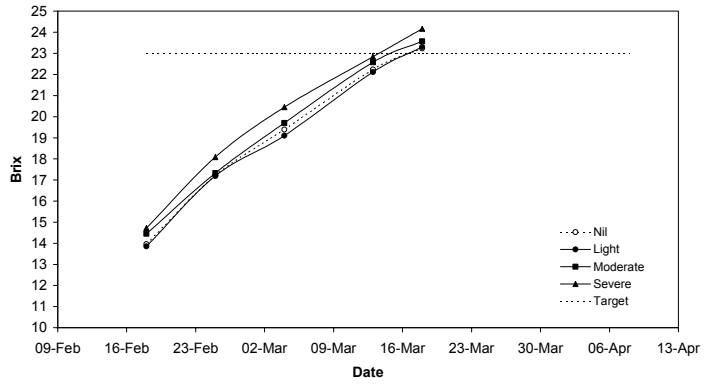

**Dookie Cabernet - bunch thinning treatments 2001**



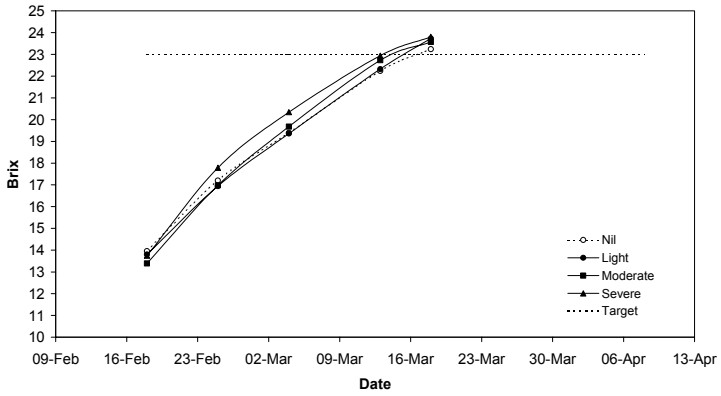
**Dookie Cabernet Sauvignon - pruning treatments 2002**



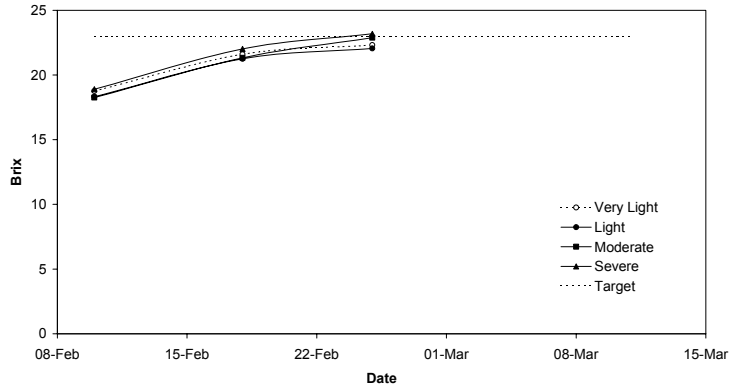

**Dookie Cabernet Sauvignon - shoot thinning treatments 2002**



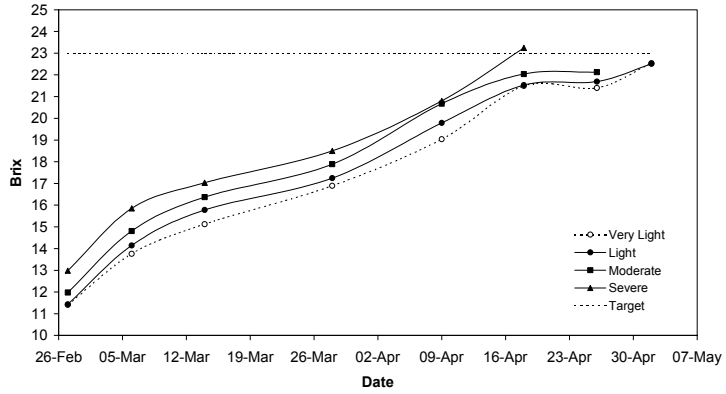

**Dookie Cabernet Sauvignon - bunch thinning treatments 2002**



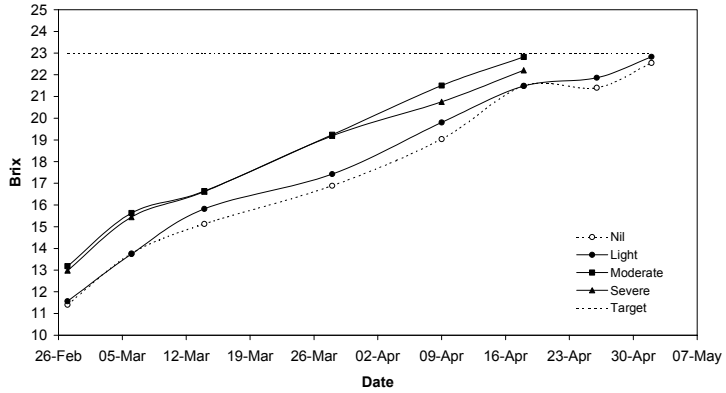
**Dookie Cabernet Sauvignon 2003 - pruning treatments**



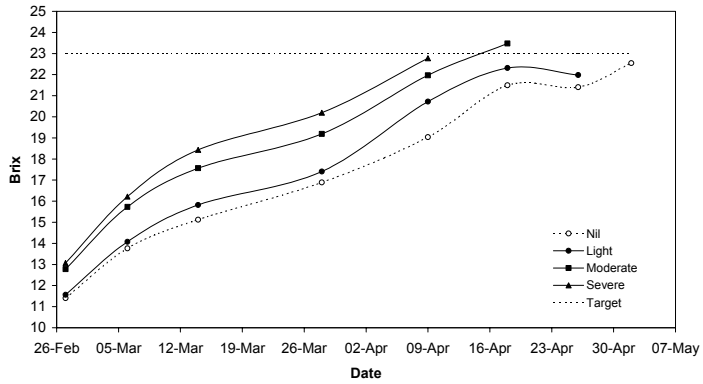

**Whitlands Cabernet Sauvignon - pruning treatments 2001**



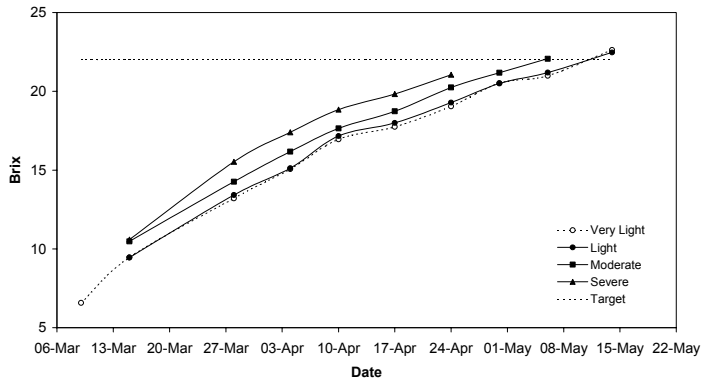

**Whitlands Cabernet Sauvignon - shoot thinning treatments 2001**



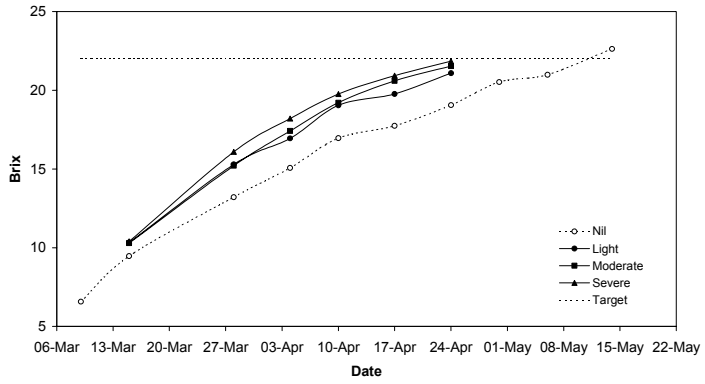
**Whitlands Cabernet Sauvignon - bunch thinning treatments 2001**



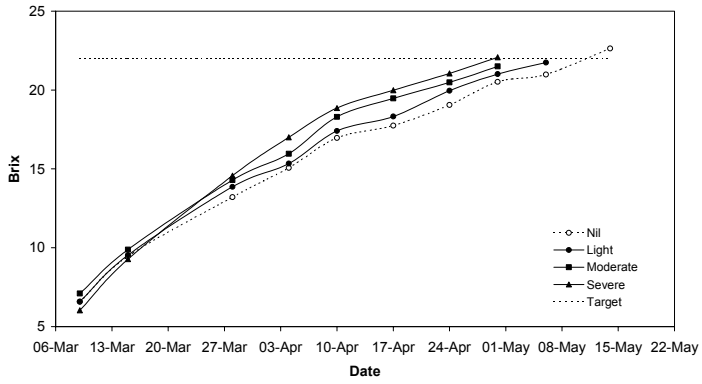

**Whitlands Cabernet Sauvignon - pruning treatments 2002**



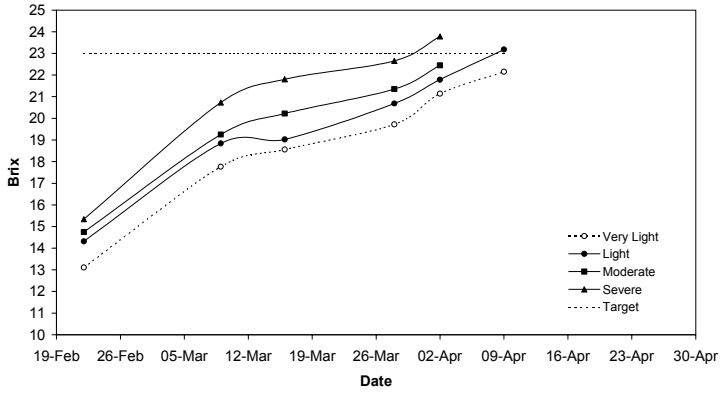

**Whitlands Cabernet Sauvignon - shoot thinning treatments 2002**



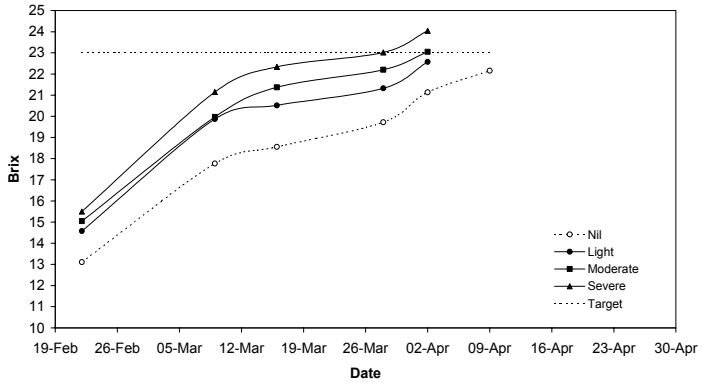
**Whitlands Cabernet Sauvignon - bunch thinning treatments 2002**



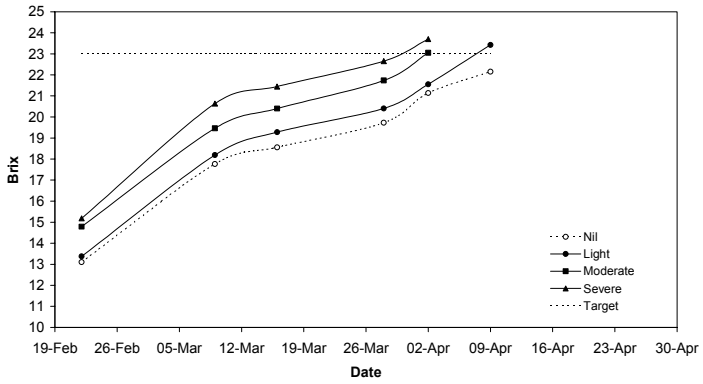

**Whitlands Pinot Noir - pruning treatments 2001**



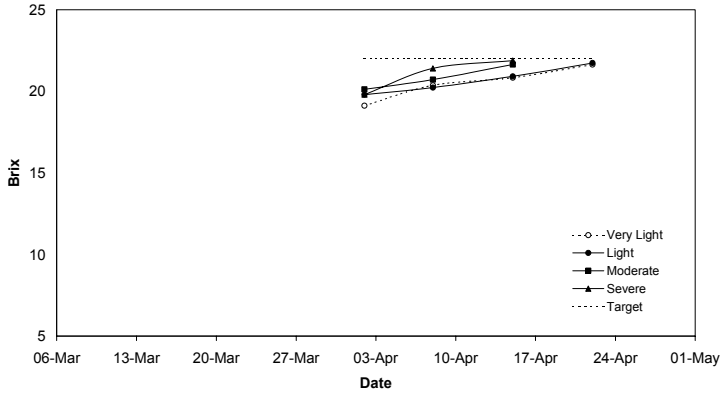

**Whitlands Pinot Noir - shoot thinning treatments 2001**



**Whitlands Pinot Noir - bunch thinning treatments 2001**




**Whitlands Pinot Noir - pruning treatments 2002**



## 3b. Using mechanical thinning to stabilise yield and improve grape maturity and colour.

***Introduction***

Grower returns and industry planning and marketing are hampered by large seasonal variations in yield of most wine grape varieties across most districts in Australia and New Zealand. Climatic effects on budburst, shoot fruitfulness, flowering, fruit set and berry growth, limit a growers ability to control crop levels by winter pruning (Clingeleffer et al. 1993). The use of other crop control techniques, in addition to winter pruning, has the potential to regulate seasonal fluctuations in yield. As crop control techniques are refined our ability to regulate yield to a target will improve and growers will be able to produce a consistent supply of grapes, produced to specifications of a given wine style. Over the duration of the project there has been ongoing study of mechanical thinning and significant industry adoption of mechanical thinning facilitated through close liaison with industry, oral, written and poster presentations in industry forums and journals and development of a grower leaflets.

Mechanical thinning is becoming more popular in Australia and is potentially a useful management tool to regulate yield (Clingeleffer 2000). However it shouldn't be used every year without question. It needs to be considered as an integral part of a growers crop forecasting and management system. Before mechanical thinning, (or any pre harvest crop reduction) growers need an accurate estimate of the vineyard yield. Without this it is hard to guess how much thinning is required. The only thing worse than not removing enough fruit when thinning is to take too much fruit off.

The next step in the process is to decide on the target yield. When deciding on a target yield growers need to consider what yields they have ripened in the past, if it will be a warm or cool season, how their contract with a winery works and the final date that the winery will accept their fruit. The potential for autumn rains or early frosts also need to be considered in some regions. The economics of mechanical thinning also needs to be considered. Before thinning a grower must consider how much the fruit is worth, how much the thinning will cost, and what they think they will get paid for their fruit with and with out thinning. Thinning post fruit set can form part of a risk management strategy, especially for growers in cooler regions where flowering can often be poor. In these regions vines can be managed to produce higher than optimal yields, and then thinned back to target levels if fruit set is high. If poor fruit set occurs, the thinning isn't needed.

Mechanical thinning is carried out when berries are at a small pea size, which is normally mid December in warm inland regions and after Christmas in cooler areas. Deciding how much of the vine to target is a critical part of thinning to a target yield. As part of the crop forecasting process, growers count the number of bunches in a cross section of their canopy using a rope ladder. To accurately thin growers need to place the middle of the ladder in the centre of the top of the canopy and count the number of bunches between each rung in the ladder. This enables the grower to estimate the position of the bunches in the canopy (as well as forecasting the vineyard yield). Only some of the beater rods are left in the harvester and the height of the harvester is adjusted so that a portion of the canopy is targeted for thinning. Mechanical thinning can target the fruit at the top of the canopy which can be susceptible to bleaching by the sun, or from the bottom of the canopy, as it is more spread out and therefore easier to thin accurately. Different strategies will be needed for different training systems. The harvester is set at a high beater speed (up to 500 beats per minute) in order to remove as much fruit as possible from the targeted

portion of the canopy. Head width is adjusted depending on the size of the canopy. It is important to follow the harvester to check that the fruit is being removed from the target section of the canopy and that too much is not being removed. Damaged bunches and berries remain within the canopy, so more fruit is removed than what you see on the ground. Damaged berries will dry in the canopy, and not become apparent for about five days.

The mechanical harvesters often have to beat grapevine canopies at a higher rate than they would during harvest in order to adequately remove the fruit. This has the potential to damage the canopy as well as the fruit, which has negative implications for the fruit development and quality. The aim of these experiments was to evaluate the use of mechanical harvesters as a tool for crop reduction to a target yield and to compare the effects of mechanical crop removal, with damage to the canopy, to crop removal by hand without damage to the canopy.

### *Methods*

Thinning was conducted between 17 and 21 December 2001, over two adjacent Cabernet Sauvignon vineyard blocks in the Riverland district of South Australia. A Gregiore G65 tow behind harvester fitted with four pairs of bow rods was driven at approximately 2.2 km per hour and rods operated at 500 beats per minute. The height of the harvester and the position of the bow rods were adjusted so that the lower third of the canopy was hit by three pairs of rods, and the very top of the canopy was hit by the fourth pair of rods. The fruit at the top of the canopy was targeted for thinning as this fruit is often bleached by high light and temperature (Bergqvist et al. 2001). Four treatments were used:

1) Control (unthinned vines)
2) Mechanically thinned vines (as described above)
3) Hand thinned vines from a similar position in the canopy to the mechanically thinned vines.
4) Mechanically thinned vines that were then hand thinned to remove the damaged bunches.

Five bunch samples were taken at approximately weekly intervals from 7 February until the 22 March, when the vines were harvested. A sample of 100 berries was removed from the bunches and weighed, the remaining berries were frozen for colour analysis. The 100 berries were then crushed and $^{o}$Brix, pH and titratable acidity were measured. The frozen berries were defrosted overnight and homogenised using an Ultra-Tarax before anthocyanin and phenolic concentrations were determined according to the method of Iland et al. (Iland 2000). At harvest fruit was removed from a one metre section of the vine, bunches were counted and weighed.

### *Results and Discussion*

Bunch number and yield per metre were decreased by the thinning treatments. The hand thinning treatment successfully reduced yield to a similar level to the mechanical thinning treatment, however the treatment that combined mechanical and hand thinning had a significantly lower yield than the others. The reduction in vine yield caused an improvement in sugar accumulation by 1.5-2 $^{o}$Brix compared to the control (un-thinned). This response is consistent with other studies where hand (Kaps and Cahoon 1989; Howell et al. 1987; Fisher et al. 1977; Winkler

1931) and mechanical thinning (Clingeleffer 1998; Fendinger et al. 1996; Clingeleffer 1993b; Clingeleffer 1993a; Pool et al. 1993) have been used to reduce crop load. The lack of a significant difference in sugar content at harvest, between the mechanical and the hand thinned treatments suggests that the damage caused to the canopy by the vine harvester did not effect sugar accumulation when the yield was consistent. Unfortunately the yield of the mechanical and hand thinning treatment was significantly lower than the other thinned treatments, probably due to the removal of too many undamaged bunches from these vines. The difference in sugar content between the thinned and un-thinned vines became apparent on the second sample date and was maintained through until harvest. Some berries had not completed veraison (the colour change at the start of the ripening process) when the first sample was made. This may have caused the lack of a difference between treatments at that time. While average bunch weight was unaffected by thinning, the 100 berry weight was reduced by mechanical thinning. Some berries damaged by mechanical thinning do not abscise, and continue to develop through to harvest, although their size is reduced.

The other indicator of wine quality considered in this study was anthocyanin concentration. Anthocyanin concentration in the fruit has been shown to correspond closely to anthocyanin concentration in the wine and wine quality (Iland 2000). Mechanical but not hand thinning caused a significant improvement in anthocyanin concentration in the fruit. This may have been caused by the reduction in berry size or canopy density due to the mechanical thinning treatment. Small berries increase the skin to pulp (surface area to volume) ratio of the fruit, as most of the anthocyanins are contained in the skin this may have a direct impact on the anthocyanin content of the must (Johnstone et al. 1996). While the mechanical thinning treatment reduced berry size the hand thinning treatment appeared to result in larger berries (although this effect was not significant).

Mechanical thinning offers the potential to regulate yield and improve fruit and wine quality of Cabernet Sauvignon in the warm irrigated grape growing regions of Australia.

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## 3c. Pruning to improve grape and wine quality in warm irrigated vineyards.

***Background***

Falling red grape prices and the use of quality indicators, additional to sugar, by many wine companies has increased grower interest in reducing production costs without compromising yield or quality. Total mechanisation of harvest and pruning combined with minimising operations for vineyard maintenance, irrigation and crop protection are key criteria for cost effective wine grape production. Pruning system is an important component of production costs. Selection of appropriate pruning system cannot be made in isolation from other management practices, especially those that target canopy growth such as irrigation and cover crop management, and knowledge of the end use requirements of the winery. Research over 30 years in warm irrigated wine regions has shown that traditional regulation of bud numbers by severe hand pruning may be unnecessary and may contribute to low wine quality generally associated with development of shaded, tight bunches with large berries which create difficulties for pest and disease control. Mechanical harvesting has allowed growers to adopt light mechanised pruning techniques as the size and position of bunches within the canopy are not important. This has removed the need for large bunches that are easy to pick by hand (Clingeleffer 2000). One of the major advantages of light pruning systems is the reduction in shoot vigour, development of smaller bunches with smaller berries which promote higher anthocyanin content in the fruit. Over the last three seasons wineries have begun to pay bonuses for fruit with high anthocyanin content.

Two approaches to light mechanical pruning are used, ie. mechanical hedging and minimal pruning. With mechanical hedging vines are pruned in both the vertical and horizontal planes, although a wide variation in the severity of pruning is used commercially, occasionally with a hand clean-up. For minimal pruning a high single or a 2-wire vertical trellis is normally used. The vines are left unpruned but are skirted below the wire, either in mid summer or winter, to stop fruit and shoots contacting the ground and to control cropping levels. Benefits from light pruning systems include control of excessive shoot vigour, development of small, loose bunches with small berries spread over a large canopy surface which lead to good disease control and improved quality, provided adequate sugar levels are reached (Clingeleffer 2000).

The aim of this study was to investigate the influence of spur and mechanised training systems on the yield and quality of Cabernet Sauvignon in a young vineyard (fourth season).

***Methods***

The research site was located in Sunraysia on a Cabernet Sauvignon vineyard in their fourth growing season. The vines were trained to a two wire vertical trellis and were pruned at four different levels:

1) Spur pruning, with approximately 10cm between two node spurs.
2) Narrow mechanical pruning, where the pruned canopy had a width of 0.2 m.
3) Wide mechanical pruning, where the pruned canopy had a width of 0.3 m.
4) Minimal pruning, no pruning during dormancy.

Five bunch samples were taken seven times between veraison and harvest, from four replicates for each treatment. Berries were pressed using a mortar and pestle and the strained juice analysed for sugar concentration.

Each treatment was picked at about 23.5 $^{o}$Brix (13 Baume), except the minimal pruning treatment which was harvested at approximately 22 $^{o}$Brix (12.2 Baume) as the block was to be

harvested commercially. At harvest all bunches within a one metre transect were removed, counted and the total were weighed. A five bunch sub-sample was taken for more detailed measurements. The berries on these bunches were weighed and counted. Samples consisting of 100 berries were pressed as above and in addition to sugar measurements, TA and pH were measured on a 5ml juice sample. A further 100 berries were blended using a 'slender blender' (Black & Decker) and processed for anthocyanin and phenolic content according to the method of Iland et al. (2000). The remaining bunches harvested from the 1 m transect were pooled and split into two replicates for winemaking, which included acid adjustment to a similar pH value.

***Results and Discussion***

The wide mechanical pruning treatment had significantly higher anthocyanin and phenol concentrations compared to all other treatments. These may have been due to changes in canopy architecture and fruit characteristics (ie. reduced shoot vigour and development of smaller bunches with smaller berries) compared to the spur pruned treatments, and due to the improved fruit maturity (as shown by percent soluble solids) compared to the minimally pruned vines. Johnson et al. (1996) has demonstrated that increasing sugar concentration and reduced berry size are correlated with anthocyanin concentration in the fruit.

Yield was unaffected by the pruning levels, however the more severely pruned treatments had fewer but larger bunches, with larger berries. These trends have been seen consistently across seasons and cultivars when light and severely pruned vines are compared (Clingeleffer 2000, McCarthy and Cirami 1990, Clingeleffer 1988). Vines with high bunch numbers are easily mechanically harvested, however it would not be practical to harvest the many small bunches from a lightly pruned vineyard by hand. The loose bunches on the lightly pruned vines are also less susceptible to fungal infections, particularly botrytis near harvest, possibly due to better fungicide penetration into the bunches and the canopy (Emmett et al. 1994).

The spur and mechanically pruned treatments were successfully harvested at a similar sugar concentration. Due to the impending commercial harvest of the block the minimal pruned vines were harvested before they had reached the intended sugar level. When sugar accumulation was tracked during the season, pruned treatments appeared to enter veraison and begin accumulating sugar earlier than the minimal pruned treatment (Fig. 1). All treatments continued to accumulate sugar up until harvest. If the minimally pruned vines had been allowed to ripen to a similar sugar concentration as the other treatments they may have recorded higher anthocyanin concentrations. When young vines are established on light pruning systems, grape growers and winemakers need to be aware that delaying harvest may improve the quality of the fruit.

In general, analysis of the small lots of wine confirmed the results from the grape analysis, in that higher levels of anthocyanins in the grapes corresponded with higher levels of anthocyanins in wines. Colour density and ionized anthocyanins were significantly lower on the spur pruned vines compared to the other treatments. The spur pruned treatment had a colour density value below 6 a.u. which would normally put it in the category of a light style red wine (Iland et al. 2000). The wine from the spur pruned vines also had a higher value for hue, which means that they had a greater proportion of brown pigments relative to red pigments. Total anthocyanin concentration in the wine also appeared higher for the wide mechanical pruning treatment

compared to the spur pruned treatment; however this result was not statistically significant, probably due to the low number of winemaking replicates. Generally wines with higher colour density and anthocyanin content score comparatively well in sensory assessment (Somers and Evans 1974), which suggests that wine quality was improved by light pruning, especially the wide mechanical pruning treatment.

Pruning can be a major cost to growers and any technique that can reduce this cost will improve the financial viability of the vineyard, as long as fruit quality is maintained. In this example mechanical pruning improved the quality of the fruit, and may have resulted in a bonus payment being made to the grower. Lighter pruning methods can cause changes in the date of maturity; allowing for this in the scheduling of harvest and winery intake dates will improve the quality of the wine. Growers and wineries need to continue to use light mechanised pruning methods in order to minimise production costs and maximise fruit and wine quality.

| | **Spur** | **Narrow Mechanical[a]** | **Wide Mechanical[b]** | **Minimal (unpruned)** | **LSD** | |
|---|---|---|---|---|---|---|
| Harvest Data | | | | | | |
| **Harvest Date (2001)** | **15/3** | **15/3** | **20/3** | **20/3** | **-** | **-** |
| **Yield (kg/m of row)** | **5.00** | **5.73** | **6.25** | **5.74** | **-** | **ns** |
| **Estimated Yield (t/ha)** | **15.0** | **17.2** | **18.7** | **17.2** | **-** | **-** |
| **Bunch Number (per m)** | **74** | **156** | **195** | **243** | **50.4** | ******* |
| **Bunch Weight (g)** | **68.8** | **37.0** | **32.2** | **23.7** | **6.20** | ******* |
| **Berry Weight (g)** | **1.03** | **0.94** | **0.91** | **0.76** | **0.081** | ******* |
| **°Brix** | **23.2** | **23.6** | **23.4** | **21.9** | **1.20** | ***** |
| **Titratable Acidity (g/l)** | **4.4** | **3.5** | **3.3** | **3.6** | **0.19** | ******* |
| **PH** | **3.70** | **3.74** | **3.73** | **3.74** | **-** | **ns** |
| **Phenolics (mg/g)** | **1.06** | **1.33** | **1.51** | **1.24** | **0.13** | ******* |
| **Anthocyanins (mg/g)** | **0.55** | **0.67** | **0.81** | **0.68** | **0.083** | ******* |
| | | | | | | |
| Wine Analysis | | | | | | |
| **Colour Density (a.u.)** | **4.9** | **6.2** | **7.0** | **6.7** | **1.09** | ***** |
| **Hue** | **0.65** | **0.61** | **0.61** | **0.61** | **0.25** | ***** |
| **Ionized Antho. (mg/l)** | **32** | **48** | **50** | **50** | **8.7** | ***** |
| **Total Antho. (mg/l)** | **302** | **316** | **336** | **309** | **-** | **ns** |
| **Total Phenolics (mg/l)** | **32** | **36** | **37** | **35** | **-** | **ns** |

Table 1. Cabernet Sauvignon yield components and fruit composition at harvest and wine spectral composition seven months after harvest. Values for harvest data are means of eight replicates, values for wine analysis are means of two replicates. LSD – Least Significant Difference. ns – not significant, (*) $p < 0.05$, (***) $p < 0.001$. [a]Mechanically pruned canopy 0.2 m wide. [b]Mechanically pruned canopy 0.3 m wide.

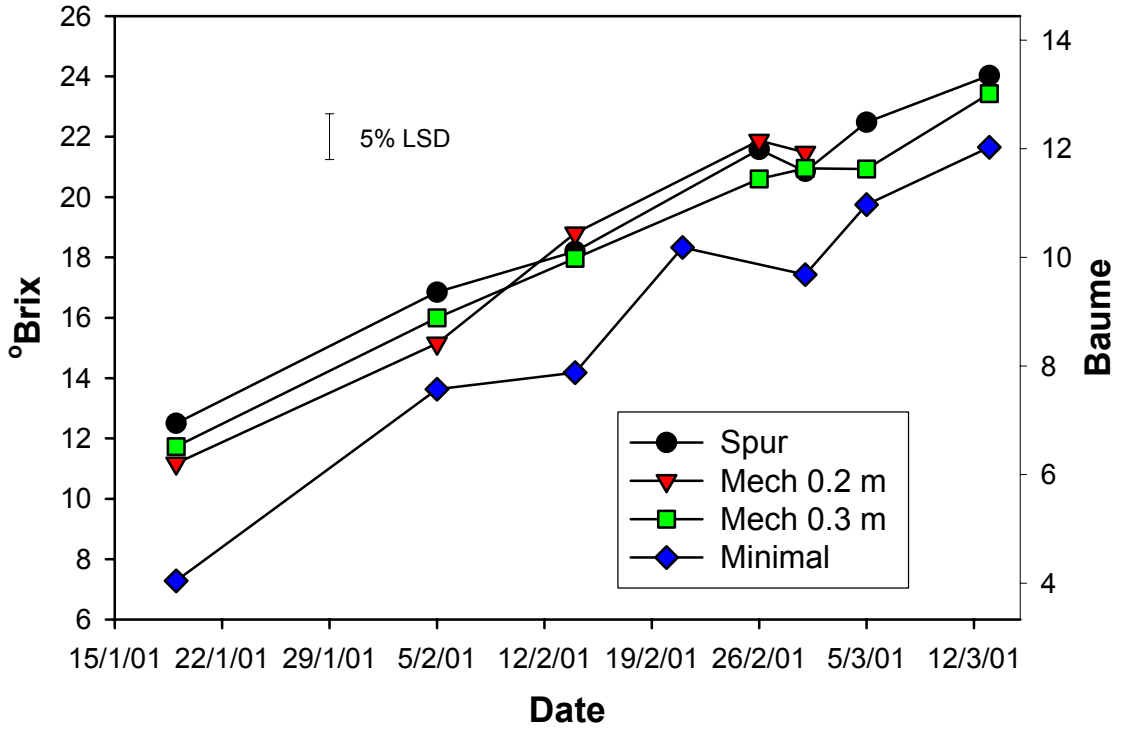



Figure 1. Sugar accumulation in grape berries of Cabernet Sauvignon trained to four different systems (see text for details). LSD – Least Significant Difference

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# Chapter 4.

# Facilitate the industry adoption of reliable , robust and objective forecasting systems

## 4a. Adoption of measurement-based crop forecasting systems

### *Introduction*

Objective 3 of the project was:

Facilitate the industry adoption of reliable, robust and objective crop forecasting systems.

This objective was defined in recognition that GWRDC project CSH 96/1 *Crop development, crop estimation and crop control to secure quality and production of major wine grape varieties: a national approach* had developed systems that had the potential to substantially improve the accuracy of crop forecasting in the industry, but that further work was needed to facilitate their widespread adoption. In addition, improved crop forecasting is an essential first step to successful yield regulation (see Chapter 2). Consequently there was and is a strong demand for application-ready packages and training courses to support implementation of measurement-based crop forecasting systems in the industry.

This section describes:

- the evolution of measurement-based crop forecasting systems
- further development of the systems from July 2000 to June 2003
- development and distribution of supporting software and "How to" manuals
- development and delivery of a supporting training course
- communications with the industry relating to crop forecasting
- an evaluation of the system, software and training
- conclusions and recommendations relating to future facilitation of adoption

It is concerned primarily with the problem of providing forecasts of deliveries to wineries of individual blocks or patches within vineyards, rather than regional forecasts.

### *Background*

*Industry performance*

At the beginning of this project there was a reasonably good awareness throughout the industry of the existence of measurement-based crop forecasting systems, but interviews with growers and wineries suggested that the vast majority of forecasts were made using various methods of subjective crop assessment that resulted in adjustments of forecasts up or down from an historical mean (Clingeleffer et al 2001). Quantitative studies of forecasts provided to wineries in January showed that there was typically a slight bias towards overestimation (approximately 6%) and that the mean absolute difference between forecast and actual deliveries (a measure of precision) was typically in the order of 33% either side of actual. During the life of the project three large wine companies used this method to analyse the crop forecasting performance of their contracted growers and own vineyard managers and confirmed a remarkably consistent tendency for forecasts to be 33% out on average.

With a desire to improve this performance, some wineries have proposed incentives such as offering a prize for the most accurate forecast each year. The project team had a look at how this might be administered fairly and whether it might work. We concluded that such an approach would be more likely to reward growers who were lucky enough to manage patches of vines that produced a similar yield each year, rather than skilful forecasters. To counteract this, the performance of a forecaster could be weighted by applying a difficulty rating related to the historical variability of production in a block, much like the way in which difficulty of dives or gymnastic manoeuvres are considered when awarding scores in sporting contests. We devised some formulae for calculating this, but there would be some severe practical difficulties in applying them. Consequently we advocate an approach consistent with the principles of Quality Management, where the long term use of a reliable and correctable system by a supplier is rewarded rather than the achievement of results in the short term.

*Development of measurement-based forecasting systems*

A method of objective 'in-season' yield forecasting in the Australian Wine Industry was proposed by Dr Peter May in the 1970s. He understood that there were cardinal times during grapevine phenology when yield potential was set and advocated predicting yield from measurements of crop components at these important phenological stages. He proposed a system based on (i) bunch counts made 4-6 weeks after budburst and (ii) berry counts made after fruit set (May 1972). May's view was that the key thing was to estimate berries per vine. Other systems, which were also based on bunch counts but estimated harvest weight per bunch by weighing bunches at veraison and then multiplying by a factor, were used in the industry during the 1980s and 1990s.

At the beginning of the 1997/98 season, the CSIRO viticultural team at Merbein developed a crop forecasting protocol for the Murray Valley Wine Grape Growers Industry Development Committee (MVWGGIDC), based on the earlier work by May and others. This protocol has since been described in a booklet issued by the Victorian and Murray Valley Wine Grape Growers Council (VMWGGC). In this report we refer to it as System 1. Its main features are summarised in Figure 4.1.

**SYSTEM 1**

**Stage 1 - one month after budburst**
***Count bunches***
Weight/block = vines/block x bunches/vine x weight/bunch

**Stage 2 - after fruit set**
***Count berries***
Weight/block = vines/block x bunches/vine x berries/bunch x weight/berry

**Stage 3 - one week before harvest**
***Count and weigh bunches***
Weight/block = vines/block x weight/vine

Figure 4.1. Summary of stages, measurements and forecasting formulae used in System 1.

The performance of System 1 was assessed in 40 vineyard blocks of Cabernet Sauvignon, Chardonnay and Shiraz between 1998 and 2000 (Figure 4.2). It was biased towards overestimation at all three of the forecasting stages, and its precision in January (average absolute difference = 34%) was no better than that achieved by growers "eyeballing" their crops (33% - see above).

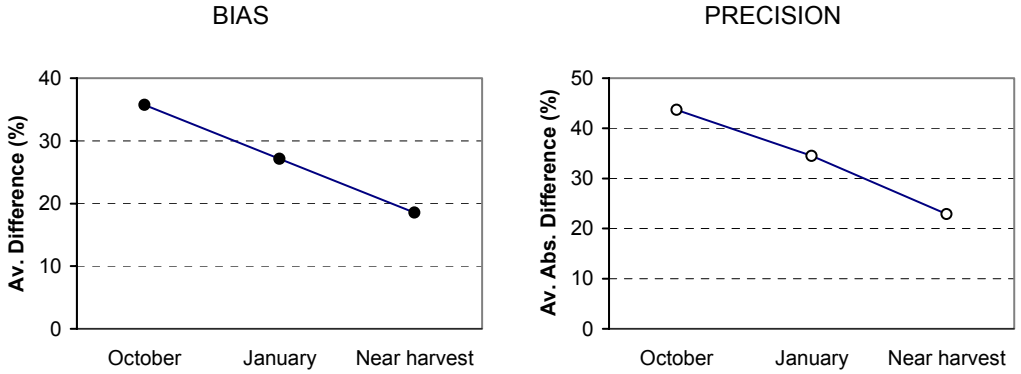



Figure 4.2. The bias and precision of 'System 1' forecasts made in 40 blocks of Cabernet Sauvignon, Chardonnay and Shiraz for the vintages from 1998 to 2000.

This intrinsic bias and unacceptable precision was due to inadequacies in the formulae that were used to predict deliveries from estimates of yield components and the sampling procedures that were used to provide the data from which estimates of yield components were calculated. Furthermore the system was not recommended for vineyards less than four years old or for patchy blocks.

By June 2000, the NRE (now DPI) viticultural team at Tatura had identified some potential improvements to System 1 and tested them. The revised protocol is referred to in this report as System 2. Some of the key improvements included in System 2 were:

- Truly unbiased and representative sampling methods (see Wolpert and Vilas 1992, and Dunn and Martin 1998).
- The determination of optimal sampling units for different yield components and viticultural systems.
- A flexible approach to sampling, allowing forecasters to tailor it to vineyard block variability.
- Tighter definitions of yield components.
- The incorporation of important factors into forecasting formula (e.g. harvest efficiency, bunch gain, berry loss).

This was supported by the development of software and a manual to facilitate simple, rapid, unbiased and efficient sampling, calculate forecasts and assess and improve forecasting performance.

The performance of System 2 was evaluated for many vineyard blocks across a broad range of climates and over three seasons (Clingeleffer et al 2001). Bias was greatly reduced in pre-flowering forecasts and eliminated completely in January and near harvest (Figure 4.3). The precision of forecasts made near harvest was excellent (Av. abs. diff. = 6%). Forecasts made in January were 23% out on average. This was achieved in some blocks that had been chosen because of their difficulty to forecast, and this performance could have been improved even more by using larger sample sizes. In subsequent years January forecasts produced by System 2 with a more stringent tolerance of doubt around estimates of sample means have consistently achieved a precision averaging approximately 15%. This represents a substantial improvement over industry performance and if widely implemented would save the industry hundreds of millions of dollars each year.

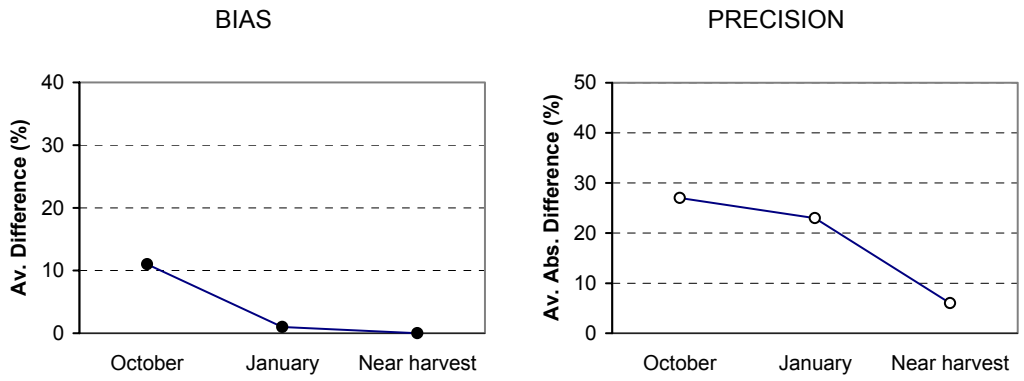



Figure 4.3. The bias and precision of 'System 2' forecasts made in 14 blocks of Cabernet Sauvignon, Chardonnay and Shiraz for the 2000 vintage.

In summary, System 2 was a large improvement on System 1. Users could expect it not to be biased if implemented faithfully. However, its precision depends on the resources that are committed to sampling and measurement, and is limited by the seasonal variability of yield components that must be estimated from historical data. For forecasts made in January it is reasonable to expect 0% bias and an Average Absolute Difference of 20%. During the early stages of the project most wineries nominated 5% as their desired precision from grower forecasts. Although a target of 5% is unrealistic at present it is not unreasonable to expect a precision of 10 to 15% in the near future. However, it was recognised that achievement of this in practice depends on the knowledge, skill and resources of the operator.

### *Further development of the crop forecasting system*

*Segment length*

It is more efficient to count bunches or pick fruit in 'segments' of vine row than whole vines (Clingeleffer et al 2001). A segment is a 'slice' of a vine row, with a known length. Selection of the right segment length is important for achieving the most efficient sampling technique to achieve an accuracy target . If the segment length is too small, the variation in the measurements

increases, more spots must be visited in the patch to achieve the accuracy target, and so more time will be spent than is necessary moving between spots. If the segment length is too big, more time will be spent counting at each spot than is necessary. The best segment length is the one that minimises the time spent in the patch to achieve the accuracy target. This varies in relation to the density and evenness of distribution of bunches along the vine row. Based on a large database of the variation of measurements of bunches per segment and grape weight per segment in a wide range of pruning and canopy systems, the recommendations contained in Table 4.1 have been provided to training groups.

Table 4.1 Recommended initial segment lengths for pruning and canopy systems

| **Pruning and canopy system** | **Recommended segment length** |
|---|---|
| Young vines | equal to vine spacing (whole vine) |
| Cane pruned vines with low bunch densities | about 0.9 - 1.2 m |
| Most spur and cane pruned systems | about 0.6 m |
| Minimally and mechanically-pruned systems | about 0.3 m if bunches evenly distributed |

As a rule of thumb we have calculated that a segment length that results in a mean of approximately 30 bunches per segment is generally also the one that achieves an optimum balance between the number of spots to visit and the time spent counting at each spot. However, there are exceptions.

A method to determine optimum segment length in any given patch has been developed and documented, and we intend to publish it as a research note in the *Australian Journal of Grape and Wine Research*. We have not disseminated this widely at this stage because we have judged that trainees have had enough information to assimilate as it is. However, we have found that as the number of people who have used the system in the industry for two or more years increases, so the demand for a method to optimise the segment length for their particular circumstance has increased. For example, growers with young vineyards have often found that using a 30 cm or 60 cm segment has resulted in a very large Best Sample Size and we have been able to help them by advising them to increase the length of the segment, commonly to a length equal to half a vine or a whole vine spacing. As more and more of the wire in their patch becomes filled in subsequent seasons they have been able to progressively decrease the segment length.

*Bunch gain or loss factors*

System 2 includes the capability to allow for a 'Bunch gain or loss factor' when making forecasts from estimates of mean bunches per metre of row derived from bunch counts. This is because it has been found that there are typically more and sometimes less bunches counted at harvest than at the common bunch counting time before flowering (Clingeleffer et al 2001). Subsequent experience with groups of growers using the system has confirmed the existence and the importance of bunch gain or loss.

When bunches have been counted by training groups in exercise patches of Chardonnay, both bunch loss and bunch gain have been observed, with a general tendency towards either no significant change or a significant gain (Table 4.2).

It is easy for both growers and researchers to accept a loss of bunches, but there is resistance to accepting that they can be gained, even though the numerical evidence indicates that it occurs. There are a number of reasons why it can occur. It might be suspected that it would be easier for counters to miss small, green inflorescences than larger, coloured bunches of grapes. However, this does not seem to be the whole story. Even when estimates of bunches per metre of row are derived from very meticulous shoot-by-shoot bunch counts, there is a consistent tendency for more bunches to be counted at harvest (e.g. Table 4.3). In most cases this is not due to "second crop" on lateral shoots. The causes are not entirely clear and deserve more investigation, but a forecaster does not need to know why it occurs; it is sufficient to know that it does and make some allowance for it.

Table 4.2. Bunch gain or loss factors (BGLF) observed in patches of Chardonnay used for crop forecasting training exercises.

| Year | Group | BGLF | Significant |
|---|---|---|---|
| 2001 | Perricoota | 0.86 | yes |
| | Yarra Valley | 0.96 | no |
| | Rutherglen | 1.07 | no |
| 2002 | Mornington Peninsula | 0.96 | no |
| | Southcorp | 1.10 | no |
| 2003 | Coonawarra | 1.01 | no |
| | Gt western | 1.09 | no |
| | Nagambie | 1.26 | yes |
| | Karadoc | 1.34 | yes |
| | Griffith | 1.37 | yes |
| | Mean | 1.10 | |

BGLF > 1 indicates a gain from pre-flowering to harvest.
Significance ($p<0.05$) was tested using a *t*-test.

Table 4.3. Bunch gain or loss factors observed over three years in pruning treatments in a crop regulation experiment in a patch of Chardonnay at Barooga.

| Pruning treatment | Vintage 2001 | 2002 | 2003 | Mean |
|---|---|---|---|---|
| Very light | 1.12 | 1.14 | 1.23 | 1.16 |
| Light | | 1.11 | 1.20 | 1.15 |
| Moderate | | 1.16 | 1.19 | 1.18 |
| Severe | | 0.91 | 1.11 | 1.01 |

Values > 1 indicates a gain from pre-flowering to harvest.

The examples given here are for Chardonnay. We also have data relating to Cabernet Sauvignon and many users of the system now have substantial databases that relate to other varieties. In general there is a consensus that, typically, approximately 10-20% more bunches are counted at harvest than at times between 6 weeks after budburst and flowering. This would clearly be a major source of error across the industry if it were to be ignored.

*Better early prediction of harvest bunch weight*

Yield predictions made early in the season are important for both forecasting and crop regulation. The earliest time that an 'in-season' yield forecast can be made reliably is approximately 6 weeks after budburst. At this time bunch number is estimated from bunch counts and bunch weight at harvest is a prediction. This prediction has proved to be difficult and a major source of error.

During the three years of the project we investigated potential early season predictors of harvest bunch weight for the varieties Chardonnay, Cabernet Sauvignon and Pinot Noir across a broad range of climates. The most promising of these proved to be the number of primary branches on the bunch, and our results show that counting these can enable detection of large seasonal deviations in bunch weight from the long-term mean. Details are provided in Chapter 5.

Incorporating an estimate of bunch weight based on the number of primary branches dramatically improved yield forecasts made six to eight weeks after budburst at five sites where crop forecasting training exercises were conducted during the 2002/03 season *viz*. Great Western, Nagambie in Central Victoria, Coonawarra, Griffith and Karadoc near Mildura (see Chapter 5). These results provide us with some confidence in the usefulness of the technique for the varieties that were studied. Since the end of the project, a leaflet explaining the technique has been published and appended to the manual *How to forecast wine grape deliveries* (see below).

*Better allowance for 'Hen and chicken'*

Commonly two distinct classes of berries can be observed when they are counted at times from about a month after fruit set until harvest. This is due to the condition that is known colloquially in the industry as 'hen and chicken'. In many regions during the 2002 vintage there was an unusually high percentage of 'chickens' in the berry populations of bunches, which troubled forecasters using the 'Berry counting' method of forecasting.

At some sites (particularly Coonawarra) in the 2002 vintage, bunches consisted mainly of chickens, so these needed to be counted and an estimate of bunch weight made by assuming a smaller berry size than historically typical. This highlighted a need to have a system that allows forecasters to use their judgment, rather than slavishly use historical statistics. The forecasting system does permit this, and when it was used skilfully it produced forecasts that were superior to subjective methods. The unusual 2002 vintage also highlighted a need to be able to exclude unusual years from historical data. Caution needs to be exercised when doing this, but the project team decided to give the user that power in new database software that was developed during the life of the project (see below).

The system can now give forecasters the ability to make a forecast based on counting more than one class of berries and assuming a different harvest berry weight for each class. This has the potential to improve the accuracy of forecasting for advanced users, but it complicates data collection and the training of new users. Consequently we have avoided including the method in the training courses that are described below.

Our research has also shown the importance of adjusting the threshold for the minimum size of 'normal' berries as all the berries in the crop population grow. If this is not done, and the same size threshold is used in-season as at harvest, 'chickens' that have grown bigger than the in-season threshold will be counted as normal, so counts of 'normal' berries can appear to increase. Unlike bunch gain, berry gain is physically impossible and in all the circumstances where it has appeared to have occurred it has always been found to be an artefact of the measurement process.

*Refinements to knowledge about weight gain from veraison to harvest*

System 2 included the option of making a forecast from counts of bunches per segment and weights of bunches at a reference time such as veraison. In the software, manual and training that was developed to support the implementation of the systems this is referred to as the 'Bunch weighing' method. One of the major limiting factors in this method is uncertainty surrounding prediction of the 'weight gain factor' from the time of in-season measurement (typically veraison) to harvest. Over the life of the project a further three years of data was collected, enabling the project team to provide forecasters with better guidance concerning typical Weight Gain Factors to use when using the system for the first time. This data will be included in updates of the 'How to' manual. In subsequent years forecasters can use the data from their own patches.

*Refinements to methods of analysing sources of inaccuracy*

One of the key features of System 2 that distinguishes it from its predecessors is that it incorporates procedures that enable forecasters to continually improve their forecasts over the years. We have found that the importance of this is often overlooked and underestimated by prospective users, but appreciated intensely by people who have completed the training and who have used the system for a year or more.

The ability to improve rests on being able to base decisions on facts and data rather than opinion, analyse sources of inaccuracy in the forecasts, distinguish a 'signal' that something needs attention from the 'noise' of chance events and know what to do to fix the problem.

In accordance with quality management techniques (e.g. see Bicheno 1994, Walton 1989, Wheeler 2000) and in consultation with biometricians, aids to analyse sources of inaccuracy in forecasts were incorporated into supporting software. For an outline of the procedures and principles see Martin et al (2002) and Martin et al (2003).

*Improvements to crop forecasting formulae*

The formulae used in the crop forecasting system that was provided to the industry during the life of the project did not change from those reported in Clingeleffer et al (2001). However, in some cases the use of a more sophisticated mathematical approach has the potential to improve forecasts.

Conventional crop forecasting formulae are based on an assumption that weight per vine can be predicted by multiplying an estimate of bunches per vine in a given year by a prediction of weight per bunch, using the formula *weight/vine = bunches/vine x weight/bunch*, where *bunches/vine* and *weight/bunch* are both estimates of mean values at harvest. This formula has

the general form $y = ax$, where $y$ is *weight/vine*, $x$ is *bunches/vine* and $a$ is *weight/bunch*. Commonly, an historical mean weight per bunch is substituted as an estimate of $a$. Somewhat surprisingly, it was found that estimates of $a$ derived by calculating the mean weight per bunch for a period of years were different to estimates derived by regression of *weight/vine* on *bunches/vine* for the same periods and did not result in as good predictions of *weight/vine* when substituted in the formula. Thus, in patches of vines where viticultural practices are held fairly constant over the years, it may be better simply to use a regression approach to predict weight per vine from bunches per vine, rather than to measure or derive weight per bunch for each season and use an historical mean. In this case, the best model to fit would be a power curve ($y = ax^b$). Predictions of yield from bunches per vine using power function coefficients tend to be closer to actual yields than predictions made using a simple multiplication by mean weight per bunch (Figure 4.3).

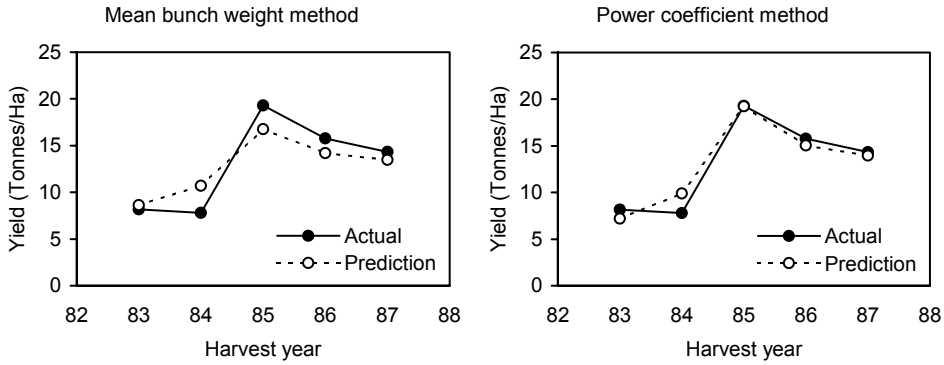



Figure 4.3. Comparison of actual yield over 5 seasons in Cabernet Sauvignon at Wahgunyah with predictions of yield made from measurements of bunches per vine using two crop forecasting methods.

The power curve relationship of weight/vine to bunches/vine is associated with a positive correlation of weight/bunch with bunches/metre. One important implication of this is that, in many cases, it may be sufficient to count bunches and use a more sophisticated forecasting formula rather than count berries. This would permit a major time saving for many growers.

*More flexible, less event-based approach*

The logic of the crop forecasting system was thoroughly reviewed in the last year of the project as a basis for the development of new database software. The details of this logic are too complex to be fully described in this report. They will be described in later reports of subsequent development. In essence, there has been a shift from a limited set of rigid, event-triggered procedures to a much more flexible system that is initiated by the need for a forecast and limited by the available data. In practice this should not result in much noticeable change to in-vineyard measurement procedures, but it has had a profound effect on the appearance and capabilities of the software. Our approach has been to provide forecasters with very flexible, powerful, 'non-parental' software and then rely on training to improve the knowledge and skills of users so that they can adapt the system and use the software to meet their particular needs.

***Development of paper-based aids to calculation***

In the 2000-01 season, a set of printed forms and notes was produced to support the procedures required to run System 2 in practice, using a hand calculator and random number tables. This was issued to participants in training courses that were run in that year (see below). This was shown to be an effective system that could be used by the trainees, but aspects of it were very time-consuming (particularly the procedures to define random 'spots' to visit for sampling purposes).

***Development of Excel workbooks***

During the 2000-01 season, a prototype Excel workbook was issued to some of the participants in training courses. At the end of that season evaluations of the success of the course revealed that a key factor in determining adoption of the system was use of this workbook. Basically, people who were using the workbook were happy to use the system, while those who had used the paper-based system were not likely to continue to do so.

Consequently, in consultation with practitioners in the industry, the project team decided to incorporate use of the custom-designed Excel workbook package, known as Grape Forecaster, as an essential component of the training course, and to inform participants that they would need to have access to a computer with Excel to be able to use the system as taught. At that stage a rapid increase in the number of on-farm computers and computing skills was occurring, so in practice this did not prove to be a significant limiting factor.

During the life of the project four versions of Grape Forecaster were developed and distributed:

- *Versions 3 and 4* were issued in September and December 2000 respectively to some participants in the training courses that were run in the 2000-01 season.
- *Version 5* was issued in October 2001 to all participants in training courses run in the 2001-02 season and was adopted as a standard in Southcorp company vineyards.
- *Version 6* was issued in October 2002 to all participants in training courses run in the 2002-03 season and was adopted as a standard in BRL Hardy company vineyards.

At various times versions of the workbook were also distributed in response to *ad hoc* requests from members of the industry who were not participants in training courses. We know that it has also been copied to a considerable degree throughout the industry (with our approval) and that it is in use in New Zealand, the USA and France.

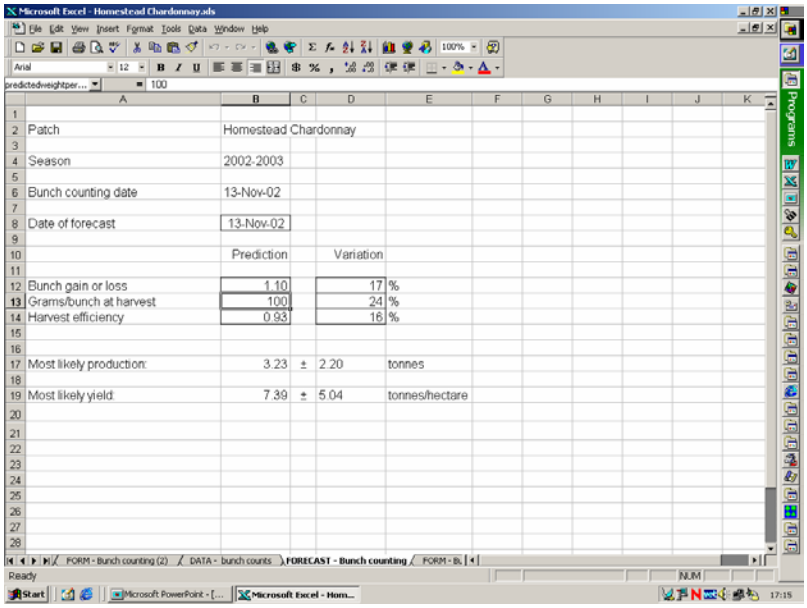



Figure 4.4. Screen image of a worksheet in the Grape Forecaster Excel workbook

***Development of a 'How to' manual***

As an aid to the use of the crop forecasting system supported by the various paper-based and Excel workbook systems, a series of manuals were written and distributed.

In 2000-01 a series of training notes and paper forms entitled 'How to forecast wine grape production' was issued to participants in the training groups that were run that season. In 2001-02 these notes formed the basis for a manual with the same title that was revised and expanded to include a complete set of procedures to enable forecasters to complete field measurements and use Grape Forecaster Version 5 to make forecasts (Martin et al 2001). In 2002-03 this manual was revised to allow for improvements in Grape Forecaster Version 6 and for use in the *Winegrape crop forecasting training module* project (Martin et al 2002). Members of the project team also contributed to the production of an associated Trainer's Guide produced by the training module project (Dunstone et al 2002) (Figure 4.5).

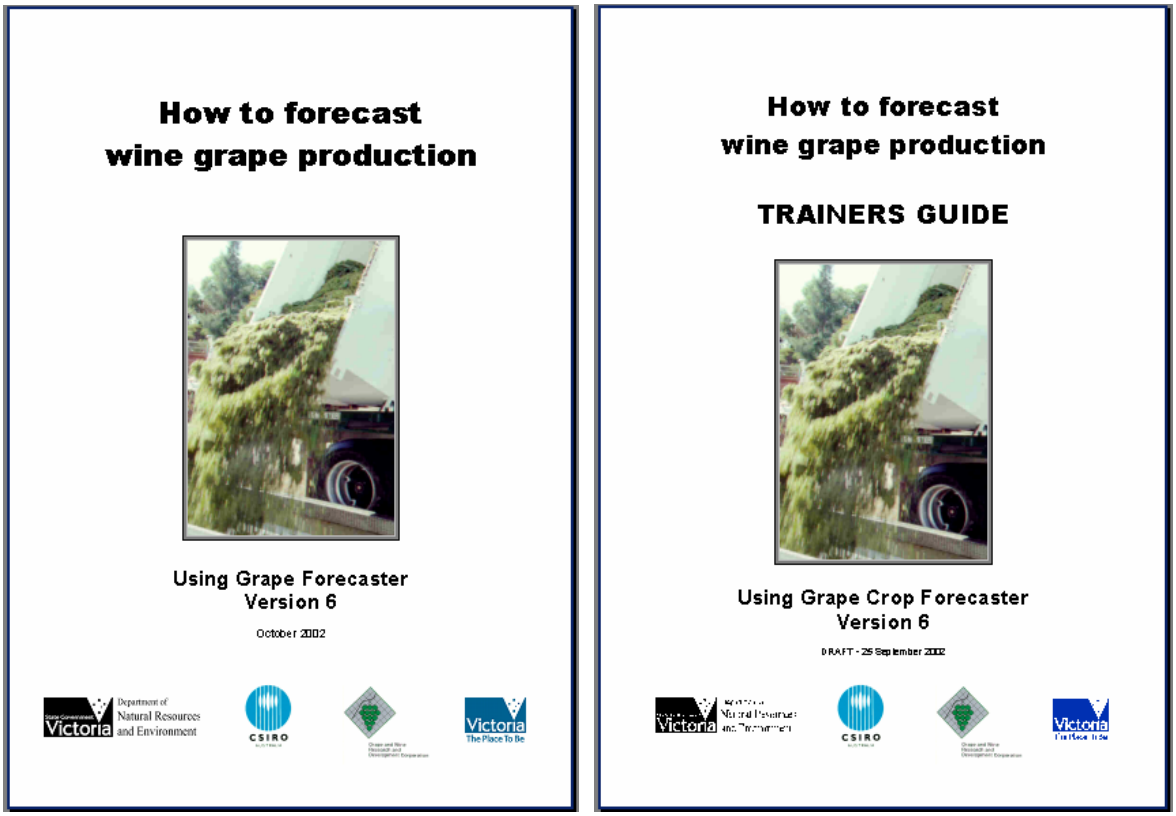



Figure 4.5. Crop forecasting manual and trainer's guide

***Development of a training course***

To promote more rapid adoption of improved crop forecasting techniques the project team was successful in securing funds from GWRDC and NRE to run an associated 12-month project called *Winegrape crop forecasting training module* during 2002-03. This project drew heavily on the products of the *Crop control for consistent supply of quality wine grapes* project. A training program consisting of four half-day workshops that had been developed during the 2000-01 and 2001-02 seasons was documented and supported by a kit of training aids and is now available for training providers to deliver. Workshops combine theory with field exercises and trainees are provided with innovative user-friendly software, also developed by the project. Training integrates best-practice adult learning principles with key outcomes derived from the research and development described above. This course is described in detail in the Final report of GWRDC Project DNR 02/02 *Winegrape Crop Forecasting Training Module* (Dunstone 2003).

***Delivery of training courses***

*2000-01*

During the 2000-01 season, the project team developed a training course and delivered it to three *grapecheque* groups and a group of growers contracted to Mildara Blass in Victoria (Table 4.4).

Table 4.4 Groups to which a crop forecasting course was delivered during 2000-01.

| Group | Vineyard | Location |
|---|---|---|
| Mildara Blass growers | Yarra Ridge | Yarra Glen |
| Yarra Valley grapecheque | Acacia Ridge | Yarra Glen |
| Perricoota grapecheque | Hunter's | Perricoota |
| Rutherglen grapecheque | Lake Modemere | Rutherglen |

The experience gained as a result of delivering these courses showed that the training approach, which combined presentation of the theory and principles of crop forecasting with practical exercises and guided experience with using paper forms to make forecasts, was effective and appropriate. However, evaluations revealed that the paper system was tedious and that an Excel workbook issued to participants was a key factor determining adoption of the system.

In general trainees were able to understand the system and use it to make accurate forecasts. For example, the group at Rutherglen made a forecast in January that predicted an unprecedented drop in the production of a patch of vines in which research had been conducted by the project team in the previous three years and in which the practical exercise was conducted in 2000-01 (Figure 4.6). This forecast was met initially with considerable disbelief, but when the actual delivery to the winery was made the forecast proved to be accurate. This experience demonstrated to the project team that a group of trainees could use the system effectively and convinced the trainees of the system's value. This reinforced the benefit of a 'hands on', 'seeing is believing' approach to training.

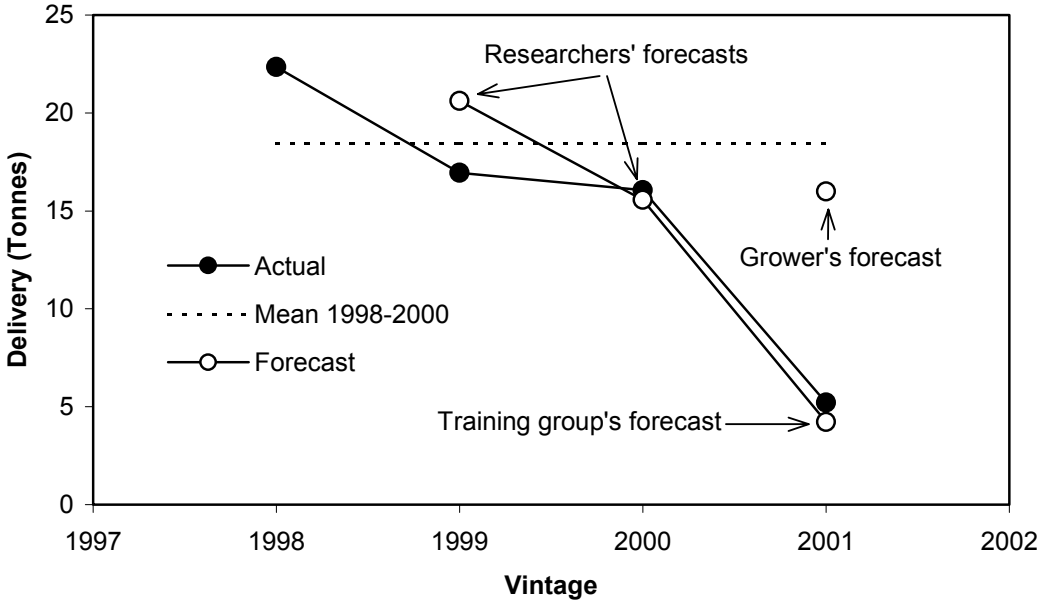



Figure 4.6. Example of how a training group used System 2 in January to forecast an unprecedented drop in the production of a block of Chardonnay in a vineyard near Rutherglen.

*2001-02*

In 2001-02 a greatly improved course, based on use of the system with Grape Forecaster Excel workbook Version 5, was delivered to Southcorp staff at Lake Cullulleraine vineyard and the Mornington Peninsula grapecheque group at Dromana Estate vineyard.

*2002-03*

In 2002-03, in association with the *Winegrape crop forecasting training module* project, two courses were developed and delivered. The first was a two-day crash course which was delivered to BRL Hardy technical staff and vineyard managers on 2-3 October 2002 at Mildura. The second was a four-half-day course which was delivered to five 'Pilot' groups at locations in New South Wales, Victoria and South Australia (Figures 4.7 and 4.8).

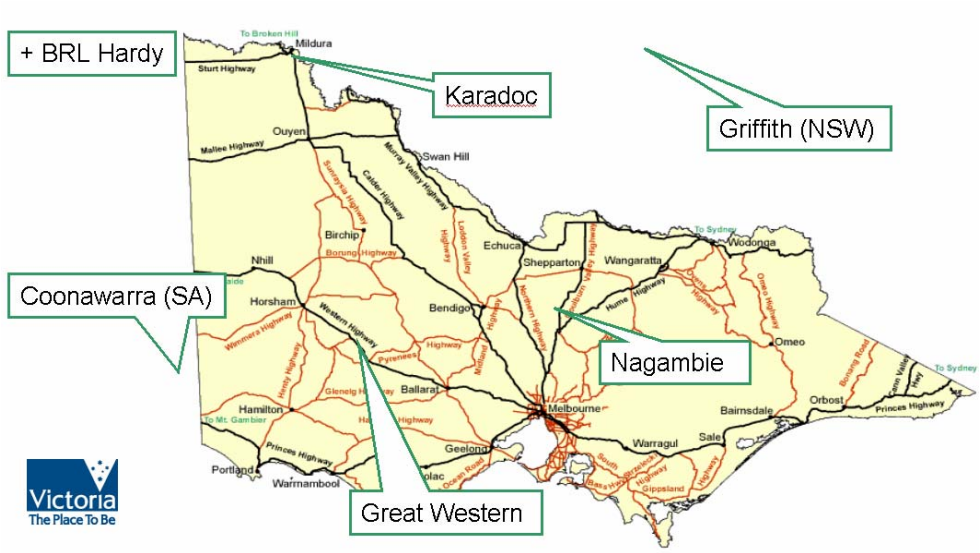
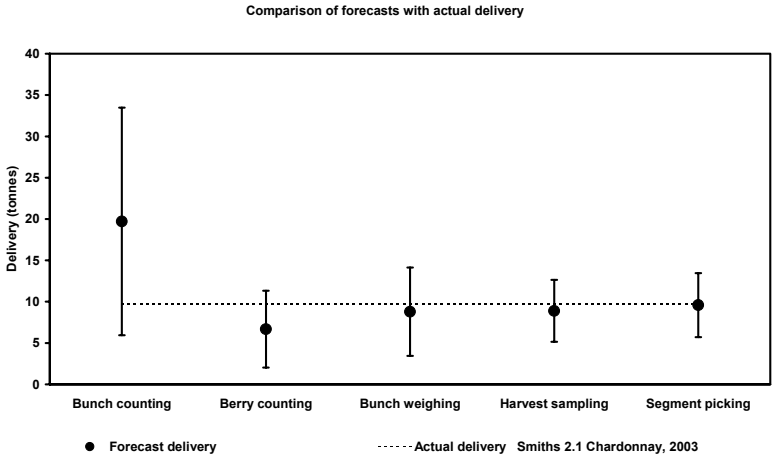



Figure 4.7. Locations of crop forecasting training groups in 2002-03.

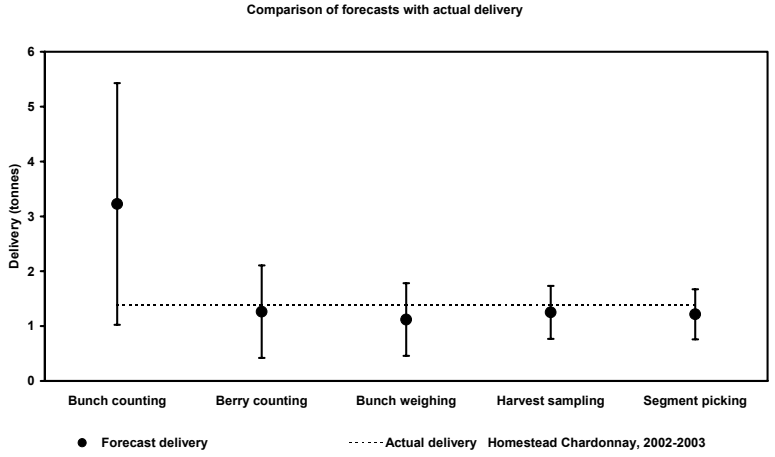


Figure 4.8. Growers doing a bunch counting exercise during a crop forecasting training course.

*Coonawarra*




*Great Western*




*Griffith*

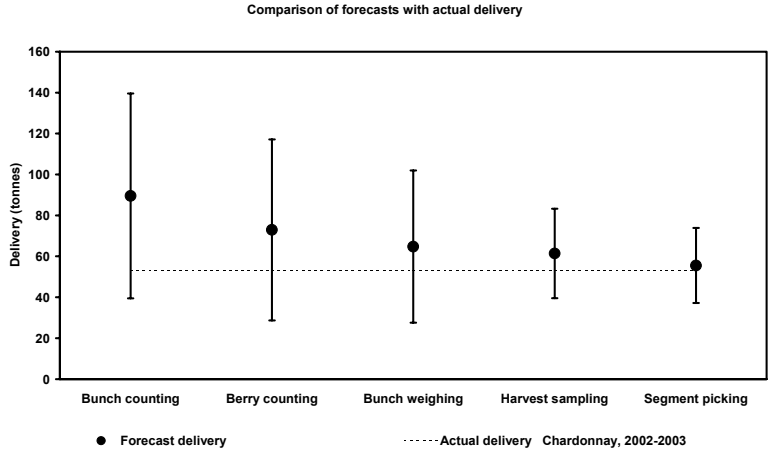
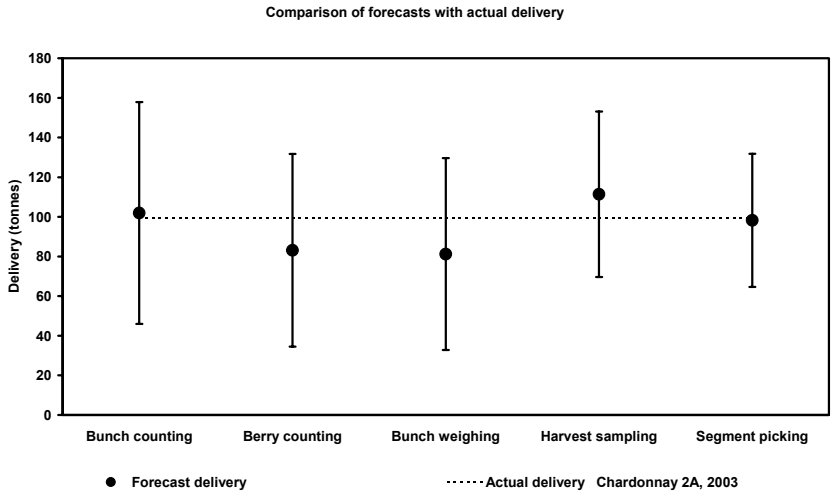


Figure 4.9. Comparison of forecasts made by training groups at Coonawarra, Great Western and Griffith in 2002-03 with actual deliveries.

*Karadoc*




*Nagambie*

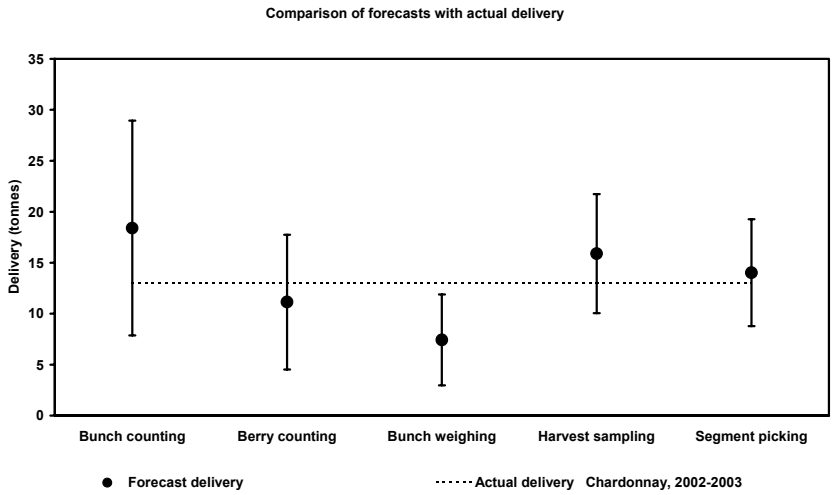



Figure 4.10. Comparison of forecasts made by training groups at Karadoc and Nagambie in 2002-03 with actual deliveries.

During the four-half-day course each group returned to the same patch of vines to sample and measure crop components and make five types of forecast. They used the Bunch counting method to make a forecast about six weeks after budburst (usually October), the Berry counting and Bunch weighing methods at the onset of veraison (January) and the Harvest sampling and Segment picking methods about a week before harvest (February – March). The exercises were all conducted in patches of Chardonnay. These patches were selected because they reached

phenological stages in advance of most patches in the region, enabling trainees to learn the system and then apply it in their own circumstance in a timely way.

There was a general tendency for groups to overestimate when they were making forecasts based on bunch counts in October (Figures 4.9 and 4.10). This was mainly due to a consistent overestimate of harvest bunch weight. The groups generally revised their forecasts downwards in January and made more accurate forecasts as harvest approached. Forecasts they made with the Segment picking method near harvest were all very accurate. This indicates that the trainees were able to use the sampling system immediately and very effectively, but their initial lack of knowledge and experience limited their accuracy at earlier stages.

***Development of database software***

The Grape Forecaster Excel workbooks were originally designed as a training aid. However, by the 2002-03 season they had been adopted as the basis for a standard system for handling data and making forecasts by two of the four large wine groups and were in widespread use throughout the industry. They were never intended as a long-term data management tool and in themselves could not fully support the continual improvement provisions of the crop forecasting system. The main problem was that one workbook file was required for each patch in each season, which resulted in folders full of a large number of files that were not linked to each other (e.g. Figure 4.11).

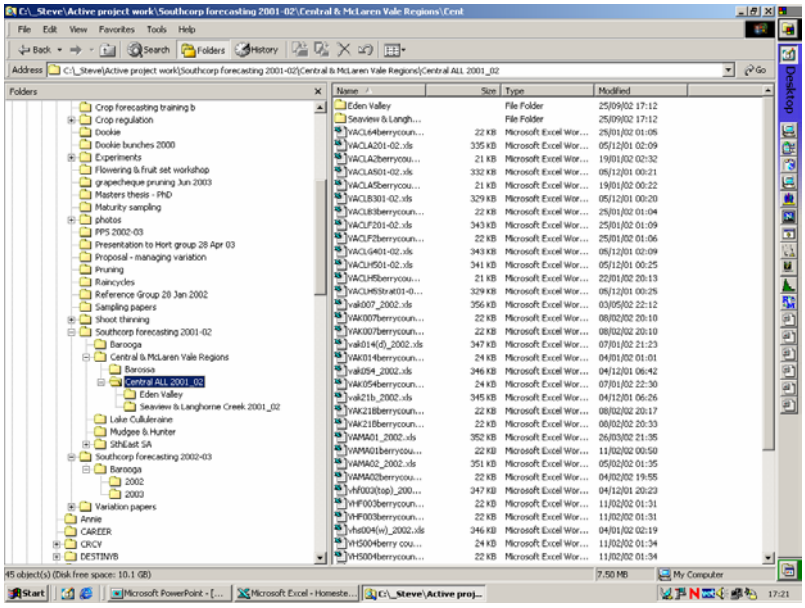


Figure 4.11. Screen image showing Excel workbook files for each patch in each season.

Consequently, as a component of the *Winegrape crop forecasting training module* project, the project team worked with a software designer to produce a customised, database version of Grape Forecaster. All data is stored in a single Access database file and the user works with a friendly Visual Basic interface (Figure 4.12). It is very flexible and powerful and includes a range of features requested by the industry. For example, it allows patches in different vineyards

to be amalgamated into one forecasting unit, which would facilitate regional forecasting. This software has since been fully commercialised. This will be the subject of a later report.

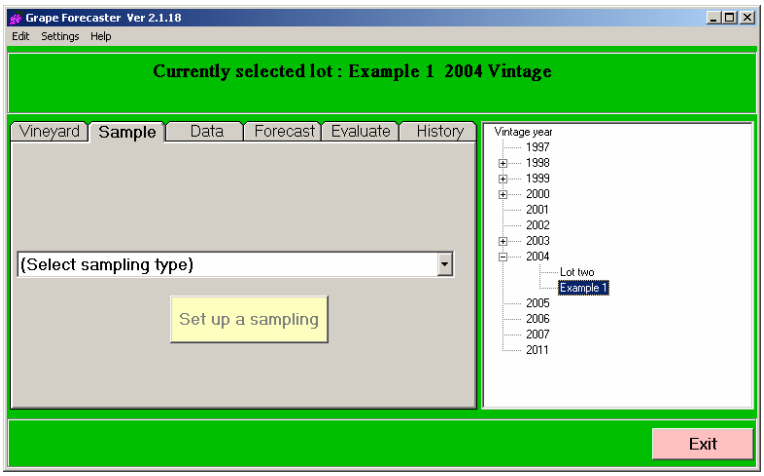



Figure 4.12. Screen image of the interface of the Grape Forecaster database software.

***Presentations to industry groups***

In addition to the training courses described above, the project team delivered audio-visual presentations and workshops to numerous groups during the life of the project. These include:

*2000-01*

Conquering the Crop Estimation Problem for Better Yield Management & Wine Quality. Presentation to Victorian Wine Industry Association, Melbourne, Victoria, 29 Aug 2000.

Forecasting wine grape crops. Presentation to Mildara-Blass Barossa Valley growers, Nuriootpa, South Australia, 1 Sept 2000.

*2001-02*

Crop estimation. Two workshops for delegates at the 11th Australian Wine Industry Technical Conference, Langhorne Creek, South Australia, 11 Oct 2001.

Variation, forecasting and control of wine grape yield. Lecture to Bachelor of Agricultural Science students, La Trobe University, Bundoora, Victoria, 16 Oct 2001.

Objective 3: Facilitate the industry adoption of reliable, robust and objective crop forecasting systems. Presentation to Industry Reference Group meeting, Tatura, Victoria, 26 Nov 2001.

Crop Forecasting. Workshop for Orlando-Wyndham technical group, Griffith, New South Wales, 13 Jun 2002.

*2002-03*

Forecasting Wine Grape Production. Presentations at two workshops convened by the Phylloxera and Grape Industry Board of South Australia, Tanunda and Coonawarra, South Australia, 28 & 29 Aug 2002.

Forecasting and regulating wine grape yield. Lecture to Bachelor of Agricultural Science students, La Trobe University, Bundoora, Victoria, 17 Oct 2002

Yield forecasting and Yield regulation. Presentation to Southcorp viticultural staff and managers, Coonawarra, South Australia, 7 Nov 2002.

Forecasting grape deliveries - How accurate can it get? Presentation to Hardy Wines Annual Technical Conference, Wilpena Pound, South Australia, 2 Jun 2003.

### *Publications*

For publications related to crop forecasting see the list of publications elsewhere in this report.

### *Evaluation*

Formal evaluations of the attitudes of course trainees to the crop forecasting system, supporting software and materials and the training courses were conducted at the concluding sessions of the courses outlined above in all three seasons covered by the project. Results from a formal evaluation of the five Pilot groups in June 2003 are detailed in Appendix 4.

By and large participants were very happy with both the training and 'the system'. However, some concerns that they shared can be summarised as follows:

- The time required and costs involved to collect data were seen as potential barriers to adoption.
- There was a lack of information for growers on the cost/benefits of improved forecasting.
- Participants felt that there was a lack of incentive for growers to 'get their forecasts right'.
- Participants felt that there was a lack of support from wineries for better forecasting and that there may be a lack of technical support for 'the system' and the new software.

The evaluation feedback has been and will continue to be used to improve the system, software, manual and training module where possible.

### *Conclusions*

At the beginning of this project in July 2000, a system had been developed that had the potential to improve the accuracy of forecasts throughout the industry. If adopted, there was a potential for the industry to reap benefits worth hundreds of millions of dollars. However, while there was an awareness of this potential in the industry, use of the system was not widespread. By June 2003, the system developed by the project team was in use on the company vineyards of two of the largest four wine companies in Australia and in widespread use throughout the rest of the

industry. This increase in adoption is directly attributable to the efforts of the project team and its supporters in the industry.

An integrated package consisting of a manual of procedures, software and training can now be delivered by providers of training and other services to the industry. Further developments since June 2003 will be the subject of later reports.

Work is already underway to address some of the barriers to adoption that remain, particularly those related to sampling and time-cost issues, in the GWRDC project *Regulating yield to improve wine quality and reduce industry costs*. An objective of this project is to support the delivery of the Crop Forecasting Training Module by training providers and another is to investigate new technologies to predict yields. Some of the barriers to adoption can be addressed by the project team and some have been and are being addressed in related GWRDC-funded projects, but others will need to be considered by the industry more broadly.

There is an opportunity to undertake further work to ensure that the crop forecasting training achieves widespread adoption throughout the Australian wine industry. How this further work is resourced will need to be identified. As a participant from the Karadoc group said,

"It would be a real shame if it dropped off now. If it drops off now after all the work that's been put into it, it would be a shame for the industry. There've been starting points before but this is a really positive starting point. I hope funding bodies recognise the importance of it. No matter where it goes from here it's a really positive starting point but it needs to move in some direction and be followed up. If there's no follow up then people who are still sceptical won't take it on but once a few other growers get to know about it and find its great and tell others about it and more people know about it then there will be a need for more training later on".

***Recommendations***

These recommendations are largely derived from the results of the evaluation described in Appendix 4 and identify actions to ensure that adoption of the crop forecasting system continues to increase throughout the Australian wine industry.

*Continue to improve the training module*

- Include the opportunity to practice with computers during the training sessions
- Include more time for discussion in the training (especially implications for individual businesses)
- Introduce an additional session to be done prior to commencing the training on how to set up the system for your vineyard
- Undertake cost-benefit analyses and case studies to demonstrate the benefits of adopting the system to growers
- Include more historic data in the manual

*Provide on-going support to crop forecasting trainees (post-course)*

- Develop a strategy for and resource the provision of further support, information and training on new advances in the crop forecasting system to participants post-workshop

*Continue to encourage widespread adoption of the system by the industry*

- Investigate opportunities for cost-sharing arrangements between wineries and growers and improvements to data collection
- Encourage wineries to provide incentives to growers who use the system to improve their forecasts
- Educate winemakers about what the system involves to lead to more realistic expectations and improved relationships between wineries and growers
- Develop a system of industry-wide data collection and management
- Develop further sampling innovations to simplify and improve the speed of data collection
- Investigate the feasibility of incorporating the crop forecasting system into a total vineyard management software program

*Recommendations for further work identified by project staff*

- Undertake quantitative evaluation with workshop participants
- Survey participants who did not complete the training to discover why they did not
- Update the manual to reflect advances in the software
- Provide Pilot group participants with a report of the evaluation
- Ask Pilot group participants to be advocates for the crop forecasting system and training
- Publicise evaluation results to the wine industry
- Investigate different models for, identify and implement an effective process to ensure the continued linkages between the R&D and extension aspects of the crop forecasting system and training
- Investigate options to enable the crop forecasting training module to become 'self-funding'
- Investigate commercialisation options for and export of the crop forecasting system and training module

In response to these concerns the project team will continue to focus on facilitating relationship changes and developing technology to promote more rapid uptake of the crop forecasting system. This will be based on present and continuing evaluations and a commitment to continual improvement.

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**Appendix 4a. Evaluation of Winegrape Crop Forecasting Training 2002-03**

Extract of a Report Prepared by Cynthia Mahoney, Department of Primary Industries, Box Hill, July 2003

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*Executive Summary*

The Winegrape Crop Forecasting Training Module was developed as a result of two large, national, collaborative projects funded by the GWRDC, the Victorian government and the CSIRO. The Winegrape Crop Forecasting Training Module has incorporated products from this research to develop a user-friendly, crop forecasting software package which is supported by a manual and four 'hands-on' training sessions. Five groups piloted the training module in the 2001-02 season. The final training session included an evaluation component, the results of which are documented in this report. The feedback from these groups is being used to further refine the existing training module and develop it into a standard training package that can be delivered by accredited training providers to wine industry personnel throughout Australia.

The Winegrape Crop Forecasting module successfully trained the participants from five pilot groups in crop forecasting. The five pilot groups had a positive training experience and the crop forecasting system was regarded favourably by most participants. Barriers to adoption were identified and suggestions for improvement were made (see Section 6. Recommendations), some of which are within the sphere of control of the training project, some which are being addressed in related GWRDC-funded research projects and others which will need to be considered by the industry more broadly.

The evaluation feedback will be used to improve the training module where possible and a report will be provided to GWRDC by the end of the year. As mentioned above work is already underway which will address some of the barriers to adoption particularly those related to sampling and time required, in a three-year project on yield regulation (2003-2005). Part of this project will include investigations into new technologies to predict yields.

There is an opportunity to undertake further work to ensure that the crop forecasting training achieves widespread adoption throughout the Australian wine industry. How this further work is resourced will need to be identified.

*Note*

Appendices referred to in this Appendix have been omitted. The original appendices to this appended report are available from the project team on request.

*1. Background*

The Winegrape Crop Forecasting Training Module was developed as a result of two large, national, collaborative projects funded by the GWRDC, the Victorian government and the CSIRO. These projects were:

- *Crop Development, Crop Estimation and Crop Control to Secure Quality and Production of Major Wine Grape Varieties: A National Approach* (1997 - 2000) and
- *Crop Control for Consistent Supply of Quality Wine Grapes* (2000 - 2003)

The above research projects resulted in the development of the following research and development products:

- a measurement-based crop forecasting system
- an Excel workbook
- a manual - *How to forecast winegrape production*
- a model for a training course
- the delivery of training

The Winegrape Crop Forecasting Training Module has incorporated these products to develop a user-friendly, crop forecasting software package which is supported by a manual and four 'hands-on' training sessions (Refer Appendix 1 for Training Session Outline).

Five groups piloted the training module in the 2001-02 season. The groups were located at Coonawarra, Great Western, Nagambie, Karadoc and Griffith. The final training session included an evaluation component, the results of which are documented in this report. The feedback from these groups is being used to further refine the existing training module and develop it into a standard training package that can be delivered by accredited training providers to wine industry personnel throughout Australia.

*2. Project aims and performance targets*

The Training Module project has three objectives:

1. To develop a Wine Grape Crop Forecasting Training Module that can be delivered by accredited training providers to wine industry personnel throughout Australia.
2. To develop high quality PC software and an interactive Web site to support wine grape crop forecasting.
3. To test the delivery of the training course and software by June 2003.

This document reports on the third objective, the evaluation component.

| **Outputs** | **Performance Targets** |
|---|---|
| 8. Evaluations of outputs by trainers and clients | Evaluations completed after each round of workshops<br>Results of evaluations documented by June 2003 |

*3. Method*

For the evaluation sessions, Edward De Bono's (1985) Six Thinking Hats technique was used to obtain feedback on the training module from each one of the five pilot groups. This method was chosen as it facilitates thinking from a variety of perspectives – each "Thinking Hat" represents a different style of thinking. It can be used to help solve problems and examine issues. Participants "put on" one hat at a time and focus on examining an issue from that point of view.

The six hats are:

| | |
|---|---|
| Blue | The process hat – what processes should we use to discuss this? What order shall we use the hats? How is everyone going with the process? |
| White | The information hat – What information do we have? What information do we need? What information is missing? |
| Yellow | The optimistic hat – What is good about this? What are the benefits? Who is going to benefit? |
| Black | The cautious hat – what are the negatives here? What are the obstacles? What might stop this from working? What hasn't been thought about? |
| Red | The feeling hat – How are we feeling now? What are out gut feelings, intuition or instincts (no need to justify feelings with logic) |
| Green | The creative hat – What are the possibilities, new ideas and alternatives? How can we overcome obstacles? |

The Blue Hat is the process hat which involves the management of the process (so is worn only by the facilitator). It was decided not to use the White Hat as the session prior to the evaluation involved a review of the three previous sessions which highlighted what information had been provided to participants.

The Six Hats session aimed to:

- Obtain participants' feedback on the positive and negative aspects of the training module (including barriers to adoption)
- Gauge the reactions of participants to the training module
- Encourage participants to identify ideas for improvement to the training module

Two aspects of the training module were evaluated:

- the crop forecasting system (ie the forecasting methodology, Excel workbook and manual)
- the training course (ie the four training sessions attended)

Participants were broken up into two groups with one being asked to discuss the crop forecasting system and the other being asked to discuss the training course whilst wearing the yellow and then the black hats. Each group reported back to the main group at the end of their discussion and participants in the other group were given the opportunity to add any new ideas.

The group was then asked to think about their reaction to the crop forecasting system and write it down on a piece of paper. Each participant was then asked to share their thoughts with the group.

Finally the group was broken into two again and asked to discuss improvements that they could identify that would make the system (forecasting methodology, training sessions, Excel workbook and manual) easier for others to use.

The Six Hats session was followed up by two "Decisional" questions from the Institute of Cultural Affairs Focussed Conversation Method (Stanfield, 1997).

The focussed conversation method uses questions at four levels:

1. The objective level – questions about facts
2. The reflective level – questions to call forth immediate personal reaction to the data, an internal response
3. The interpretive level – questions to draw out meaning, values, significance and implications
4. The decisional level – questions to elicit resolution, bring the conversation to a close and enable the group to make a resolve about the future

Two decisional questions were added to the end of the Six Hats session. One was asked to ascertain how the participants intended to change their behaviour as a result of attending the training and to enable participants to verbalise this. The other was asked to obtain feedback on what support participants believed they needed after completing the training course to enable them to continue to use the system.

The questions were:

1. Based on your experiences during this training course and what you have learnt about crop forecasting, what will you do differently next season than you would have if you had not attended this course?
2. Given that this has been your last training session and you will be leaving here to do your own forecasts for next season, what follow-up (if any) would help you to apply more effectively what you have learnt?

After experience with the first session, it was decided to tape the remaining four sessions to ensure thorough data recording. Permission was gained from each group to do this.

The running sheet for the Evaluation Workshop is contained in Appendix 2.

*4. Results and discussion*

The results below are qualitative data and are based on comments made by the participants at the five workshops. They have not been quantified and are **not** listed in order of importance.

The responses to the questions asked during each Thinking Hat session were grouped into similar ideas. Each group was assigned a heading summarising the individual responses and these headings were listed in point form (refer to Appendix 3 for the specific comments made by participants relating to each point). To highlight different perspectives, shaded boxes containing some key quotes made by individual participants are also included.

The responses to the decisional question about what follow-up participants required after leaving the workshop has been incorporated into Section 4.4. New ideas or opportunities for improvement (the Green Hat).

Responses to the decisional question which asked what participants were going to do differently after attending the training are not contained in the results section but can be found in Appendices 3 and 4. The purpose of this question was to bring the workshop conversation to a close and to enable participants to make a resolve about the future in applying what they had learnt from the course to their own situation.

Appendix 3 contains results from all five workshops which were grouped into major categories and detail all the different suggestions and feedback provided by participants. This report has concentrated on identifying the common themes raised across the five groups. It should be noted however that, whilst many of the points raised were similar between the five groups, each group had its own characteristics. Appendix 4 contains each workshop's own evaluation report.

*4.1. Positive aspects of the training module – what the participants liked (the Yellow Hat)*

The questions asked for the Yellow Hat were:

- *What was good about the training module (ie the training course and the crop forecasting system)?*
- *What did you like about it? What appealed to you? What worked well?*
- *Who in the industry benefits from improved crop forecasting and how do they benefit?*

Positive comments were received about the group training aspect and inclusion of practical sessions. Participants found the manual and Excel workbook to be comprehensive, user-friendly and useful and thought that the information was interesting and well explained by the presenters. They thought the industry data from different regions that was included as a reference in the manual was very useful. They also liked the fact that the system formalised data sampling procedures.

*4.1.1. Training sessions*

- Group training was beneficial as it resulted in opportunities to network and share information
- Inclusion of practical vineyard exercises in training sessions were valued as participants could reinforce theory and practise techniques
- Training and information were well presented by the project staff
- Information was well set-out, easy to follow, user-friendly, logical
- Logistics were well co-ordinated and organised
- Training session structure suited participants eg four sessions mirroring the season
- Training resulted in learnings including crop forecasting, randomising, harvest efficiency, sampling
- Opportunity to enter results from the vineyard exercise at the training session was valued and built participants' confidence in the system

***"Because there were people coming to the workshops from a number of areas there was a lot of talking and networking going on so we were able to find out what was happening in the Yarra Valley or wherever which was quite useful."***

***"Good - four sessions and tied to season (practical) was a great advantage – going out and seeing it in the field rather than looking at photos on a board."***

*"I'm a hands-on person so getting out into the field was good and getting the idea of measuring the offset – I couldn't understand it in the class but got it when we went out into the field."*

***"People learnt about crop forecasting in the end and thought much more about all the components of it that all of us wouldn't normally think of."***

*"Learnt about harvest efficiency so how much you lose during harvest, a few guys commented that we knew we lost a bit but had not quantified it before or thought about it so much"*

*"Forecasts laid out that can be faxed to a winery and you were able to respond quickly."*

*"Was useful to let you know that you had higher yields than you were really looking for earlier in the season so you had the opportunity to take some yield off."*

*4.1.2. Manual*

- Comprehensive reference ie no need for notes during the session, self-explanatory
- Practical, easy-to-follow and understand
- Well set-out
- Inclusion of industry area information and historic data was valuable
- Information in the folders mirrored that structure of the training session

*"Things were well defined (in the folder) – took out all the guesswork."*

*"It's not too technically written so this helps growers coming in who aren't really with it."*

*"If you had to explain it to someone else it (the manual) made it a lot easier.'"*

*"It was set out well, sections were good, was easy to flick through and find the bits that you wanted – all the information was in there."*

*"The folder was useful if you wanted to do it manually, for those who didn't have the excel spreadsheet."*

*"There was also getting the winery to understand what doubt was - that an average is not just one number but that there's an degree of doubt associated with that so if you put in an estimate of 10 tonnes minus four a winery won't know what you're on about but there is information in that manual so that you can explain when you talk to the winery about what doubt meant."*

*4.1.3. Excel Workbook*

- Print out for random selection was a highly valued feature of the system
- Self-calculating formulae and statistical analysis were other valued features
- User-friendly
- All the data is in one file which assists with data management – can use as a database
- Comprehensive
- Enabled easy experimentation with different scenarios and variables
- Assisted with training staff members
- Unique program that fulfils an industry need
- Enabled data, results, charts to be easily viewed
- Had indirect benefits such as using for yield management

***"The stand out item was the print out for the random selection particularly by indicating the variability within the block – because that became obvious, once you did the print out and then you went out and did the counts or selecting the berries for weighing you could see for yourself whether your block was variable or how much variability was within your block. Leads you to ask questions about why things happen."***

*"I noticed variance in my patch that I hadn't seen before ie from one end to the other. I looked at the figures and noticed that bunch counts were higher at one end consistently."*

*"User-friendly as long as you knew how to get around an Excel spreadsheet."*

***"You put the info in and it punches out the statistics for you so you don't have to have any real 'smarts' with statistics is a huge benefit because very few people would be able to do that themselves***

***so gives you a lot of information in the background that you wouldn't be able to do yourself."***

*"Does calculations for you – this is different to other systems I know of from talking with other growers."*

*"A good means for recording data instead of having it on different bits of paper, it was all there."*

*"Can also experiment and see how variations impact on final yield."*

*"New program looks good and both the spreadsheet and the new software are good because there's nothing else around like this so its good the industry has this. It fulfils a need. There's no other program currently for this so its good to have something."*

*"The whole thing is fairly significant piece of work to get all this together in one package and the benefits of that are fairly far reaching for an integrated package."*

*4.1.4. Who in the industry benefits from improved crop forecasting and how?*

Participants were asked a question about who in the wine industry they perceived benefited from improved crop forecasting and how they benefited. The general consensus was that wineries were the greatest beneficiaries of improved crop forecasting although a number of benefits for growers were also identified.

Growers in the Coonawarra and Great Western groups particularly were very aware of some companies tightening up their contract system so that suppliers cannot exceed their contracted amount. If yields exceed the contracted amount the winery may still take the fruit but will not pay for it. These growers were highly aware of the need to more accurately predict yields so that they have the opportunity to reduce yields or make alternative arrangements for excess fruit in a timely manner. They also felt disempowered in their relationship with wineries, particularly multinational companies. They thought that, although there needed to be support for growers from wineries through cost-sharing arrangements, incentives or rewards, they were not in a strong negotiating position. The groups strongly doubted that multinationals and big wineries would support growers to make more accurate forecasts. They also did not feel confident that wineries would accept growers providing their forecasts with the "degrees of doubt" (eg a forecast of 50 tonnes +/- 10 tonnes) that this crop forecasting system promotes.

Benefits of more accurate forecasting were identified for both large and small wineries – winemakers, intake co-ordination and winery staff. These included increasing efficiency of production and making cost savings through improved harvest logistics, placement of fruit, better targeting of labour and improved management of storage capacity. The financial returns from these efficiency gains and savings were recognised by growers as being very

significant to wineries which explains grower frustration with there being no cost-sharing with or incentive or reward from the wineries for them in investing in improved crop forecasting whilst bearing all the costs.

Although the perception of growers was that the wineries had the most to gain from improved crop forecasting whilst not contributing to the costs, they also identified a number of benefits to themselves.

These were:

- Improved reputation and credibility with the winery (perhaps becoming a preferred supplier because of their accuracy)
- Fulfilment of winery delivery specifications eg ensuring growers supply their contracted amount and are able to make arrangements for excess fruit in advance
- More accurate budgets and costings
- Enables big trends to be flagged (eg this year if you went with averages you would have been way out)
- Empowerment and knowledge – ability to do own crop forecasting and provide to winery instead of using a consultant
- Indirect benefits eg getting out into the vineyard a couple of times more each year to undertake measurements and being in a position to notice things like disease at important stages such as veraison and flowering
- Crop forecasting system can also be used as a management tool (eg regulate the crop for yield and quality) and as a data management system

***"What's the incentive for a grower to get it (crop forecasting) right? If you predict 25t and you deliver 25t you still get paid for 25t."***

*"It benefits growers in that we develop higher credibility with the winery but other than that it doesn't benefit us."*

*"You can only go 2t over your contract with Southcorp and if you get 5t/ha instead of 4t then you're talking hundreds of tonnes and Southcorp will take your extra grapes but they won't pay for them so they're making thousands of dollars from you. So its very worth doing accurate forecasts so you can plan what to do if you look like exceeding your contract."*

*"I guess the risk is can we afford not to do it? I think the wineries will get to a point where they'll say unless you can give us an accurate forecast well we're not going to… (take your grapes)."*

*"Benefits of the system are much greater for wineries than for growers and if you were going to apply to general growers you would have to point out very early on to them what their benefits were and how it related to their bottom-line."*

***"This is also something that's a little bit left field but there are almost some intangible benefits like getting out into the vineyard a couple of times more each year – and you're in there quite specifically and you might notice things like disease."***

*"I think it's the same principle as monitoring – you can't really afford not to do it even though it's a cost."*

*"Grower needs to have a good idea of what the crop the vineyard is carrying and how to regulate that crop – if you're trying to achieve certain quality goals, you need to know where you're at early in the season and that way if you are planning to bunch thin if you're not going to achieve a certain yield you can't afford to do that."*

### *4.2. Negatives - where participants thought the system could be improved (the Black Hat)*

The questions asked for the Black Hat were:

- *What didn't you like about the training module (ie the training course and the crop forecasting system)?*
- *What were the negatives? What didn't work for you?*
- *What will stop the crop forecasting system being adopted by the industry? What are some of the barriers?*

There were some conflicting opinions about what participants didn't like about the training module. For example some thought the explanations of the statistical theory went into too much detail at times, others thought that the pace of the course was too fast at times. There were other comments received that four sessions were a good number and that half a day was just right (or that it would be even better if it could be shorter) whilst others wanted to include more time for personalised discussion and opportunities to practice on computers.

Many of the things the participants didn't like about the software have been improved already, such as the reliance on Excel. The software has been further developed as part of the project and is now a stand-alone software package with more user-friendly features such as enabling information from different patches to be stored in the one program.

Ideas for improving the training module and for overcoming barriers to adoption are contained in

Section 4.4. New Ideas or opportunities for improvement (the Green Hat).

*4.2.1. Manual/Excel workbook*

- Needed to be computer literate to operate the system
- Workbook is Excel-based so hard to operate for those unfamiliar with or without Excel
- Sampling and measuring – too much work required & hard to ensure the accuracy of those undertaking the sampling
- Variation and doubt – after all the work there can still be a lot of doubt if the patch being sampled is variable – therefore hard to demonstrate benefits to growers of changing from their existing crop forecasting method
- Lack of historic data for each region in the folder (what is there is useful but it needs to be more extensive)
- Accurate information is required to set up the system effectively (eg vine spacing, vine numbers) – otherwise rubbish in, rubbish out!
- Complexity of the system (workbook and manual) is daunting

*"(I had) trouble setting up vineyard information initially – I don't know my way around Excel at all. I had trouble initially getting the whole thing up and running on my computer."*

*"People who hadn't been trained in Excel had a lot of difficulty getting up to speed with using that."*

*"Someone else didn't have Excel so couldn't use the spreadsheet – so it was all based on the spreadsheet there was nothing in the book so they could do it manually – there weren't a set of random numbers or anything like that in the book so they could do it manually."*

***"The berry counting and actual bunch counting were the difficulties – in training staff how to do it. This took up time and took up manager's time and vineyard staff's time where they could be doing something else so this is a cost."***

*"Frustration – you could still be 25-30% out even with all that work. I expected that after all this work we'd be right – if history is variable also things will always be variable – although if you know a patch is variable you can focus your management on that bit."*

*"Set-up requires good information on vine spacing and number ie requires accurate survey data prior to set-up."*

*"Hard to set up workbooks for every patch – tricky, complicated, cumbersome."*

*4.1.2. Training course*

- Start time of 9am was too early for some growers who had to travel
- Training could be streamlined – sometimes went into too much unnecessary detail for some participants
- Pace of the training was too fast for some participants
- There was no time included to allow individuals to discuss and explore their own results during the session
- The timing of some training sessions clashed with busy times on the vineyard for some participants
- Finding suitable equipment was difficult for some participants eg scales and the sampling equipment was difficult to use eg ropes for counting
- Time was not allocated during the session to practice with computers
- Some participants expressed a concern about sessions containing growers from both Phylloxera and Phylloxera-free areas
- There was a lack of local historic data which assists with making predictions about bunch weights etc.
- The system was too time consuming especially with regards to measuring and counting data

*"Some delivery above some people's mathematical knowledge re principles vs practice."*

*"Not enough time to do personal work – people had bought their personal information along but there was no time to look at this."*

*"The timing of it is hard – have to do it in vintage but it is hard to take half a day off so you wouldn't want it to be more than half a day – would probably be better if it was less."*

*"Finding suitable equipment was difficult – getting scales out of the kitchen, finding a quadrant and those sorts of things."*

*"Not having hardware and software on hand to practice."*

*"Lack of historic information about what bunch weights to expect – didn't have much to go on."*

*"Very time consuming to do sampling particularly for owner-operators."*

*"Level of detailed measuring required in real vineyard practice. The fact that there's so much measuring and counting and in practical terms how you do this – that's a fair obstacle."*

*4.1.3. Barriers identified to the adoption of the crop forecasting system*

As part of the Black Hat session, participants were asked to consider the barriers to the crop forecasting system being taken up by the industry based on their experience of participating in the training and using the software and manual.

The main barriers were:

- Time required – collection of data (eg berry counting) and inputting data into the computer
- Costs involved – putting on extra resources to collect data as well as the opportunity costs of existing labour being taken away from another job
- Lack of data on cost-benefit to growers (growers not convinced of the benefits to their bottom line of implementing the system)
- Lack of support for growers from wine companies (when growers see that the companies are the major beneficiaries of improved forecasting)
- No incentives to growers for getting forecasts right
- Computer knowledge required
- Complexity (of the system)
- Doubts about accuracy – a grower can put a lot of effort and still not be accurate – especially when (its perceived by some) that visual forecasts are no less accurate. One quote was, "With this model – there are still so many estimates you put in, best guesses, which still leaves you with a big fudge factor and you say is the value of it really there?"
- Concerns about the value of the system to a smaller grower
- Understanding (or lack thereof) of statistics
- Limited support for people going through the system. If they experience a problem that they can't work out themselves there isn't the back-up support to assist them eg a helpline

*4.3. Reactions (the Red Hat)*

The questions asked for the Red Hat were:

> *- What is your gut reaction to the training module? Having been through it how do you feel about it? There's no need to justify what you feel – its just how you react. Some examples may be excited, cautious, overwhelmed, positive etc.*

The reactions included variations on the main themes of positive, mixed and overwhelmed. The points below are direct quotes from participants at the five workshops.

*4.3.i. Positive*

- Very likely I'd use it again to verify gut
- It seems to work
- Thing that impressed me is that we've never taken enough samples and we've never had random sampling
- Random selection process in the computer is good. It works eg in patches with no vines. It works.
- Maturity sampling was random and it worked
- Feel comfortable with random sampling at the end of the course

- Definitely not a waste of time – the bit of how we feel about it – I'm here for you to deliver information to me – I think the course is great and I see a direct benefit from this
- Very organised and straightforward and consistent
- Positive and excited after initially being confused
- Very positive that this can work very well
- Positive particularly with the new software and branch number info coming
- Positive, eager to learn more, look forward to the database - if they get it going it will be beneficial to larger and smaller growers, beneficial
- All too hard, overwhelmed at first and confused. Generally feeling a bit more confident after each session. Looking forward to implementing it this season – I think confident. From being totally overwhelmed initially to being more positive and confident about crop forecasting.
- Optimistic
- Enthusiastic. Definitely worthwhile
- Positive – looking forward to collecting data and putting it into use next season. General out look – excited
- Confused at first, now satisfied
- Looking forward to using this year's data for next vintage and putting it into practice and knowing how it works now will be much faster and more streamlined this year. Should be good getting more growers to use it

*4.3.ii. Mixed*

- Confused, excited, frustrated, OK – almost convinced, satisfied
- Positive. Oh no, look at the work. Worthwhile in some things. How can I streamline this?
- Confused but at the end of the course determined - had doubts about it at the start but once I went home and looked at it and used it a bit now I'm pretty determined to make it work
- Had some doubts at first but after doing first couple of sessions then quite positive. Still doubtful that our whole area of growers will take it up, but we need a (crop forecasting) program and the industry doesn't have one so good starting point. In the end positive but having doubts about all the growers would take up the system
- Very positive with stats background and excel useability. Very versatile for research. Sill not convinced the work is worth the result. Overall very positive direction for information
- Very good for our viticulture business. Technically good but a lot of work/time/resource for inaccurate predictions
- Excited with the possibility of what could be achieved with the system. Overwhelmed by the theoretical concepts and the complexity of the system. Very positive about the system. Enlightened
- Positive but concerned that the industry is not able to totally commit themselves. Convinced of concept myself but concerned that the industry not able to commit themselves
- Definitely worthwhile, frustrated, confused but in the end happy that people doing it

*4.3.iii. Confused*

- A bit of confusion over randomness of sample

*4.3.iv. Overwhelmed*

- totally overwhelmed

- needs streamlining – feel positive about it but also overwhelmed
- needs simplification
- pretty daunting
- needs simplifying – I feel the idea will work, it's a good idea but needs to be simplified down and tuned for different operators
- overwhelmed
- Overwhelmed – Oh no I have to do all that counting. Finding time to enter all the info into the computer may be difficult. Will be very happy with an accurate forecast in the end – one reaction now is overwhelmed

*4.3.v. Unconvinced*

- Around veraison and to see +/acre not going over what the winery wants. If I can see that we'll be over I can make sure that we're not over
- Response I got when I said 20t +/- 50% aspect of it – when dealing with major wine companies they're not interested in it

*4.3.vi. Frustrated*

- The main thing is the variation in the results that you get – that's pretty frustrating – you can be way up or way down
- Frustrated – that harvest sampling and segment picking couldn't be done due to time and too busy

*4.3.vii. Disappointed*

- Like its technical excellence but disappointed with the accuracy and the work that's required to come up with that result – disappointed at the accuracy but like the system I think technically its very good

*4.3.viii. Challenged*

- challenging! (to get our growers to do it), difficult to sell to growers, needs to be more streamlined, huge TIME factor

*4.3.ix. Cautious*

*4.4. New ideas or opportunities for improvement (the Green Hat)*

The questions asked for the Green Hat were:

- *What are the possibilities, new ideas and alternatives that would improve the training sessions and crop forecasting system?*
- *What are your left field ideas that would benefit the project?*
- *How can we overcome some of the barriers to adoption?*

New ideas to improve the system were many and varied. Some have already been picked up as part of the training module project (such as suggestions of the system not being dependent on Excel). Others will be passed onto other related GWRDC-funded research projects including the new three- year project on yield regulation (2003-2005) which includes investigations into new technologies to predict yields. Some ideas participants raised highlight gaps or opportunities for

further work that are beyond the scope of the training module project but that will need to be addressed by the industry if the crop forecasting system is to achieve widespread adoption in the Australian wine industry.

The ideas for improvement included:

- to overcome computer literacy issues and time involved in entering data, growers suggested that:
  - wineries could manage the system so growers send their data to the winery for analysis (that way the winery could also collect historic data on bunch weights etc)
  - in the same way that the industry has contract harvesters, there could also be contract yield estimators
- participants wanted to be kept up-to-date with software advances and research developments eg bunch-branch counting technique
- participants suggested investing in research to help streamline the system to save time and also to increase the accuracy of the system
- there was also a demand for regional data collection and management
- growers thought that wineries' awareness of the forecasting system needed to be increased and that their expectations of forecasting accuracy needed to be more realistic - this would help with improving relationships between growers and wineries

For the following results section, the major recommendation being made is presented as the heading (in bold and italics). Underneath is the issue the recommendation seeks to address followed by the general idea for improvement and then finally the range of specific suggestions made by participants during the evaluation session. It will be the Training Module Project Manager's decision as to which suggestions will be incorporated into the project.

*4.4.1. Ideas for the training project*

***4.4.1.i. Include the opportunity to practice with computers during the training sessions.***
**Issue:** The training currently consists of four training sessions involving theory and practical vineyard exercises but practising on the computer with a trainer present is not part of the course.
**Improvement opportunity:** Provide participants with the opportunity to practice on computers during the sessions.
**Specific suggestions:**

- Have computers to practice on during the session.
- Introduce an optional session in the afternoon for participants who want to practice the software with a trainer present.

***4.4.1.ii. Include more time for discussion into the training (especially implications for individual businesses).***
**Issue:** Participants identified that there is currently no opportunity within the existing training sessions to discuss implications of what they have learnt for their own situation
**Improvement opportunity:** Either add time within the existing training for more discussion or add an optional afternoon session to give those interested the opportunity to discuss their own results.
**Specific suggestions:**

- Include optional afternoon session to give participants the opportunity to discuss their own results in more detail (and practice on computers).
- Include more time for discussion in the existing training course structure.
- Perhaps add in an informal discussion instead of taking up workshop time.
- Would have liked to input real data from one of our blocks and discuss implications and software issues.

***4.2.1.iii. Introduce an additional session to be done prior to commencing the training on how to set up the system for your vineyard.***
**Issue:** Data collection after the first training session is a big task due to the need to set up the computer program for your own vineyard as well as undertake the data collection to make the first yield estimation.
**Improvement opportunity:** Allow participants to undertake some pre-course work to be better prepared and reduce workload after the first session and include an additional session on how to set up the program for your vineyard.
**Specific suggestions:**

- Have five sessions instead of four, with the first one being a very short one on how to set up your own vineyard survey and prepare for the season. That way when people come to the second session (which is currently the first one) they are prepared and can enter their own data straight away rather than having to set up the whole thing after the first session plus go and collect their data to make the first estimation.
- Introduce a pre-session (as above) plus provide participants with a checklist prior to attending this first session advising participants on what data they need to collect before commencing the course. Participants would then have their own data on hand at the first session and can raise any issues with the trainer.

#### *4.4.1.iv. Include cost-benefit analyses and case studies to demonstrate to growers the benefits of adopting the system.*

**Issue:** At present there is no hard data presented to demonstrate clearly to growers what the dollar benefits of adopting the system are so a major barrier to adoption is that some growers are unsure that the work entailed in using the system is outweighed by the benefits. They can see how the wineries benefit but are unsure of the direct benefits to themselves.

**Improvement opportunity:** Include cost-benefit analyses and case studies of different sized businesses to compare adopters and non-adopters and include this in the training and in the publicity to attract growers to the training.

**Specific suggestions:**

- Undertake cost-benefit analyses.
- Present as case studies to show the development of businesses who have adopted the system and what the benefits were to them (pecuniary and non-pecuniary).

#### *4.4.1.v. Include more historic data in the manual.*

**Issue:** At the back of the manual there is a section on district averages which is used by growers to provide some estimates in their initial set up of the system. Growers found this extremely helpful but thought that it was not extensive enough.

**Improvement opportunity:** Include other districts in the manual and have some more years of historic data.

**Specific suggestions:**

- Include more references in the folder for district averages for berry loss and gain and weights etc so when growers use the program originally they have more help for numbers to enter.
- Provide workbooks to new users that already have more regionally relevant historic data that would encourage wider use and adoption of the system (as people might be put off by the data collection required).

### *4.4.2. Ideas to provide on-going support to participants (post-workshop)*

One issue that has been identified during the training module project is the challenge of keeping the growers who participate in the workshops engaged post-workshop and linked into any new developments or improvements in the crop forecasting system made by other GWRDC-funded projects. For example, the software originally provided to the pilot group participants has been further developed during the training module project from an Excel-based system to a stand-alone, more user-friendly system. A new technique has also been developed by a related GWRDC-funded research project which has the potential to improve the accuracy of the first forecast of the season (the bunch-branch counting technique).

This highlights a more strategic issue of the need to ensure that research advancements are closely linked into the training module at regular intervals and that resources are provided to enable this to happen. Following the completion of the five pilot training sessions funding was sought from the GWRDC's Regional Innovation and Technology Adoption (RITA) project to develop a short workshop series to bring the pilot groups up to date with these advancements. If funding is secured this will address the issue for this particular group of participants but it is ad-

hoc and not a suitable long-term, strategic approach for projects which require strong on-going linkages between research, development and extension.

Since the aim of this project is to "train the trainers" (so that the training module is delivered by a range of people or groups with training expertise) the issue of continuous improvement and ensuring the on-going linkages with related research projects will need to be considered. Once the trainers receive the training module how will new techniques and improvements in crop forecasting resulting from research projects be incorporated into the existing training module and how will past participants of the training be kept informed of new advances? Will there be anyone or any group who will be resourced to have a strategic overview of crop forecasting training in the industry and who will be in a position to manage these kinds of issues?

There are three groups that the industry will need to consider in the marketing and provision of the crop forecasting training and in the post-workshop support:

1. Potential users of the crop forecasting system (target markets, key messages, how to encourage them to participate in the training)
2. Current participants in the crop forecasting training (providing training to them)
3. Past participants in the training program (how to support them post-workshop eg providing them with new information)

***4.4.3.i. Develop a strategy for and resource the provision of further support, information and training on new advances in the crop forecasting system to participants post-workshop.***

**Issue:** Once participants have undertaken the training at present there is no follow-up support to encourage them to keep using the system or to advise or train them in any new advances or improvements in the system. For example participants in the pilot training project have only experienced the Excel-based software and have not had the opportunity to see or use the new, improved stand-alone program.

**Improvement opportunity:** Ensure that a strategy is developed and resourcing provided to keep participants engaged and supported post-workshop (the strategy may incorporate some of the suggestions made by growers below).

**Specific suggestions:**

- Develop a short workshop for pilot program participants to show them the new software and provide them with a copy to use.
- Alert participants to any changes or upgrades to the system or approaches to forecasting eg branch counting technique.
- Introduce an annual session for participants who have been through the course to allow them to compare notes and share their increased knowledge and experience and update them on new developments.
- Facilitate get-togethers to discuss results, share data and/or problems so that people who have been through the training are encouraged to keep using the system.
- Hold a session at the end of the next season to see how participants went on their own.
- Establish a peer group with training group participants to keep in touch and help/discuss forecasting in following season.
- Send a reminder letter pre-bud burst with summary of critical points eg measurement times (count <u>all</u> bunches) and include:
  - regional data (average, mode, variance) on bunch weights and

  - seasonal factors if available ie dry year estimates, wet year estimates
- Set up a summary of growers' estimates and provide individual feedback so that growers have follow-up and encouragement to go out and do it all again next season.
- Provide more hands-on training with software packages so participants are more confident in using it outside of training – all using computers
- Would be good for the presenters to go over each individual's information in their office. We've got a heap of stuff in our computer at the moment and for you to have a look at that and say this is where you could have taken more tests there. You can also use our data to go back in that list which is what we're looking for anyway – more regional data
- A visit from one of the suppliers of the system – software and a 1-2 hour training or refresher
- Someone coming out to the vineyard to help plan which patches to do
- The facilitator to go over results with each participant
- More support from someone who knows and understands the process
- Since have been part of the pilot, being able to ring someone up to ask questions would be good
- Access to technical support in using the spreadsheet
- Access to someone if I strike problems with the program
- A help line for if confusion occurs
- I will need to teach people at other vineyards how to use the system so I would like to know that I could ring someone to ask them questions
- *Help with analysis of data and forecasts interpretation etc*
- We used the model on several blocks (greater than 30). Some we completed, others we only managed to collect half of the data
- We now need to see where we've succeeded and where we've gone wrong
- Feedback and contact details would be great
- Short course for staff involved in sampling/data collection to enforce and ensure that they understand about the accuracy at critical points
- To encourage wider adoption of use of model with new users, provide workbook with regionally suitable historic information without reliance on individuals generating own history (a "put-off" to investing initial time)
- If we (the pilot groups) have done this training then, rather than training another 100 people through to our level, it would be good to get us to the stage where we are confident that we think it works and I believe that word of mouth will spread and people will see that I've been getting it right every year (or within 10-20%) which is acceptable by the industry because they understand you are never going to get 100% right so maybe that's another option

### *4.4.3. Ideas to encourage widespread adoption of the system by the industry*

The information below is compiled from ideas put forward by workshop participants that will need to be addressed if the crop forecasting system is to achieve widespread adoption in the Australian wine industry. The issues raised are outside the scope of this training module project but failure to address them will impact on the effectiveness

***4.4.3.i. Cost-sharing arrangements between wineries and growers to aid the rate adoption of the crop forecasting system and improvements to data collection.***

Issue: Participants identified that the major beneficiaries of improved crop forecasting are the wineries yet growers are required to make the investment of time and labour in providing more accurate forecasts to the wineries. They perceived that there was no support from wineries in bearing the cost required to make more accurate forecasts.

Improvement opportunity: Wineries could support growers in improving their forecasts and share some of the costs by managing the system set-up, random number generation, data entry and analysis. Growers could undertake the data collection. Another suggestion was that contract yield estimators could be employed to undertake crop forecasting and this cost could be shared between wineries and growers.

Specific suggestions:

- Wineries could manage the system since they are the main beneficiary of improved forecasting. Growers could be trained on how to sample correctly. The winery could then send out the random selection sampling sheets to growers who then send in their data each year to a central point (ie the winery) and receive a yield estimate back. This may encourage smaller growers and computer illiterate growers to use the system (although one participant said that growers need to maintain an interest in their property and know their own figures to keep control and not have the winery tell them).
- Have a professional group of contract yield estimators who have the equipment and the expertise to undertake crop forecasting efficiently. This should allow them to keep costs down and growers could pay so much per production unit to have it done.
- If we could funnel it (the data from individual growers) through one point, the winery, and then they've got that information for this region and their growers then when they put their figures in, the winery can ring up and say look that figure you've put in must be wrong because we've got 400 growers in this region and the average is this much, put that in and see how you go. And it's all in to one point and coming back out towards you.
- You get home with the computer program and you read the manual and you can use it. But at the starting point you've got no history. And in two to three years from now when another group comes through the door the winery can have all that history from all those growers who have funnelled it through and they have a starting point – otherwise you have maybe 100 growers out there with all this information sitting in their computers.

***4.4.3.ii. Wineries provide incentives to growers to use the system to improve their forecasts.***

**Issue:** At present there is no reward or incentive for growers who use the system to make their forecasts.

**Improvement opportunity:** Wineries could provide an incentive for growers who use the system to make more accurate forecasts via a premium or an accreditation system.

**Specific suggestions:**

- Wineries provide incentives to growers who use the system.
- Introduce accreditation for vineyards to adopt the system so there would be an incentive for people to take it up – eg a certificate for your vineyard, the course is recognised as best practice for your vineyard, needs to carry some weight that you're a step ahead of everyone else.

#### *4.4.3.iii. Educate winemakers about what the system involves to lead to more realistic expectations and improved relationships between wineries and growers.*

**Issue:** Growers perceived that there was a lack of understanding by winemakers about what is involved in using the system to make more accurate forecasts and that this lack of understanding may lead to unrealistic expectations and cause tension between growers and winemakers. Many growers feel disempowered in their relationships with wineries.

Improvement opportunity: Involve winemakers and other winery staff in the training so they understand some of the issues faced by growers in making accurate forecasts and what some of the concepts mean (eg when a forecast is 10 tonnes +/- 5 tonnes).

Specific suggestions:

- Educate winemakers about what is involved in more accurate crop forecasting and on what you can realistically expect from a forecast eg by them doing the course with growers.
- Bring in influential winery staff at the start of the course and define their expectations and those of growers to build understanding of both groups.
- Make the system industry-wide so that everyone is speaking the same language.

#### *4.4.3.iv. Develop a system of industry-wide data collection and management.*

**Issue**: Participants (both growers and wine industry staff) identified that there was a lack of co-ordination across the industry of historic data collection.

**Improvement opportunity:** For regions to develop a system of collecting and recording regional data which can be shared between growers to reduce guesswork.

**Specific suggestions:**

- Forecasting is an industry problem and there could easily be a lot more historic data collated that would support the information required by the crop forecasting system and that would reduce the guesswork.
- Develop a whole-of-region approach especially for historic data as it is hard for individuals to obtain this information eg the Murray Valley have a central data system tool that you could draw off that data against average bunch and berry weights and a regionally and industry combined approach.
- Regional historic data collected and related to weather data eg a minimum and maximum that most people were at and a mean also how it varies depending on weather conditions so if you have a very wet year you can expect it to be this much ahead of where you were last year, if you have a very dry year you can expect this – just some rules of thumb like those for the district.

#### *4.4.3.v. Further development of sampling innovations to simplify and improve the speed of data collection.*

**Issue:** The data-collection requirements of the current crop forecasting system are time-consuming and a barrier to adoption.

**Improvement opportunity:** Identification, development and promotion of techniques or technologies to improve ease and speed of data collection.

**Specific suggestions:**

- Development of an attachment so you can quickly walk up and push it through the canopy and count your bunches and take it off and go (at present you need to throw ropes over the canopy and when it's windy they don't stay in the right place and it's a two-person job). If we had a user- friendly attachment it would encourage more people to adopt the system.

- Use digital cameras – particularly for photographing (both sides of the canopy), a record of that would be very useful over the years.
- Talk to system users about different modifications they've made in their sampling techniques or little time saver techniques that they've discovered and include these in the training.
- Develop a scanner to count berries or bunches in the area of the trellis and track it with your spray cart so it drives along and scans how many bunches there are as it goes through (because they're a different structure to the leaf).
- Developing a berry counter or a tray that could make counting a bit quicker eg like an ice cube tray so that instead of counting, you still have to pick berries off, but you can flatten them out and know you have 100 in the tray.
- Investigate different ways to take samples eg taking the same amount of bunches but from less locations so that you are narrowing time spent walking or measuring.
- Using maturity samples to make yield estimates – the sampling is being done for other reasons but the data can be put be used to make an estimate also.
- Undertake research to identify shortcuts to reduce data collection whilst maintaining integrity and still obtaining a reasonably accurate result as the system in its entirety is very time consuming at present.
- Undertake more research to reduce workload eg regional information having more correlations between some of the parametres being measured so that simple measurements will give you that information without having to count every berry etc.
- Examine other methods to develop an early determinant of bunch weight.
- Concentrate your management effort on particular patches eg if you are unable to sample all patches you need some way of prioritising which ones to put effort into doing.
- Developing a "crop factor" so that simple bunch weight samples weighed can be multiplied by a crop factor for time of the year to equal yield. These figures would need to be compiled through years of data and research so at flowering for example 50 bunches weighed come to so much multiplied by a crop factor in normal situations to give yield

#### *4.4.3.vi. Investigate the feasibility of incorporating the crop forecasting system into a total vineyard management software program.*

**Issue:** Growers identified that data collection and management is a growing requirement for them in all aspects of their business including crop forecasting, quality assurance, fertiliser management, irrigation scheduling etc.

**Improvement opportunity:** Growers suggested that it would be useful to have a total vineyard management software program rather than having a variety of different programs that all require different ways of entering data.

**Specific suggestions:**

- Can we have it included in a big module? Some quality assurance programs require this information so need one big program of vineyard management – software devised to link into different vineyard programs – a total vineyard management package, mainly for QA purposes
- Instead of having to do a survey for irrigation schedule, fertiliser schedule etc, build them all into the system

*4.5. Opportunities for further work*

Training module project staff have identified some other opportunities for further work that will need to be considered. At present, due to funding constraints, these actions have not been resourced.

*4.5.1. Undertake quantitative evaluation with workshop participants*
The evaluation undertaken and reported upon in this document provided qualitative data. It would be worth also using a quantitative evaluation technique such as a brief survey to "ground truth" the qualitative data obtained in this evaluation. In addition, undertaking a follow-up survey in the longer term (eg in a year's time) would also enable behaviour change to be measured ie the participants attended the training but how many of them are still using the system in a year's time?

*4.5.2. Survey participants who did not complete the training to discover why*
The evaluation undertaken at the end of the workshop series involved feedback from only those people who participated in all four training sessions. Table 1 shows the attendance numbers for each workshop and for the five in total with the percentage of the original number shown in brackets. An opportunity for further evaluation would be to contact some of the participants who dropped out of the training along the way to find out why they didn't complete the training and use their feedback to improve the training module. It would also be interesting to look at other wine industry training courses to see if the drop-off rate is similar ie do most other industry training courses have a drop-out rate of 50%?

Table 1: Attendance numbers for the Crop Forecasting Training

| **Group** | **Session 1** | **Session 2** | **Session 3** | **Session 4** |
|---|---|---|---|---|
| Coonawarra | 26 (100%) | 20 (77%) | 13 (50%) | 9 (35%) |
| Great Western | 13 (100%) | 9 (70%) | 6 (46%) | 7 (54%) |
| Griffith | 14 (100%) | 11 (79%) | 6 (43%) | 11 (79%) |
| Karadoc | 19 (100%) | 16 (84%) | 10 (53%) | 11 (58%) |
| Nagambie | 15 (100%) | 14 (93) | 7 (50%) | 7 (50%) |
| **Total** | **87 (100%)** | **70 (80%)** | **42 (48%)** | **45 (52%)** |

*4.5.3. Update the Crop Forecasting Manual to reflect advances in the software*
The Crop Forecasting software has been developed from the Excel workbook to a stand-alone, user-friendly software package. The manual used in the workshops is based on the original Excel workbook and will need to be updated.

*4.5.4. Provide Pilot group participants with a report of the evaluation*
Participants in the evaluation were told that they will receive a copy of their group's evaluation report, a summary of the overall evaluation, the new software and manual and the other groups' forecasts. This has not occurred so a decision will need to be made to resource it or, if it is decided not to, to communicate with participants that it is not happening.

*4.5.5. Ask Pilot group participants to be advocates for the crop forecasting system and training*

From a marketing viewpoint the most effective way to "sell" a product is by a personal recommendation from a respected peer. The participants who completed the crop forecasting training are now in a good position to act as advocates for the training to others in the industry (as the vast majority of participants' experiences of the training were very positive). The Training Project has the opportunity to develop some key messages that it would like to communicate and ask the Pilot Group participants to assist them in getting these messages across to others.

*4.5.6. Publicise evaluation results to the wine industry*

The evaluation results need to publicised throughout the Australian wine industry via media, industry forums etc. to promote the crop forecasting system and training module (although being mindful of creating a demand for the training and ensuring that resources are available to be able to meet it).

*4.5.7. Investigate different models for, identify and implement an effective process to ensure the continued linkages between the R&D and extension aspects of the crop forecasting system and training*

A major ingredient of the success of the Training Module project has been the flow from research and development to extension and the continuing close links between the two. Feedback from Pilot group participants highlighted a demand for updated information and new advances in technology. A threat to the continued success of the project is the loss of this continuous improvement link which is reliant on the regular feeding in from research in to the training project. There are ways that this issue can be managed to ensure these linkages are maintained which should be investigated and put into place.

*4.5.8. Investigate options to enable the crop forecasting training module to become 'self-funding'*

The Australian wine industry has invested (and continues to invest) in research and development of crop forecasting technology and has resourced a one-year project to develop a training module to facilitate the extension of the technology to the industry. The training has been piloted successfully and is at a crucial stage where it is ready to be promoted and delivered to groups throughout Australia. There is demand for the training from grower groups eg Yarra Valley and Western Australia. A major threat to the ultimate success of the project achieving widespread adoption throughout the industry is a lack of resources for the "roll-out" and further adoption of the training. This project requires further support to engage a network of trainers to deliver the training and hence fully realise the returns for the investment the industry has already made. If this support is not forthcoming from the industry there may be possibilities of making the training module "self-funding" by generating income which can be put back into the project.

*4.5.9. Investigate commercialisation options for and export of the crop forecasting system and training module*

Feedback from the pilot groups strongly suggests that the crop forecasting training module works and can assist growers in making more accurate forecasts. This technology is not only applicable in Australia but has potential benefits for the wine industry globally. At present the model can be given to and used by anyone in the world without the Australian industry having the opportunity to receive returns for the investment it has made in the development of the product.

An issue for the Australian wine industry and the GWRDC to consider is the viability of commercialising this product and exporting it to other countries. Commercialisation has the potential of ensuring that the investment the Australian industry has made in the research, development and extension of crop forecasting (or any other product of research) can be returned to the industry.

*5. Outcomes/conclusions*

The Winegrape Crop Forecasting module successfully trained the participants from five pilot groups in crop forecasting. The five pilot groups had a positive training experience and the crop forecasting system was regarded favourably by most participants. Barriers to adoption were identified and suggestions for improvement were made (see Section 6. Recommendations), some of which are within the sphere of control of the training project, some which are being addressed in related GWRDC-funded research projects and others which will need to be considered by the industry more broadly.

The evaluation feedback will be used to improve the training module where possible and a report will be provided to GWRDC by the end of the year. As mentioned above work is already underway which will address some of the barriers to adoption particularly those related to sampling and time required, in a three-year project on yield regulation (2003-2005). Part of this project will include investigations into new technologies to predict yields.

There is an opportunity to undertake further work to ensure that the crop forecasting training achieves widespread adoption throughout the Australian wine industry. How this further work is resourced will need to be identified.

As a participant from the Karadoc group said, “It would be a real shame if it (the crop forecasting training) dropped off now. If it drops off now after all the work that’s been put into it, it would be a shame for the industry. There’s been starting points before but this is a really positive starting point. I hope funding bodies recognise the importance of it. No matter where it goes from here it’s a really positive starting point but it needs to move in some direction and be followed up. If there’s no follow up then people who are still sceptical won’t take it on but once a few other growers get to know about it and find its great and tell others about it and more people know about it then there will be a need for more training later on”.

*6. Recommendations*

These recommendations identify actions to ensure the crop forecasting training module and technology achieve widespread adoption throughout the Australian wine industry. The decision about which will be undertaken and how they are undertaken will need to be made by the Training Project manager and GWWRDC and industry at large.

*6.1. Recommendations for further work based on Pilot Group feedback*

*6.1.1. To improve the training module*

- Include the opportunity to practice with computers during the training sessions
- Include more time for discussion in the training (especially implications for individual businesses)
- Introduce an additional session to be done prior to commencing the training on how to set up the system for your vineyard
- Undertake cost-benefit analyses and case studies to demonstrate the benefits of adopting the system to growers
- Include more historic data in the manual

*6.1.2. To provide on-going support to participants (post-workshop)*

- Develop a strategy for and resource the provision of further support, information and training on new advances in the crop forecasting system to participants post-workshop

*6.1.3. To encourage widespread adoption of the system by the industry*

- Investigate opportunities for cost-sharing arrangements between wineries and growers and improvements to data collection
- Wineries provide incentives to growers who use the system to improve their forecasts
- Educate winemakers about what the system involves to lead to more realistic expectations and improved relationships between wineries and growers
- Develop a system of industry-wide data collection and management
- Further development of sampling innovations to simplify and improve the speed of data collection
- Investigate the feasibility of incorporating the crop forecasting system into a total vineyard management software program

*6.2. Recommendations for further work identified by Training Module project staff*

- Undertake quantitative evaluation with workshop participants
- Survey participants who did not complete the training to discover why
- Update the Crop Forecasting Manual to reflect advances in the software
- Provide Pilot group participants with a report of the evaluation
- Ask Pilot group participants to be advocates for the crop forecasting system and training
- Publicise evaluation results to the wine industry
- Investigate different models for, identify and implement an effective process to ensure the continued linkages between the R&D and extension aspects of the crop forecasting system and training
- Investigate options to enable the crop forecasting training module to become ‘self-funding’
- Investigate commercialisation options for and export of the crop forecasting system and training module

## 4b. The Development of a Regional Crop Forecasting System in the Murray Valley

### *Introduction*

The establishment of a reliable regional wine grape crop forecasting system was an important goal for industry members in the Murray Valley region. Such a system would improve planning for the production, processing and marketing of wine. During the 2002-03 season, the DPI Mildura crop forecasting project team committed resources to assist the Murray Valley Wine Grape Industry Development Committee (MVWIDC) and the Victorian and Murray Valley Wine Grape Growers Council (VMVWGGC, now Murray Valley Winegrowers Incorporated – MVWI) in the collection of yield component data. This project was initiated with the understanding that a number of seasons of data would need to be collected to make such a system more reliable and accurate in the long-term.

1. Estimate probable sampling requirements for conducting accurate regional yield forecasts in future years.
2. Quantify variation in key indices of yield within the Murray Valley region.

### *Materials and Methods*

The vineyards sampled during the 2002-03 season were selected from respondents to a survey of wine grape growers conducted by the MVWIDC. A total of 63 vineyards, owned by 25 different growers, of varieties Cabernet Sauvignon, Chardonnay, Merlot and Shiraz were selected. These were located within a 65 km range of Mildura, Victoria and included vineyards in NSW. Project staff, including Ms Susan Byrne (VMVWGGC Industry Development Officer) conducted assessments at 3 different stages of crop development. These were:

1. Post flowering (29th Oct - 19th Nov)
2. Post berry-set (12th Dec - 20th Jan)
3. Pre harvest (10th Feb - 25th Mar)

Counts of bunches arising in randomly selected 30 cm transverse segment of vine canopy were made at each stage of crop development. Counts were made at stages 2 and 3. Also at stages 2 and 3, assessments were made of bunch weight, number and weight of berries per bunch, and berry numbers per bunch.

### *Results and Discussion*

*Spatial (Big block)*

An assumption of the study is that the varietal blocks in a region can be combined and aggregated as one “big block” for the purposes of sampling and yield estimation to calculate a regional yield forecast. The aim of the first seasons work was to simply collect yield component

data at the three key stages of crop development that could then be used in the following seasons to accurately predict regional yields.

The average bunch counts (per 30cm segment) for each variety (Cabernet Sauvignon, Charonnay, Merlot and Shiraz) was collected from selected vineyards (approximately 16 individual vineyards for each variety). At each vineyard approximately 20 segments were counted and the data combined at a whole of variety level across the 16 separate vineyards (Table 1). This table shows that the average bunch numbers per 30cm transect for Chardonnay was almost double that recorded for Shiraz and Merlot in the same season. Based on previous crop forecasting research, where bunch numbers per unit canopy length were shown to relate well with yield, we automatically expected the yield of Chardonnay to be higher than most of the other varieties examined in 2003. This proved to be the case once all data was examined after vintage (data not shown). This conclusion was supported by stage 3 (pre-harvest) yield assessments on those selected vineyards (Table 2).

Table 1. Means and coefficients of variation of bunches counted per 30 cm segment, for all vineyards, at each stage of development.

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| Variety | Stage | Bunches per meter per 30 cm segment | |
|---|---|---|---|
| | | Bunches counted | |
| | | All vineyards | |
| | | Mean | C.V.(%) |
| Cab. Sauv. | 1 | 90 | 44.4 |
| | 2 | 72 | 46.1 |
| | 3 | 69 | 28.8 |
| Chard. | 1 | 133 | 42.0 |
| | 2 | 109 | 50.0 |
| | 3 | 98 | 33.0 |
| Merlot | 1 | 71 | 45.0 |
| | 2 | 75 | 50.0 |
| | 3 | 68 | 31.9 |
| Shiraz | 1 | 76 | 54.0 |
| | 2 | 63 | 44.9 |
| | 3 | 69 | 42.0 |

The coefficient of variation in bunch numbers per segment ranged from 28.8% through to 54.0%, indicating the high variation which was expected in aggregating the data from a number of different vineyards across the Sunraysia region (Table 1).

Table 2. Means and coefficients of variation of yield per 30 cm segment, for all vineyards, at stage 3 (pre-harvest).

| Variety | Stage | Yield per 30 cm segment (kg/m) | |
|---|---|---|---|
| | | Yield picked | |
| | | All vineyards | |
| | | Mean | C.V. (%) |
| Cab. Sauv. | 3 | 5.24 | 44.1 |
| Chard. | 3 | 8.14 | 53.9 |
| Merlot | 3 | 7.36 | 42.1 |
| Shiraz | 3 | 6.79 | 51.4 |

The mean number of berries per bunch was highest in Merlot (78.6 – stage 2), while the lowest number of berries per bunch on average was recorded in the Cabernet Sauvignon vineyards (67.3 – stage 2) (Table 3). The number of berries per bunch did not change significantly between stages 2 and 3, indicating that no berry loss factor was required in modifying the crop estimate at stage 2 (Table 3). The coefficient of variation in berries per bunch tended to be generally higher that those observed in the number of bunches per 30cm segment or the yield per 30cm segment.

Table 3. Means and coefficients of variation of berries per bunch for all vineyards, at stages 2 and 3

| Variety | No. Berries per bunch | | | |
|---|---|---|---|---|
| | | | | |
| | All vineyards Stage 2 | | All vineyards Stage 3 | |
| | Mean | C.V. (%) | Mean | C.V. (%) |
| Cab. Sauv. | 67.3 | 69.5 | 76.9 | 60.0 |
| Chard. | 72.2 | 57.2 | 69.5 | 56.8 |
| Merlot | 78.6 | 67.2 | 68.4 | 68.2 |
| Shiraz | 74.3 | 70.1 | 75.3 | 51.0 |

Following the yield components through further, the highest average bunch weights were recorded in Merlot (56.9g per bunch), while the smallest bunches were observed in Cabernet Sauvignon (30.8g per bunch) (Table 4). The weight per bunch data related somewhat to the berries per bunch data as expected, where the higher berries per bunch varieties had on average higher average bunch weights (Table 3 and 4).

Table 4. Means and coefficients of variation of weight per bunch for all vineyards, at stages 2 and 3

| Variety | Weight per bunch (g) | | | |
|---|---|---|---|---|
| | | | | |
| | All vineyards Stage 2 | | All vineyards Stage 3 | |
| | Mean | C.V. (%) | Mean | C.V. (%) |
| Cab. Sauv. | 30.8 | 78.6 | 67.1 | 66.3 |
| Chard. | 43.9 | 67.4 | 64.0 | 62.1 |
| Merlot | 56.9 | 77.0 | 84.1 | 70.2 |
| Shiraz | 52.7 | 95.5 | 89.5 | 61.3 |

The average weight per berry at harvest (stage 3) was highest in Merlot (1.17g per berry on average) compared to Cabernet Sauvignon, which had an average berry weight of 0.81g at stage 3 (pre-harvest) (Table 5).

Table 5. Means and coefficients of variation of mean berry weight per bunch for all vineyards, at stages 2 and 3

| Variety | Mean berry weight per bunch (g) | | | |
|---|---|---|---|---|
| | All vineyards Stage 2 | | All vineyards Stage 3 | |
| | Mean | C.V. (%) | Mean | C.V. (%) |
| Cab. Sauv. | 0.40 | 67.2 | 0.81 | 27.4 |
| Chard. | 0.59 | 60.3 | 0.89 | 29.9 |
| Merlot | 0.65 | 48.9 | 1.17 | 19.0 |
| Shiraz | 0.60 | 42.2 | 1.13 | 28.3 |

***Conclusions***

- This data represents a summary of the first season of data collection for the VMVWGGC (now MVWI) regional crop forecasting project.

- In the following season, this data will be used to generate regional crop estimates for the varieties Merlot, Cabernet Sauvignon, Chardonnay and Shiraz.

- It is anticipated that the regional crop estimates will only improve over time.

- The biggest limitation to producing an accurate regional forecast of yield, is knowing the area of planting (full bearing) with some degree of accuracy for each varietal.

## 4c. Optimum segment width for rapid yield and bunch number assessment in Chardonnay and Shiraz in the Murray Valley

### *Introduction*

One objective of the national project was to adapt existing forecasting methods to accommodate modern vineyard management practices in all wine grape growing regions across Australia. In the Murray Valley, between 1997 and 2000, the crop forecasting team based its assessments on a 20cm wide 'transect ladder', or segment apparatus for estimating bunch numbers per vine. This could be laid over a vine canopy to provide boundaries within which bunches could be counted or picked. This was an important innovation. Counting in smaller segments saves forecasters time and aggravation, thus removing a barrier to adoption of measurement-based wine grape crop forecasting systems. In other fields of research, it has been recognised that the size of the sample unit influences the accuracy and efficiency of estimating a population mean. Measurements of sample units smaller than the Representative Elementary Volume (REV) are often characterised by high variation and the means calculated from them may not be reliable and accurate. Measuring sample units larger than the REV does not produce additional information or reduce variation further, thus increasing costs without having any additional benefit.

In previous research, forecasts based on repeated measures using a single 20cm segment tended to overestimate yield by more than 30% (data not shown). This suggested that 20cm was not the optimum segment length for accurately estimating bunch numbers and yield in Murray Valley vineyards. A trial was conducted to test the efficiency of 20 different segment widths, ranging from 5cm to 120cm. In comparing costs associated with time, the standard for comparison was the time taken to assess a site to a level of 15% doubt in the means for bunch number and yield respectively.

The objective of this study was to test the effect of segment width on the efficiency and accuracy of measuring bunch numbers and yields in Chardonnay and Shiraz vineyards in the Murray Valley (Victoria and New South Wales).

### *Materials and Methods*

*Design of Sampling Apparatus*

The apparatus used in the trial was formed from coloured ropes attached to 120cm lengths of 15mm diameter PVC conduit, arranged in the manner of Fig. 4.1.1 (a). It comprises 15 individual strips (9x10cm, and 6x5cm). This apparatus was located at various predetermined random points in the vineyard. At each location, the apparatus was staked in place on the canopy, and an operator on either side of the trellis picked bunches arising from each strip, starting with the central, 10cm strip. Subsequent strips were picked alternating between each side of the centre strip. Bunches were picked into labelled trays, counted, weighed using a digital field balance and the values recorded.

*Experimental Sites*

Five vineyards were assessed in the trial, 3 Chardonnay and 2 Shiraz. Vineyards were located in the Murray Valley, within a 45km radius of Mildura. The segments were positioned on the canopy at a different number of randomly selected places in each vineyard. The number of randomly located segments in each vineyard ranged between 1 and 12.

*Data Analysis*

All data was analysed using Genstat® v.6.1 statistical software. The means and variance for bunches per strip per site were calculated. This data was then used to calculate the means and coefficients of variation for each variety. The best sample size was calculated using the formula $BSS = t^2 ( CV^2 / TD^2)$, where *BSS* is the Best Sample Size, *t* is a value from the *t*-distribution, *CV* is the Coefficient of Variation and *TD* is the Tolerance of Doubt (i.e. the maximum Coefficient of Doubt that will be tolerated). The standard Tolerance of Doubt for this experiment was set at 15%.

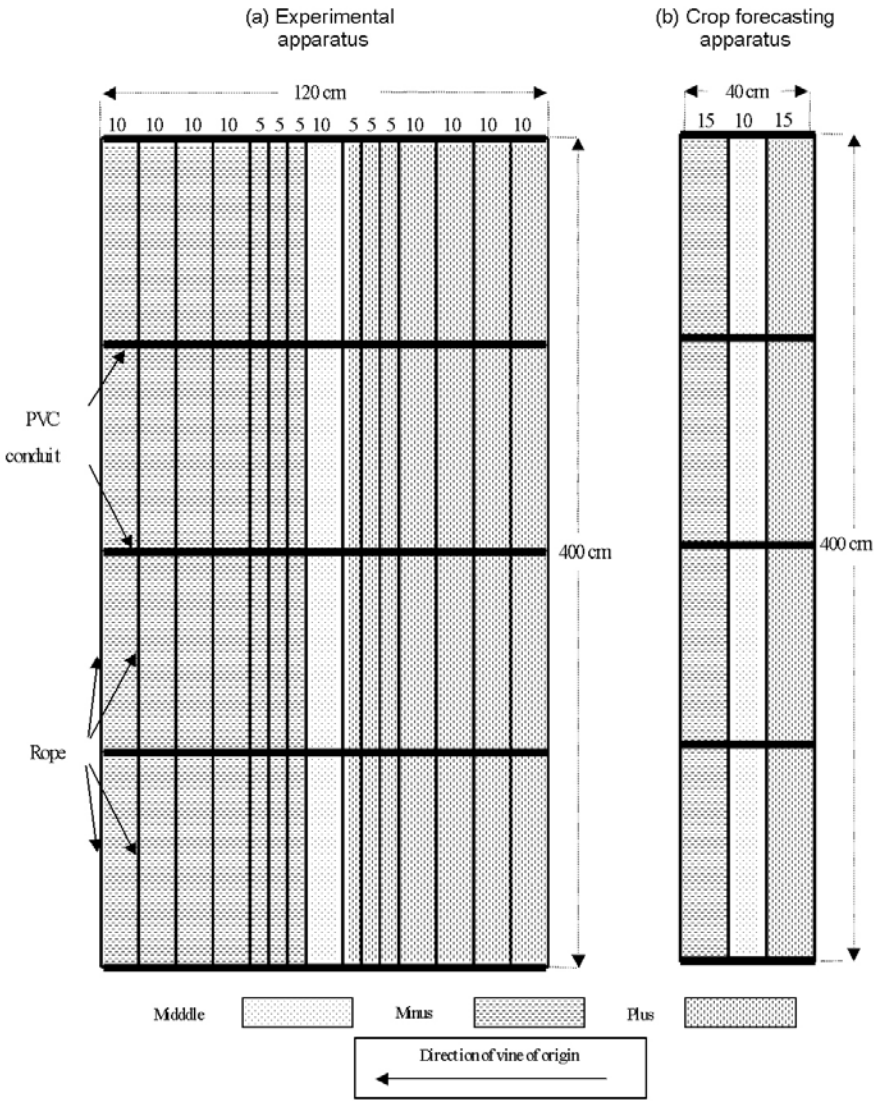


Figure 4.4.1. Segment width apparatus. The device used to define 5 and 10 cm strips of vine canopy for objective assessments of vine bunch number and yield.

***Results and discussion***

*Bunch numbers*

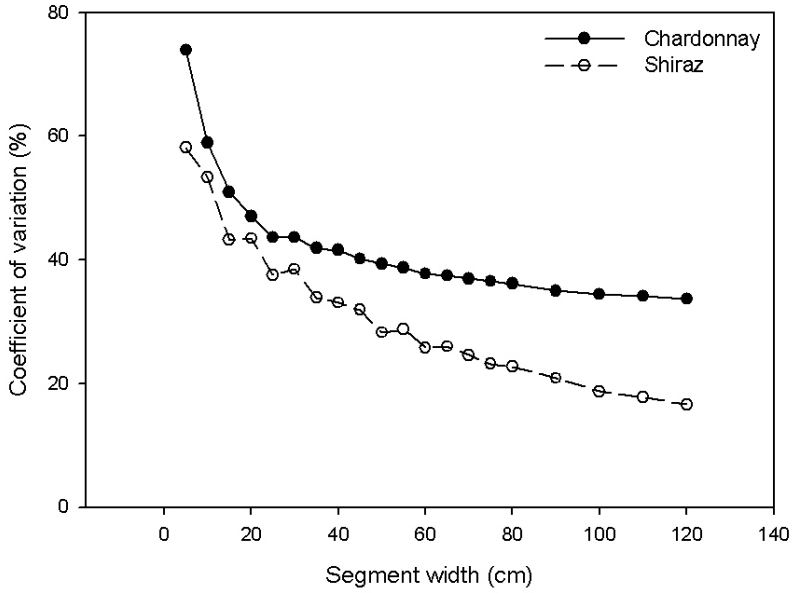



Figure 4.4.2. Effect of segment width on mean coefficient of variation of counts of bunches picked per segment in 3 Chardonnay and 2 Shiraz vineyards in the Murray Valley, 2001/02

Increasing the segment width decreased the Coefficient of Variation (%CV) of counts of bunches picked per segment in both varieties (Fig. 4.4.2). Consequently, the Best Sample Size decreased with increasing segment width. The Shiraz vineyards were generally less variable than the Chardonnay at all segment widths. The mean %CV for all segment widths in the Chardonnay and the Shiraz vineyards were 44.1% and 31.3%, respectively.

*Yield*

The curves for the coefficients of variation (%CV) of yield for the two varieties were less different than were those for bunch numbers (Fig. 4.4.3.). This suggests that yield was similarly distributed in vineyards which had different bunch distributions. The coefficients of variation of yield for both varieties were higher than the corresponding values for bunch numbers (Fig. 4.4.2). More segments need to be sampled to achieve the desired level of doubt in yield per segment than need be for bunches per segment.

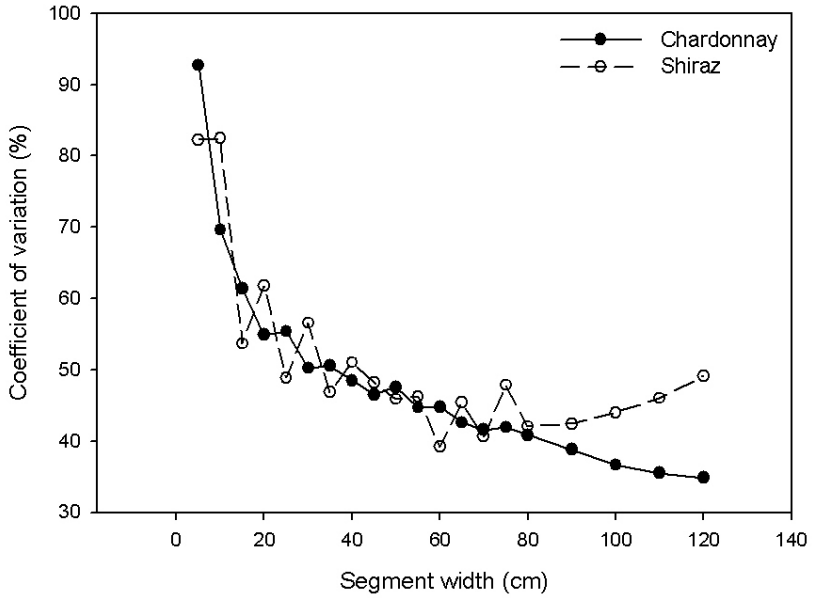



Figure 4.4.3. Effect of segment width on mean coefficient of variation of yield picked per segment in 3 Chardonnay and 2 Shiraz vineyards in the Murray Valley, 2001/02

The time required to achieve the desired Tolerance of Doubt in yield per segment in the Chardonnay blocks was at a minimum when the segment width was 20cm, although the differences between the total time for a block using a 20cm segment and a 10cm segment was only 12 minutes (Figure 4.4.4). The Shiraz vineyards took the least time to achieve confidence in the means for yield when a segment width of 10cm was used, although this data displayed a less consistent trend than did that of the Chardonnay. Segments in the range of 10 cm to 20 cm had the least measurement times for both varieties.

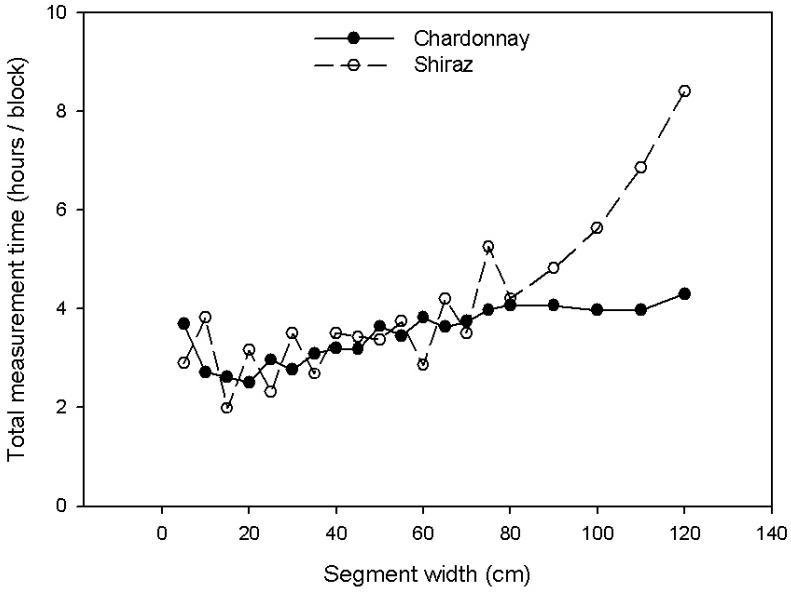



Figure 4.4.4. Effect of mean segment width on time required to pick and count bunches to achieve 15% Tolerance of Doubt in the yield per segment in 3 Chardonnay and 2 Shiraz vineyards in the Murray Valley, 2001/02.

### *Conclusions*

- Yield was a more variable parameter than bunch number for both Chardonnay and Shiraz.
- Segments of width 10 cm to 20 cm took the least amount of time to achieve 15% doubt in the means for bunch number and yield in the trial of the experimental segment apparatus
- The optimal segment width for accurate and time effective crop estimation in the Murray Valley region for Shiraz and Chardonnay appears to be somewhere between 30-40cm.
- A segment width of 40cm is recommended to wine industry in the Murray Valley as the standard segment width to conduct bunch number assessments at particular random vine locations in selected vineyards where accurate crop estimation is desired.

### *References*

1. Antcliff, A.J., May, P., Webster, W.J. and Hawkes, J. (1972). The Merbein bunch count, a method to analyse the performance of grapevines. HortScience 7(2), pp196-197.

# Chapter 5.

# Physiological, environmental and cultural determinants of crop yield components

## 5a. Determinants of crop yield components

***Introduction***

Substantial cost savings and revenue gains could be realised if the volume of grape intake did not fluctuate so much and the intrinsic composition of grapes could be more reliably matched to desired wine styles, which are shifting towards better-flavoured, premium and super-premium (particularly red) bottled wine. In pursuit of these aims, major producers and purchasers of grapes are stipulating that particular yield targets should be met, in the belief that this will improve and maintain wine quality. Thus, there is a strong demand for sound crop regulation guidelines and cost-effective techniques.

Integral to effective crop regulation is the development of improved crop forecasting techniques. A component of this work includes better prediction of bunch weight.

*Predicting yield early in the season*

Yield predictions made early in the season (before flowering) are important for both forecasting and crop regulation. The earliest time that an 'in-season' yield forecast can usefully be made is approximately 6 weeks after budburst. At this stage the following formula is often used:

Yield = bunches/block (estimated from bunch counts and block dimensions) x bunch weight (predicted)

Recent research (Clingeleffer, 2001) has shown that block forecasts made at this time can be significantly improved by:

- having an accurate knowledge of block dimensions,
- employing adequate sampling techniques to estimate bunch number,
- using a better formula (eg. include factors for harvest efficiency and bunch gain), and
- improving the prediction of final bunch weight.

Solutions for improving the first three are understood and if implemented will save the Industry a substantial amount of money each year. However, they will only improve forecasts so much. Further improvement relies on the development of methods to accurately predict bunch weight at harvest. Figure 1 presents an example of typical year to year fluctuations in bunch weight.

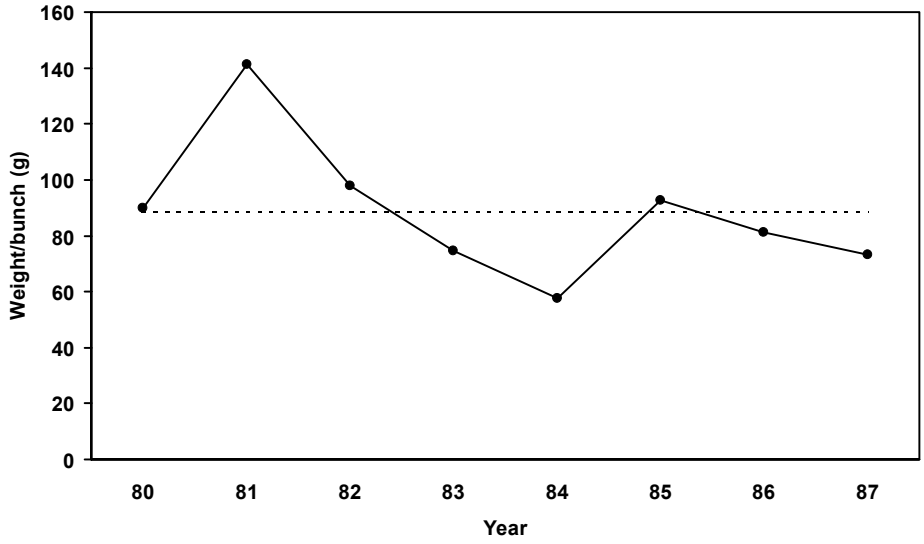



Figure 1. Average weight of Shiraz bunches at harvest over 8 consecutive seasons at Wahgunyah.

*Predicting bunch weight*

*Counting flowers*

One method that can be used to assess potential bunch size after budburst is to count flowers on bunches (at this stage they are more correctly referred to as inflorescences but we will call them bunches). Even though it may not be necessary to count all the flowers on a bunch (May 1987), the process is labour intensive and impractical for most growers.

There are reports of good correlations between bunch length, dry weight, and flower number (Mark Krstic, personal communication). Although these will be valid within a population of bunches in any given year, they are unlikely to be useful in another season, for another variety or at another site. During the early stages of berry and bunch development the rachis (the main axis of the bunch) may be elongating rapidly, making it difficult to determine an appropriate sampling date. Also, across any given vine, shoots may burst over a 2 to 4 week period, and the bunches on them develop at different rates under a complex set of environmental influences and plant factors that can vary markedly from one year to the next. Thus, it is not possible to produce a reliable set of generic relationships between bunch weight and these dynamic measurements that would remain stable from season to season.

*'Lag phase' assessments*

Other methods based on measurements made during the 'lag phase' of berry development (ie. just before veraison) have been proposed. These include weighing a sample of bunches during the lag phase and then multiplying the average bunch weight by an empirically derived factor. However, the timing of the lag phase may be difficult to assess and require repeated trips into the vineyard. Seed hardening has been used to indicate the onset of the lag phase but this is very labour intensive. More importantly, these methods are too late to produce an 'early season'

forecast or to provide a sound basis for regulating yield using any technique other than bunch removal.

*Temperature based models*
Temperature-based models, which predict the date that fruit reaches 50% of its final weight, have been developed for some varieties. The idea is that when a set number of degree-days have been accumulated (eg. for Concord near Cornell University this is 1100 Fahrenheit degree-days (50$^{o}$F base)), bunches are harvested and weighed and then the average bunch weight is doubled to arrive at harvest bunch weight. Establishing these relationships requires harvesting many bunches periodically (every 10 to 12 days after fruit set) over several seasons. Furthermore, as with forecasts made during the 'lag phase', this method will not produce an 'early season' yield forecast.

*Primary branches*
During the project we investigated potential early season predictors of harvest bunch weight for the varieties Chardonnay Cabernet Sauvignon and Pinot Noir across a broad range of climates. The most promising of these is proving to be the number of primary branches on the bunch. Because this is a structural character that is determined soon after budburst and remains relatively constant until flowering the timing of sampling can be flexible. Other advantages are: it is simple to assess, it can be measured non-destructively and it could lend itself to rapid spatial analysis techniques already being used or under development. Our results show that the number of primary branches has the potential to detect large seasonal deviations of bunch weight from the long-term mean at an early stage, provided that branch loss and berries/branch do not vary too much from season to season.

Grape bunches are conical branched structures (Pratt 1971). A main axis carries primary side branches, which are also branched and look like small bunches. The nearest branch to the base of the stalk (Branch 1) is sometimes called the 'outer arm' (May 1987) or 'wing' and can be very variable in form. The results presented here are based on counting the 'wing' as one branch only. The size of the rest of the primary branches tends to decrease towards the tip of the bunch giving grape bunches their familiar conical shape (Figure 2). Larger bunches generally have more primary branches.

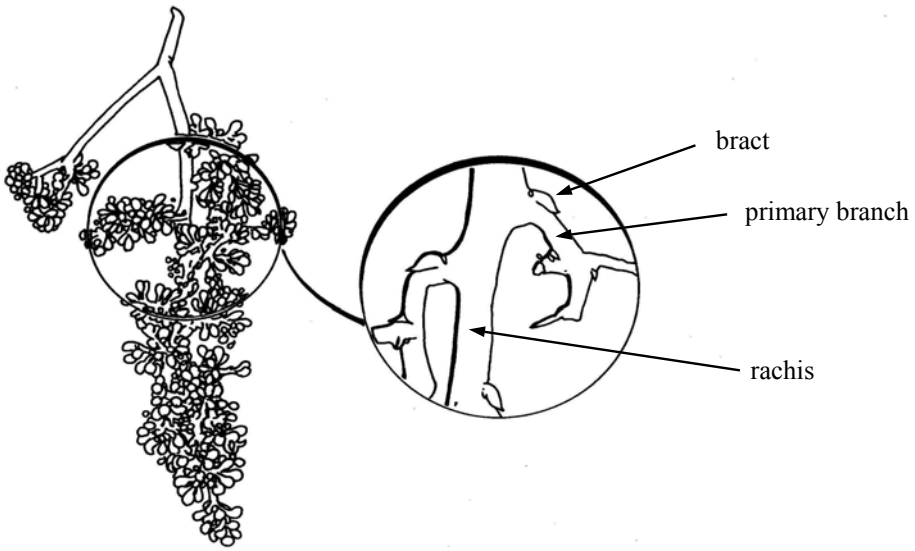



Figure 2. A grapevine bunch (inflorescence) prior to flowering: expanded section details the rachis, primary branches and the position of bracts.

***Materials and methods***

*Variety and site selection*

Fieldwork was undertaken in five vineyards and on the Cultivars Chardonnay, Cabernet Sauvignon and Pinot Noir grown over a wide climatic range (from very hot to cool) and under different vine management systems (Table 1) and over a number of seasons. Clusters were destructively harvested 6 weeks after budburst, at veraison and at harvest to collect information on bunch architecture. Bunch collection and analysis was done in parallel with best-practice yield forecasts for each block during the 2000/01, 2001/02 and 2002/03 seasons. Measurements were also made for Dookie Cabernet Sauvignon during the 1998/99 and 1999/2000 seasons.

Table 1. Varieties and Site Characteristics

| Site | Cultivar | Climate | Pruning | Row and Vine Spacing |
|---|---|---|---|---|
| Barooga | Chardonnay | Hot | Mechanically Hedged | 2.75 m x 2 m |
| Dookie | Cabernet Sauvignon | Hot | Spur Pruned | 3.4 m x 2.4 m |
| Dromana Estate | Cabernet Sauvignon | Mild/Cool | Cane Pruned | 3 m x 1.5 m |
| | Chardonnay | Mild/Cool | Cane Pruned | 2.5 m x 1.2 m |
| Lake Cullullera ine | Chardonnay | Very Hot | Hedged & Minimal Pruned | 3 m x 2.4 m |
| Whitlands | Cabernet Sauvignon | Cool | Arched Cane | 1.7 m x 1 m |
| | Chardonnay | Cool | Arched Cane | 1.7 m x 1 m |
| | Pinot Noir | Cool | Arched Cane | 1.7 m x 1 m |

*Measurements*

*After budburst*
Six weeks after budburst 60 to 100 flower clusters were randomly collected be from all vineyard blocks with the exception of the Cabernet Sauvignon block at Dookie. At Dookie, 52 bunches each were randomly sampled from 4 pruning treatments (very light, light, medium and severe) which were shown to affect bunch size (more severe pruning leads to more flowers per bunch) in the previous season. At each of the experimental sites bunch counts were carried out in order to forecast yield.

After collection bunches were transported to the laboratory where the number of 'first order' branches (Figure 1) and flowers per bunch were counted. Some bunches could not be processed immediately and these were frozen for processing later. Branches and flowers on the wing were counted separately. The wing is considered by some researchers to be anatomically another bunch. It can range from a tendril through to carrying upwards of 100 flowers and, therefore, it contributes a great deal of variation to bunch size. The branch number parameter referred to in this report assumes the wing to be just one branch.

*After fruit set*
At the onset of veraison bunches were collected from all of the experimental sites as per flower cluster assessment. Bunches were placed in labelled plastic bags and transported to the laboratory where they were either processed or frozen for later processing. The number of first order branches and berries per bunch were counted. As with flower clusters, branches and

berries on the wing were counted separately and the wing was counted as a single branch. Berries were weighed for the 'main' bunch and wing separately.

*Near to harvest*
Immediately prior to harvest, weight/vine, bunches/vine, weight/bunch, berries/bunch, weight/berry were measured.

*Statistical Analysis*
Statistical analyses were performed using Genstat© 5 Release 4.1 (Lawes Agricultural Trust, 1997). For the Dookie Cabernet Sauvignon, Analysis of Variance (ANOVA) was used to test the effect of treatment on yield, its components and bunch characteristics. Treatment means will compared using Fisher's unrestricted least significant difference ($LSD_{5\%}$). Other relationships will be assessed by regression analysis.

## *Results and Discussion*

*Flowers and branches*
Analysis of the complete flower cluster data across all sites and varieties showed that branches per cluster accounted for a substantial amount of the variation (44% to 75%) in flowers per cluster. The results also show that for varieties grown in different climates but pruned similarly, relationships between branches per bunch and flowers per cluster were similar. There seemed to be a trend toward fewer flowers per branch in hotter climates. However, it may also be that vines at these sites were mechanically pruned as opposed to spur pruned or cane pruning at the cooler sites.

Figure 3 illustrates that within the 2001/02 season the relationship between flowers per bunch and branches per bunch for Cabernet Sauvignon was stable across a wide climatic range (cool to hot). These results provide some confidence that the technique can be reliably used to improve estimates of yield potential at a relatively early stage of bunch and berry development.

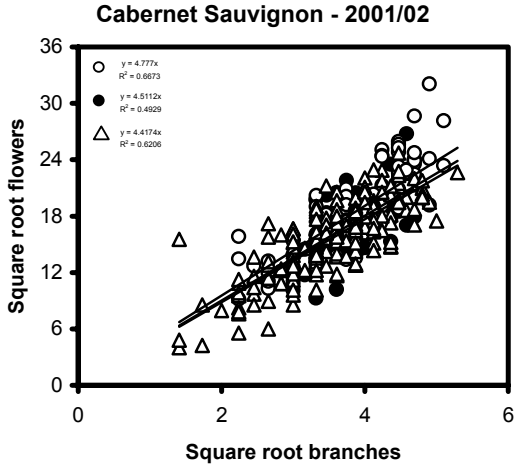


Figure 3. Scatter plots of associations between √(flowers) and √(first order branches) at Dromana Estate (o) – a warm site, Whitlands (•) – a cool site and Dookie (△) – a hot site.

A range of pruning treatments was imposed on Cabernet Sauvignon at Dookie *viz*. very light, light, medium and severe. Pruning affected flower number, berry number and bunch size. In general more severe pruning led to more flowers per bunch (Figure 4). Differences in flower numbers per cluster were also associated with differences in branches per cluster. However, these effects were small in magnitude. As pruning severity increased from 177 to 30 retained nodes per vine flowers per branch increased from 18.15 to 20.05. This would suggest that the technique might not need to take into account normal differences in pruning severity from one season to the next, at least for Cabernet Sauvignon.

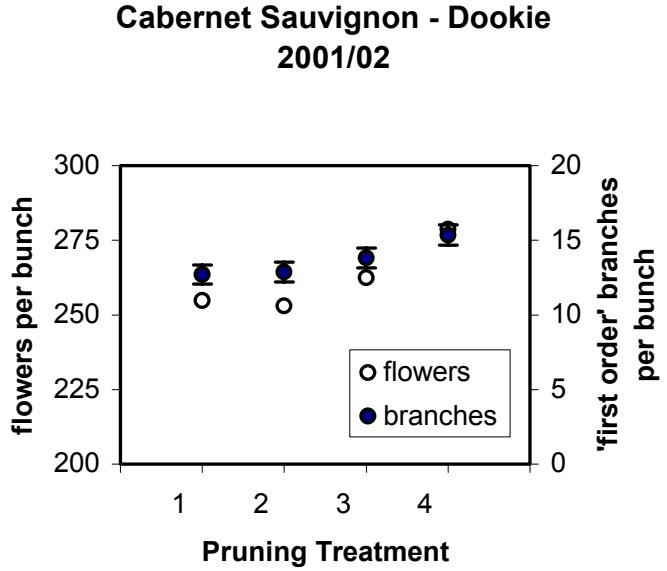



Figure 3.The effect of pruning intensity on flowers per bunch and branches per bunch at Dookie for the 2001/02 season.
1 – very light pruning (177 retained nodes per vine)
2 – light pruning (93 retained nodes per vine)
3 – moderate pruning (51 retained nodes per vine)
4 – severe pruning (30 retained nodes per vine).

However, there were effects of pruning type on branches per bunch and flowers per cluster for Chardonnay. Minimally pruned Chardonnay bunches have substantially fewer branches per bunch and flowers per branch than hedged or spur-pruned Chardonnay (Figure 4). This has implications for understanding the relative importance of branching prior to dormancy compared to differentiation during budburst in controlling potential cluster size. It also suggests that forecasting systems using branch number as input may have to be adjusted to cater for systems where vines are hedged or minimal pruned.

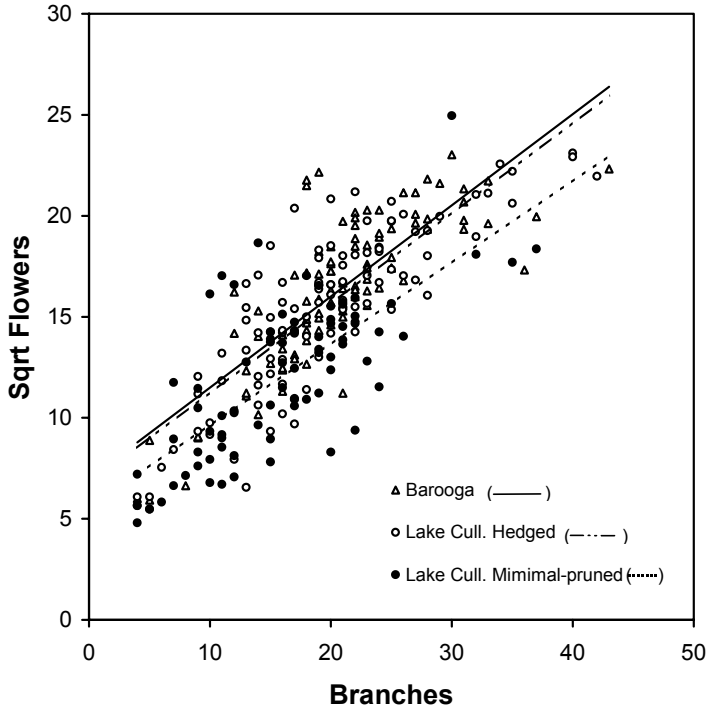



Figure 4. Relationships between √flowers/cluster and branches/cluster for Chardonnay in the 2001/2002 season at Lake Cullulleraine and Barooga.

Regressions Relationships:

Barooga (Hedged) √flowers/cluster = 0.4512(branches/cluster) + 6.9855 ($R^2$ = 0.65)

Lake Cull. (Hedged) √flowers/cluster = 0.4473(branches/cluster) + 6.7243 ($R^2$ = 0.70)

Lake Cull. (MP) √flowers/cluster = 0.4053(branches/cluster) + 5.5576 ($R^2$ = 0.53)

As 2001/02 was the first year we colleted data there was little opportunity to investigate the stability of relationships between flower number and branch number from season to season. Fortunately, as part of a previous project funded by GWRDC this relationship was described for Cabernet Sauvignon at Dookie in the 1998/99 season. This enabled us to make direct comparisons on the same vines grown at the same site during two seasons. The results show that relationships seems to be relatively stable (Figure 5).

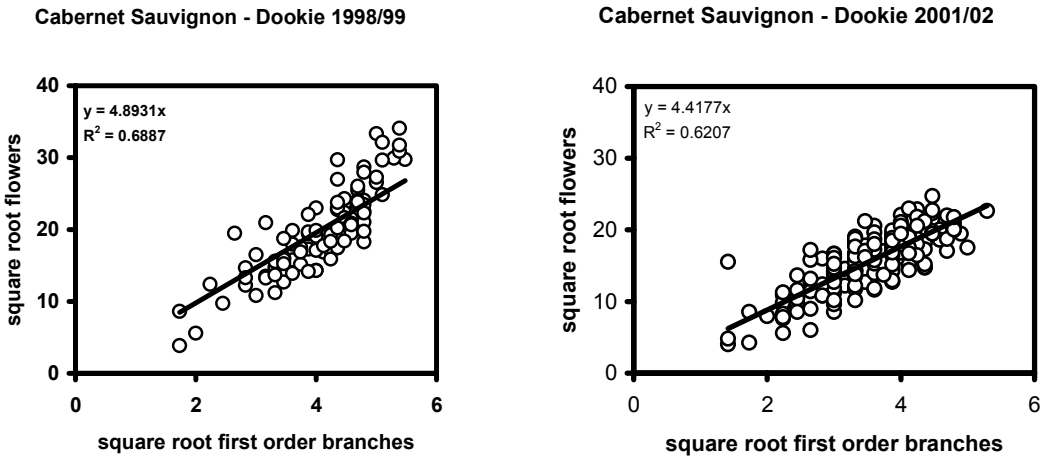



Figure 5. Association between √(flowers per bunch) and √(branches per bunch) for Cabernet Sauvignon at Dookie in 1998/99 and 2001/02.

A small test was carried out to test the effectiveness of *in situ* branch counting before flowering. Counting branches *in situ* led to a small (approx 5%) underestimation of branch numbers (data not presented).

*Predicting berry number and berry weight at harvest*

As well as describing relationships between primary branches and flowers per bunch, we have investigated relationships between primary branches and berry number per bunch and bunch weight. These relationships typically explain between 55 and 77% of the variation in berry number at harvest (see Figure 5) and also remain relatively stable from one season to the next. However, some sites can present difficulties in certain seasons particularly when conditions during fruit set are adverse (eg. Cabernet Sauvignon and Chardonnay at Dromana Estate in 2001/02). Thus it is important to exercise caution when using relationships developed for other sites and years, particularly at cooler sites where developmental events that take place after an early forecast can have large impacts on bunch size. It may be that crop forecasting at these sites will involve berry counting after fruit set, perhaps in conjunction with monitoring climatic conditions during flowering.

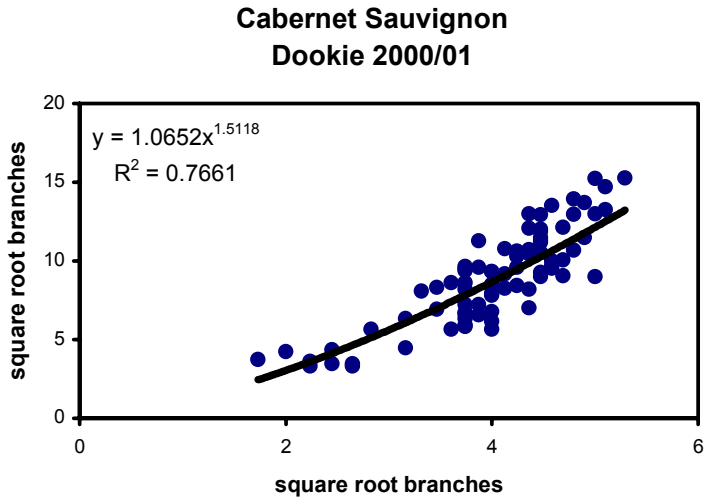



Figure 5. The relationship between the number of primary branches per bunch and the number of berries per bunch for Cabernet Sauvignon bunches at Dookie in the 2000/01 season.

Predictive equations were developed for Chardonnay and Cabernet Sauvignon in the 2001/02 season. These equations were tested at 7 Chardonnay sites, including the 5 sites where crop forecasting training exercises were conducted, during the 2002/03 season (as part of GWRDC project DNR 02/02) *viz.* Great Western, Nagambie in Central Victoria, Coonawarra, Griffith, Karadoc near Mildura, Barooga in Southern NSW and Dromana Estate on the Mornington Peninsula. Considering how early they were made, predictions of berry number at these sites were very good (Figure 6).

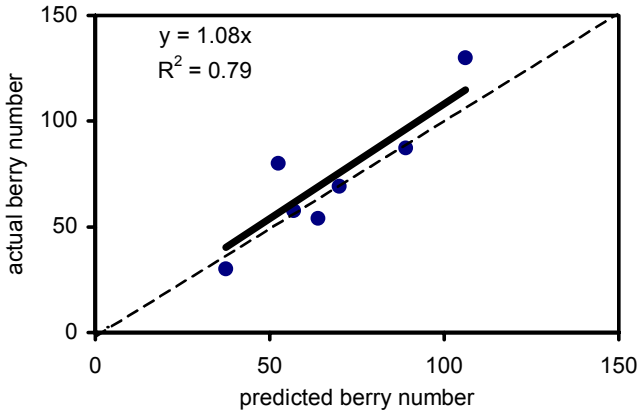



Figure 6. Predicted berry number per bunch based on the number of primary branches compared with actual berry number per bunch at 7 Chardonnay sites in the 2002/03 season. The dashed line represents a 1:1 relationship.

From counts of bunch branches we detected smaller bunches (fewer berries) in the 2002/03 season. This suggests that the reasons behind berry numbers per bunch being down across the board were more to do with processes that determined flower number per bunch than they were to do with processes that determined fruit set.

Incorporating an estimate of bunch size (berries/bunch) based on the number of primary branches dramatically improved yield forecasts made 6 to 8 weeks after budburst at the 5 crop forecasting training sites (Figure 7). These results provide us with some confidence in the usefulness of the technique for the varieties that were studied. However, again we must emphasise some caution for cooler sites where conditions during flowering can have a large impact on berries per bunch.

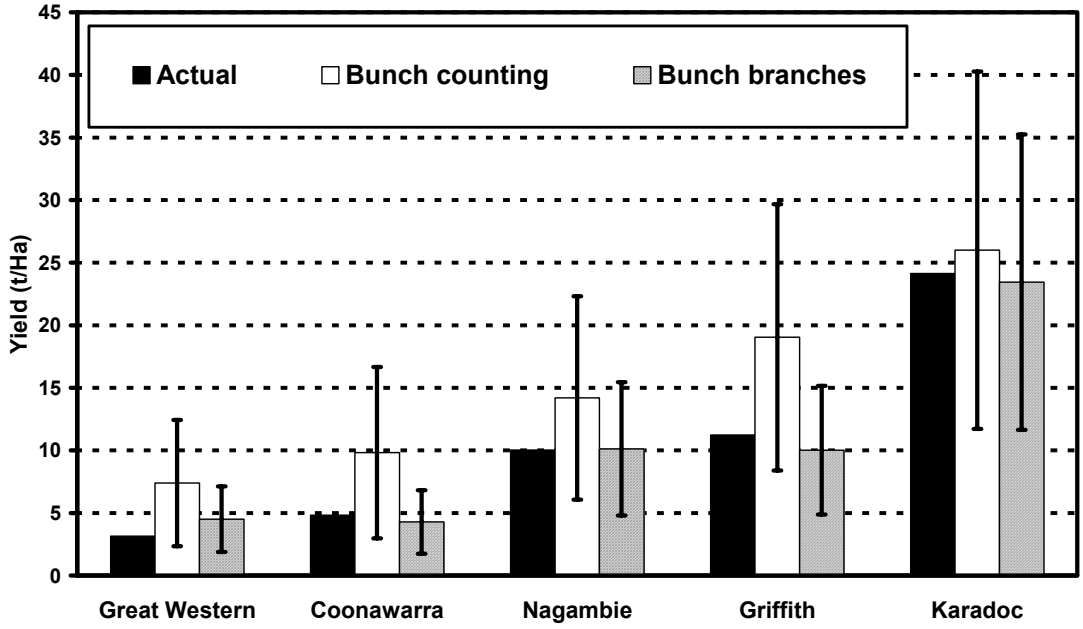



Figure 7. A comaparison of actual yield with 2 yield forecasts made 6 weeks after budburst at 5 Chardonnay sites. The 'bunch branch' forecast uses the number of primary branches to predict berry number per bunch. The bars indicate the 95% confidence interval or 'doubt'around the forecasts.

Guides outlining the technique and including predictive relationships for the varieties studied have been developed (Dunn 2003). The results have also been incorporated into crop forecasting software. However, the project team recognises that relationships are likely to differ with variety. Thus, simple methods that growers can use to establish their own predictive relationships for other varieties will also be recommended.

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## 5b. Improving the Early Prediction of Bunch Weight By Counting Branches

***Why Count Branches?***

Forecasts of vineyard yield are often required by wineries in advance of flowering. These early predictions are also important for decisions about crop regulation. A forecast made prior to flowering is based on counting bunches and predicting harvest bunch weight. Average bunch weight at harvest can vary substantially from one season to the next and predicting it early in the season has proved difficult. It continues to be a major source of error in 'early season' yield forecasts. Researchers at the Department of Primary Industries (DPI), Tatura have recently developed a simple, reliable technique to dramatically improve the early prediction of harvest bunch size.

Final bunch size is determined by:

(i) the number of flowers formed on bunches (at this stage they are more correctly referred to as inflorescences but we will call them bunches),
(ii) the number of these flowers that become berries (i.e. fruit set),
(iii) the proportion of berries lost after fruit set and
(iv) berry size at harvest.

Of these, berry size at harvest is less variable from season-to-season than the number of flowers per bunch or the number of berries per bunch.

Strong relationships between the number of primary branches (Figure 1) per bunch and the number of flowers per bunch have been described for Chardonnay, Cabernet Sauvignon and Pinot Noir. These relationships typically account for 50 to 75% of the variation in flower number per bunch and remain relatively stable from season-to-season and across climates. They do, however, vary with variety and with pruning type (e.g. minimal pruning versus cane or spur pruning). Strong relationships between primary branches and berry number and bunch weight have also been described.

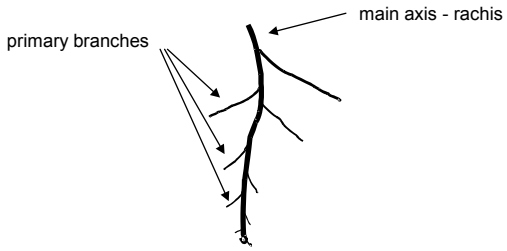



Figure 1. Grape bunches are conical branched structures. A main axis called the rachis carries 'primary' side branches, which are also branched. Larger bunches generally have more primary branches.

Overall, the results show that the number of primary branches has the potential to detect large seasonal deviations of bunch weight from the long-term mean prior to flowering. Furthermore, because the number of primary branches is a structural character that is determined soon after

budburst the timing of sampling can be flexible. It is simple to assess and it can be measured non-destructively.

This leaflet gives recommendations for how to collect bunches, how to count primary branches and how to use this data to predict bunch size at harvest

*Collecting Bunches*

*When to count branches*

Theoretically it is possible to count branches soon after budburst as both branch and flower formation should be complete. However, we recommend waiting until at least 6 to 8 weeks after budburst. By this time nearly all the bunches will be visible and will have elongated sufficiently for easy identification and counting of branches. This timing also coincides with that recommended for early forecasts based on bunch counts (GWRDC 2001).

*Selecting bunches in the vineyard*

Because we are estimating average branch number from a population of bunches across the vineyard, it is important that sampling is **random** and **representative**. A bunch is defined as a stalk with **one or more flowers or berries** on it. This definition is used because it allows the **true** mean of the population to be estimated and is consistent. It is important not to overlook small bunches.

Random sampling means that sampling locations are randomly selected before entering the vineyard. DPI has developed software that selects random locations (vines or vine spaces) within vineyard blocks and random sampling positions at these locations. To discuss obtaining the software or EXCEL spreadsheet from which the software was developed contact: Rebecca Dunstone at DPI Tatura (phone:03 5833 5365, email: rebecca.dunstone@dpi.vic.gov.au).

Because the variation in bunch size is much greater within a vine than from vine to vine, it is more efficient to sample a greater number of bunches (say 6) from fewer locations (say 10) than it is to sample each bunch from a separate location. For instance to select 6 bunches from the one location, locate the randomly selected vine and sampling position, identify the nearest bunch (Figure 2) and then select it and the next 5 bunches in one direction. This should help ensure that smaller bunches are not overlooked.

*Removing bunches*

Although it is possible to count branches on bunches non-destructively it is easier to remove them and then count branches back in the shed, laboratory or office. When removing bunches snip or pinch them off at the base of the stalk.

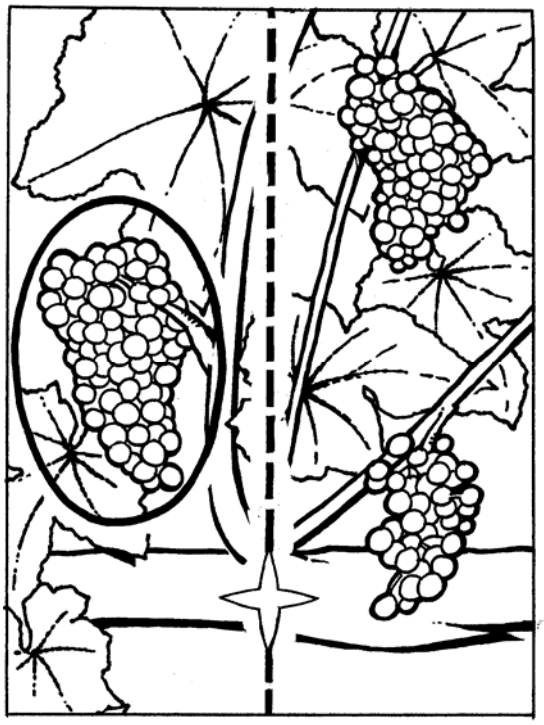


Figure 2. The circled bunch has the base of its stalk nearest to the imaginary line or plane (dashed line) at a randomly selected sampling position (designated by the star on the cordon) within a randomly selected vine (illustration by Bob Bennett).

*Have you sampled enough bunches*

Results show that a sample of between forty and sixty bunches is usually adequate for estimating branches per bunch prior to flowering at a 95% confidence level and percentage error of 10%. After counting branches per bunch and entering the data it is easy to use the aforementioned software to determine whether the sampling has been adequate.

*Counting Branches*

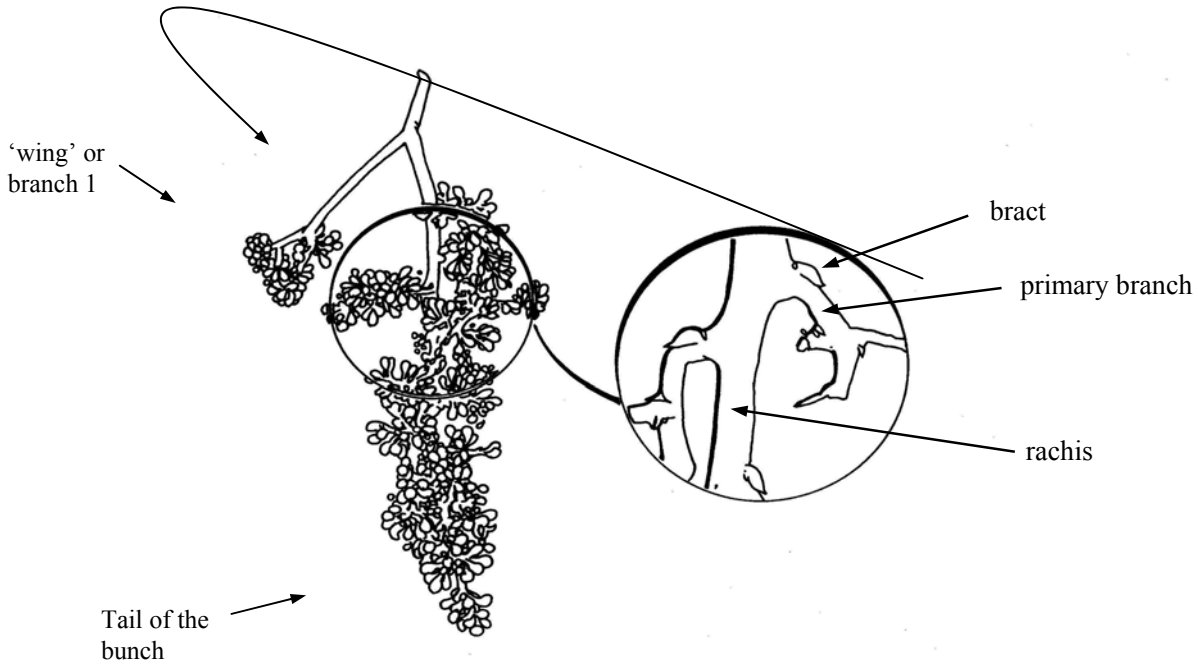



Figure 3. A grapevine bunch (inflorescence) prior to flowering: expanded section details the rachis, primary branches and the position of bracts (illustration by Bob Bennett).

Primary branches are only those that arise directly from the rachis, the main axis of the grapevine bunch. In the axil of each primary branch is a bract (Figure 3). This bract is a useful aid when identifying and counting primary branches.

Results from 30 site x variety combinations between 1998 and 2003 have shown that the average number of branches per bunch for the varieties studied ranged from 10 to 20.

Counting branches per bunch prior to flowering is relatively quick but it is very important to be as accurate as possible. Because primary branches tend to spiral around the rachis they can be easily missed. So it is best to count slowly and methodically from the base of the stalk to the tail of the bunch. It may help to move the tip of a pencil or a finger from one branch to the next to ensure that branches are not counted twice or missed altogether. Particular care is needed at the tail of the bunch. The relationships that are recommended in this leaflet are based on counting the 'wing' (sometimes referred to as branch 1) as just one branch.

Once the primary branches have been counted for the sample of bunches, the average number of primary branches per bunch can be calculated. This number can then be used to calculate either berries per bunch or bunch weight at harvest.

*Calculating Bunch Weight at Harvest*

**Berries per bunch** or **weight per bunch** at harvest can be estimated by **entering average branch number** into one of the following formulae.

If the average number of berries per bunch is calculated then this will need to be multiplied by berry weight to estimate harvest bunch weight. This approach may be preferable in situations where berry weight at harvest can be predicted with some confidence.

**Chardonnay (cane pruned or spur pruned)**

berries/bunch = 4.74 *x* branches per bunch (assessed pre flowering)

weight/bunch (g) = 4.66 *x* branches per bunch (assessed pre flowering)

**Chardonnay (minimally pruned or mechanically pruned)**

berries/bunch = 2.93 *x* branches per bunch (assessed pre flowering)

weight/bunch (g) = 3.63 *x* branches per bunch (assessed pre flowering)

**Cabernet Sauvignon (cane pruned or spur pruned)**

berries/bunch = 4.79 *x* branches per bunch (assessed pre flowering)

weight/bunch (g) = 4.40 *x* branches per bunch (assessed pre flowering)

*Note*

However, some sites can present difficulties in certain seasons, particularly when conditions during fruit set are adverse. Thus, it is important to exercise caution when using these relationships at cooler sites where developmental events that take place after an early forecast can have large impacts on bunch size. It may be that crop forecasting at these sites will involve monitoring of climatic conditions during flowering and possibly berry counting after fruit set.

Also, it is important to validate these relationships with measurements of bunch weight and/or berry number and berry weight at harvest.

*Developing Relationships for Other Varieties*

Individuals may wish to develop their own relationships for other varieties or sites. To develop these relationships, berries per bunch and bunch weight would need to be assessed at harvest along with the branch number assessments earlier in the season. Also, it would be necessary to collect data for at least two seasons to determine how stable relationships are from season-to-season. To describe relationships appropriate statistical analyses, possibly including data transformation, would be required. If you are interested in describing your own set of relationships for other varieties or sites please contact Dr Gregory Dunn at DPI Tatura (phone: 03 5833 5303 or email: gregory.dunn@dpi.vic.gov.au).

*References*

GWRDC Project CSH 96/1 (2001). Final Report - Crop Development, Crop Estimation and Crop Control to Secure Quality and Production of Major Wine Grape Varieties: A National Approach. 148p.

## 5c. Determination of critical weather periods associated with annual variations in Sultana (Vitis vinifera L.) yield.


***Abstract***

Variations in yield have serious implications for growers, processors and marketers. A better understanding of the environmental factors that cause yield variation will give the industry a greater warning so they can plan to regulate their production. An analytical method that generates $\chi^2$ indices of association was used to determine the "critical" levels of daily weather occurrences associated with annual variations in Sultana yield. The yield data were collected from the Sunraysia and the Riverland regions over a 52-year period (1951-2002). The weather data recorded at the Mildura Airport included the daily maximum and minimum temperatures, the average daily temperature, the temperature range, rainfall and daily sum of solar radiation. Years were divided into 13 high yielding seasons, 26 normal seasons and 13 poor yielding seasons. The gradual increase in yield over time was negated by selecting high and low yielding seasons by their departure from the five year average yield. The analysis determines when during the growing season (approximately 18 months from inflorescence initiation until harvest) a significant excess or deficit of a specific weather parameter occurs in either high or low yielding seasons. The cultivar Sultana is a strong candidate for this type of analysis due to the long period of yield data available, large variations in yield due to changes in bud fertility (especially of the basal buds) and the large amount of research that has been conducted on environmental effects on Sultana fruitfulness and yield. Once the technique is validated it can be extended to other cultivars or environments where the appropriate data sets are available. Initial results confirm that higher than average temperatures immediately after bud burst in the initiation season (18 months before harvest) are associated with high yields. High temperatures in late December were also associated with low yields in the following season. This was probably due to heat and/or water stress on the developing inflorescence primordia. This technique provides a broad first approximation on the likely weather factors that cause variations in vine yield (or other factors), or could be used to select periods where regression equations may be used as the basis for yield modelling. It may also highlight critical stages of development for further research.

## 5d. The effect of post-veraison water deficit on yield components and maturation of irrigated Shiraz (*Vitis vinifera* L.) in the current and following season.


***Abstract***

Water allocation policies in the Murray Darling basin have the potential to restrict water availability late in the season when water storages are low and flow requirements for environmental and down stream users must be met. As a perennial crop, water deficit can affect grapevines during the current season and the following season even if irrigation practices return to normal. Three post-veraison irrigation treatments were imposed on spur, mechanical and minimal pruned Shiraz vines that were already receiving restricted water application using Partial Rootzone Drying. The treatments resulted in the vines receiving 1.25 mega litres per hectare pre veraison and the three irrigation treatments receiving 1.25, 0.65 and 0 mega litres per hectare of water in the post-veraison period. Water deficit during the current season reduced berry, and bunch weight and yield. Sugar concentration was reduced, and phenolic concentration increased when less water was applied, but anthocyanin concentration was unaffected. Although irrigation was returned to the standard practice (Partial Rootzone Drying) in the following season yield was reduced by the deficit irrigation treatments. This reduction in yield was primarily caused by fewer bunches as a result of fewer shoots per vine (lower bud burst). The lower crop load on the vines that had received restricted irrigation post-veraison in the previous seasons resulted in higher sugar and anthocyanin concentrations in the fruit in the following season. Lighter pruning resulted in more, smaller bunches containing smaller berries. In both seasons the minimal pruning treatment delayed fruit maturity as measured by sugar accumulation. Post veraison water deficit has the potential to have a negative impact on yield and fruit composition during the current and following seasons.

## 5e. The effect of temperature and light before and after budburst on inflorescence morphology and flower number of Chardonnay (*Vitis vinifera* L.).

***Abstract***

The number of flowers present at anthesis represents the upper limit of the potential yield from a vineyard. Studies in controlled environment cabinets have suggested that high temperatures at budburst may reduce flower differentiation, which occurs at this time. It was not clear however if temperatures normally encountered in the field could impact on flower numbers. Plastic containers were used as small 'glass houses' to increase the temperature surrounding the buds in the field, open containers with holes cut in them were used as controls. Shade cloth and reflective foil were placed over the containers to alter the light intensity as well as the temperature. Buds were treated for 14 days before and 13 days after budburst and the temperature and light intensity were monitored adjacent to the buds. Before budburst, the closed containers increased the bud temperatures and reduced flower numbers per inflorescence. The clear and foil treatments resulted in similar flower numbers, however, the shading treatment increased flower numbers by approximately 13%. Before budburst, there was a significant but weak correlation between average temperature and flower number per inflorescence for both the basal and apical inflorescence. Average light intensity was not significantly correlated with flower number on either inflorescence, and did not improve the correlation when included with temperature in a multiple linear regression. After budburst, the flower numbers were decreased by the closed container but were unaffected by the shading/foil treatment. The correlation between the temperature and the apical inflorescence was maintained but the correlation between temperature and the basal inflorescence was no longer apparent.

These results suggest that temperatures encountered in the field at budburst can influence the number of flowers per inflorescence. Temperature however causes only a 15 to 25% variation in flower number. Light intensity, separate from its impact on temperature, does not appear to influence flower number. The effect of temperature on flower differentiation decreases as budburst advances.

## 5f. Within season bunch loss in a Chardonnay vineyard in the Murray Valley

### *Introduction*

In order to make reliable yield forecasts it is essential to have a sound idea of the number of bunches in a block. The experience of the DPI and CSIRO Crop Forecasting team has been that bunch numbers do not appear to remain constant during a season. When bunch numbers were measured and compared at 3 stages after bud-burst (six weeks after budburst, after fruit-set and prior to harvest), there was apparent loss of bunches during crop development. Although the trends evident in the data were strong, observations did not support any critical analysis of when, where and why bunches were lost. This difference is currently taken into account by using a bunch loss factor when a crop forecast is calculated.
In response to this gap in our knowledge of crop development, a trial was conducted with the goal of better understanding the development of bunches during the period from bud-burst to harvest.

This study had two objectives:-

- To quantify budburst and fruitfulness in a block of Chardonnay vines, at intervals between budburst and harvest.
- To account for differences in budburst and fruitfulness, within the season and the vine, by way of observation.

### *Methods and materials*

*Grapevine Measurements*

A modified form of the Merbein Bunch Count, a method published by Antcliff, May, Webster and Hawkes (1972) was adopted for the study. The method involves non-destructive observations of the growth arising from the nodes of 1 year old, mature shoots, and other verdant tissue on grapevines. This is done by recording integer values for the observed combinations of bud-burst and fruitfulness at node positions.
The modifications to the original MBC method in this study where;

- Observations were made of nodes on canes arising from randomly positioned 20cm long, transverse segments of vine canopy, rather than whole vines
- Node positions were numbered in acropetal order, with node position 1 being the first of the two accessory buds at the base of canes, rather than the first node position clear of these.
- Shoots from accessory buds of canes and spurs, and true or apparent water shoots (i.e. shoots which do not arise from canes, or spurs), were not considered to be "extras". These shoots were not set apart from those that apparently arose from true canes and spurs.
- An additional MBC integer code was used to describe shoots that had burst, but were insufficiently developed to determine their fruitfulness. These observations were treated as missing values in the analysis of node fruitfulness.

*Grapevine Sampling*

In mid-August 2002 forty, 20 cm long segments were randomly positioned within a block of Chardonnay vines located at DPI, Mildura. The segment boundaries were marked and the canes arising in each segment were marked and allocated an identifying number. A random sub-sample of these canes was additionally marked to provide a population of canes that could be used to monitor the progress of bud-burst prior to conduct of the first MBC. The total number of nodes on this sub-sample of canes and the number which had burst, was recorded on 4 dates between the 11$^{th}$ and 20$^{th}$ of September. These observations suggested that budburst commenced on the 9$^{th}$ of September, and that by the 20$^{th}$ of September 35% of all buds on marked canes had burst. The 7$^{th}$ of October 2002 (one month after the onset of budburst) was chosen as the date for commencement of the first Merbein Bunch Count (MBC). At the first MBC, 58.7% of nodes on these canes had burst.

At the first MBC bud-burst and fruitfulness were recorded for all nodes on all marked canes. Any shoot or cane not marked in the preliminary bud-burst assessments was marked and its MBC data was recorded. Subsequent MBC's were made on the 28$^{th}$ October 2002 (flowering 90% complete), 2$^{nd}$ December 2002 (after fruit set) and 2$^{nd}$ of February 2003 (2 days prior to harvest). During each MBC, changes in the bud-burst and fruitfulness of nodes from the previous assessment were noted and comments regarding the apparent cause of the change were recorded. For the final MBC, whole canes and shoots were cut from the vine, and MBC observations were recorded in the laboratory. All bunches were individually weighed. Photographic records were made where possible.

*Data Analysis*

All data was analysed using Genstat® v.6.1 statistical software. Bud-burst data was analysed using Generalised Linear Mixed Models, with binomial distribution and logit link function. Bunch count data was analysed using REML (Residual maximum likelihood). Observations that were noted as errors during the trial were excluded from bud-burst and bunch count analysis. Bunch count analysis was restricted to observations of nodes that had burst. This was because these observations best represent the population of living, potentially productive shoots.
Bunches at node positions 1 to 6 represented more than 95% of the sampled population (data not presented). Analysis was restricted to these nodes.

## *Results and discussion*

Percentage bud-burst was significantly higher on the first two dates than on the final two dates at node positions 1 and 2 (Table 1). All node positions were observed to have a lower percentage of burst buds at each subsequent date. This suggests that there was significant loss of shoots at basal node positions (node positions 1, 2 and 3) in the period before flowering was complete.

Table 1. Effect of assessment-date on percentage bud-burst (nodes 1 to 6) at 4 times during the season; 1 month after bud burst (07-Oct-01), 90% flowering (28-Oct-01), 100% fruit-set (02-Dec-01), 2 days prior to harvest (02-Feb-02). Back transformed means.

| | Node Position | | | | | |
|---|---|---|---|---|---|---|
| Date | **1** | **2** | **3** | **4** | **5** | **6** |
| **07-Oct-01** | 24.92[a] | 54.79[a] | 59.26[a] | 55.99[a] | 60.61[a] | 68.33[a] |
| **28-Oct-01** | 24.03[a] | 53.57[a] | 58.10[a] | 57.53[a] | 58.63[a] | 67.43[a] |
| **02-Dec-01** | 20.32[b] | 46.72[b] | 51.06[b] | 51.96[a] | 55.65[a] | 66.69[a] |
| **02-Feb-02** | 18.99[b] | 41.84[b] | 48.74[b] | 50.11[a] | 52.37[a] | 62.80[a] |

*Letters in superscript denote significance between back-transformed means (Student-t probability < 0.05) of the comparison of differences between dates within a column.

There was significant loss of bunches in the period between the first and second assessments but thereafter bunch numbers remained stable (Figure 2). The loss was observed to be associated with the death of whole shoots (Figure 1) and to a lesser extent the death of individual bunches on otherwise sound shoots. The average percentage bunch loss after the initial count was 18.0% (Table 2).

Table 2. Total number of bunches counted at four stages after bud-burst (1 month after bud burst, 90% flowering, 100% fruit set, 2 days prior to harvest), and the percentage bunch loss between the initial bunch count and each subsequent count.

| **Stage** | **Total bunch count** | **Bunch loss (%)** |
|---|---|---|
| 1 month after bud burst | 870 | |
| 90% flowering | 704 | 19 |
| 100% fruit-set | 745 | 14 |
| 2 days prior to harvest | 679 | 22 |
| **Average** | | 18 |




Figure 1. Dead shoots on basal nodes of Chardonnay vines. A) Dead shoots (approx. 14 mm long) at node position three of a cane; B) dead shots on nodes at node positions two and three of a cane.

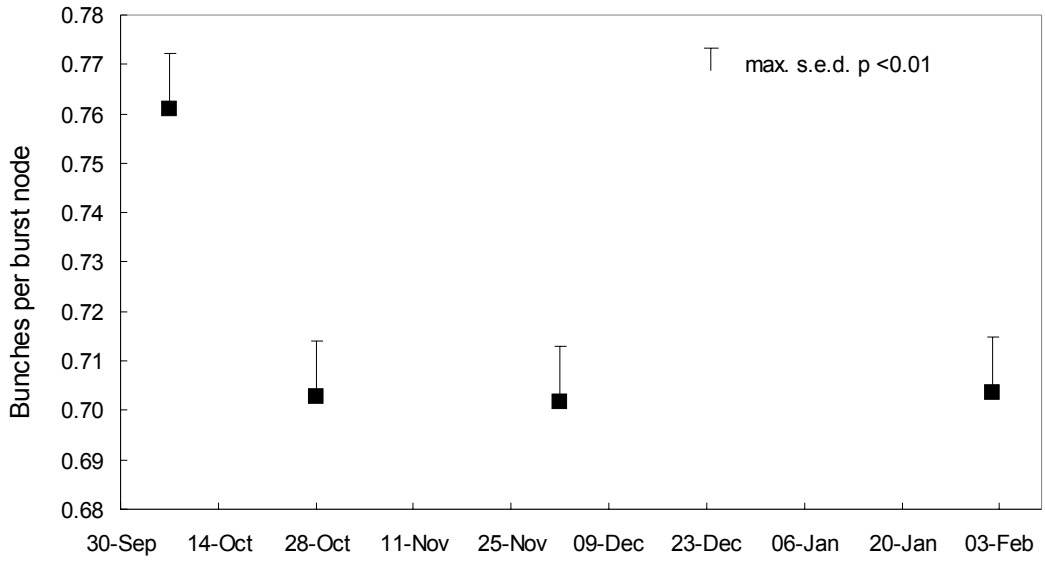



Figure 2. Average number of bunches per burst node at four stages after bud-burst (1 month after bud burst, 90% flowering, 100% fruit set, 2 days prior to harvest).

Determination of the cause, or causes, of the observed bunch loss during the trial is not possible from the data. It is, however reasonable to speculate that the apparent shoot and bunch necrosis was caused by environmental, physiological or pathological effects, or a combination of effects. Experimental error may also have contributed. A possible physiological cause could be the existence of a feedback/response mechanism that operates to create a balance between the vine's crop potential, and its potential to bring the crop to maturity. The vine may shed bunches which it doesn't have the resources to ripen. Alternatively, the shoots and bunches which died may have arisen from buds which were poorly exposed or underdeveloped in the season in which they were initiated. Pathological infection of buds is also a possible explanation for the loss of shoots and bunches. It is also possible that the act of counting bunches in the canopy caused tissue damage that led to shoot and bunch loss.

*Bunch loss factor*

A bunch loss factor is calculated by expressing the mean bunch counts at a later part of the season as a ratio of bunch counts earlier in the season. When this ratio is calculated over number of seasons the mean can be used as an indicator of how much the crop early in the season can be expected to differ from counts at harvest. This is important because bunch counts are the best indicator of yield, and a crop forecasting method must predict final bunch counts from data collected early in the season.

## *Conclusion*

The loss in bunches between dormancy assessments of bud fruitfulness and spring Merbein Bunch Counts has been observed consistently in Sunraysia grown Chardonnay in the previous crop forecasting project. Bunch abortion during the first couple of weeks after bud burst appears to occur. The cause of this loss in bunch numbers in Chardonnay is unknown. A general recommendation for the use of a general bunch loss factor in the yield forecasting of Chardonnay

vineyards in Sunrayisa is unwise, without good evidence that the phenomenon exists in vineyards in all seasons.

### *Reference*

Antcliff, A.J., May, P., Webster, W.J. and Hawkes, J. (1972). The Merbein bunch count, a method to analyse the performance of grapevines. HortScience 7(2), pp196-197.

## 5g. Response of Shiraz grown in Sunraysia to pruning and thinning treatments

***Background***

Crop control treatments were superimposed on an established pruning trial on a commercial property in December 2001. The established pruning treatments were spur pruning, mechanical hedging (the commercial standard) and minimal pruning. Crop removal treatments involved random selection of bunches to remove either one in five or one in three bunches. The experimental layout was a randomized, split plot design with pruning treatments as main plots and thinning treatments as subplots. In total there were six, eight vine replicates. The vines were drip irrigated with an RDI stress period applied after fruit set. Detailed assessment of crop development, fruit maturation and berry quality were made. Small-scale wine lots were produced from all treatments in each season.

***Spring assessment of inflorescence characteristics***

*Inflorescence length*

Pruning and season had highly significant effects, but not thinning on inflorescence length (Table 1). None of the interactions except the pruning x thinning x season were significant. Compared to spur pruning, mechanical and minimal pruning treatments had 9% and 23% shorter inflorescences. Bunch lengths were shortest in season 2003. Because the thinning treatments were applied after fruit set in year 1 (season 2002) a separate analysis was performed for the latter two seasons. While both pruning and season effects remained highly significant there was no effect of thinning and all interactions were not significant.

Table 1. Effect of pruning (spur, mechanical and minimal) and thinning treatments on inflorescence length over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 98.2 | 130.5 | 140.7 | 134.1 | 109.3 | 109.9 | 89.7 | 96.8 | 103 | 112.5b |
| 2002-2003 | 115.0 | 108.9 | 115.7 | 98.9 | 104.7 | 101.8 | 86.2 | 82.1 | 75.5 | 98.8a |
| 2003-2004 | 124.7 | 159.3 | 128.1 | 116.4 | 118.5 | 129.7 | 105.1 | 118.6 | 111.7 | 123.6c |
| Thinning mean | 112.6 | 132.9 | 128.2 | 116.5 | 110.9 | 113.8 | 93.7 | 99.2 | 96.7 | |
| Pruning mean | 124.6c | | | 113.7b | | | 96.5a | | | |

*LSD for the significant PxTxY was 20.6*

*Inflorescence length with branches*

Pruning and season had highly significant effects, but not thinning on the length of the inflorescence with branches (Table 2). The pruning x year and the pruning x thinning x season interactions were also significant. Compared to spur pruning, mechanical and minimal pruning treatments had 8% and 27% narrower inflorescences. Bunch widths were narrowest in 2004 and widest in 2002. Because the thinning treatments were applied after fruit set in year 1 (season 2002) a separate analysis was performed for the latter two seasons. While both pruning and season effects remained highly significant there was no effect of thinning and all interactions were not significant.

Table 2. Effect of pruning (spur, mechanical and minimal) and thinning treatments on the length of inflorescence with branches over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 63.2 | 83.3 | 100.1 | 93.1 | 83.8 | 93.1 | 61.4 | 64.6 | 59.8 | 76.0c |
| 2002-2003 | 67.6 | 67.4 | 68.7 | 56.4 | 64.2 | 56.4 | 51.8 | 48.0 | 51.4 | 59.5b |
| 2003-2004 | 52.6 | 70.9 | 55.1 | 46.3 | 48.8 | 46.3 | 38.7 | 41.4 | 41.8 | 49.5a |
| Thinning mean | 61.1 | 73.9 | 74.6 | 65.3 | 65.6 | 61.5 | 50.7 | 51.4 | 51.0 | |
| Pruning mean | 69.9c | | | 64.1b | | | 51.0a | | | |

*LSD's for the significant PxY and PxTxY interactions were 6.3 and 11.8 respectively*

*Branches per inflorescence*

Pruning, thinning and season had significant effects branches per inflorescence (Table 3). The pruning x year, thinning x year and the pruning x thinning x season interactions were also significant. Compared to spur pruning, mechanical and minimal pruning treatments had 6% and 12% fewer inflorescence branches. Branch numbers were lowest in season 2003. Because the thinning treatments were applied after fruit set in year 1 (season 2002) a separate analysis was performed for the latter two seasons. Apart from the significant seasonal effect, pruning, thinning and all interactions were not significant.

Table 3. Effect of pruning (spur, mechanical and minimal) and thinning treatments on branches per inflorescence over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 14.5 | 16.3 | 26.1 | 17.8 | 14.6 | 16.1 | 13.9 | 11.5 | 16.8 | 16.4b |
| 2002-2003 | 15.2 | 15.3 | 15.8 | 14.0 | 15.3 | 16.3 | 14.1 | 13.9 | 15.3 | 15.0a |
| 2003-2004 | 16.3 | 17.2 | 18.6 | 16.7 | 17.6 | 18.2 | 17.4 | 17.4 | 16.7 | 17.4b |
| Thinning mean | 15.3b | 16.3c | 20.2d | 16.2c | 15.8bc | 16.9c | 15.1b | 14.3a | 16.3c | |
| Pruning mean | 17.3b | | | 16.3ab | | | 15.2a | | | |

*LSD's for the significant PxY, Tx Y and PxTxY interactions were 2.0, 1.8, 3.2*

*Flowers per inflorescence*

There were no significant effects of pruning or thinning but a highly significant effect of season on flower number per inflorescence (Table 4). None of the interactions except the pruning x thinning x season were significant. Flower numbers were lowest in season 2003 and highest in 2002. Because the thinning treatments were applied after fruit set in year 1 (season 2002) a separate analysis was performed for the latter two seasons. Again there were no significant pruning or thinning effects and all interactions were not significant.

Table 4. Effect of pruning (spur, mechanical and minimal) and thinning treatments on flowers per inflorescence over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 198.0 | 313.8 | 398.3 | 353.1 | 334.5 | 255.8 | 312.7 | 302.5 | 381.6 | 316.7c |
| 2002-2003 | 155.8 | 168.9 | 166.7 | 155.2 | 166.0 | 173.5 | 173.5 | 185.3 | 169.4 | 168.3a |
| 2003-2004 | 235.7 | 253.2 | 268.9 | 247.9 | 259.3 | 264.6 | 252.8 | 303.7 | 276.4 | 262.5b |
| Thinning mean | 196.5 | 245.3 | 278 | 252.1 | 253.3 | 231.3 | 246.4 | 263.8 | 275.8 | |
| Pruning mean | 239.9 | | | 245.5 | | | 262.0 | | | 249.1 |

*LSD for the significant PxTxY interaction was 66.9*

*Dry weight per flower*

There were significant effects of pruning and season but not thinning on individual flower weight (Table 5). None of the interactions were significant. Flower weights were lowest in season 2002. Compared to spur pruned vines, the dry weight of flowers on mechanical and minimal pruned vines were 21% and 40% smaller respectively. Because the thinning treatments were applied after fruit set in year 1 (season 2002) a separate analysis was performed for the latter two seasons. In this case there was no significant difference between seasons but a significant pruning and pruning x year interaction.

Table 5. Effect of pruning (spur, mechanical and minimal) and thinning treatments on dry flower weight (mg/flower) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 1.154 | 1.069 | 1.033 | 0.664 | 0.799 | 1.035 | 0.551 | 0.534 | 0.584 | 0.825a |
| 2002-2003 | 1.986 | 1.679 | 1.675 | 1.297 | 1.408 | 1.206 | 1.048 | 0.912 | 0.933 | 1.349b |
| 2003-2004 | 1.617 | 1.420 | 1.673 | 1.227 | 1.446 | 1.464 | 1.179 | 1.031 | 1.210 | 1.363b |
| Thinning mean | 1.586 | 1.389 | 1.461 | 1.063 | 1.218 | 1.235 | 0.926 | 0.825 | 0.909 | |
| Pruning mean | 1.479c | | | 1.172b | | | 0.887a | | | 1.179 |

*Fruit set (%)*

Pruning, thinning and season had significant effects on % fruit set (Table 6). The pruning x year, thinning x year and pruning x thinning x year interactions were also significant. Compared to spur pruning, mechanical and minimal pruning treatments had 20% and 39% lower fruit set. Fruit set was highest in 2003. Thinning treatments tended to have lower fruit set than the control except for the minimal pruned, 1 in 3 removal treatment. Because the thinning treatments were applied after fruit set in year 1 (season 2002) a separate analysis was performed for the latter two seasons. While both pruning and season effects remained highly significant there was no effect of thinning and all interactions were not significant.

Table 6. Effect of pruning (spur, mechanical and minimal) and thinning treatments on %fruit set (ie. berries set /flower number) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 30.9 | 22.4 | 18.2 | 16.1 | 12.0 | 18.1 | 11.3 | 4.0 | 23.3 | 17.4a |
| 2002-2003 | 51.9 | 30.5 | 31.2 | 42.8 | 35.3 | 34.7 | 28.8 | 31.3 | 34.1 | 35.6c |
| 2003-2004 | 32.9 | 28.0 | 27.0 | 16.9 | 20.5 | 20.4 | 16.2 | 8.5 | 9.0 | 19.9b |
| Thinning mean | 38.6d | 27.0c | 25.5bc | 25.3bc | 22.6bc | 24.4bc | 18.7ab | 14.6a | 22.2bc | |
| Pruning mean | 30.3c | | | 24.1b | | | 18.5a | | | |

*LSD's for the significant PxY, TxY and PxTxY interactions were 5.0, 5.5, and 9.1 respectively.*

***Yield components and bunch architecture at harvest***

*Bunch number per metre*

Pruning and thinning treatments, year and all interactions had highly significant effects on bunch number (Table 7). Compared to spur pruning, control vines of mechanical and minimal pruning treatments had 1.7- and 3.8-fold more bunches respectively over the seasons. There were very large seasonal effects with seasons 2003 and 2004 having the lowest and highest bunch numbers respectively. However the magnitude of the response varied for control vines of each pruning system, ie. 2.1-, 3.3- and 7.4-fold differences for spur, mechanical and minimal pruned vines respectively. While both the 1 in 5 and 1 in 3 thinning treatments reduced bunch numbers in all pruning treatments (ie. by 20% and 35% for spur, 23% and 24% for mechanical and 22% and 27% for minimal) over the seasons the significant PxT and PxTxY interactions indicate complex responses due mainly to the higher bunch numbers with the 1 in 3 treatment in 2003, the low bunch year. This response is most likely due to carryover effects of the treatment on either budburst (shoots per node) or fruitfulness (bunches per shoot) in 2002. As a consequence the 1in 3 treatment gave stable bunch numbers with spur pruning and reduced the seasonal variation with mechanical and minimal pruning.

Table 7. Effect of pruning (spur, mechanical and minimal) and thinning treatments on bunch number per metre of row over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | Yearly Mean |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 66.2 | 60.5 | 47.5 | 127.2 | 99.3 | 106.2 | 282.8 | 233.0 | 176.8 | 133.3b |
| 2002-2003 | 49.7 | 40.2 | 45.7 | 56.0 | 54.8 | 59.5 | 66.0 | 66.8 | 70.2 | 56.5a |
| 2003-2004 | 105.7 | 77.7 | 51.0 | 187.2 | 130.8 | 114.7 | 489.7 | 351.4 | 230.8 | 193.2c |
| Thinning mean | 73.8b | 59.4ba | 48.1a | 123.4d | 95.0c | 93.4c | 279.5g | 217.1f | 159.3e | |
| Pruning mean | | 60.4a | | | 104.0b | | | 218.6c | | |

*Interaction LSD's (p=0.05) were 19.2, 17.4, 30.9 for PxY, TxY and PxTxY respectively*

*Bunch weight*

There were no significant effects of thinning treatments or any interactions with thinning on bunch weight. Pruning and year and the pruning x year interaction had highly significant effects on bunch weight (Table 8). Compared to spur pruning, vines of mechanical and minimal pruning treatments produced smaller bunches (ie. 34% and 58% respectively over the seasons). The large seasonal effect and the significant PxY is largely due to development of bigger bunches on mechanical (1.5) and minimal (2-fold) pruned vines in the low bunch year (Table 7), season 2003.

Table 8. Effect of pruning (spur, mechanical and minimal) and thinning treatments on mean bunch weight (g) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | Yearly Mean |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 110.2 | 106.6 | 114.2 | 59.7 | 61.5 | 60.6 | 37.8 | 33.9 | 36.0 | 68.9b |
| 2002-2003 | 107.3 | 105.8 | 98.3 | 91.3 | 75.2 | 81.4 | 60.9 | 57.9 | 59.6 | 82.0c |
| 2003-2004 | 82.1 | 84.0 | 88.8 | 57.2 | 54.2 | 58.8 | 26.9 | 30.1 | 30.0 | 56.9a |
| Pruning mean | 99.7c | | | 66.7b | | | 41.5a | | | |

*Interaction LSD (p=0.05) for PxY was 9.9*

*Berry weight*

Pruning and thinning treatments and year had highly significant effects on mean berry weight (Table 9). While there were no significant pruning x thinning interactions, pruning x year and

thinning x year interactions were significant due to differences in magnitude of the responses. Compared to spur pruning, control vines of mechanical and minimal pruning treatments had 6% and 24% smaller berries. There were very large seasonal effects (30%) with seasons 2003 and 2004 having the largest and smallest berries respectively indicating some compensation for differences in bunch number (Table 1). Berry weights were increased by up to 7% by thinning, except for the mechanical, 1 in 5 pruning treatment again indicating post set compensation for differences in bunch number.

Table 9. Effect of pruning (spur, mechanical and minimal) and thinning treatments on mean berry weight (g) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 1.331 | 1.463 | 1.473 | 1.221 | 1.226 | 1.283 | 0.949 | 1.068 | 1.117 | 1.237b |
| 2002-2003 | 1.445 | 1.425 | 1.537 | 1.390 | 1.324 | 1.409 | 1.125 | 1.113 | 1.112 | 1.320c |
| 2003-2004 | 1.091 | 1.209 | 1.128 | 1.013 | 1.044 | 1.100 | 0.861 | 0.926 | 0.855 | 1.025a |
| Thinning mean | 1.289f | 1.365g | 1.379g | 1.208e | 1.198d | 1.264f | 0.978a | 1.036c | 1.028b | |
| Pruning mean | 1.345c | | | 1.223b | | | 1.013a | | | |

*Berry number per bunch*

Pruning and thinning treatments and year had significant effects on mean berry number per bunch (Table 10). While there were no significant pruning x thinning interaction, the pruning x year interaction was significant. Compared to spur pruning, control vines of mechanical and minimal pruning treatments had 27% and 46% fewer berries per bunch. There were significant seasonal and year x pruning effects due to bunches of mechanical and minimal pruning treatments having more berries in season 2003, possibly due to higher %set. Although just significant, the thinning effect was small and associated with fewer berries on bunches of the 1 in five treatment, particularly with spur and hedge pruning.

Table 10. Effect of pruning (spur, mechanical and minimal) and thinning treatments on calculated berry number per bunch over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 81.0 | 73.6 | 79.0 | 49.9 | 50.0 | 51.3 | 40.3 | 29.4 | 32.5 | 54.1a |
| 2002-2003 | 76.8 | 65.0 | 68.7 | 68.5 | 56.8 | 57.9 | 50.4 | 52.0 | 54.5 | 61.2b |
| 2003-2004 | 72.6 | 69.2 | 83.3 | 55.0 | 52.3 | 52.9 | 34.3 | 31.8 | 35.4 | 54.1a |
| Thinning mean | 76.8e | 69.3d | 77.0e | 57.8c | 53.0b | 54.0bc | 41.7a | 37.7a | 40.8a | |
| Pruning mean | 74.3c | | | 54.9b | | | 40.1a | | | |

*Bunch length*

Pruning and season had highly significant effects on bunch length while thinning effects were just significant (p=0.046) (Table 11). None of the interactions were significant. The small effect showing development of shorter bunches with thinning treatments may have been due to selective removal of larger bunches when treatments were applied across all pruning systems. Compared to spur pruning, control vines of mechanical and minimal pruning treatments had 7% and 23% shorter bunches. Bunch lengths were shortest in season 2003.

Table 11. Effect of pruning (spur, mechanical and minimal) and thinning treatments on bunch length (mm) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 207.0 | 200.5 | 193.7 | 187.3 | 170.7 | 181.9 | 153.7 | 141.1 | 147.9 | 176.0b |
| 2002-2003 | 155.1 | 155.2 | 150.9 | 147.8 | 127.4 | 152.7 | 117.5 | 107.5 | 118.0 | 136.9a |
| 2003-2004 | 208.1 | 155.1 | 186.2 | 200.0 | 187.5 | 184.3 | 169.7 | 154.4 | 157.4 | 182.6b |
| Thinning mean | 190.1 | 183.7 | 177.0 | 178.4 | 161.9 | 173.0 | 147.0 | 134.3 | 141.1 | |
| Pruning mean | 183.6c | | | 171.1b | | | 140.8a | | | |

*Number of branches per bunch*

Pruning and season had highly significant effects on the number of branches per bunch (Table 12). None of the interactions were significant. Compared to spur pruning, control vines of

mechanical and minimal pruning treatments had 14% and 25% fewer branches per bunch. Bunches in the highest number of branches in 2004 and the least in 2003.

Table 12. Effect of pruning (spur, mechanical and minimal) and thinning treatments on the number of branches per bunch over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 17.5 | 17.2 | 17.1 | 14.7 | 13.6 | 13.2 | 12.1 | 11.2 | 11.3 | 14.2b |
| 2002-2003 | 12.8 | 13.6 | 12.7 | 12.5 | 11.6 | 10.9 | 10.1 | 10.3 | 10.8 | 11.7a |
| 2003-2004 | 19.8 | 18.5 | 19.4 | 18.0 | 16.6 | 16.5 | 16.8 | 14.7 | 14.4 | 17.2b |
| Thinning mean | 16.7 | 16.4 | 16.4 | 15.1 | 13.9 | 13.5 | 13.0 | 12.1 | 12.2 | |
| Pruning mean | 16.5c | | | 14.2b | | | 12.4a | | | |

*Bunch compactness*

Pruning and season had highly significant effects on bunch compaction (Table 13). Pruning x year and pruning x year x thinning interactions were also significant. Compared to spur pruning, mechanical and minimal pruning treatments had 21% and 28% less compact bunches. Compaction was the highest (84%) in season 2003, presumably due to compensation effects associated with low bunch numbers and the shorter bunch structure. The significant PxTxY interactions were largely associated with the larger response of mechanical and minimal pruned vines in season 2003.

Table 13. Effect of pruning (spur, mechanical and minimal) and thinning treatments on bunch compactness (bunch weight /bunch length, g/mm) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | .549 | .498 | .432 | .330 | .295 | .264 | .225 | .229 | .212 | .337a |
| 2002-2003 | .701 | .693 | .628 | .735 | .678 | .525 | .538 | .559 | .517 | .619b |
| 2003-2004 | .554 | .460 | .391 | .331 | .317 | .409 | .248 | .234 | .242 | .354a |
| Thinning mean | .601 | .550 | .484 | .465 | .430 | .399 | .337 | .340 | .324 | |
| Pruning mean | .545c | | | .431b | | | .334a | | | |

*Interaction LSD's (p=0.05) for PxY and PxTxY were 0.081 and 0.129 respectively*

*Yield per metre*

Pruning and thinning treatments, year and pruning x year and thinning x year interactions had highly significant effects on bunch number (Table 14). Effects of the pruning x thinning were not significant. Compared to spur pruning, control vines of mechanical and minimal pruning treatments had 9% and 23% higher yields over the seasons. There were very large seasonal effects with seasons 2003 and 2004 having the lowest and highest yields respectively. However the magnitude of the response varied for control vines of each pruning system, ie. 0.6, 2.1- and 2.9 fold differences for spur, mechanical and minimal pruned vines respectively. While both the 1 in 5 and 1 in 3 thinning treatments reduced yields in all pruning treatments (ie. by 18% and 35% for spur, 24% and 22% for mechanical and 23% and 33% for minimal) over the seasons the significant TxY interactions indicate complex responses due mainly to lack of a response in the low bunch year, 2003.

A viable economic yield from the vineyard would be 20 $tha^{-1}$ (7.3 kg $m^{-1}$).The results quite clearly indicate that none of the treatments produced an adequate yield in 2003, ie the season when bunch numbers were low. In that season if the low fruitfulness had been predicted (eg. by modeling techniques such as described by VineLOGIC) changes to management, particularly of water could have been implemented to maximise retention and development of bunch primordia and after budburst, bunch development and fruit set. The results also clearly show that the minimal pruned vines were more prone to the conditions that led to low fruitfulness and probably required different approaches to irrigation management to reduce stress between budburst and fruit set and during the post set, RDI period. The potential to regulate yields of lightly pruned vines by bunch thinning was demonstrated in seasons 2002 and 2004 for both mechanical and minimal pruned vines.

Table 14. Effect of pruning (spur, mechnical and minimal) and thinning treatments on yield per metre (kg) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 7.04 | 6.48 | 5.19 | 7.26 | 6.01 | 6.40 | 10.59 | 7.93 | 6.32 | 7.02b |
| 2002-2003 | 5.32 | 4.14 | 3.89 | 5.08 | 4.12 | 4.83 | 3.87 | 3.81 | 4.09 | 4.35a |
| 2003-2004 | 8.56 | 6.44 | 4.51 | 10.47 | 7.10 | 6.61 | 11.32 | 8.14 | 6.73 | 7.77c |
| Thinning mean | 6.97c | 5.69b | 4.53a | 7.60d | 5.74b | 5.95b | 8.59e | 6.63c | 5.71b | |
| Pruning mean | 5.73a | | | 6.43b | | | 6.98b | | | |

*Interaction LSD's (p=0.05) were 0.99 and 0.95 for PxY and TxY respectively*

***Berry characteristics***

*Seeds*

Berries were dissected to determine seed number and fresh and dry weights of berry components (ie. seed, flesh and skin) in seasons 2003 and 2004. While there were no significant pruning or thinning effects on seed numbers there was a significant year effect with lower seed numbers in 2004 (Table 15). There were however significant pruning effects on total wet (data not presented) and dry seed weight (Table 16) but no effect of thinning or season. These results indicate that minimal pruning produced berries with a similar number of smaller seeds (13%).

Table 15. Effect of pruning (spur, mechnical and minimal) and thinning treatments on seed number over two seasons (2002/2003- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2002-2003 | 2.47 | 2.50 | 2.22 | 2.38 | 2.23 | 2.18 | 2.15 | 2.25 | 1.98 | 2.26b |
| 2003-2004 | 1.85 | 1.98 | 1.85 | 2.03 | 1.95 | 2.12 | 1.60 | 2.08 | 1.85 | 1.92a |
| Thinning mean | 2.16 | 2.24 | 2.03 | 2.21 | 2.09 | 2.15 | 1.88 | 2.17 | 1.92 | |
| Pruning mean | 2.25 | | | 1.99 | | | 2.14 | | | |

*Table 16*. Effect of pruning (spur, mechnical and minimal) and thinning treatments on dry seed weight per berry over two seasons (2002/2003- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2002-2003 | .520 | .545 | .508 | .531 | .510 | .490 | .480 | .490 | .441 | .503 |
| 2003-2004 | .481 | .504 | .480 | .508 | .519 | .545 | .358 | .458 | .440 | .477 |
| Thinning mean | .501 | .525 | .494 | .519 | .514 | .517 | .419 | .474 | .440 | |
| Pruning mean | .506b | | | .517b | | | .442a | | | |

*Flesh*

There were significant pruning and seasonal effects but not thinning on both wet and dry flesh weight of berries (Table 17a,b). Compared to spur pruning, mechanical and minimal pruned berries had lower 10% and 22 % lower wet flesh weights and 13% and 24% lower dry fresh weights respectively. Both the fresh and dry flesh weights were 24% lower in 2004 compared to

2003. There was no effect of pruning or season on the ratio of dry to fresh weight (ie. 0.24) indicating that the differences in dry weight reflected differences in berry size rather than cellular structure or sugar contents.

Table 17. Effect of pruning (spur, mechanical and minimal) and thinning treatments on wet (a) and dry (b) flesh weight per 10 berries over two seasons (2002/2003- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| **(a)** | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2002-2003 | 10.85 | 10.78 | 10.75 | 10.41 | 9.99 | 9.75 | 8.92 | 8.23 | 8.12 | 9.76b |
| 2003-2004 | 7.74 | 7.31 | 7.24 | 5.99 | 6.41 | 6.54 | 5.33 | 5.86 | 6.08 | 6.50a |
| Thinning mean | 9.30 | 9.05 | 8.99 | 8.20 | 8.20 | 8.15 | 7.13 | 7.05 | 7.10 | |
| Pruning mean | 9.11c | | | 8.18b | | | 7.09a | | | |

| **(b)** | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2002-2003 | 2.50 | 2.49 | 2.48 | 2.35 | 2.25 | 2.24 | 2.09 | 1.96 | 1.85 | 2.25b |
| 2003-2004 | 1.94 | 1.90 | 1.88 | 1.49 | 1.59 | 1.61 | 1.23 | 1.38 | 1.55 | 1.62a |
| Thinning mean | 2.22 | 2.19 | 2.18 | 1.92 | 1.92 | 1.93 | 1.66 | 1.67 | 1.70 | |
| Pruning mean | 2.20c | | | 1.92b | | | 1.68a | | | |

*Skin*

There were significant pruning and seasonal effects but not thinning on both wet and dry skin weight of berries (Table 18 a, b). Compared to spur pruning berries from mechanical pruning had similar wet and dry skin weights while minimal pruned vines had 21% and 14 % lower wet and dry skin weights respectively. Both flesh weights were lower in 2004 compared to 2003. There was no effect of pruning or season on the ratio of dry to fresh skin weight (ie. 0.30) indicating that the differences in dry weight reflected differences in berry size rather than cellular structure or sugar content.

Table 18. Effect of pruning (spur, mechnical and minimal) and thinning treatments on wet (a) and dry (b) skin weight of 10 berries over two seasons (2002/2003- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| **(a)** | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2002-2003 | 2.93 | 2.55 | 2.66 | 2.86 | 2.60 | 2.46 | 2.20 | 2.29 | 2.35 | 2.54b |
| 2003-2004 | 2.49 | 2.52 | 2.25 | 2.97 | 2.46 | 2.35 | 1.54 | 1.90 | 1.97 | 2.27a |
| Thinning mean | 2.71 | 2.54 | 2.46 | 2.91 | 2.53 | 2.40 | 1.87 | 2.09 | 2.16 | |
| Pruning mean | 2.57b | | | 2.62b | | | 2.04a | | | |

| **(b)** | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2002-2003 | .876 | .836 | .755 | .851 | .805 | .675 | .796 | .719 | .806 | .791b |
| 2003-2004 | .725 | .713 | .697 | .828 | .720 | .664 | .473 | .554 | .618 | .666a |
| Thinning mean | .801 | .775 | .726 | .839 | .762 | .670 | .634 | .637 | .712 | |
| Pruning mean | .767b | | | .757b | | | .661a | | | |

*Skin:Flesh ratio*

There were no significant pruning and thinning effects on the ratio of the wet or dry skin:flesh ratios (Table 19) despite the significant effects of these treatments on berry weight (table 9). There was a significant seasonal effect with higher skin to flesh ratios in 2004 compared to 2003.

Table 19. Effect of pruning (spur, mechnical and minimal) and thinning treatments on the ratio of skin:flesh (wet and dry) over two seasons (2002/2003- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

**Ratio wet skin weight: wet flesh weight**

| | **Pruning** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | Yearly Mean |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2002-2003 | .273 | .238 | .247 | .278 | .260 | .260 | .247 | .282 | .289 | .264a |
| 2003-2004 | .334 | .360 | .320 | .513 | .397 | .372 | .319 | .342 | .342 | .366b |
| Thinning mean | .303 | .299 | .284 | .395 | .329 | .316 | .283 | .312 | .315 | |
| Pruning mean | .295 | | | .347 | | | .303 | | | |

**Ratio dry skin weight: dry flesh weight**

| | **Pruning** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | Yearly Mean |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2002-2003 | .350 | .336 | .313 | .362 | .358 | .301 | .381 | .367 | .435 | .352a |
| 2003-2004 | .373 | .376 | .371 | .556 | .453 | .412 | .384 | .401 | .400 | .411b |
| Thinning mean | .360 | .353 | .333 | .437 | .397 | .348 | .381 | .381 | .419 | |
| Pruning mean | .349 | | | .394 | | | .394 | | | |

***Yield component relationships***

*Spring measurements*

Significant correlations are shown to describe relationships between inflorescence measurements in spring and harvest measurements across all pruning, thinning and seasonal means (Table 20). The results show that bunch number was the main factor contributing to differences in yield across the treatments and seasons. Bunch number was negatively correlated with the length of the branched part of the inflorescence, flower weight, % set and at harvest, bunch weight, berry weight, berry number and bunch compactness and positively correlated with flower number. Total inflorescence length was positively linked to the length of the branched part of the inflorescence, branch number, flower number, flower weight and at harvest, bunch length and berry number. The length of the branch part of the inflorescence correlated positively with flower number, bunch weight, berry weight and berry number per bunch. The number of branches on the inflorescence correlated with flower number and at harvest, bunch length and the number of branches per bunch. Flower number was negatively correlated with flower weight, %

set, bunch weight and compaction and positively correlated with bunch length and yield. Flower weight was positively correlated with % set, bunch weight, berry weight, berry number, branch number and compaction. Fruit set (%) was negatively linked to yield but positively correlated with bunch weight, berry weight, berry number and compaction.

Table 20. Correlation matrix describing significant relationships between inflorescence measurements in spring and harvest measurements over pruning and thinning treatments and seasons (n=27, values in bold p<0.05, normal text p<.10 ).

| **All pruning** | **Bunch no.** | **IFL1** | **IFL2** | **Branch no.** | **Flower no.** | **Flower wt.** | **Set (%)** |
|---|---|---|---|---|---|---|---|
| **IFL1** | | | | | | | |
| **IFL2** | **-.43** | **.38** | | | | | |
| **Branch no.** | | **.64** | | | | | |
| **Flower no.** | .36 | **.42** | **.39** | **.48** | | | |
| **Flower wt.** | -.37 | .35 | | | **-.57** | | |
| **Set (%)** | **-.63** | | | | **-.74** | **.61** | |
| **Bunch wt.** | **-.77** | | **.48** | | -.32 | **.56** | **.65** |
| **Bun length** | | **.61** | | **.47** | **.42** | | |
| **Berry wt.** | **-.76** | | **.65** | | | .34 | **.58** |
| **Berry no.** | **-.74** | .37 | .35 | | | **.63** | **.66** |
| **Branches** | | | | **.52** | | .38 | |
| **Bun comp.** | **-.70** | | | | **-.76** | **.61** | **.88** |
| **Yield** | **.79** | | | | **.43** | | **-.57** |

Similar relationships to those described above are provided in Tables 21-23 for each pruning system, ie. over thinning treatments and seasons. For spur pruning bunch number was the only factor contributing to differences in yield over thinning treatments and seasons, accounting for 85% of the variation (Table 21). Bunch number was negatively correlated with bunch weight, berry weight and positively correlated with branches per bunch. Total inflorescence length was positively linked to flower number and negatively correlated with compaction. The length of the branch part of the inflorescence correlated positively with inflorescence branch number, bunch weight and berry weight but was negatively correlated with flower weight. The number of branches on the inflorescence correlated positively with flower number and negatively with % set and bunch compactness. Flower number was negatively correlated with flower weight, %set and bunch compactness. Flower weight was positively correlated with % set and compaction and negatively correlated with bunch length. Fruit set (%) was positively correlated with bunch compactness.

Table 21. Correlation matrix describing significant relationships between inflorescence measurements in spring and harvest measurements for spur pruning over thinning and seasons (n=9, values in bold p<0.05, normal text p<.10 ).

| Spur | Bunch no. | IFL1 | IFL2 | Branch no. | Flower no. | Flower wt. | Set (%) |
|---|---|---|---|---|---|---|---|
| **IFL1** | | | | | | | |
| **IFL2** | | | | | | | |
| **Branch no.** | | | **.69** | | | | |
| **Flower no.** | | .63 | **.67** | **.85** | | | |
| **Flower wt.** | | | -.63 | | **-.73** | | |
| **Set (%)** | | | | -.58 | **-.77** | **.79** | |
| **Bunch wt.** | -.65 | | .64 | | | | |
| **Bun length** | | | | | | **-.62** | |
| **Berry wt.** | **-.71** | | .65 | | | | |
| **Berry no.** | | | | | | | |
| **Branches** | **.68** | | | | | | |
| **Bun comp.** | | -.65 | | -.61 | **-.80** | **.58** | **.71** |
| **Yield** | **.92** | | | | | | |

For mechanical pruning bunch number was the only factor contributing to differences in yield over thinning treatments and seasons, accounting for 96% of the variation (Table 22). Bunch number was negatively correlated with % set, bunch weight, berry weight and compaction and positively correlated with inflorescence length, branch number, bunch length and branches per bunch. Total inflorescence length was positively linked to branch number, flower number, bunch length, branches per bunch and negatively correlated with %set, bunch weight, berry weight, berry number and bunch compactness. The length of the branched part of the inflorescence correlated negatively with flower weight. Branch number per inflorescence correlated negatively with bunch weight and berry weight and positively with bunch length and branches per bunch. The number of branches on the inflorescence correlated positively with flower number and negatively with % set and bunch compactness. Flower number was positively correlated with bunch length and negatively correlated with flower weight, %set, bunch weight, berry weight and bunch compactness. Fruit set (%) was positively correlated with bunch weight, berry weight, berry number, branches per bunch, and bunch compactness and negatively correlated with bunch length and yield.

Table 22. Correlation matrix describing significant relationships between inflorescence measurements in spring and harvest measurements for mechanical pruning over thinning and seasons (n=9, values in bold p<0.05, normal text p<.10 ).

| Mechanical | Bunch no. | IFL1 | IFL2 | Branch no. | Flower no. | Flower wt. | Set (%) |
|---|---|---|---|---|---|---|---|
| **IFL1** | .64 | | | | | | |
| **IFL2** | | | | | | | |
| **Branch no.** | .58 | **.85** | | | | | |
| **Flower no.** | .59 | **.74** | | | | | |
| **Flower wt.** | | | **-.85** | | **-.70** | | |
| **Set (%)** | **-.76** | **-.66** | | | **-.91** | | |
| **Bunch wt.** | **-.81** | **-.74** | | **-.67** | **-.77** | | **.92** |
| **Bun length** | **.91** | **.71** | | .65 | **.70** | | **-.81** |
| **Berry wt.** | **-.89** | **-.66** | | -.63 | **-.82** | | **.68** |
| **Berry no.** | | **-.65** | | | | | **.90** |
| **Branches** | **.92** | **.69** | | .62 | | | .63 |
| **Bun comp.** | **-.74** | **-.58** | | | **-.82** | | **.95** |
| **Yield** | **.98** | | | | | | -.64 |

For minimal pruning bunch number was the only factor contributing to differences in yield over thinning treatments and seasons, accounting for 86% of the variation (Table 23). Bunch number was negatively correlated with % set, bunch weight, berry weight, berry number and bunch compactness and positively correlated with inflorescence length, bunch length and branches per bunch. Total inflorescence length was positively linked to branch number, flower number, bunch length, branches per bunch and negatively correlated with %set, bunch weight, berry weight, berry number and bunch compactness. The length of the branched part of the inflorescence correlated negatively with branch number, flower weight and branches per bunch and positively with berry weight. The number of branches on the inflorescence correlated positively with flower weight and branches per bunch. Flower number was positively correlated with bunch length and negatively correlated with flower weight, %set, bunch weight, berry number and bunch compactness. Fruit set (%) was positively correlated with bunch weight, berry weight, berry number and compaction and negatively correlated with bunch length and yield.

Table 23. Correlation matrix describing significant relationships between inflorescence measurements in spring and harvest measurements for minimal pruning over thinning and seasons (n=9, values in bold p<0.05, normal text p<.10 ).

| Minimal | Bunch no. | IFL1 | IFL2 | Branch no. | Flower no. | Flower wt. | Set (%) |
|---|---|---|---|---|---|---|---|
| **IFL1** | **.71** | | | | | | |
| **IFL2** | | | | | | | |
| **Branch no.** | | .59 | **-.71** | | | | |
| **Flower no.** | | .65 | | | | | |
| **Flower wt.** | | | **-.94** | .58 | -.65 | | |
| **Set (%)** | **-.68** | **-.73** | | | | | |
| **Bunch wt.** | **-.87** | **-.87** | | | **-.77** | | **.85** |
| **Bun length** | **.90** | **.80** | | | **.70** | | **-.76** |
| **Berry wt.** | **-.83** | **-.70** | .58 | | | | **.67** |
| **Berry no.** | **-.72** | **-.85** | | | **-.86** | | **.86** |
| **Branches** | **.91** | **.75** | **-.68** | **.69** | | | |
| **Bun comp.** | **-.75** | **-.77** | | | **-.90** | | **.85** |
| **Yield** | **.93** | | | | | | **-.72** |

These results highlight the complex nature of issues involving crop development. They show that seasonal factors and treatment responses (pruning and thinning) have an influence on inflorescence development in spring with significant impacts on bunch architecture and yield components at harvest. While most of the relationships described were expected, the relationships in Table 20 between the length of the branched part of the inflorescence and berry weight; flower number and bunch compactness; and flower weight and % set indicate that many of the issues involving crop development, particularly with respect to inflorescence development in different seasons are poorly understood and rarely studied. Furthermore, relationships between spring and harvest measurements were different for each pruning system (Tables 21-23) indicating a need for ongoing research if seasonal and treatment responses are to be fully understood. For example inflorescence length, flower number and % set were linked to many of the harvest measurements with mechanical and minimal pruning but not with spur pruning over seasons and thinning treatments (Tables 21-23).

*Harvest measurements*

The correlations shown in Table 24 describe significant relationships between measurements made at harvest, although those relating to bunch number are described and discussed above (Table 20). Over the treatments and seasons bunch length was positively correlated with berry number per bunch, branches per bunch and yield. Bunch weight correlated positively with berry number, berry weight and compaction and negatively with yield. Berries per bunch correlated positively with berry weight, branch number, bunch compactness and negatively with yield. Berry weight correlated positively with compaction and negatively with yield. The number of branches per bunch correlated positively with yield. Bunch compactness was negatively correlated with yield.

Table 24. Correlation matrix describing significant relationships between harvest measurements over pruning, thinning and seasons (n=27, values in bold p<0.05, normal text p<.10 ).

| All pruning | Bunch no. | Bunch length | Bunch wt. | Berries /bun | Berry wt. | Branches /bun | Bunch Compact. |
|---|---|---|---|---|---|---|---|
| **Bun length** | | | | | | | |
| **Bunch wt.** | **-.77** | | | | | | |
| **Berry no.** | **-.74** | **.38** | **.94** | | | | |
| **Berry wt.** | **-.76** | | **.87** | **.70** | | | |
| **Branches** | | **.84** | | **.44** | | | |
| **Bun Comp.** | **-.70** | | **.76** | **.69** | **.70** | | |
| **Yield** | **.79** | **.47** | **-.51** | **-.42** | **-.62** | **.42** | **-.64** |

For spur pruned vines relationships between harvest measurements are described by the correlations in Table 25. Bunch length was positively correlated with berry number, the number of branches and yield. Bunch weight correlated positively with berry weight while berry weight was negatively correlated with the number of branches on a bunch. Branches per bunch was positively correlated with yield and negatively correlated with bunch compactness.

Table 25. Correlation matrix describing significant relationships between harvest measurements for spur pruned vines over thinning and seasons (n=9, values in bold p<0.05, normal text p<.10 ).

| Spur | Bunch no. | Bunch length | Bunch wt. | Berries /bun | Berry wt. | Branches /bun | Bunch Compact. |
|---|---|---|---|---|---|---|---|
| **Bun length** | | | | | | | |
| **Bunch wt** | -.65 | | | | | | |
| **Berry no.** | | .58 | | | | | |
| **Berry wt.** | **-.71** | | **.80** | | | | |
| **Branches** | **.68** | **.70** | | | **-.81** | | |
| **Bun Comp.** | | | | | | **-.81** | |
| **Yield** | **.92** | **.67** | | | | .64 | |

For mechanically pruned vines relationships between harvest measurements are described by the correlations in Table 26. Bunch length was positively correlated with the number of branches and yield and negatively correlated with bunch weight, berry number, berry weight and bunch compactness. Bunch weight correlated positively with berry number, berry weight and compaction and negatively with the number of branches on a bunch and yield. Berries per bunch correlated positively with bunch compactness. Berry weight correlated positively with compaction and yield and negatively with branch number. Branches per bunch was positively correlated with yield and negatively correlated with compaction. Bunch compactness correlated negatively with yield.

Table 26. Correlation matrix describing significant relationships between harvest measurements for mechanical pruning over thinning and seasons (n=9, values in bold p<0.05, normal text p<.10).

| Mechanical | Bunch no. | Bunch length | Bunch wt. | Berries /bun | Berry wt. | Branches /bun | Bunch Compact. |
|---|---|---|---|---|---|---|---|
| **Bun length** | **.91** | | | | | | |
| **Bunch wt** | **-.81** | **-.82** | | | | | |
| **Berry no.** | | -.58 | **.88** | | | | |
| **Berry wt.** | **-.89** | **-.80** | **.84** | | | | |
| **Branches** | **.92** | **.85** | **-.82** | | **-.97** | | |
| **Bun Comp.** | **-.74** | **-.85** | **.89** | **.86** | **.63** | -.58 | |
| **Yield** | **.98** | **.88** | **-.67** | | **.82** | **.88** | **-.64** |

For mechanically pruned vines relationships between harvest measurements are described by the correlations in Table 27. Bunch length was positively correlated with the number of branches and yield and negatively correlated with bunch weight, berry number, berry weight and bunch compactness. Bunch weight correlated positively with berry number, berry weight, branch number and bunch compactness and negatively with yield. Berries per bunch correlated positively with compaction and negatively with branch number and yield. Berry weight correlated positively with bunch compactness and negatively with branch number and yield. Branches per bunch was positively correlated with yield and negatively with bunch compactness. Bunch compactness correlated negatively with yield.

Table 27. Correlation matrix describing significant relationships between harvest measurements for minimal pruning over thinning and seasons (n=9, values in bold p<0.05, normal text p<.10 ).

| Minimal | Bunch no. | Bunch length | Bunch wt. | Berries /bun | Berry wt. | Branches /bun | Bunch Compact. |
|---|---|---|---|---|---|---|---|
| **Bun length** | **.91** | | | | | | |
| **Bunch wt** | **-.86** | **-.95** | | | | | |
| **Berry no.** | **-.72** | **-.83** | **.94** | | | | |
| **Berry wt.** | **-.83** | **-.83** | **.77** | | | | |
| **Branches** | **.91** | **.85** | **.79** | -.58 | **-.92** | | |
| **Bun Comp.** | **-.75** | **-.92** | **.95** | **.94** | .62 | -.60 | |
| **Yield** | **.93** | **.88** | **-.82** | **-.69** | **-.75** | **.73** | **-.80** |

The results for relationships between the various harvest measurements again highlight the complex nature of crop development and compensatory responses that can occur between seasons and treatments (ie. pruning and thinning) and further reinforce the need for studies to measure the full suite of variables required to fully understand crop development. For example there were many significant relationships between harvest variables with mechanical and minimal pruning (Tables 26 and 27) compared to spur pruning (Table 25). In particular, with the lighter pruning treatments yield was related not only to bunch number but also to bunch and berry weight.

***Fruit maturation***

Samples of berries collected over the maturation period were assessed for berry weight, total soluble solids, sugar per berry, pH, titratable acidity, total anthocyanins and phenolics. The main treatment effects (ie. pruning and thinning) are presented for each season in figures below.

*Berry weight (Figs.1 and 2)*
Berry weight over the maturation period is likely to be affected by fruit maturity (sugar content), seasonal climatic conditions and timing of irrigations as well as imposed treatment effects. Losses in berry weight of all pruning treatments in all seasons indicate that desiccation plays a significant role in achieving acceptable sugar levels in Shiraz (Fig.1, 2). Pruning treatments had significant effects on berry weight at almost all sample dates over the maturation period (ie. spur> mechanical> minimal) in all seasons (Fig1). There were however seasonal effects with all pruning treatments showing a steady decline in berry weight over maturation of about 15% in 2002, a slight increase followed by little change for most of the period with small decreases towards harvest (ie. < 10%) across all treatments in 2003 while in 2004, increases in berry weight early in the period were followed by large decreases (around 20%), particularly with minimal pruning towards harvest which was extended due to delayed maturation (see below).

Thinning treatments tended to have larger berries at early sample dates in all seasons suggesting that berry development was delayed with the control treatment (Fig. 2). However towards harvest these differences had largely disappeared in 2002 and 2003 but remained significant in 2004.

Figure 1.

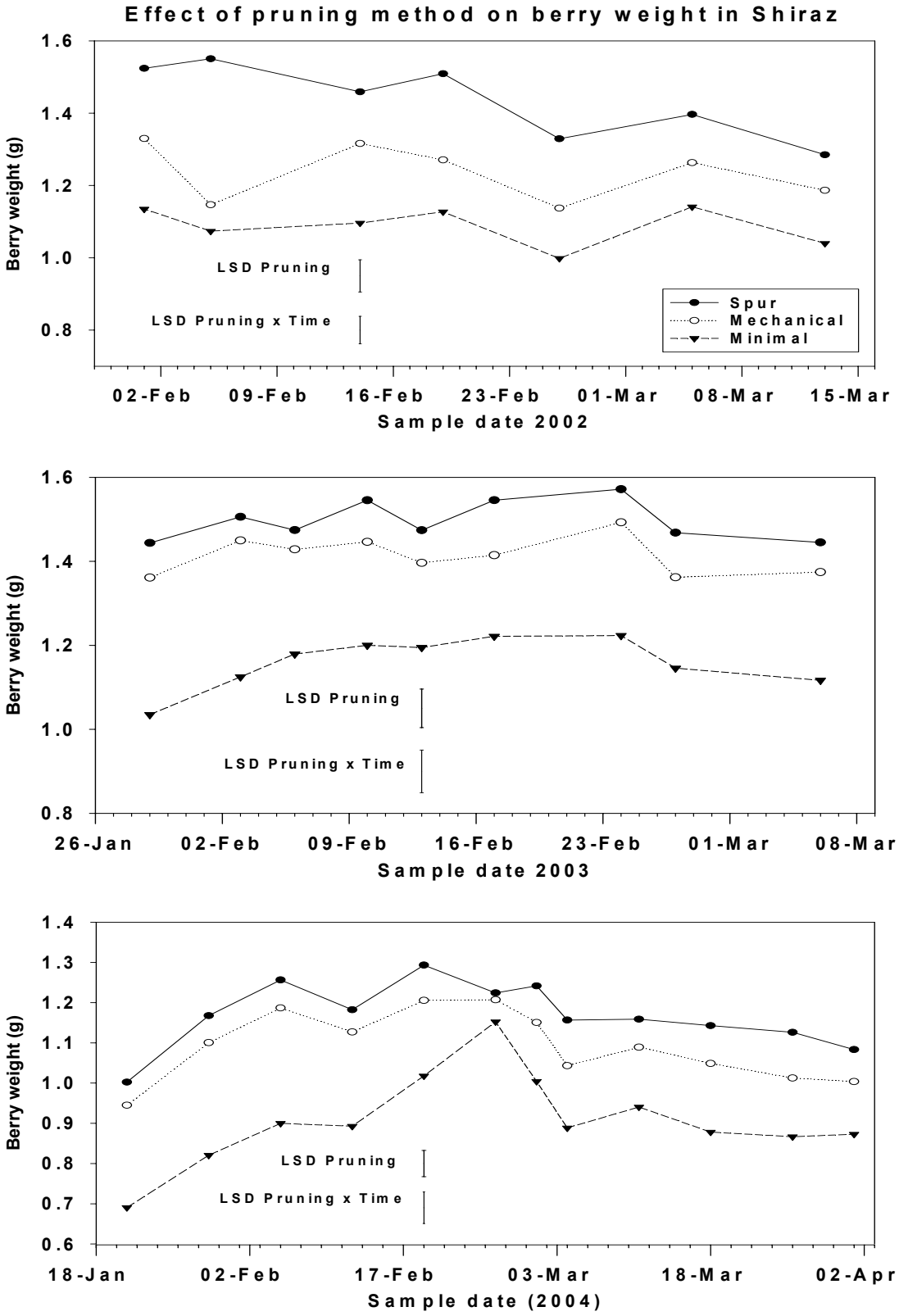
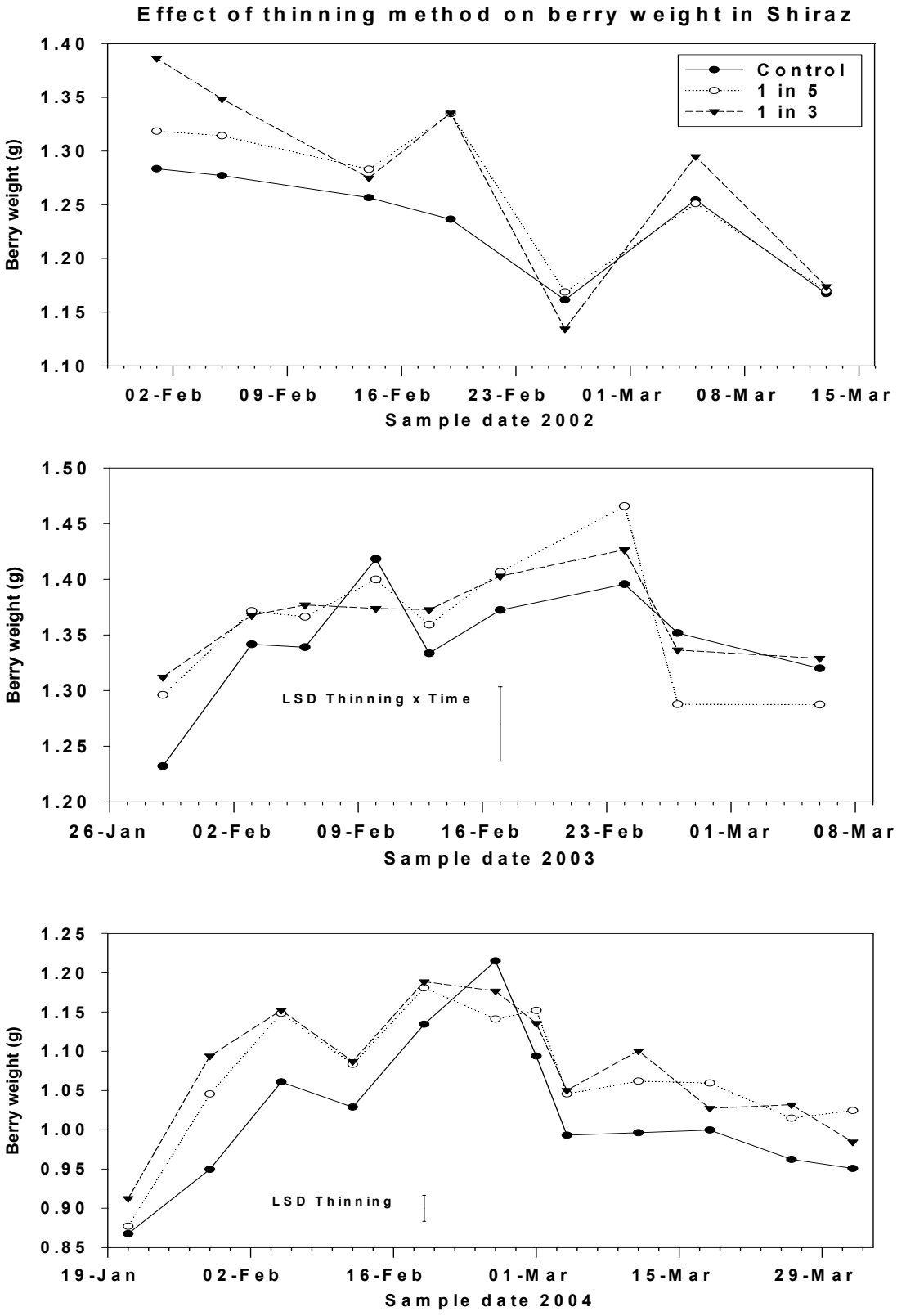

Effect of pruning method on berry weight in Shiraz
Berry weight (g)
1.6
1.4
1.2
1.0
0.8
LSD Pruning
LSD Pruning x Time
Spur
Mechanical
Minimal
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
15-Mar
Sample date 2002
Berry weight (g)
1.6
1.4
1.2
1.0
0.8
LSD Pruning
LSD Pruning x Time
26-Jan
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
Sample date 2003
Berry weight (g)
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
LSD Pruning
LSD Pruning x Time
18-Jan
02-Feb
17-Feb
03-Mar
18-Mar
02-Apr
Sample date (2004)

Figure 2.


Effect of thinning method on berry weight in Shiraz
Control
1 in 5
1 in 3
Berry weight (g)
1.40
1.35
1.30
1.25
1.20
1.15
1.10
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
15-Mar
Sample date 2002
1.50
1.45
1.40
1.35
1.30
1.25
1.20
LSD Thinning x Time
26-Jan
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
Sample date 2003
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
LSD Thinning
19-Jan
02-Feb
16-Feb
01-Mar
15-Mar
29-Mar
Sample date 2004

*Total soluble solids (Figs.3 and 4)*
The increase in sugar level over the maturation period varied between seasons, between pruning treatments and between thinning treatments (Fig. 3,4). In 2002 there was a constant rate of sugar accumulation from early February to harvest (ie. 0.24 $^0$Brix/day). In 2003 a similar rate (0.26 $^0$Brix/day) was recorded until mid February followed by a period of slow sugar accumulation until harvest in early March. By contrast, in season 2004 the rate of sugar accumulation was very high until mid February (0.64 $^0$Brix/day) after which there was little change until the fruit was harvested at less than optimum sugar levels in late March. The 2004 result was most likely associated with very mild temperatures in January favouring photosynthesis followed by some days of high temperature in mid February (ie. up to 47 $^0$C) which caused the vines to shut down their photosynthetic capacity leading to no net accumulation of sugar. It should be noted that there was no net gain in sugar per berry after the heat stress in 2004 (data not shown). Similarly in 2003 there was no net gain in sugar per berry after mid February indicating that the slow increase in $^0$Brix was associated with the decrease in berry weight, ie. dehydration.

Significant differences in sugar accumulation due to pruning treatments in 2002 and 2004 were associated with lower sugar at the start of the sampling period with minimal pruning, presumably due to delayed veraison rather than to effects on the rate of accumulation (Fig. 3). Consequently minimal pruned vines struggled to achieve adequate sugar levels in 2004. In 2003 when yields were low there was no effect of pruning on the maturation process. Crop thinning enhanced fruit maturity significantly in all seasons although the differences were small in 2003 (Fig. 4). These differences can be attributed to higher sugar levels at the start of the sampling period (ie. at the completion of veraison) rather than to changes in the rate of sugar accumulation. Both the pruning and crop thinning responses indicate that differences in crop load have a significant impact on the time of veraison rather than significant effects on the rate of sugar accumulation.

*Juice pH (Fig. 5,6)*
In general the increase over time in pH reflected differences in sugar level attributed to the pruning and thinning treatments with a constant linear response in 2002 and asymptotic responses in 2003 and 2004 (Fig.5, 6). As a consequence, minimal pruned vines tended to have lower pH values at most sampling dates in 2002 and 2003 while thinning treatments tended to promote higher pH values. The delay in harvest date in 2004 produced significantly higher pH values (pH >4) than in 2002 or 2003 (pH < 3.7).

*Juice titratable acidity (Fig.7,8)*
Titratable acidity decreased rapidly in all seasons and across all treatments during the initial part of the post-veraison ripening period (Figs. 7,8). Towards harvest the decline in titratable acidity was reduced with an asymptotic response to about 4 g/L. Although treatment effects were small, minimal pruning gave higher titratable acidity levels at most sampling dates in 2004 while thinning treatments promoted lower acid levels in all seasons although differences tended to disappear by harvest.

Figure 3.

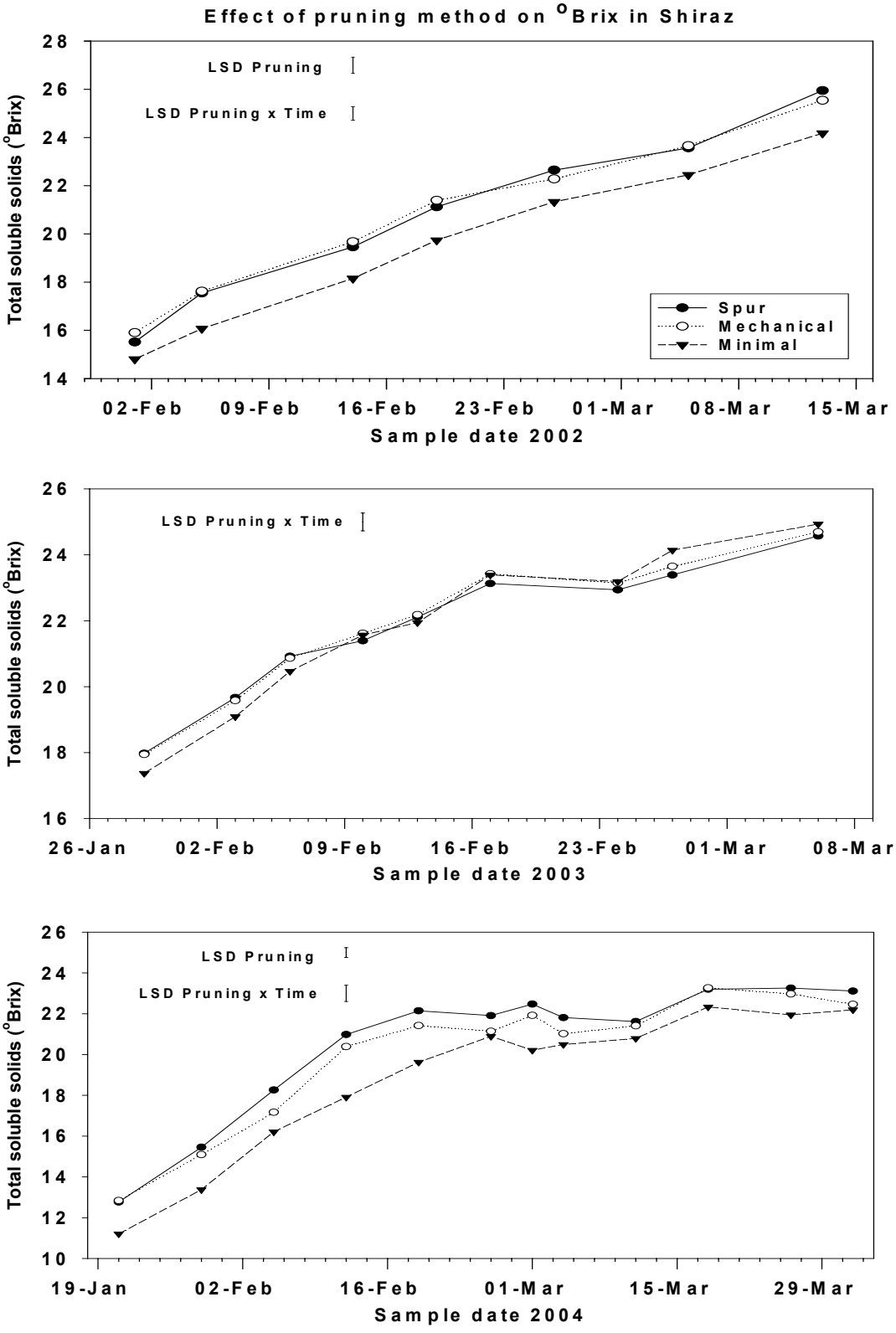

Effect of pruning method on °Brix in Shiraz
LSD Pruning
LSD Pruning x Time
Spur
Mechanical
Minimal
Total soluble solids (°Brix)
Sample date 2002
Sample date 2003
Sample date 2004

Figure 4.

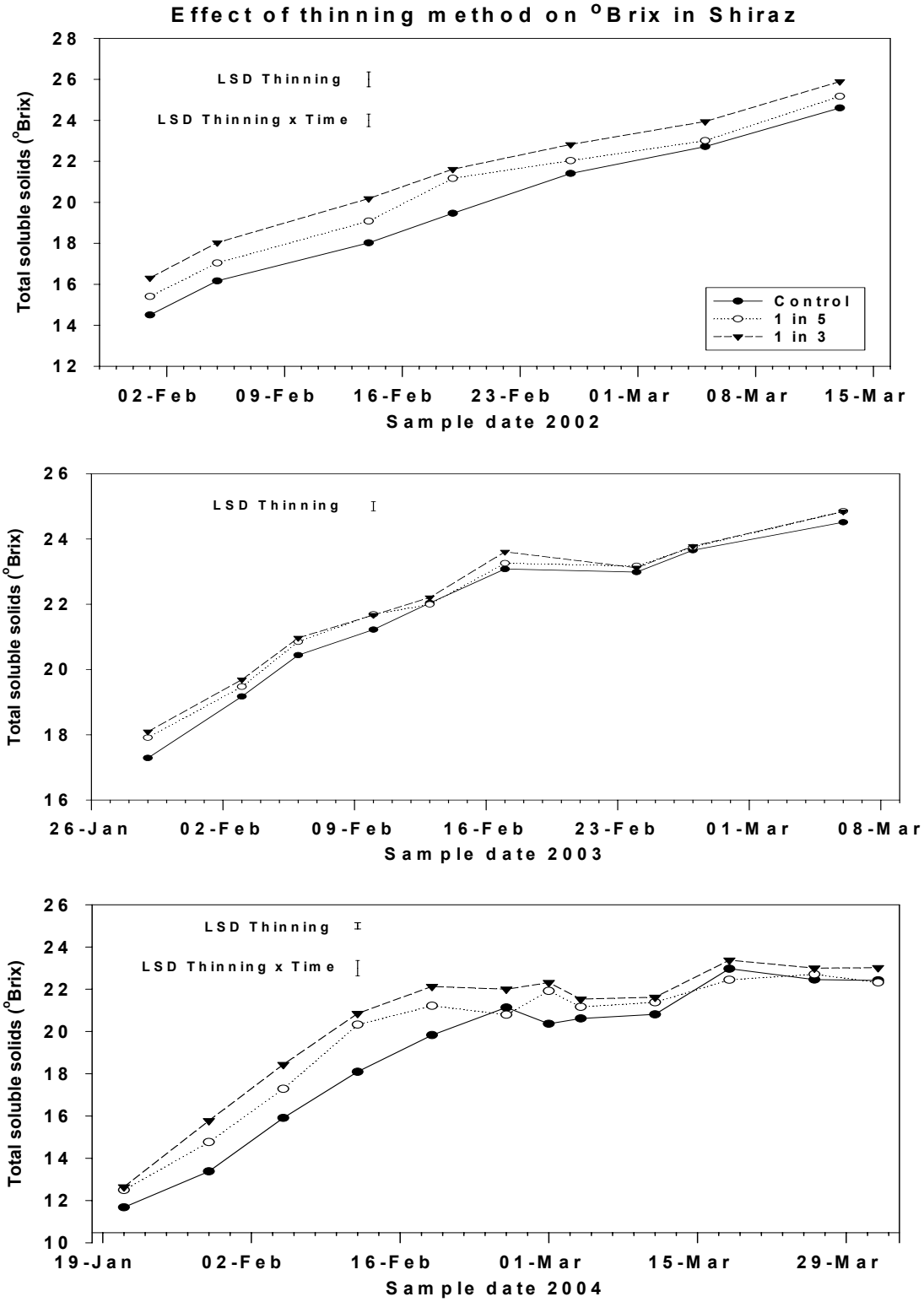

Effect of thinning method on °Brix in Shiraz
LSD Thinning
LSD Thinning x Time
Control
1 in 5
1 in 3
Total soluble solids (°Brix)
Sample date 2002
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
15-Mar
LSD Thinning
Total soluble solids (°Brix)
Sample date 2003
26-Jan
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
LSD Thinning
LSD Thinning x Time
Total soluble solids (°Brix)
Sample date 2004
19-Jan
02-Feb
16-Feb
01-Mar
15-Mar
29-Mar

Figure 5.

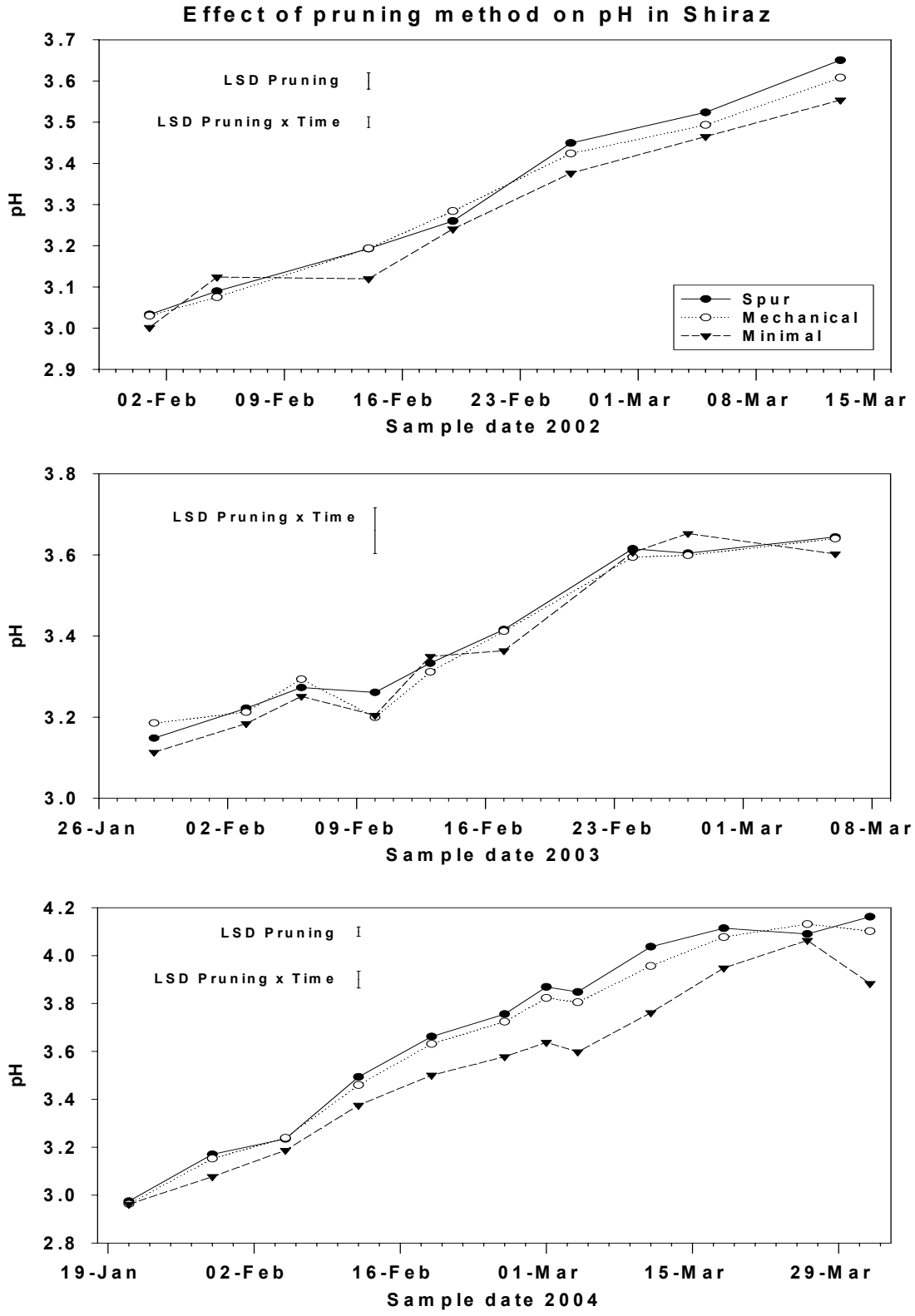

Effect of pruning method on pH in Shiraz
LSD Pruning
LSD Pruning x Time
Spur
Mechanical
Minimal
pH
Sample date 2002
LSD Pruning x Time
pH
Sample date 2003
LSD Pruning
LSD Pruning x Time
pH
Sample date 2004

Figure 6.

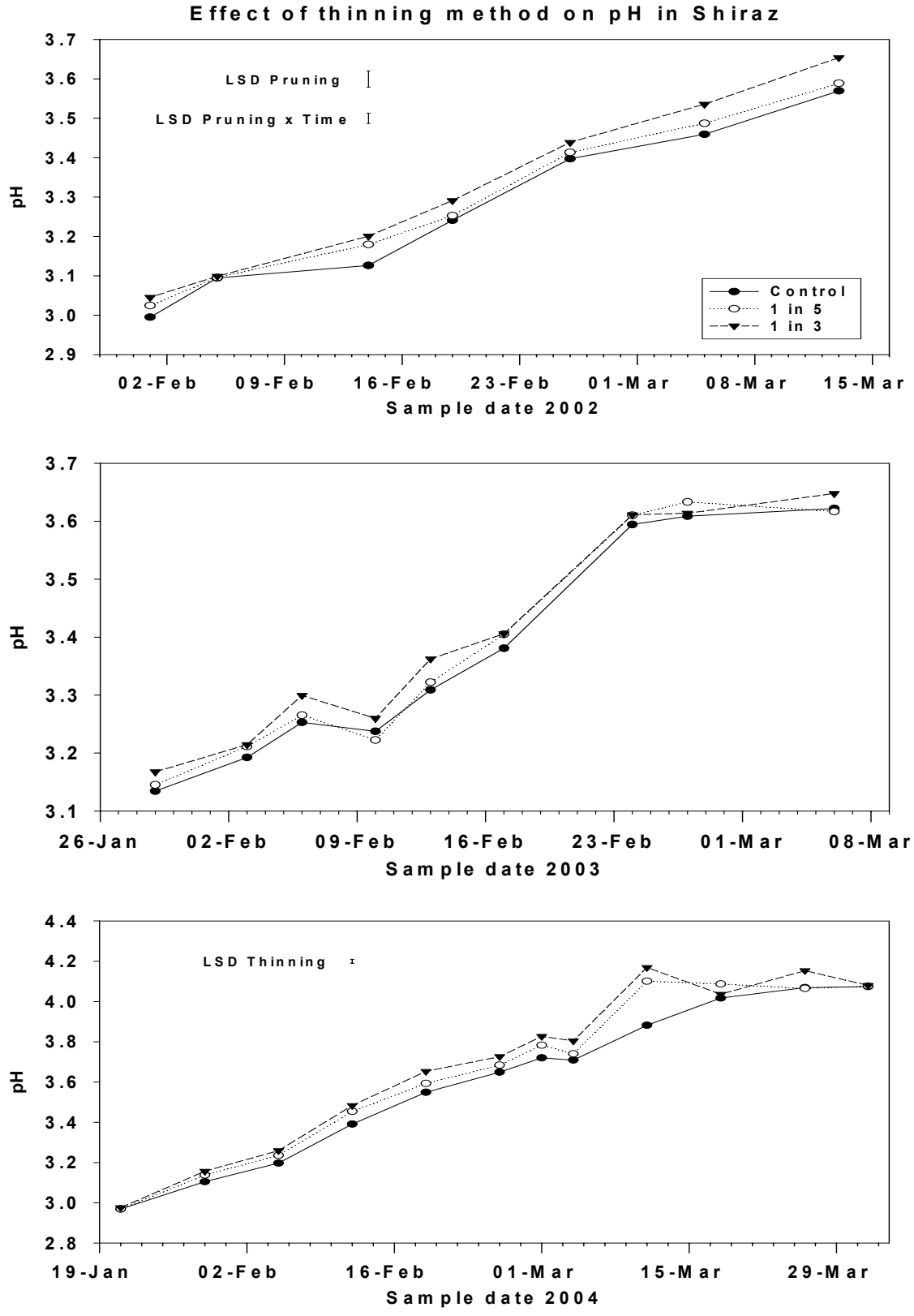

Effect of thinning method on pH in Shiraz
LSD Pruning
LSD Pruning x Time
Control
1 in 5
1 in 3
pH
Sample date 2002
Sample date 2003
LSD Thinning
Sample date 2004

Figure7.

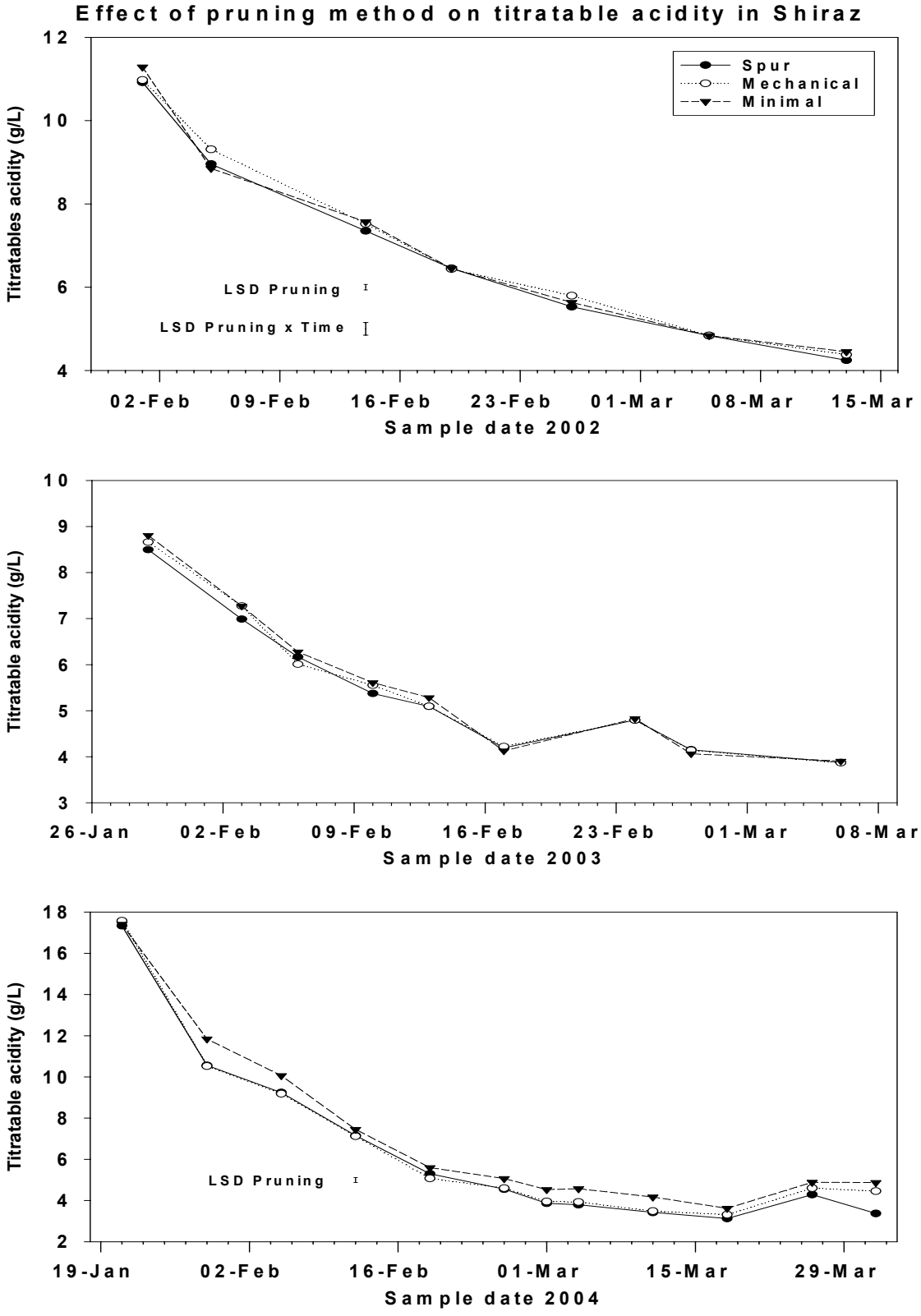
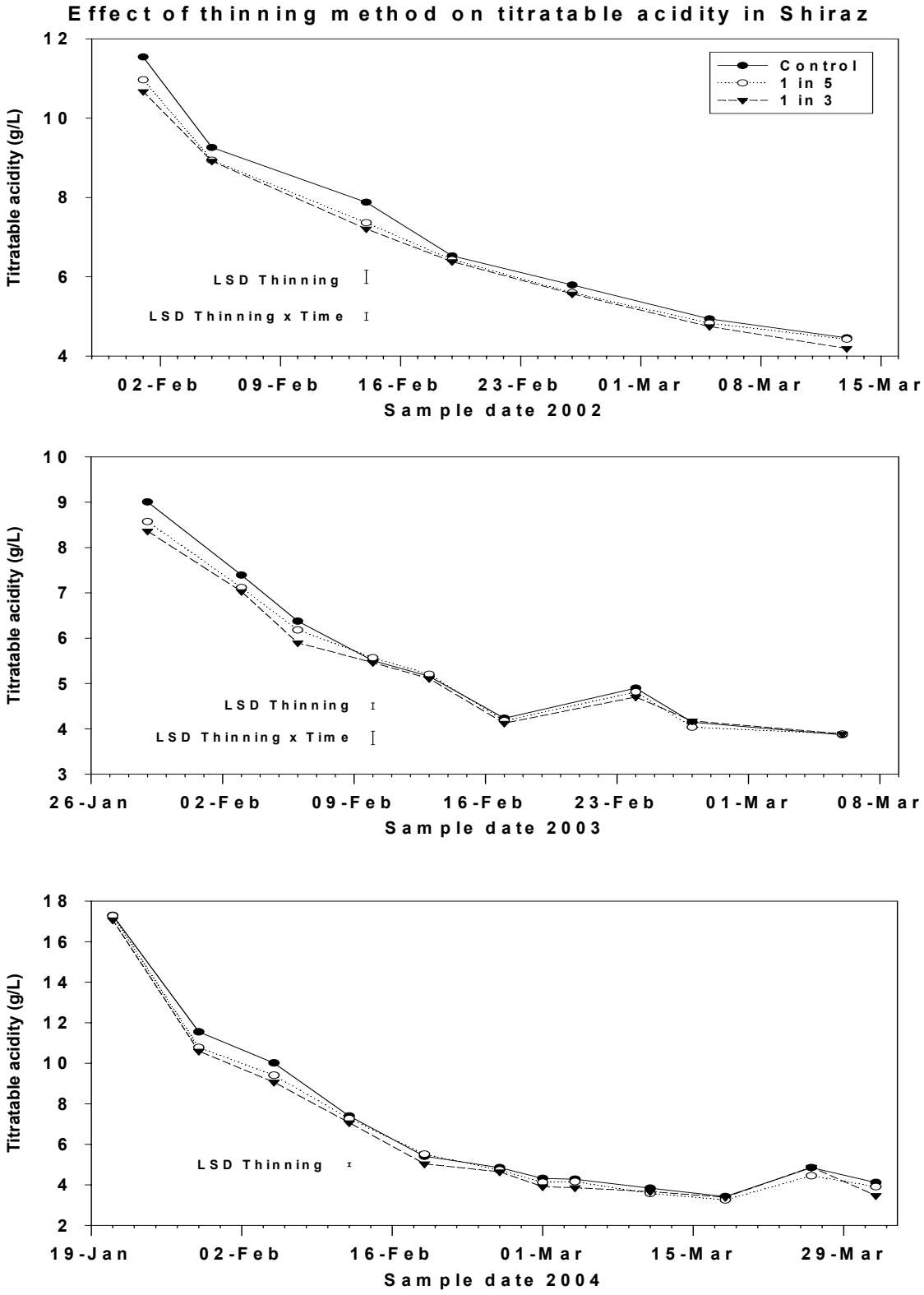

Effect of pruning method on titratable acidity in Shiraz
Spur
Mechanical
Minimal
Titratables acidity (g/L)
LSD Pruning
LSD Pruning x Time
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
15-Mar
Sample date 2002
Titratable acidity (g/L)
26-Jan
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
Sample date 2003
Titratable acidity (g/L)
LSD Pruning
19-Jan
02-Feb
16-Feb
01-Mar
15-Mar
29-Mar
Sample date 2004

Figure 8.


Effect of thinning method on titratable acidity in Shiraz
Titratable acidity (g/L)
Control
1 in 5
1 in 3
LSD Thinning
LSD Thinning x Time
Sample date 2002
Titratable acidity (g/L)
LSD Thinning
LSD Thinning x Time
Sample date 2003
Titratable acidity (g/L)
LSD Thinning
Sample date 2004

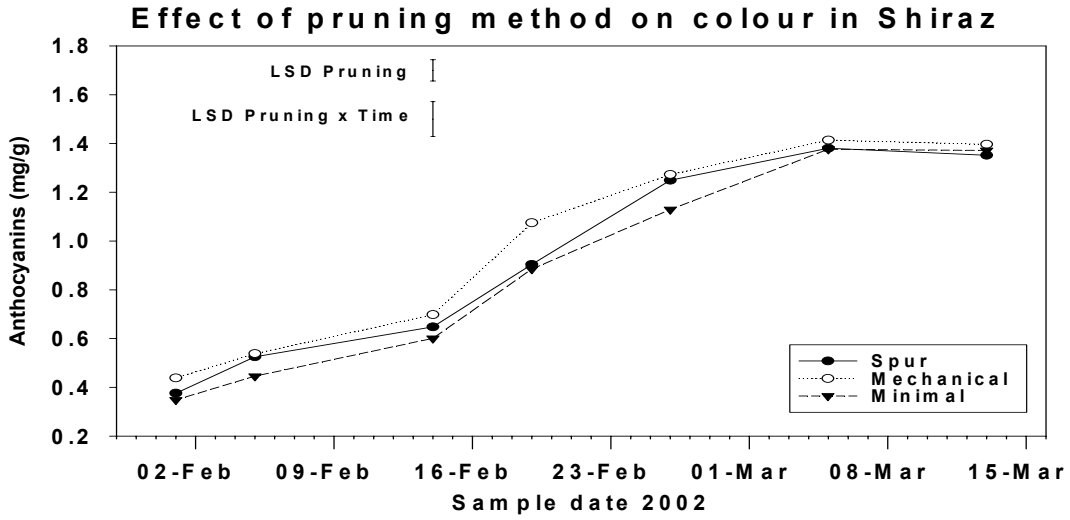
*Berry anthocyanins (Figs .9,10)*

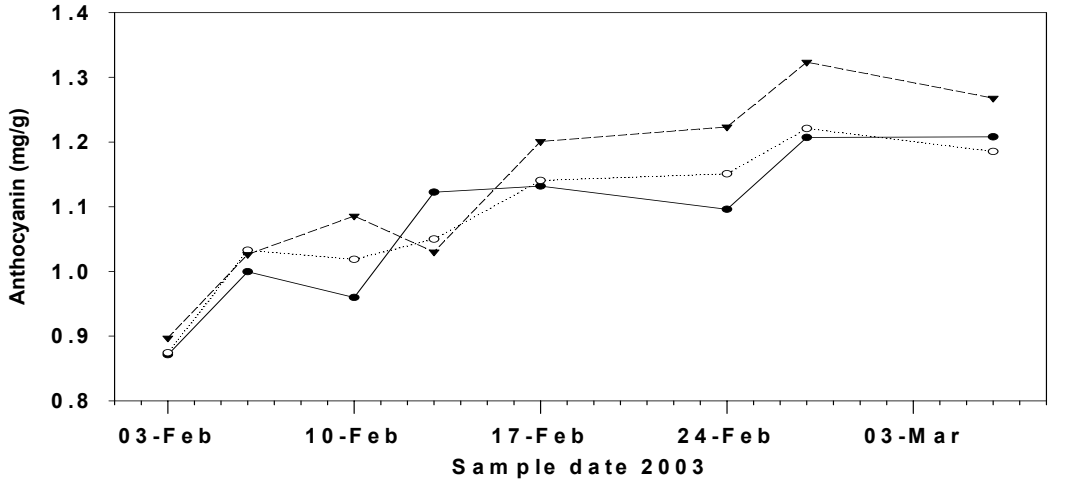
Berry anthocyanins increased over time during the early stages of maturation in all seasons and across all treatments but tended to plateau at sampling dates closer to harvest (Figs. 9, 10). This was particularly noticeable in season 2004 after the high temperatures in mid February. While there were significant pruning responses in 2002 and 2004 associated with a delay in anthocyanin development with minimal pruning the differences had largely disappeared by harvest. In the low cropping 2003 season pruning effects were not significant. Crop removal treatments promoted earlier anthocyanin development in all seasons although the differences disappeared towards harvest in 2004 after the high temperatures in mid February.

*Berry phenolics (Figs.11, 12)*

Berry phenolics increased over the maturation sampling period in 2002 and 2003 whereas in 2004 a period of rapid increase in early February was followed by a period of decline after the period of high temperatures in mid February with some increase when sampling was extended to the end of March (Figs. 11, 12). The significant pruning response was associated with higher phenolic levels with lighter pruning, particularly minimal pruning at most sampling dates (Fig11). Crop removal appeared to have little impact on phenolic levels (Fig.12).

Figure 9.


Effect of pruning method on colour in Shiraz
LSD Pruning
LSD Pruning x Time
Anthocyanins (mg/g)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Spur
Mechanical
Minimal
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
15-Mar
Sample date 2002


Anthocyanin (mg/g)
1.4
1.3
1.2
1.1
1.0
0.9
0.8
03-Feb
10-Feb
17-Feb
24-Feb
03-Mar
Sample date 2003

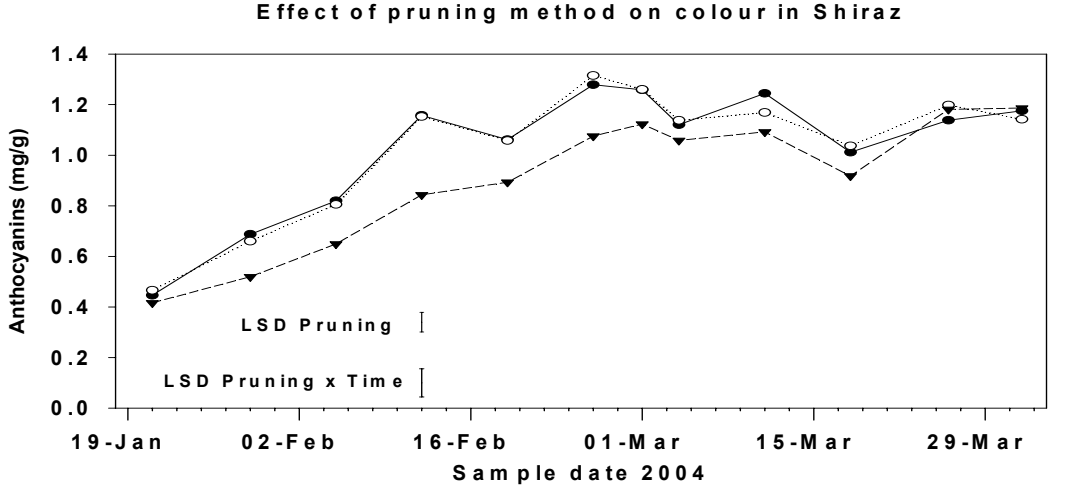

Effect of pruning method on colour in Shiraz
Anthocyanins (mg/g)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
LSD Pruning
LSD Pruning x Time
19-Jan
02-Feb
16-Feb
01-Mar
15-Mar
29-Mar
Sample date 2004

Figure 10.

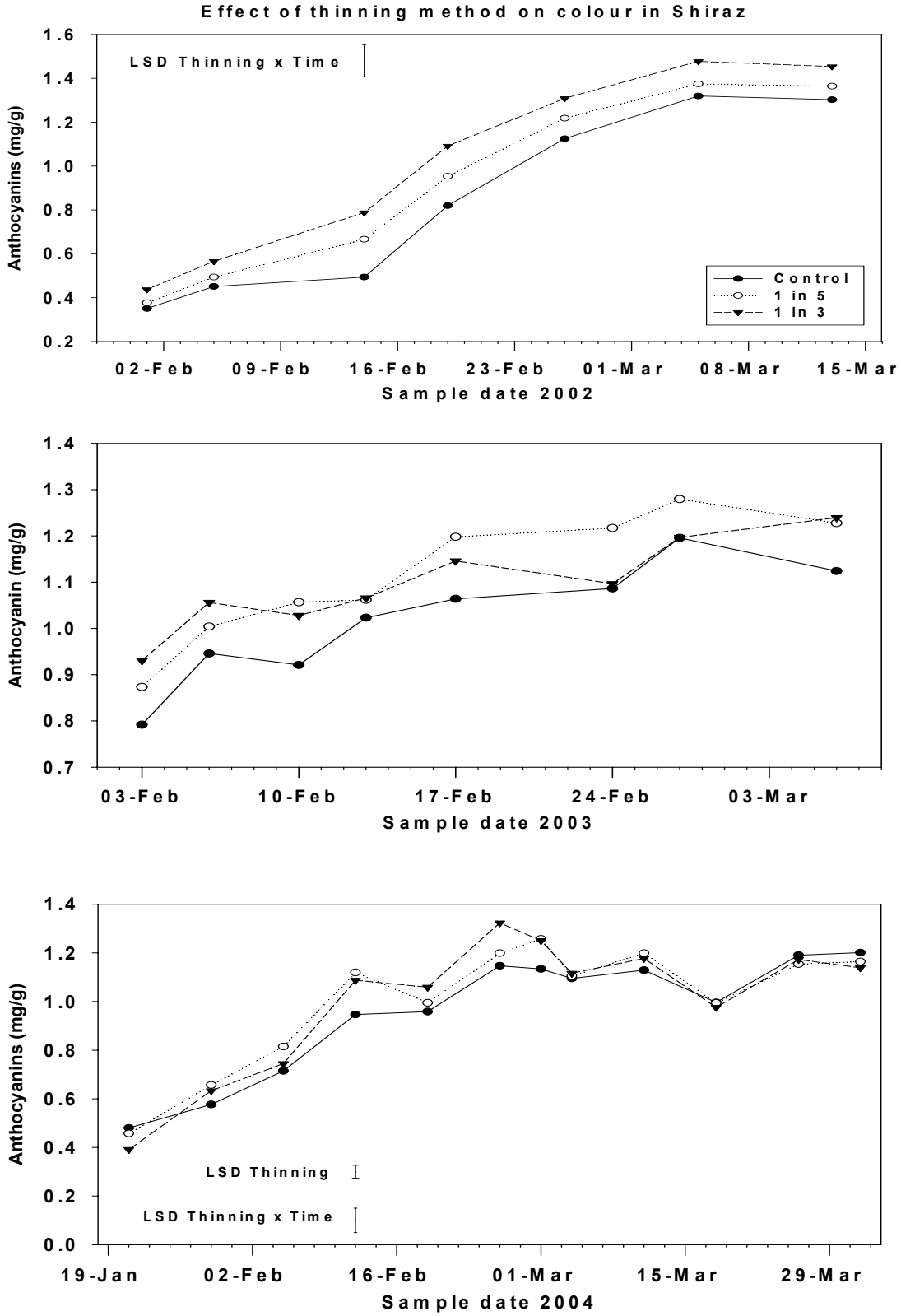

Effect of thinning method on colour in Shiraz
LSD Thinning x Time
Anthocyanins (mg/g)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Control
1 in 5
1 in 3
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
15-Mar
Sample date 2002
Anthocyanin (mg/g)
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
03-Feb
10-Feb
17-Feb
24-Feb
03-Mar
Sample date 2003
Anthocyanins (mg/g)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
LSD Thinning
LSD Thinning x Time
19-Jan
02-Feb
16-Feb
01-Mar
15-Mar
29-Mar
Sample date 2004

Figure 11.

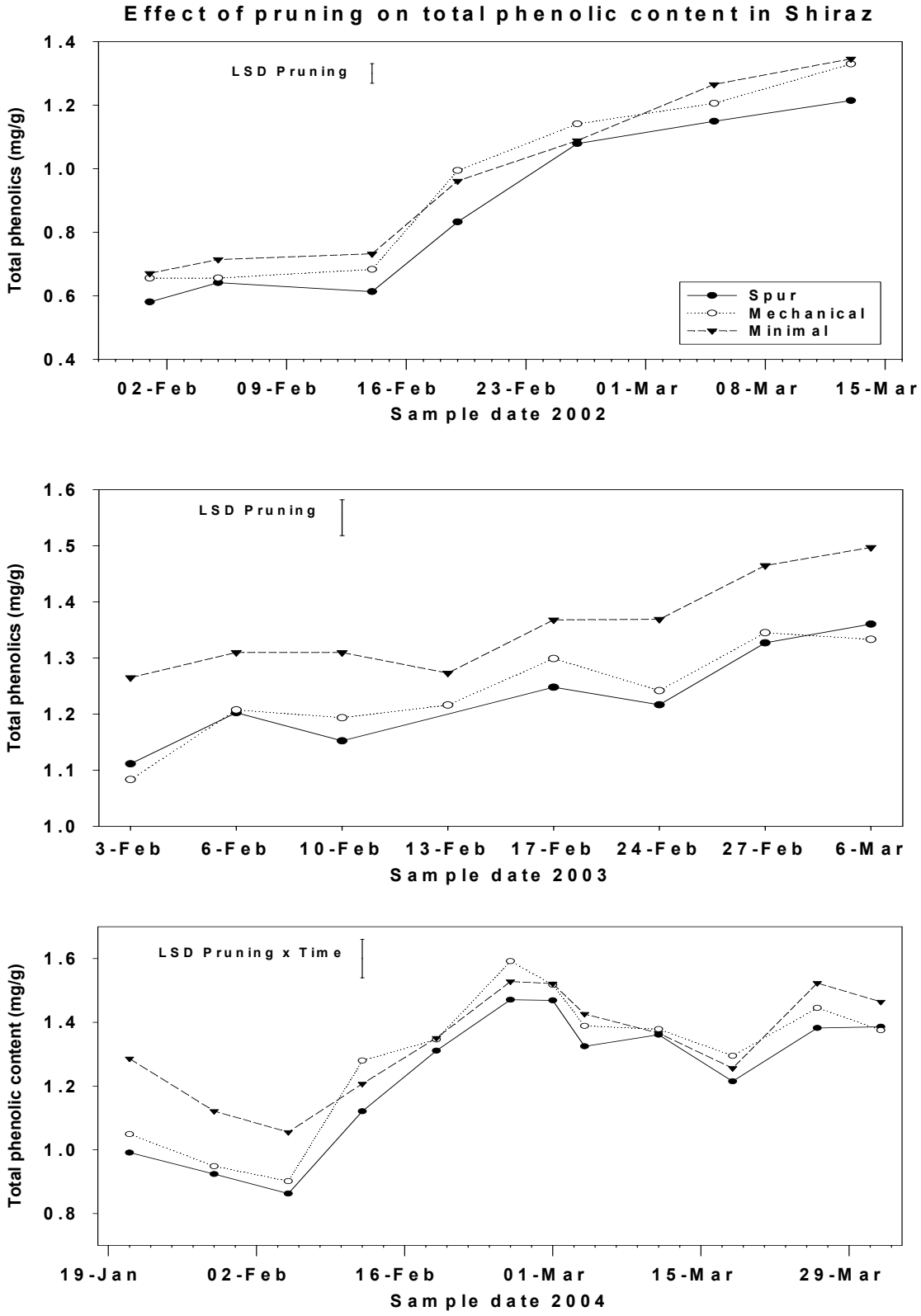
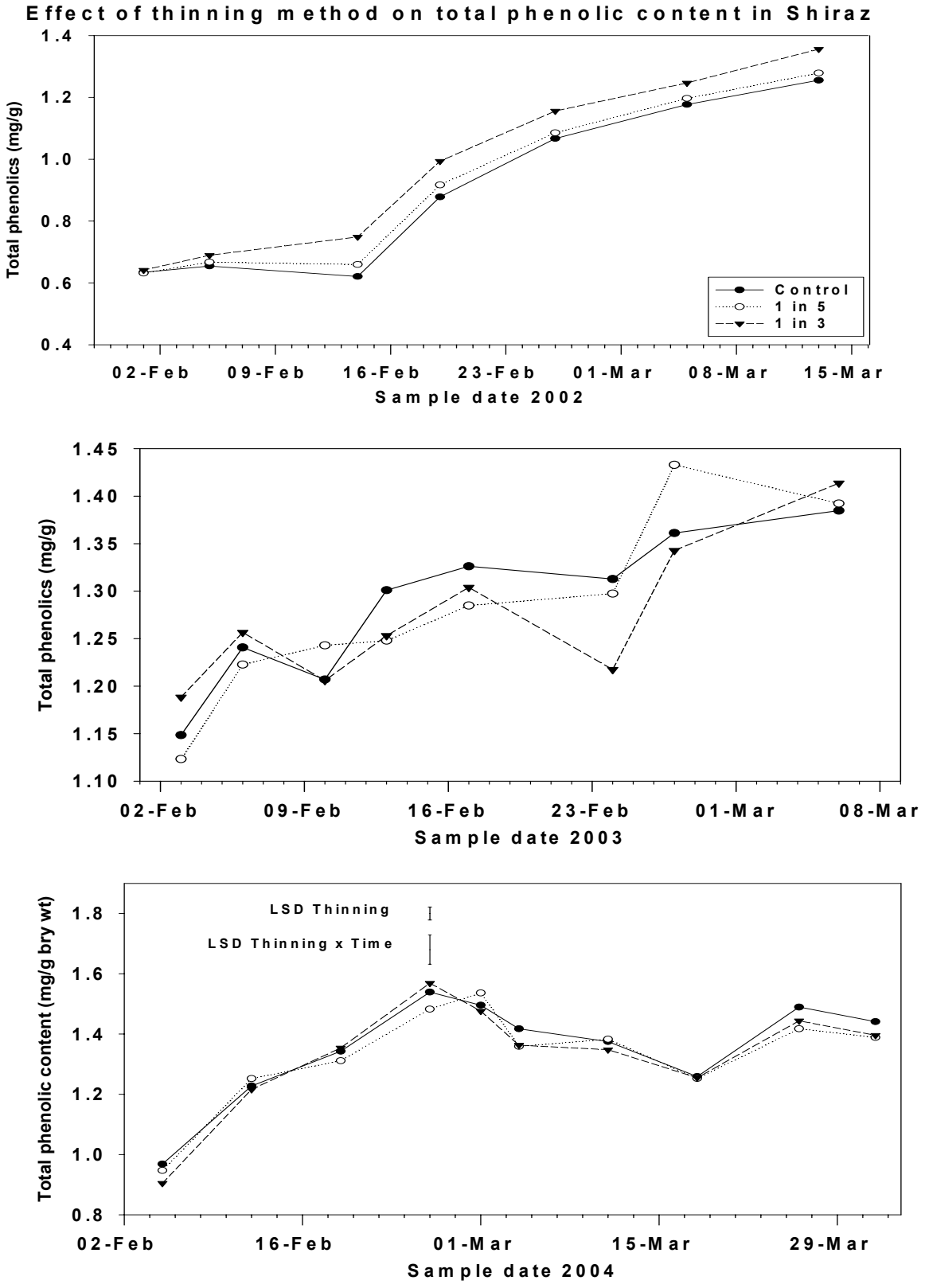

Effect of pruning on total phenolic content in Shiraz
LSD Pruning
Total phenolics (mg/g)
1.4
1.2
1.0
0.8
0.6
0.4
Spur
Mechanical
Minimal
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
15-Mar
Sample date 2002
LSD Pruning
Total phenolics (mg/g)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
3-Feb
6-Feb
10-Feb
13-Feb
17-Feb
24-Feb
27-Feb
6-Mar
Sample date 2003
LSD Pruning x Time
Total phenolic content (mg/g)
1.6
1.4
1.2
1.0
0.8
19-Jan
02-Feb
16-Feb
01-Mar
15-Mar
29-Mar
Sample date 2004

Figure12.


Effect of thinning method on total phenolic content in Shiraz
Total phenolics (mg/g)
1.4
1.2
1.0
0.8
0.6
0.4
Control
1 in 5
1 in 3
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
15-Mar
Sample date 2002
Total phenolics (mg/g)
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
02-Feb
09-Feb
16-Feb
23-Feb
01-Mar
08-Mar
Sample date 2003
Total phenolic content (mg/g bry wt)
LSD Thinning
LSD Thinning x Time
1.8
1.6
1.4
1.2
1.0
0.8
02-Feb
16-Feb
01-Mar
15-Mar
29-Mar
Sample date 2004

***Harvest assessment of berry composition***

The study aimed to harvest all treatments at similar maturities (ie. 23.5-24 $^0$Brix) based on samples collected over the maturation period. In 2002 this was achieved by harvesting various treatments on different dates (28th February, 4th and 11th March) while in season 2003, when all treatments had similar low yields, harvest was on 6th March. In season 2004 fruit was harvested at below the desired maturity level on 18th March followed by a second harvest on 29th March for winemaking purposes.

*Total soluble solids*

There were differences between seasons but no significant effects of pruning or thinning on sugar level (Table 28). This indicates that the fruit of each treatment was harvested at similar maturities, despite the lower overall sugar level in 2004. The significant pruning x year interaction can be linked to the lower maturities of minimal pruning in season 2004.

Table 28. Effect of pruning (spur, mechanical and minimal) and thinning treatments on berry total soluble solids ($^0$Brix) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| **Thinning** | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 24.3 | 24.5 | 24.4 | 24.6 | 24.0 | 23.3 | 22.7 | 24.2 | 25.1 | 24.1b |
| 2002-2003 | 24.3 | 24.8 | 24.6 | 24.5 | 24.7 | 24.2 | 24.8 | 25.1 | 25.0 | 24.7c |
| 2003-2004 | 23.3 | 22.7 | 24.2 | 23.2 | 22.7 | 23.9 | 22.4 | 21.9 | 22.7 | 23.0a |
| Thinning mean | 24.0 | 24.0 | 24.4 | 24.1 | 23.8 | 23.8 | 23.3 | 23.7 | 24.2 | |
| Pruning mean | 24.1 | | | 23.9 | | | 23.8 | | | |

*Interaction LSD (P=.05) for PxY was 0.71*

*pH*

There were seasonal and pruning but not thinning effects on berry juice pH at harvest (Table 29). Seasons 2002 and 2004 produced the lowest and highest pH values respectively. Minimal pruning gave lower pH values than spur or mechanical pruning.

Table 29. Effect of pruning (spur, mechanical and minimal) and thinning treatments on pH over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| **Thinning** | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 3.60 | 3.53 | 3.52 | 3.65 | 3.51 | 3.44 | 3.49 | 3.57 | 3.61 | 3.55a |
| 2002-2003 | 3.64 | 3.61 | 3.68 | 3.63 | 3.61 | 3.68 | 3.60 | 3.62 | 3.58 | 3.63b |
| 2003-2004 | 4.03 | 4.15 | 4.17 | 4.08 | 4.14 | 4.01 | 3.94 | 3.97 | 3.94 | 4.05c |
| Thinning mean | 3.76bc | 3.76bc | 3.79c | 3.79c | 3.75bc | 3.71ab | 3.68a | 3.72ab | 3.71ab | |
| Pruning mean | 3.77b | | | 3.75b | | | 3.70a | | | |

*Significant interaction LSD's (P=0.05) for PxY and PxTxY were 0.07 and 0.11 respectively.*

*Titratable acidity*

Berry juice titratable acidity levels were low at harvest, generally <4.0g/L (Table 30). Seasons 2002 and 2004 had the highest and lowest acid levels respectively. While there was no significant pruning effect, thinning treatments had higher acid levels (ie. 3.9 cf 3.4 g/L).

Table 30. Effect of pruning (spur, mechanical and minimal) and thinning treatments on titratable acidity (g/L) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| **Thinning** | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 2.33 | 4.85 | 5.09 | 2.25 | 4.94 | 5.36 | 4.54 | 4.32 | 2.25 | 3.99b |
| 2002-2003 | 3.93 | 3.86 | 3.84 | 3.85 | 3.90 | 3.85 | 3.83 | 3.90 | 3.98 | 3.88b |
| 2003-2004 | 3.27 | 2.98 | 3.15 | 3.31 | 3.23 | 3.42 | 3.50 | 3.58 | 3.60 | 3.34a |
| Thinning mean | 3.17a | 3.90 b | 4.03c | 3.14a | 4.02 c | 4.21 c | 3.96b | 3.93b | 3.27 a | |
| Pruning mean | 3.70 | | | 3.79 | | | 3.72 | | | |

*Significant interaction LSD's (P=0.05) for PxY, TxY and PxTxY were 0.19, 0.18 and 0.31 respectively.*

*Berry colour (total anthocyanins)*

Berry anthocyanin levels differed significantly between seasons with season 2002 having the highest and season 2004 the lowest levels (Table 31). Overall, pruning treatments had no effect on anthocyanins while thinning, particularly the 1 in 3 tended to promote colour, although differences were only just significant (P= 0.08). The significant pruning x year response can be attributed to the higher levels of anthocyanins with minimal pruning in 2003 and lower levels with minimal pruning in 2004.

Table 31. Effect of pruning (spur, mechanical and minimal) and thinning treatments on berry colour (total anthocyanins, mg/g) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| **Thinning** | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 1.36 | 1.31 | 1.31 | 1.34 | 1.35 | 1.40 | 1.32 | 1.33 | 1.48 | 1.36c |
| 2002-2003 | 1.19 | 1.21 | 1.24 | 1.19 | 1.18 | 1.20 | 1.23 | 1.32 | 1.29 | 1.23b |
| 2003-2004 | 1.05 | 1.12 | 1.15 | 1.13 | 1.08 | 1.17 | 0.85 | 0.97 | 1.03 | 1.06a |
| Thinning mean | 1.20 | 1.21 | 1.23 | 1.22 | 1.21 | 1.25 | 1.13 | 1.21 | 1.27 | |
| Pruning mean | 1.22 | | | 1.23 | | | 1.20 | | | |

*Interaction LSD (P=.05) for PxY was 0.11*

*Berry phenolics*

Berry phenolic levels differed significantly between seasons with seasons 2002 and 2004 having the lowest and highest levels respectively (Table 32). The significant pruning effect was due to minimal pruning having higher levels of phenolics compared to spur or mechanical pruning. There was no effect of thinning treatments on berry phenolics. The significant pruning x year response can be attributed to the lower levels of phenolics with minimal pruning in 2004.

Table 32. Effect of pruning (spur, mechanical and minimal) and thinning treatments on berry phenolics (mg/g) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| **Thinning** | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 1.18 | 1.12 | 1.12 | 1.30 | 1.18 | 1.19 | 1.32 | 1.28 | 1.43 | 1.24a |
| 2002-2003 | 1.34 | 1.36 | 1.39 | 1.36 | 1.31 | 1.33 | 1.45 | 1.50 | 1.52 | 1.40c |
| 2003-2004 | 1.26 | 1.34 | 1.36 | 1.36 | 1.29 | 1.41 | 1.22 | 1.26 | 1.28 | 1.31b |
| Thinning mean | 1.26 | 1.27 | 1.29 | 1.34 | 1.26 | 1.31 | 1.33 | 1.35 | 1.41 | |
| Pruning mean | 1.28a | | | 1.30a | | | 1.36b | | | |

*Interaction LSD (P=.05) for PxY was 0.11*

***Wine data***

*Must characteristics*

Harvest strategies to ensure all treatments were harvested and wines produced from fruit of similar maturities were generally successful except in 2004 when sugar levels were generally lower, particularly with minimal pruning (Table 33). Must pH levels were lowest in 2002 and highest in 2004 but not affected by pruning or thinning treatments (Table 34). Titratable acidity of the must was highest in 2002 and lowest in 2004 (Table 35). Spur and minimal pruning had the lowest and highest acid levels respectively. The least amount of tartaric acid was added in 2003 and with minimal pruning for pH adjustment (Table 36).

Table 33. Effect of pruning (spur, mechanical and minimal) and thinning treatments on total soluble solids (0Brix) of the must over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 25.1 | 23.9 | 24.2 | 24.9 | 23.0 | 23.6 | 23.6 | 24.4 | 24.1 | 24.1b |
| 2002-2003 | 23.6 | 25.2 | 24.2 | 23.9 | 24.3 | 24.4 | 24.5 | 24.1 | 24.5 | 24.2b |
| 2003-2004 | 23.0 | 23.1 | 22.8 | 22.8 | 23.3 | 23.3 | 21.9 | 21.5 | 21.5 | 22.6a |
| Thinning mean | 23.9 | 24.1 | 23.7 | 23.7 | 23.5 | 23.8 | 23.3 | 23.3 | 23.4 | |
| Pruning mean | 23.9b | | | 23.7b | | | 23.3a | | | |

Table 34. Effect of pruning (spur, mechanical and minimal) and thinning treatments on must pH over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 4.11 | 3.77 | 3.73 | 3.83 | 3.71 | 3.65 | 3.95 | 3.84 | 3.77 | 3.82a |
| 2002-2003 | 3.99 | 4.02 | 4.03 | 3.98 | 4.01 | 4.02 | 3.97 | 4.01 | 3.97 | 4.00b |
| 2003-2004 | 4.27 | 4.30 | 4.21 | 4.25 | 4.22 | 4.22 | 4.08 | 4.09 | 4.08 | 4.19c |
| Thinning mean | 4.12 | 4.03 | 3.99 | 4.02 | 3.98 | 3.96 | 4.00 | 3.98 | 3.94 | |
| Pruning mean | 4.05 | | | 3.99 | | | 3.97 | | | |

Table 35. Effect of pruning (spur, mechanical and minimal) and thinning treatments on titratable acidity (g/L) of the must over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 3.98 | 4.43 | 4.73 | 4.43 | 4.83 | 4.95 | 4.96 | 4.49 | 4.36 | 4.57c |
| 2002-2003 | 4.00 | 3.92 | 3.90 | 4.02 | 3.98 | 3.85 | 3.99 | 3.89 | 4.10 | 3.96b |
| 2003-2004 | 2.80 | 2.81 | 3.02 | 2.81 | 2.91 | 2.97 | 3.27 | 3.26 | 3.25 | 3.01a |
| Thinning mean | 3.59 | 3.72 | 3.88 | 3.75 | 3.91 | 3.92 | 4.07 | 3.88 | 3.90 | |
| Pruning mean | 3.73a | | | 3.86b | | | 3.95c | | | |

Table 36. Effect of pruning (spur, mechanical and minimal) and thinning treatments on tartaric acid added (g/L) to the must for pH adjustment over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 2.50 | 5.00 | 3.30 | 2.50 | 3.73 | 4.73 | 3.30 | 5.00 | 3.30 | 3.71b |
| 2002-2003 | 2.95 | 2.52 | 2.58 | 2.55 | 2.75 | 2.88 | 2.38 | 2.75 | 2.65 | 2.67a |
| 2003-2004 | 4.00 | 4.00 | 2.73 | 4.00 | 4.00 | 4.00 | 3.00 | 3.00 | 3.00 | 3.53b |
| Thinning mean | 3.55 | 3.84 | 2.94 | 3.02 | 3.49 | 3.87 | 2.89 | 3.58 | 2.98 | |
| Pruning mean | 3.44b | | | 3.46b | | | 3.15a | | | |

*Wine characteristics*

There were no major treatment or seasonal effects on wine pH (mean 3.53), titratable acidity (mean 8.18) or hue (mean 0.53) because of addition of tartaric acid to adjust must pH (data not shown).

Wine colour density differed significantly between seasons, with seasons 2002 and 2004 having the lowest and highest levels respectively (Table 37). There were significant pruning effects, with spur pruning having the lowest and minimal pruning the highest colour densities respectively. Thinning treatments, particularly the 1 in 3 treatment significantly enhanced wine colour density irrespective of pruning treatment.

Table 37. Effect of pruning (spur, mechanical and minimal) and thinning treatments on wine colour density (au) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 7.50 | 8.04 | 10.18 | 8.63 | 8.01 | 10.69 | 9.22 | 9.57 | 9.24 | 9.01a |
| 2002-2003 | 9.32 | 9.51 | 9.97 | 9.92 | 9.73 | 9.55 | 10.80 | 11.24 | 9.89 | 9.99b |
| 2003-2004 | 10.98 | 12.50 | 12.20 | 10.60 | 12.88 | 12.25 | 10.41 | 10.75 | 13.34 | 11.76c |
| Thinning mean | 9.27a | 10.00b | 10.78c | 9.72ab | 10.21b | 10.83c | 10.14b | 10.52c | 10.82c | |
| Pruning mean | 10.02a | | | 10.25b | | | 10.49c | | | |

There were significant seasonal differences in the degree of ionization of the anthocyanins (%) with 2002 and 2004 having the highest and lowest values respectively (Table 38). Pruning and thinning treatments had no effect on the degree of ionization of anthocyanins.

Table 38. Effect of pruning (spur, mechanical and minimal) and thinning treatments on %ionized anthocyanins over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 9.3 | 10.1 | 11.2 | 10.0 | 10.4 | 12.7 | 10.8 | 11.2 | 10.9 | 10.7a |
| 2002-2003 | 12.0 | 10.9 | 12.0 | 12.0 | 11.2 | 11.7 | 13.4 | 13.0 | 12.0 | 12.0b |
| 2003-2004 | 13.9 | 13.8 | 12.3 | 12.9 | 14.7 | 14.3 | 13.2 | 13.3 | 16.3 | 13.8c |
| Thinning mean | 11.7 | 11.6 | 11.8 | 11.6 | 12.0 | 12.9 | 12.5 | 12.5 | 13.1 | |
| Pruning mean | 11.7 | | | 12.2 | | | 12.7 | | | |

There were significant differences between seasons in total anthocyanins with 2002 and 2003 having higher levels than 2004 (Table 39). While pruning treatments had no effect on total anthocyanins, thinning produced higher levels with spur pruning but not with mechanical or minimal pruning.

Table 39. Effect of pruning (spur, mechanical and minimal) and thinning treatments on wine total anthocyanins (mg/L) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 677 | 709 | 855 | 736 | 688 | 800 | 785 | 778 | 756 | 754b |
| 2002-2003 | 695 | 784 | 749 | 742 | 766 | 723 | 748 | 787 | 754 | 750b |
| 2003-2004 | 673 | 746 | 794 | 701 | 736 | 703 | 696 | 674 | 727 | 717a |
| Thinning mean | 682a | 746b | 799c | 736b | 730b | 742b | 743b | 746b | 746b | |
| Pruning mean | 742 | | | 736 | | | 745 | | | |

There were significant differences between seasons in the level of ionised anthocyanins, being lowest in 2002 and highest in 2003 respectively (Table 40). Ionised anthocyanins were highest with minimal pruning and lowest with spur pruning. Thinning treatments, particularly the one in 3 treatment, enhanced the level of ionised anthocyanins of all pruning treatments.

Table 40. Effect of pruning (spur, mechanical and minimal) and thinning treatments on wine ionized anthocyanins (mg/L) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 62.9 | 71.1 | 95.2 | 73.8 | 71.7 | 101.3 | 84.2 | 87.5 | 82.5 | 81.1a |
| 2002-2003 | 83.0 | 85.7 | 89.9 | 88.9 | 85.6 | 84.4 | 100.4 | 102.5 | 90.0 | 90.0b |
| 2003-2004 | 93.4 | 102.9 | 97.1 | 90.0 | 108.4 | 100.3 | 91.7 | 89.4 | 118.2 | 99.1c |
| Thinning mean | 79.8 | 86.6 | 94.1 | 84.2 | 88.6 | 95.3 | 92.1 | 93.1 | 96.9 | |
| Pruning mean | 86.8a | | | 89.4ab | | | 94.0b | | | |

There were significant differences between seasons in wine phenolics with 2002 having lower values than 2003 and 2004 (Table 41). Wines from minimal pruning had higher phenoloic levels than spur or mechnical pruning. Thinning treatments had no effect on wine phenolics.

Table 41. Effect of pruning (spur, mechanical and minimal) and thinning treatments on wine phenolics (au) over three seasons (2001/2002- 2003/2004). Means within selected comparisons followed by different letters are significantly different (P=0.05).

| | **Pruning** | | | | | | | | | Yearly Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| | Spur | | | Mechanical | | | Minimal | | | |
| **Thinning** | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | Control | 1 in 5 | 1 in 3 | |
| 2001-2002 | 55.4 | 55.4 | 67.2 | 62.3 | 55.3 | 63.9 | 66.8 | 65.8 | 64.0 | 61.8a |
| 2002-2003 | 43.7 | 70.9 | 71.6 | 69.4 | 68.5 | 66.1 | 71.1 | 74.4 | 70.2 | 67.3b |
| 2003-2004 | 65.0 | 71.3 | 74.1 | 67.7 | 70.8 | 68.5 | 69.1 | 67.6 | 72.9 | 69.7b |
| Thinning mean | 64.7 | 65.9 | 70.9 | 66.5 | 64.9 | 66.2 | 69.0 | 69.2 | 69.0 | |
| Pruning mean | 67.2ab | | | 65.9a | | | 69.1b | | | |

***Summary***

The study aimed to assess the potential to stabilise yield and fruit and wine quality of Shiraz across seasons through application of various commercial pruning treatments (ie. spur, mechanical hedging and minimal pruning) in combination with crop thinning treatments (20% and 33% bunch removal). A very comprehensive study of crop development and impacts on fruit and wine composition was undertaken. Key results are identified below.

- A 2-fold difference in yield between seasons was largely due to a 3.4-fold difference in bunch number over all pruning treatments. Furthermore, inflorescences in seasons of low fruitfulness were also shorter and had fewer branches and flowers. Compensation for low fruitfulness involved higher fruit set (range 17.4 - 35.6%) and development of larger berries leading to larger, but more compact bunches with fewer branches.
- There was a strong interaction between seasonal differences in fruitfulness and pruning system. Seasonal differences in fruitfulness were stronger with lighter pruning treatments, ie. 2-, 3- and 7-fold differences between seasons with spur, mechanical and minimal pruning respectively.
- Lighter pruning treatments produced higher yields associated with higher bunch numbers (ie. 74, 123 and 280 bunches per metre for spur, mechanical and minimal pruning). Compensatory responses leading to development of smaller bunches with lighter pruning (ie. 100g , 67g and 42g for spur, mechanical and minimal pruning) included development of shorter inflorescences with fewer branches and smaller flowers, reduced fruit set and hence; fewer and smaller berries per bunch.
- Post-set bunch thinning treatments had little effect on crop development in the current or following season, as bunch weights were largely unaffected although berries were 7% larger.
- Seed number per berry differed between seasons but was unaffected by pruning or thinning treatments. Minimal pruning produced smaller seeds than spur or mechanical pruning.
- Seasonal effects on berry weight were not only reflected in differences in both the wet and dry weight of flesh and skin but also in the skin:flesh ratio, with potential ramifications for interpretation of seasonal effects on fruit and wine composition and quality.
- Lighter pruning produced smaller berries, lower flesh and skin weights (fresh and dry) but had no effect on the skin:flesh ratio. This result indicates that smaller berries associated with lighter pruning, which have a greater surface area to volume ratio must develop thinner skins and do not have higher skin to flesh ratios as is frequently reported, but not substantiated in the literature.
- Minimal pruning had lower levels of soluble solids at the commencement of sampling in all seasons, indicating a delay in veraison whereas post-set bunch removal appeared to promote veraison. In general, these differences were maintained over the ripening period, hence harvest dates were adjusted to provide fruit of similar maturity for winemaking purposes.
- Berry anthocyanin levels differed between seasons but were largely unaffected by pruning and thinning treatments when comparisons were made at similar maturities.
- Berry phenolics differed between seasons and were also increased by minimal pruning.

- Must pH and titratable acidity differed between seasons requiring different levels of tartaric acid addition for pH adjustment. Pruning and thinning treatments had little effect on must pH although less tartaric acid addition was required for pH adjustment with minimal pruning.
- There were large seasonal effects on wine spectral properties (ie. colour density, total phenolics and ionised anthocyanins) resulting from differences in both the total and the degree of ionisation of the anthocyanins. The seasonal effects on wine spectral properties were not linked to crop yield as the highest yielding season, 2004, also had the highest colour
- Wines from lighter pruning treatments, particularly minimal pruning had enhanced spectral properties (ie. higher colour density, ionised anthocyanins and phenolics).
- Post-set bunch thinning treatments had enhanced wine spectral properties (ie. higher colour density across all treatments and higher total anthocyanins with spur pruning).

In conclusion, the results clearly demonstrate large seasonal differences in Shiraz yield, yield components and grape and wine quality. Over the time frame of this study the ability to stabilize yields from season to season through combinations of lighter pruning and crop removal was not possible due to the overriding effect of low yields across all treatments in season 2003 associated with very low bunch numbers in that season. While lighter pruning treatments produced higher yields associated with a greater number of bunches, significant compensatory effects occurred to minimise this response.

In general treatment effects on wine quality were quite small compared to large seasonal differences. The study revealed that the ability to stabilize wine spectral properties from season to season through combinations of lighter pruning and crop removal was not possible. Indeed the highest yielding season, 2004, produced wines with the highest levels of colour (ie. colour density and ionized anthocyanins) due to the degree of ionization of anthocyanins despite having the lowest levels of total anthocyanins. In general wines from lighter pruning treatments, particularly minimal pruning, had higher levels of colour and phenolics which could not be attributed to differences in the skin to flesh ratio. Thinning treatments enhanced wine colour but had little effect on total phenolics.

The research has highlighted a number of deficiencies in existing knowledge, which require further study. A number of these issues are identified below.

- The study has shown the significant impact that fruitfulness and inflorescence development in spring can have on development of the crop. Much more attention should be given to these measurements if significant advances are to be made in understanding impacts of season and management and their interactions on crop development.
- The study has shown significant seasonal effects on berry components, ie. flesh to skin ratio. More research is required to understand links between berry anatomy and variations in fruit composition and wine quality.
- The study has shown that the ratio of skin to flesh was constant when berry size decreased with lighter pruning. This is not consistent with most unsubstantiated reports regarding the impact of berry weight on red wine quality. The concept that smaller

berries have a higher skin to flesh ratio, and hence high levels of colour and flavour, needs re-evaluation in the light of these results.

## 5h. Response of Chardonnay grown in Sunraysia to pruning and thinning treatments

***Background***

A crop removal treatment was applied to 4 established pruning systems arranged in a replicated field trial. The thinning treatment aimed to remove 30% of bunches at random in early December, once fruit set was completed. The four pruning treatments, selected to cover the complete range of systems in commercial use were:-

- Traditional spur pruning
- Mechanical hedging, 0.2m wide
- Mechanical hedging, 0.3m wide
- Minimal pruning, ie. vines were left unpruned but skirted 0.5m from the ground.

The trial was analysed as a split plot design with pruning treatments as main plot and thinning treatment subplots. In total there were 8 replicates.

***Results***

All treatments were harvested on the same date in each season for commercial reasons, ie. 25th February in 2002, 23rd January in 2003 and 3rd February in 2004. It should be noted that the site was badly affected by hail at flowering in November 2003, affecting the 2004 harvest.

*Yield components at harvest*

The site was badly affected by hail and wind damage at flowering in season 2003/2004. Despite this, there were no significant effects of season or pruning system on yield (Table 1). The significant pruning x thinning interaction is due to the lack of response with the 0.2m mechanical pruning treatment and significantly higher yield of the control treatment with lighter pruning (0.3m mechanical and minimal pruning) compare to the spur or 0.2m mechanical treatments. Overall, thinning significantly reduced yields across all treatments by 19%. The thinning response was largest with the higher yielding, lighter pruning treatments (ie. 0.3m mechanical, 26%, and minimal pruning, 30%).

Table 1. Effect of pruning (spur, mechanical, 0.2m and 0.3m wide, and minimal treatments) and thinning treatment (control, thinned) on yield (kg/m) over three seasons (2001/2002 – 2003/2004). Means within selected comparisons followed by different letters are significantly different (p=0.05)

| | Spur | | Mech. 0.2m | | Mech. 0.3m | | Minimal | | Year |
|---|---|---|---|---|---|---|---|---|---|
| | Con | Thin | Con | Thin | Con | Thin | Con | Thin | |
| 2002 | 7.25 | 6.04 | 6.57 | 6.75 | 7.97 | 7.15 | 7.34 | 4.72 | 6.38 |
| 2003 | 7.31 | 5.86 | 5.85 | 6.82 | 10.06 | 5.57 | 7.40 | 4.71 | 6.86 |
| 2004 | 6.69 | 5.80 | 7.89 | 6.59 | 7.73 | 6.47 | 7.27 | 5.94 | 6.70 |
| Prun x Thin | **7.08de** | **5.90b** | **6.77cd** | **6.72cd** | **8.59f** | **6.39c** | **7.34e** | **5.13a** | |
| Pruning mean | 6.49 | | 6.75 | | 7.49 | | 6.23 | | |

Bunch number was significantly affected by season, pruning and thinning (Table 2). Despite the effects of hail, bunch numbers were still highest in 2004 and lowest in 2002. Bunch numbers increased with light pruning compared to the spur pruned vines by 6%, 22%, and 46% for the 0.2m and 0.3m mechanical hedge and minimal pruned vines control vines respectively. Thinning reduced bunch numbers by 19% over all pruning treatments. However, the magnitude of the reduction in bunch number varied with pruning system being greatest with the lighter pruning systems (ie. 20% with 0.3m mechanical hedging and 30% with minimal pruning). This suggests that accuracy of hand bunch removal is dependent on pruning system.

Table 2. Effect of pruning (spur, mechanical, 0.2m and 0.3m wide, and minimal treatments) and thinning treatment (control, thinned) on bunch number per metre over three seasons (2001/2002 – 2003/2004). Means within selected comparisons followed by different letters are significantly different (p=0.05)

| | Spur | | Mech. 0.2m | | Mech. 0.3m | | Minimal | | Year |
|---|---|---|---|---|---|---|---|---|---|
| | Con | Thin | Con | Thin | Con | Thin | Con | Thin | |
| 2002 | 85 | 68 | 93 | 89 | 105 | 101 | 142 | 91 | **99a** |
| 2003 | 141 | 137 | 125 | 135 | 193 | 108 | 226 | 147 | **171b** |
| 2004 | 150 | 128 | 182 | 149 | 160 | 157 | 180 | 145 | **156b** |
| Prun x Thin | **125b** | **111a** | **133b** | **125b** | **152c** | **122ab** | **183d** | **128b** | |
| Pruning mean | **118a** | | **129ab** | | **137ab** | | **155b** | | |

Bunch weight was significantly affected by season and pruning but not by thinning (Table 3). The lack of a thinning response indicates that there were no significant compensatory effects post crop removal. Bunch weights were highest in 2002 and lowest in the hail affected 2004 season. Bunch weights decreased with light pruning compared to the spur pruned vines (ie. by 10% for mechanical treatments and 30% for minimal). The significant year x pruning interaction can be accounted for by the non-significant pruning effect in 2004, following hail damage. These results suggest that bunches on lighter pruned treatments, particularly minimal pruning are less susceptible to hail damage.

Table 3. Effect of pruning (spur, mechanical, 0.2m and 0.3m wide, and minimal treatments) and thinning treatment (control, thinned) on bunch weight (g) over three seasons (2001/2002 – 2003/2004). Means within selected comparisons followed by different letters are significantly different (p=0.05)

| | Spur | | Mech. 0.2m | | Mech. 0.3m | | Minimal | | Year |
|---|---|---|---|---|---|---|---|---|---|
| | Con | Thin | Con | Thin | Con | Thin | Con | Thin | |
| 2002 | 164.2 | 181.5 | 140.8 | 148.8 | 146.6 | 137.4 | 101.7 | 97.6 | **131.0c** |
| 2003 | 113.3 | 115.2 | 100.0 | 107.1 | 106.7 | 104.1 | 80.6 | 78.5 | **94.8b** |
| 2004 | 84.4 | 82.3 | 82.6 | 84.1 | 91.7 | 78.2 | 81.9 | 79.9 | **81.6a** |
| Prun x Thin | 120.6 | 126.3 | 107.8 | 113.3 | 115.0 | 106.6 | 88.1 | 85.3 | |
| Pruning mean | **123.5c** | | **110.6b** | | **110.8b** | | **86.7a** | | |

*LSD (p=0.05) for the significant Y x P interaction was 22.9*

Berry numbers per bunch generally reflected bunch weight effects being significantly affected by season and pruning but not by thinning (Table 4). Berry numbers were highest in 2002 and lowest in the hail affected 2004 season. Berry numbers per bunch decreased with light pruning compared to the spur pruned vines (ie. by 5% for mechanical treatments and 23% for minimal). The significant year x pruning interaction can be accounted for by the non-significant pruning effect in 2004, following hail damage. These results suggest that berry numbers per bunch were less affected by the hail with lighter pruning, particularly minimal pruning.

Table 4. Effect of pruning (spur, mechanical, 0.2m and 0.3m wide, and minimal treatments) and thinning treatment (control, thinned) on berries per bunch over three seasons (2001/2002 – 2003/2004). Means within selected comparisons followed by different letters are significantly different (p=0.05)

| | Spur | | Mech. 0.2m | | Mech. 0.3m | | Minimal | | Year |
|---|---|---|---|---|---|---|---|---|---|
| | Con | Thin | Con | Thin | Con | Thin | Con | Thin | |
| 2002 | 149.0 | 168.2 | 135.7 | 140.2 | 146.9 | 138.7 | 86.7 | 96.4 | **122.1c** |
| 2003 | 112.7 | 107.1 | 106.7 | 109.3 | 108.2 | 101.5 | 91.4 | 89.3 | **100.5b** |
| 2004 | 79.7 | 82.0 | 81.5 | 84.3 | 92.9 | 79.3 | 88.7 | 86.4 | **84.4a** |
| Prun x Thin | 113.8 | 119.1 | 108.0 | 111.3 | 116.0 | 106.5 | 88.9 | 90.7 | |
| Pruning mean | **116.4b** | | **109.6b** | | **111.3b** | | **89.8a** | | |

*LSD (p=0.05) for the significant Y x P interaction was 20.1*

Berry weights were significantly affected by season and pruning but not by thinning (Table 5). Berry weights were lowest in 2003. Minimal pruning produced significantly smaller berries (7%) than the other treatments. The lack of a thinning response indicates that berry weight compensation did not occur after bunch removal. The significant year x pruning interaction can be accounted for by the development of larger berries with minimal pruning in season 2002.

Table 5. Effect of pruning (spur, mechanical, 0.2m and 0.3m wide, and minimal treatments) and thinning treatment (control, thinned) on berry weight (g) over three seasons (2001/2002 – 2003/2004). Means within selected comparisons followed by different letters are significantly different (p=0.05)

| | Spur | | Mech. 0.2m | | Mech. 0.3m | | Minimal | | Year |
|---|---|---|---|---|---|---|---|---|---|
| | Con | Thin | Con | Thin | Con | Thin | Con | Thin | |
| 2002 | .984 | 1.078 | 1.000 | 1.007 | .934 | .927 | 1.061 | 1.036 | **.995b** |
| 2003 | .983 | 1.039 | .937 | .966 | .980 | 1.020 | .855 | .872 | **.923a** |
| 2004 | 1.066 | 1.005 | 1.028 | 1.011 | .991 | .985 | .942 | .948 | **.979b** |
| Prun x Thin | 1.011 | 1.037 | .988 | .995 | .968 | .977 | .953 | .952 | |
| Pruning mean | **1.024b** | | **.992ab** | | **.973ab** | | **.952a** | | |

*LSD (p=0.05) for the Y x P interaction was 0.090*

Changes in berry weight over the ripening period are presented in the Figures below to show the overall effects of pruning system and thinning treatments on berry development. In general spur pruned vines had larger berries than the mechanical hedged or minimal pruned vines. However, the extended period of maturation in season 2003, compared to the other seasons led to loss in

berry weight by harvest particularly with the more severely pruned treatments. If the harvest had been conducted in early February in 2003 the severely pruned treatments (spur and 0.2m mech.) had larger berries than both the 0.3m mechanical or minimal pruned vines. The effects of pruning on berry weight were much larger in 2003 than in the other seasons. Thinning produced larger berries at all sampling dates in 2002 and 2003 but not in 2004 after the hail.

Figure 1.

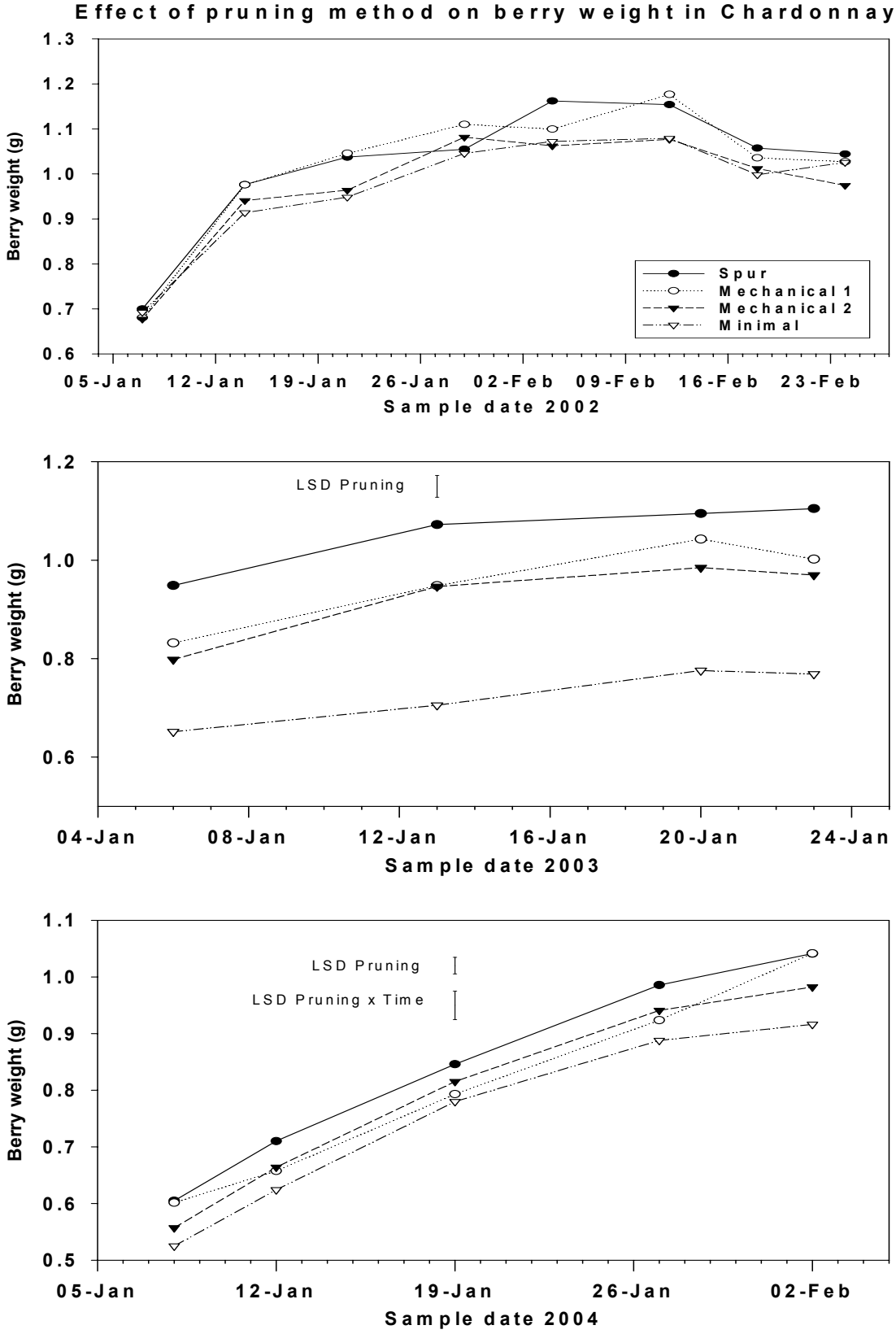
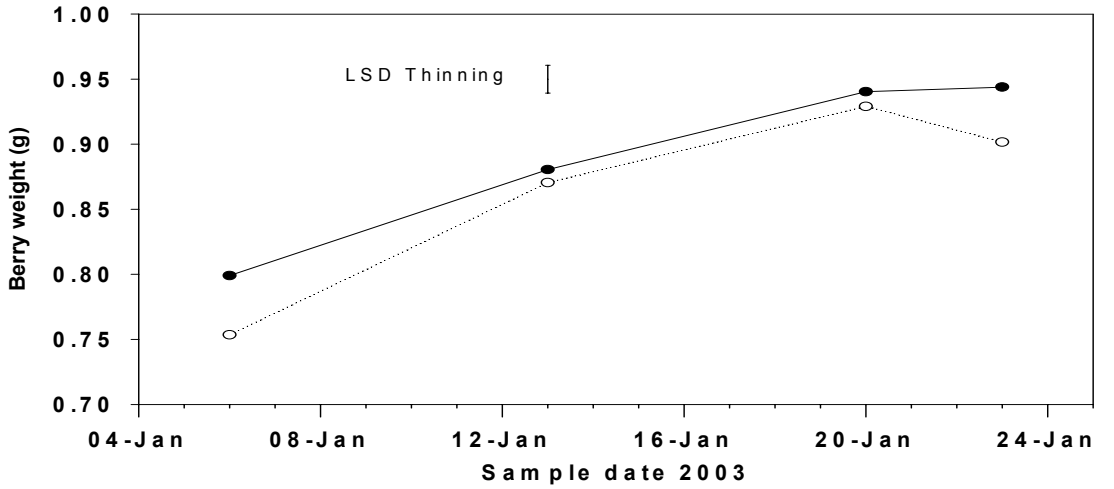
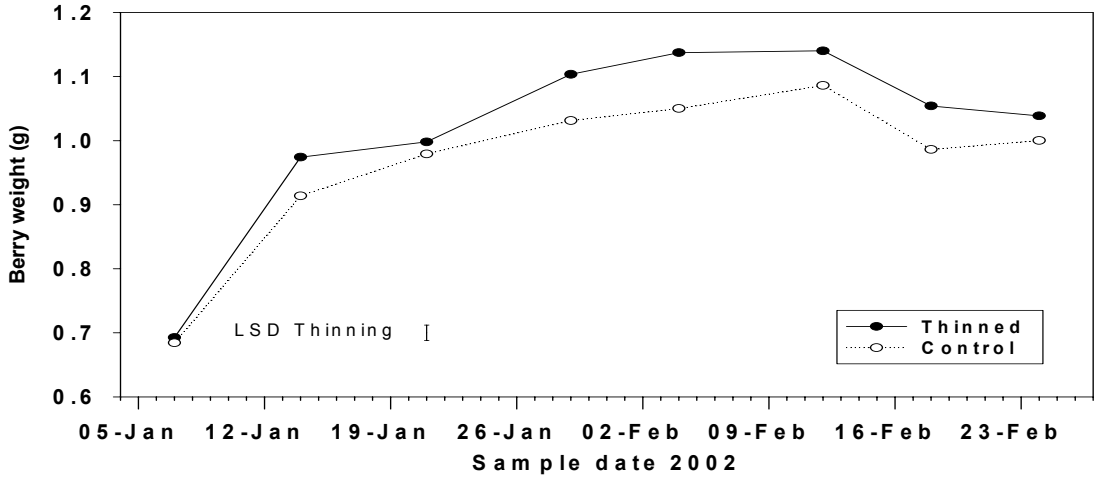
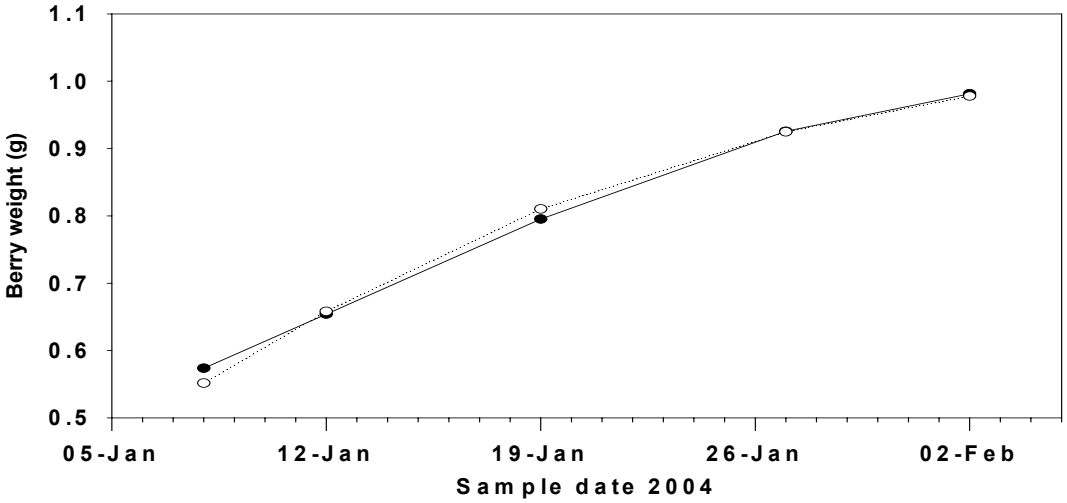

Effect of pruning method on berry weight in Chardonnay
Berry weight (g)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
Spur
Mechanical 1
Mechanical 2
Minimal
05-Jan
12-Jan
19-Jan
26-Jan
02-Feb
09-Feb
16-Feb
23-Feb
Sample date 2002
Berry weight (g)
1.2
1.0
0.8
0.6
LSD Pruning
04-Jan
08-Jan
12-Jan
16-Jan
20-Jan
24-Jan
Sample date 2003
Berry weight (g)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
LSD Pruning
LSD Pruning x Time
05-Jan
12-Jan
19-Jan
26-Jan
02-Feb
Sample date 2004

Figure2




Effect of thinning method on berry weight in Chardonnay



Wet and dry weights of berry flesh, skin and seeds were also determined in season 2003 and 2004. There were no significant thinning effects and few seasonal differences in berry components, hence for simplicity only pruning effects over the two seasons are presented (Table 6). Compared to spur pruning, light pruning treatments with smaller berries, particularly minimal pruning produced less wet and dry flesh (25%) and skin weight (20%). However there were no significant effects on the ratio of flesh to skin weights. There were no significant effects of pruning on seed number but significant differences in seed weight. Compared to spur pruning, lighter pruning treatments, in particular minimal pruning, produced smaller wet and dry seed weight. There were no significant effects on the ratio of flesh to seed. These results indicate that the significant effects of pruning on berry components did not alter the ratios of skin to flesh or flesh to seed ratios hence effects on juice yield or flavour characteristics would be minimal.

Table 6. Effect of pruning (spur, mechanical, 0.2m and 0.3m wide, and minimal treatments) berry components over thinning treatments (control, thinned) and two seasons (2002/2003 – 2003/2004). Means within selected comparisons followed by different letters are significantly different (p=0.05)

| | Spur | Mech. 0.2m | Mech. 0.3m | Minimal |
|---|---|---|---|---|
| Wet flesh (g) | .739c | .625b | .644b | .570a |
| Dry flesh (g) | .160c | .141b | .150bc | .118a |
| | | | | |
| Wet skin (g) | .240b | .216ab | .195a | .192a |
| Dry skin (g) | .070b | .068b | .058a | .056a |
| | | | | |
| Seed number | 1.94 | 1.92 | 1.98 | 1.83 |
| Wet seed weight (g) | .097b | .082ab | .090b | .067a |
| Dry seed weight (g) | .052b | .047ab | .054b | .041a |

*Juice composition*

Sugar levels were significantly affected by season, pruning and thinning treatments (Table 7). Higher sugar levels were achieved at harvest in 2002 compared to the other seasons. In general sugar levels were increased by 1-2 $^{0}$Brix with thinning except spur pruning in 2002 and 2004 and minimal pruning in 2004. Such results suggest that responses to thinning are most likely to occur with lighter pruned vines. The significant year x pruning interaction can be attributed to the low sugar level with minimal pruning in 2003. The significant year x thinning can be attributable to the lack of response to thinning in 2004 with spur pruning and the reversal with minimal pruning after the hail.

Table 7. Effect of pruning (spur, mechanical, 0.2m and 0.3m wide, and minimal treatments) and thinning treatment (control, thinned) on total soluble solids ($^0$Brix) over three seasons (2002/2002 –2003/2004). Means within selected comparisons followed by different letters are significantly different (p=0.05)

| | Spur | | Mech. 0.2m | | Mech. 0.3m | | Minimal | | Year |
|---|---|---|---|---|---|---|---|---|---|
| | Con | Thin | Con | Thin | Con | Thin | Con | Thin | |
| 2002 | 26.6 | 26.6 | 26.2 | 27.3 | 26.4 | 27.3 | 26.3 | 27.9 | **26.7b** |
| 2003 | 22.2 | 24.5 | 23.2 | 24.7 | 22.1 | 24.4 | 19.9 | 23.0 | **22.6a** |
| 2004 | 22.5 | 22.6 | 22.3 | 23.0 | 22.1 | 23.2 | 22.7 | 22.0 | **22.5a** |
| Prun x Thin | **23.8b** | **24.6cd** | **23.9bc** | **25.0d** | **23.5b** | **25.0d** | **23.0a** | **24.3c** | |
| Pruning mean | **24.2ab** | | **24.5b** | | **24.3ab** | | **23.6a** | | |

*LSD's (p=0.05) for the significant Y x P and Y x T interactions were 1.2 and 0.7 respectively.*

Details of changes in sugar over the sampling period are shown for the overall pruning and thinning effects in the figures below. Quite clearly there were differences in fruit maturation between seasons. In season 2002 pruning treatments did not have a significant effect on maturation whereas in 2003 minimal pruning produced a significant delay in maturity. In 2004 minimal pruning advanced maturation early in the sampling period but the differences had disappeared by harvest. Thinning advanced maturation in 2002 and 2003 but had no effect in 2004 after the hail.

Figure3

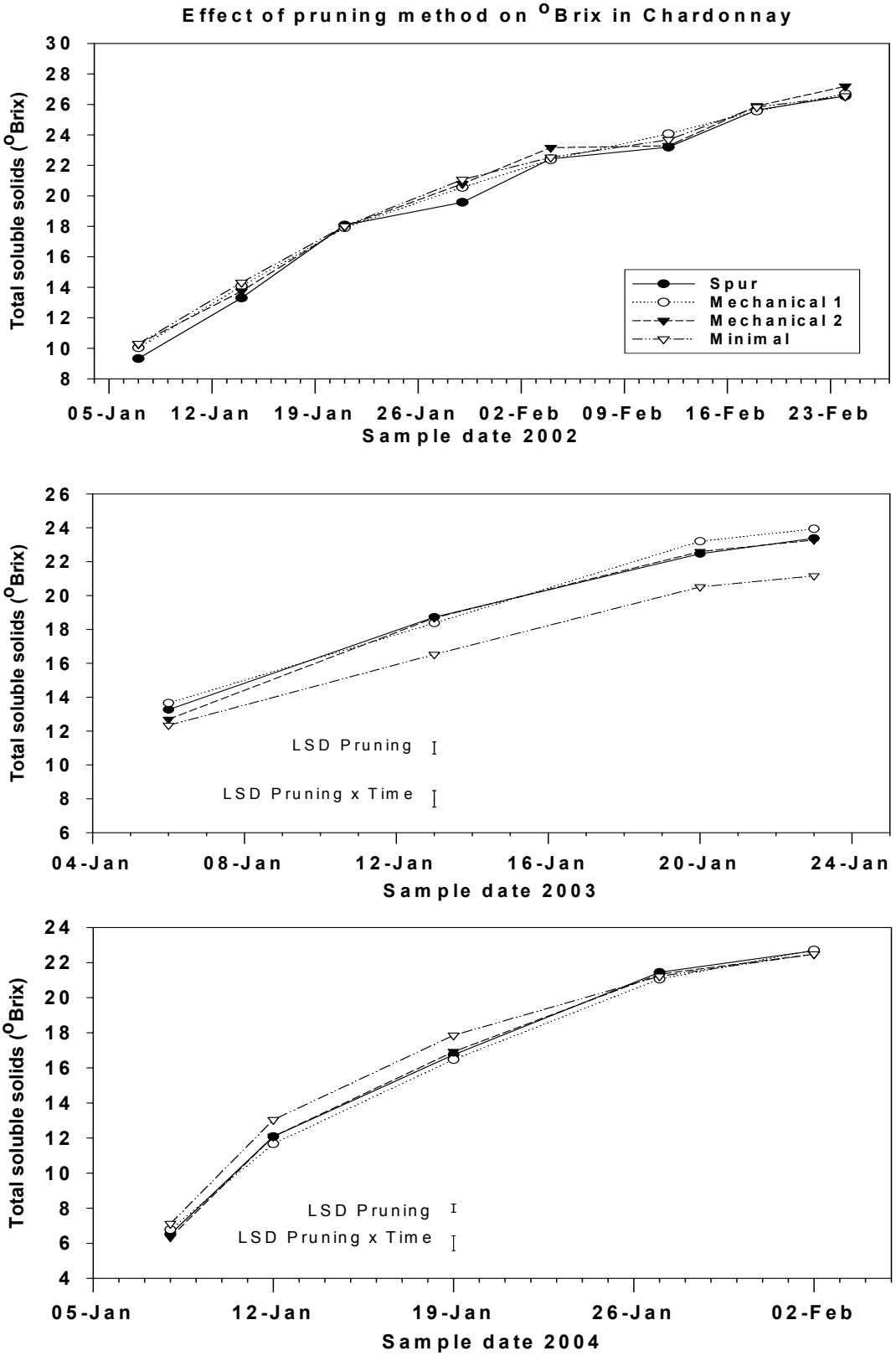
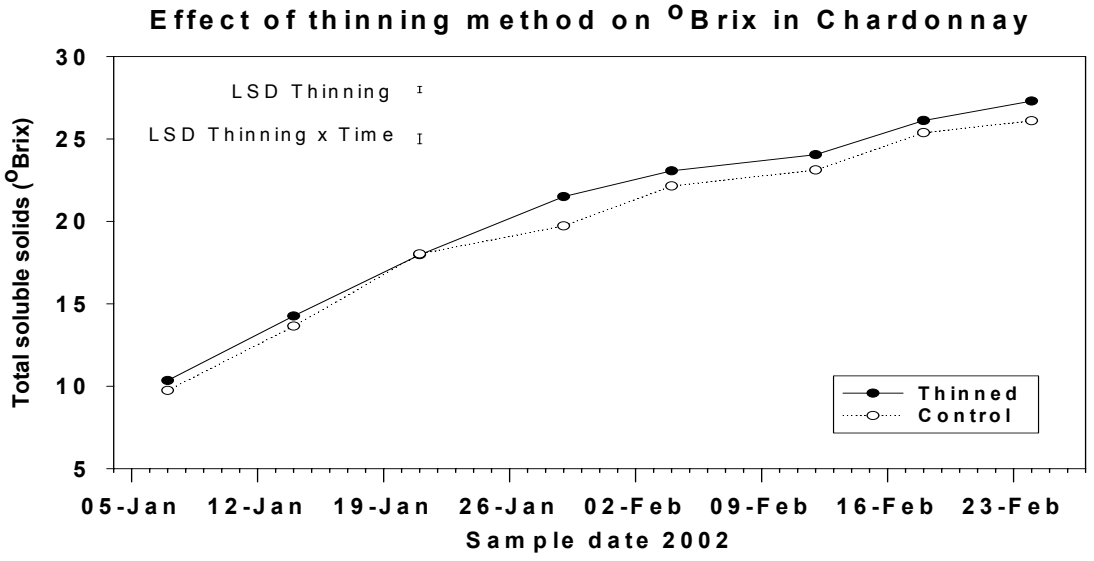
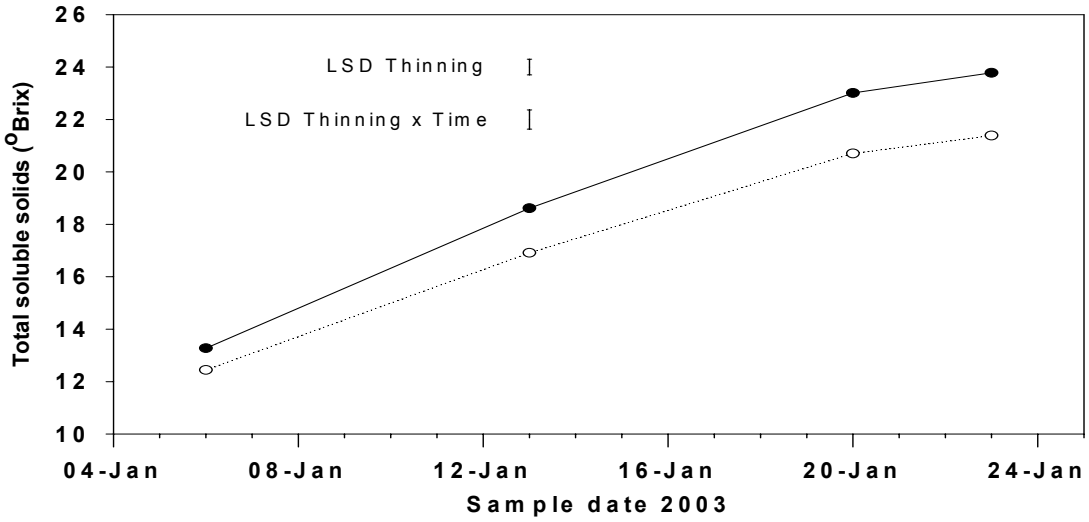
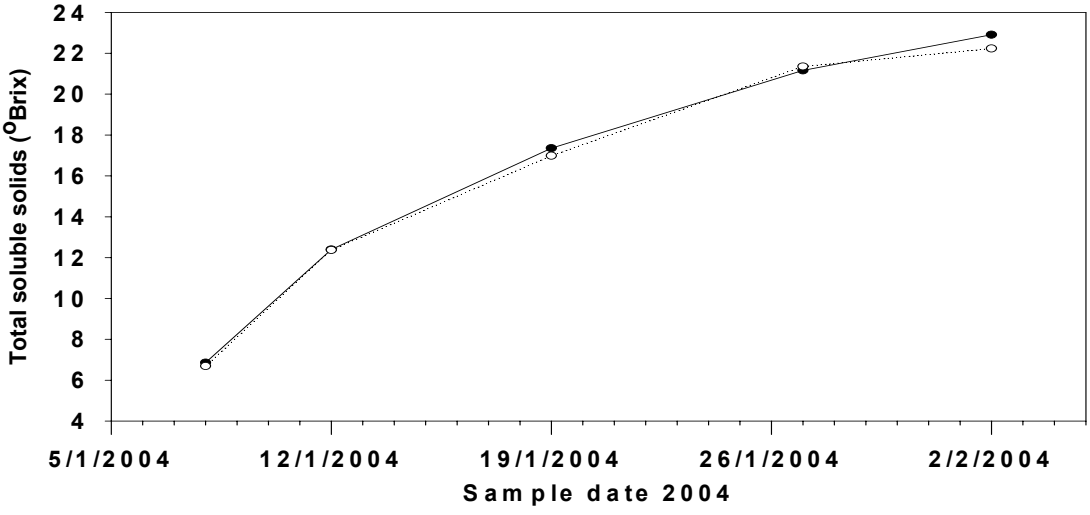

Effect of pruning method on °Brix in Chardonnay
Total soluble solids (°Brix)
30
28
26
24
22
20
18
16
14
12
10
8
Spur
Mechanical 1
Mechanical 2
Minimal
05-Jan
12-Jan
19-Jan
26-Jan
02-Feb
09-Feb
16-Feb
23-Feb
Sample date 2002
Total soluble solids (°Brix)
26
24
22
20
18
16
14
12
10
8
6
LSD Pruning
LSD Pruning x Time
04-Jan
08-Jan
12-Jan
16-Jan
20-Jan
24-Jan
Sample date 2003
Total soluble solids (°Brix)
24
22
20
18
16
14
12
10
8
6
4
LSD Pruning
LSD Pruning x Time
05-Jan
12-Jan
19-Jan
26-Jan
02-Feb
Sample date 2004

Figure4


Effect of thinning method on °Brix in Chardonnay
LSD Thinning
LSD Thinning x Time
Thinned
Control
Total soluble solids (°Brix)
30
25
20
15
10
5
05-Jan
12-Jan
19-Jan
26-Jan
02-Feb
09-Feb
16-Feb
23-Feb
Sample date 2002


LSD Thinning
LSD Thinning x Time
Total soluble solids (°Brix)
26
24
22
20
18
16
14
12
10
04-Jan
08-Jan
12-Jan
16-Jan
20-Jan
24-Jan
Sample date 2003


Total soluble solids (°Brix)
24
22
20
18
16
14
12
10
8
6
4
5/1/2004
12/1/2004
19/1/2004
26/1/2004
2/2/2004
Sample date 2004

There were significant effects of season and thinning but no pruning effects on juice pH (Table 8). Higher pH values achieved in 2002 and with thinning treatments reflected higher maturity levels (Table 7). By contrast, with titratable acidity there were significant effects of season and pruning but no effects of thinning (Table 9). Both the lighter 0.3 mechanical and minimal pruning treatments had lower acid levels.

Table 8. Effect of pruning (spur, mechanical, 0.2m and 0.3m wide, and minimal treatments) and thinning treatment (control, thinned) on juice pH over three seasons (2002/2002 –2003/2004). Means within selected comparisons followed by different letters are significantly different (p=0.05)

| | Spur | | Mech. 0.2m | | Mech. 0.3m | | Minimal | | Year |
|---|---|---|---|---|---|---|---|---|---|
| | Con | Thin | Con | Thin | Con | Thin | Con | Thin | |
| 2002 | 3.49 | 3.56 | 3.49 | 3.52 | 3.54 | 3.54 | 3.53 | 3.61 | **3.53b** |
| 2003 | 3.36 | 3.43 | 3.39 | 3.41 | 3.37 | 3.44 | 3.38 | 3.45 | **3.40a** |
| 2004 | 3.37 | 3.39 | 3.40 | 3.40 | 3.36 | 3.39 | 3.43 | 3.40 | **3.40a** |
| Prun x Thin | **3.41a** | **3.46b** | **3.43ab** | **3.44b** | **3.42a** | **3.46b** | **3.44b** | **3.49c** | |
| Pruning mean | 3.43 | | 3.43 | | 3.44 | | 3.47 | | |

Table 9. Effect of pruning (spur, mechanical, 0.2m and 0.3m wide, and minimal treatments) and thinning treatment (control, thinned) on titratable acidity (g/L) over three seasons (2002/2002 – 2003/2004). Means within selected comparisons followed by different letters are significantly different (p=0.05)

| | Spur | | Mech. 0.2m | | Mech. 0.3m | | Minimal | | Year |
|---|---|---|---|---|---|---|---|---|---|
| | Con | Thin | Con | Thin | Con | Thin | Con | Thin | |
| 2002 | 4.98 | 5.64 | 5.36 | 5.87 | 5.09 | 5.05 | 4.61 | 4.54 | **5.22a** |
| 2003 | 6.17 | 5.82 | 5.95 | 5.92 | 5.73 | 5.45 | 5.71 | 5.57 | **5.80b** |
| 2004 | 8.83 | 8.27 | 8.75 | 8.66 | 8.57 | 8.17 | 8.06 | 8.08 | **8.42c** |
| Prun x Thin | 6.66 | 6.58 | 6.69 | 6.81 | 6.46 | 6.22 | 6.13 | 6.06 | |
| Pruning mean | **6.62b** | | **6.75b** | | **6.34ab** | | **6.09a** | | |

In season 2003 juice samples collected from each treatment were assessed by sensory techniques for aroma using forced paired comparisons with a 16 member panel. There was a significant effect of thinning across pruning treatments in juice aroma. However, because all treatments were harvested on the same day at different maturity levels, Table 7 the significant effect attributed to thinning may be confounded with fruit maturity. In season 2004 small-scale wine lots were produced from high and low yielding vines of each pruning and thinning treatment. At the time of report preparation bottling was completed but no assessment of the wines had been undertaken.

***Summary***

Effects on Chardonnay crop development and fruit maturation of commercial pruning treatments (severe to light) and bunch thinning (30%) were assessed over three seasons in an integrated study. Pertinent results are described below.

- Chardonnay yields were very stable from season to season, despite 2-fold differences in bunch number, due to compensatory effects occurring with bunch development (ie. berries per bunch and berry weight).
- Chardonnay yields were largely unaffected by pruning treatment, despite significant differences in bunch number between severe and light pruning treatments, again because of compensatory effects occurring with bunch development (berries per bunch and berry weight)
- Post-set bunch thinning reduced yield across all treatments but were more accurately applied with the lighter pruning treatments (ie. 0.3m hedge and minimal pruning) which had higher bunch numbers.
- Post-set bunch thinning had little impact on bunch weight, which indicates that berry weight compensation was small.
- Lighter pruning treatments developed smaller berries with reductions in total flesh weight, skin weight and seed weight. However the ratio of skin to flesh was unaffected when determined as fresh or dry weights.
- Bunch thinning enhanced sugar levels and increased juice pH without a significant effect on titratable acidity across all pruning treatments, although the response varied from season to season.

In conclusion, there appears to be little value in adopting bunch thinning to stabilise yield or quality stability in warm climate Chardonnay based on this study. With respect to crop development, Chardonnay proved to be a very plastic variety as yields were largely unaffected by seasonal conditions or pruning system. Interpretations of the effects of small berries on white wine flavour and aroma based on lower flesh to skin ratios need revision if the results from this study showing no significant differences in the ratios of flesh to skin, are applicable more generally to white wine varieties.

# Project outputs, outcomes and recommendations

## Project outputs, outcomes and recommendations

Over the course of the project results have been published in scientific and industry journals, presented in major industry forums including ASVO seminars, the 12th Wine Industry Technical Conference and the Viticulture 04 Conference as well as at the regional and local level. A list of the key publications is provided below. There has been significant facilitation and interaction with industry with respect to adoption of improved crop forecasting and techniques for crop regulation, in particular mechanical thinning which was widely used in both the hot and cool regions in recent seasons. A significant output from the project has been the development of enhanced, Excel and computer based crop forecasting systems. Furthermore, data from a number of the detailed studies have been assembled and provided to researchers in the CRCV Viti$ys project to underpin and verify routines in VineLOGIC for sugar accumulation and changes in titratable acidity, colour and phenolics during ripening.

### Project Publications


Clingeleffer P.R., Krstic M.P., Welsh M.A., and Petrie P.R. (2002) Pruning & grape quality : warm area irrigation vineyards. Grapevine (May), 8-9.

Clingeleffer, P. R., Petrie, P. R., and Krstic, M. P. (2004) Understanding the interaction between yield and quality [abstract]. Viticulture '04 : growing our future, Mildura, Vic. (Dept. of Primary Industries: Mildura, Vic.).

Clingeleffer, P. R., Petrie, P. R**.**, and Krstic, M. P. (2003) Warm climate Cabernet Sauvignon studies . Riverlink Workshop on Cabernet Sauvignon, Merbein, Vic. (Riverlink: [Mildura]) pp. 3-6.

Clingeleffer P.R., Tarr C.R., and Petrie P.R. (2004) Trends in Sultana production and crop forecasting . Dried Fruits News **NS 31** (2), 14-15.

Clingeleffer P.R., Tarr C.R., Petrie P.R., and Emmamuelli D.R. (2002) Trends in Sultana production and utilisation in Australia. Dried Fruits News **NS 29** (2), 9.

Dunn, G.M., Martin, S.R., Whiting, J.R., Krstic, M.P. and Clingeleffer, P.R. (2001) Yield targets: how do we hit them and how important are they? Paper presented to the 11th Australian Wine Industry Technical Conference, Adelaide October 2001. (11 pp.)

Dunn, G.M. (2003) Crop forecasting for better vineyard efficiency and wine quality. Australian Grapegrower and Winemaker **473**, 17-18.

Dunn, G.M. and Martin, S.R. (2003) Better early prediction of bunch weight. Australian Viticulture **7 (4)**: 37-41.

Dunn, G.M. and Martin, S.R. (2003) Improving bunch weight prediction in winegrape yield forecasting, Australian and New Zealand Grapegrower and Winemaker **470**, 19-20.

Dunn, G.M. and Martin S.R. (2003) The status of crop forecasting in the Australian wine Industry. Proceedings of the ASVO Seminar Series: Grapegrowing at the Edge, Tanunda, Barossa Valley, South Australia, July 2003 pp. 4-8.

Dunn, G.M., Lothian, P.A. and Clancy, T. (editors) Flower formation, flowering and berry set in grapevines. Proceedings of a workshop held at the Victorian Department of Primary Industries, Tatura, 22nd & 23rd May 2003 (in press)

Dunn, G.M. (2004) Windows of sensitivity in grapevine reproduction. Paper presented at the Flower formation, flowering and berry set in grapevines workshop held at the Victorian Department of Primary Industries, Tatura, 22nd & 23rd May 2003 19pp.

Petrie, P. R. and Clingeleffer, P. R**.** (2003) Determination of critical weather periods associated with annual variations in Sultana (*Vitis vinifera* L.) yield [abstract]. 2nd Australian Grapevine Physiology Conference, Sunbury, Vic. (University of Melbourne: Melbourne) 7.

Martin, S.R. and Dunn, G.M. (2003). What really caused lower yields in 2003? Australian Viticulture **7 (4)**: 35-36.

Martin, S.R., Dunn, G.M. and Dunstone, R. (2003) How to Forecast Winegrape Deliveries (using Excel spreadsheet Grape Forecaster version 7). Department of Primary Industries

Martin, S.R., Dunn, G.M and Kelly, G. (2004) Timing of cane sampling for bud dissection. Australian and New Zealand Grapegrower and Winemaker **484**, 46-48.

Petrie P.R. and Clingeleffer P.R. (2003) Trends in Sultana production & yield forecasting for 2004. Dried Fruits News **NS 30** (2), 10-11.

Petrie P.R., Clingeleffer P.R., and Krstic M.P. (2003) Mechanical thinning to stabilise yield and improve grape maturity and colour. Australian & New Zealand Grapegrower & Winemaker (473a), 118-120.

Petrie, P. R., Clingeleffer, P. R., and Krstic, M. P. (2003) Using mechanical thinning to improve maturity and anthocyanin content of Cabernet Sauvignon in a warm climate [abstract]. Riverlink Workshop on Cabernet Sauvignon, Merbein, Vic. (Riverlink: [Mildura]) 14.

Petrie P.R., Clingeleffer P.R., Krstic M.P., and Welsh M.A. (2003) Pruning to improve grape and wine quality in warm, irrigated vineyards. Australian & New Zealand Grapegrower & Winemaker (472), 55-58.

Petrie P.R., Cooley N.M., and Clingeleffer P.R. (2004) The effect of post-veraison water deficit on yield components and maturation of irrigated Shiraz (*Vitis vinifera* L.) in the current and following season. Australian Journal of Grape and Wine Research **10**, 203-215.

Petrie, P. R**.**, Dunn, G. M., Martin, S. R., Krstic, M. P., and Clingeleffer, P. R. (2003) Crop stabilisation. Proceedings, ASVO Seminars : grapegrowing at the edge, managing the wine business, impacts on wine flavor, Tanunda, S. Aust. (Australian Society of Viticulture and Oenology: Adelaide) pp. 11-16.

Petrie, P.R. and Clingeleffer, P.R. The effect of temperature and light before and after budburst on inflorescence morphology and flower number of Chardonnay (*Vitis vinifera* L). Australian Journal Grape and Wine Research **11**, 59-65.

Petrie, P.R. and Clingeleffer, P.R. Using mechanical thinning to improve maturity and anthocyanin concentration in Cabernet Sauvignon in a warm climate. Australian Journal Grape and Wine Research (submitted).

**Recommendations**

The project, which aimed to develop and evaluate crop control techniques to stabilise yield and quality from season-to-season has identified a number of important issues of relevance to the wine industry and the wider research community. Key recommendations are listed below, i.e. that:

1. Industry assess the potential for mechanisation of techniques for accurate crop control by shoot thinning, bunch and berry removal to stabilise yield from season to season. Adoption should be soundly based on accurate crop forecasts and recognise that impacts on quality, apart from early maturity will vary with variety and seasonal effects.
2. Industry utilise the enhanced crop forecasting techniques at both the vineyard and regional level. In the latter case this can be achieved with minimum input to accurately describe regional trends from season to season.
3. Industry assess integration of lighter pruning techniques with application of crop control techniques when necessary to optimise both yield and fruit quality.
4. Industry assess the impact of berry weight loss on final yields across all varieties, not just Shiraz.
5. Further research be conducted to enhance understanding of the interactions between seasonal climatic effects and vine management on bud and shoot fruitfulness and subsequent effects on crop development and final yield.
6. Data collection of inflorescence characteristics (ie. length, branch number, flower number and size, %set etc.) be included in grapevine research projects to elucidate seasonal and management effects on critical yield components and development of the final crop.
7. Further research be conducted to identify the causes and control bunch loss in Chardonnay
8. Further research be conducted to assess relationships between berry anatomy and grape composition and wine quality with reference to both seasonal and management effects.
9. Researchers and industry personnel exercise caution when attributing berry size and the skin to flesh ratio as factors contributing to differences in berry composition.

**Intellectual Property**

The project has generated considerable information and knew knowledge, which has been published or will be made available largely in the public domain. The key issues, with respect to intellectual property, has been the development of the Excel based crop forecasting spreadsheets (eg. Grape Forecaster *version* 6) and manuals and inputs into development of software for an enhanced computer 'Database Crop Forecasting System' and 'Trainers Guide', which was funded by GWRDC as in a separate project (ie. 'Winegrape Crop Forecasting Training Module' project).