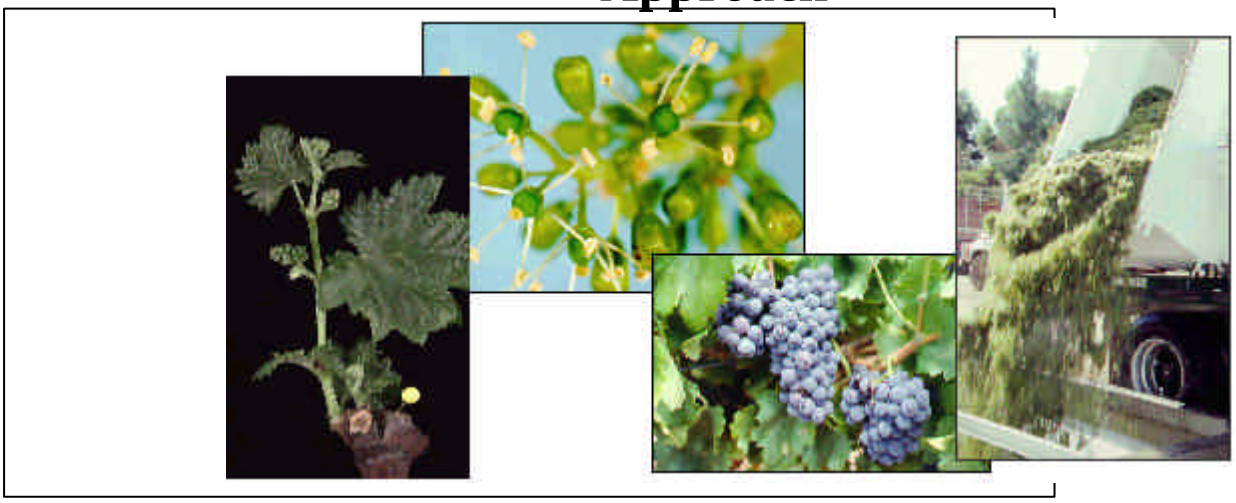
Crop Development, Crop Estimation and Crop Control to Secure Quality and Production of Major Wine Grape Varieties: A National Approach



FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Project Number: **CSH 96/1**

Principal Investigator: **Peter Clingeleffer**

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EXECUTIVE SUMMARY

During the 1996 vintage the Australian wine industry suffered problems associated with unexpectedly large deliveries of grapes to wineries. This followed a vintage during which deliveries were generally lower than expected. Coming at a time of rapid industry growth to meet increasing demand for Australian wine in export markets, these unforeseen fluctuations in grape supply had an adverse impact throughout the entire industry. This focused the attention of the industry on its general inability to accurately forecast the production of particular classes of grapes at regional, vineyard and block levels. It also raised questions as to why large fluctuations in wine grape yield occur and how they might be controlled.

Against this background, a workshop was held at Attwood, Victoria, in June 1996. Participants included members of GWRDC, CRCV, CSIRO, NRE and CSU. Based on the priorities agreed upon at this meeting and broader industry consultation, the GWRDC facilitated the development of the project *Crop Development, Crop Estimation, and Crop Control to Secure Quality and Production of Major Wine Grape Varieties: A National Approach*.

Project Objectives

1. Review existing literature, unpublished results and anecdotal evidence on the physiological and environmental controls of crop development, particularly as they relate to bunch number, bunch size, bunch architecture and berry development
2. Adapt existing forecasting methods to accommodate modern vineyard management practices
3. Utilise historical data sets to provide baseline data on regional and seasonal impacts on crop potential and final yield for the major wine grape varieties
4. Integrate data obtained in the vineyard with statistical information on vineyard area and vine management to forecast district yield of a given variety
5. Undertake physiological studies to enhance control of crop development and crop estimation, and secure quality and production of major wine grape varieties in the various climatic regions of Australia

Personnel

This project was funded by GWRDC, NRE and CSIRO, with in-kind support from the wine industry. It was led by CSIRO Merbein, in collaboration with NRE (Department of Natural Resources and Environment, Victoria) researchers based at Irymple and Tatura, and ran from January 1997 to June 2000. The principal researcher was Peter Clingeleffer, based at CSIRO Merbein. Dr Mark Krstic was appointed to a Post Doctoral position at Merbein to undertake physiological research and to develop and extend crop forecasting systems. He was supported by Mark Welsh, who was employed by NRE and based at CSIRO Merbein. Dr Gregory Dunn was appointed to a new position of Senior Viticultural Physiologist at NRE Tatura, supported by Steve Martin. Rob Hayes (NRE Irymple) and Bill Ashcroft (NRE Tatura) provided supervision. In addition, the project was supported by strong input from Dr Karl Sommer (CSIRO Merbein) and John Whiting (NRE Tatura). The project team reported to and was advised by an Industry Reference Group, which consisted of technical representatives from major wine companies, grower organisations and government agencies. During the life of the project, considerable in-kind support and guidance was also provided by growers who allowed research to be conducted in their vineyards.

Results

Review

The review focused on three major areas: 1. A description and discussion of temporal and spatial variation in yield and its components, 2. The physiology of flower formation in grapevines, and 3. options for stabilising yield and quality in wine grapes.

Flower formation in grapevines is complex and is greatly influenced by the environment and cultural practices. Critical stages of flower formation appear to be induction, initiation and early differentiation, and budburst. Despite the large amount of work done the influence of environmental and cultural factors on flower development, the process remains poorly understood. For instance, the relative importance of branching prior to dormancy compared to differentiation during budburst in controlling potential inflorescence size and flower numbers. This has significant implications for both forecasting and stabilising yield variation. A combination of adequate light and exposure to high temperatures are required for maximum inflorescence initiation and differentiation in grapevines. However most experiments focus on bunches per shoot, which is the combined result of both of these processes. We know that aside from any effects of initiation (and differentiation) that bunches per shoot can be modified by temperatures at budburst and also by the types of shoots that burst (i.e.

ratio of primary shoots to secondary shoots). There are many lines of evidence that point to the importance of conditions (including temperature and light) leading up to the initiation and differentiation of anlagen. Therefore, there is an urgent need to describe the time-course of induction and initiation for our major wine grape varieties in a range of climatic regions and to link these processes to well defined phenological stages.

Baseline data on the nature and extent of variation was reviewed and some of this data was used by the project to design sensible sampling strategies for improved yield forecasting. However, the review highlighted the need for continued investment in research and development of rapid and accurate methods for assessing crop load and berry composition. Current research into yield mapping (Precision Agriculture) was discussed. Using yield mapping to stabilise temporal variation in yield and quality was seen as a challenge. It is undeniable that seasonal variation in weather exerts (the) major influence over yield and quality. While detailed spatial map of yields are potentially very useful we won't realise this potential until we assemble a better understanding of the interaction between management and weather during critical stages of reproduction. Gaining this is made more challenging by our lack of detailed, quantitative knowledge about the influence of conditions in the previous season on yield in the current season for wine grapes. In the absence of any obvious nutritional or water availability limits to yield, bunch or shoot removal appear to be the simplest and most powerful ways to control crop during the current season. Also, given the obvious influence of light and temperature in the previous season on yield, improved canopy management during critical stages of the previous season will be important. Nevertheless, irrespective of how one might stabilise yield any methods will rely on both accurate estimates of crop potential and monitoring of crop development during the season.

Crop forecasting

In 1997 a crop forecasting system and training package was developed in collaboration with the Victorian & Murray Valley Winegrape Growers Council Inc. (VMVWGC) and Sunraysia College of TAFE. It was based on existing forecasting methods, with refinements to allow it to be used with mechanised viticultural systems. The design allowed the forecast made from individual vineyard blocks to be improved during the growing season. Over 1000 copies of the instruction video have been distributed which is a testament to the industries desire to improve its crop forecasting practices. Developments in forecasting technique during the course of the project have allowed the original forecasting system to be refined. It has now been developed into a computerised system that should provide more accurate forecasts, as sample numbers are tailored to the existing variability within the vineyard. Techniques to forecast yield potential prior to budburst were also evaluated, with a view to incorporating them into the system later.

In order to provide a baseline to assess the performance of prediction systems when used by the industry, crop forecasts provided to wineries in January were compared with actual deliveries. Typically, wineries recorded forecasts of deliveries of batches of grapes at a grower x variety level. Measures of forecaster performance that are in use in the industry are the mean difference and the mean absolute difference between forecast and actual production, expressed as a percentage of actual delivery. The absolute difference is probably the most useful single measure of performance, because under- and over-estimates do not cancel each other out and the total impact on the winery of a batch-by-batch level can be quantified. At present, the mean absolute difference achieved by grape growers is 33% of actual.

The refined forecasting system has the potential to reduce the mean absolute difference between forecast and actual production from 33% to approximately 20% of actual production across the industry. This is well above the 5% mean absolute difference generally sought by wineries. However, the value to the industry of a reduction from 33% to 20% would be in the order of $85 million per year. The performance of the crop forecasting system is limited chiefly by expenditure on sampling by growers and reliance on historical means as predictors of yield components not yet formed at the time of each forecast. It may be possible to reduce the mean absolute difference between forecast and actual production to approximately 10% by predicting mean bunch weight at harvest from measurements of bunch characteristics before flowering and after fruit set. This is the subject of ongoing research.

Forced single node cuttings were used in an attempt to estimate yield potential during dormancy. Difficulties were encountered with poor budburst from lower nodes and in the case of Chardonnay poor correlation with inflorescence numbers counted in spring. Although the technique is simple because it does not require a dissecting microscope or a detailed knowledge of bud anatomy, it is relatively labour intensive and, in our opinion this time would be better spent acquiring the necessary skills and knowledge to dissect latent buds. Estimating bud fertility by microscopic dissection has the advantage of being quick and instantaneous. This means that information on node fertility is available soon after buds are collected. Variances around sample means can be calculated and if more buds need to be collected and dissected for a better prediction then this can

be done easily. Early results indicate that if proper care is taken, and some simple rules are applied, bud dissection is a reliable method for estimating yield potential during dormancy. This research is continuing.

Yield forecasts from vineyard blocks can be significantly improved by improving the prediction of final bunch weight. This has proved difficult and continues to represent a substantial source of error. One method for assessing potential bunch size after budburst is to count flowers. However this is time consuming, and impractical for most growers. Preliminary research has shown that branch numbers (primary branches on rachis), whether measured after budburst, around veraison or before harvest usually explains between 60 to 70% of the variation in flower number and berry number at harvest. This estimator of bunch weight may be a significant improvement on using historical averages and would also lend itself to rapid spatial analysis techniques already being used or under development.

Collection and analysis of Historical data sets

Analyses of a range of medium- and long-term yield data sets for a wide range of varieties grown in a diverse range of climates (from cool to hot) consistently show that bunches/vine explains 60-70% of the seasonal variation in vine yield. Yield fluctuations are less sensitive to berries/bunch (ca. 30%) and less sensitive again to berry size (ca. 10%). Although bunches/vine is a product of node fertility and budburst, most of the variation is due to bunches/shoot. This is important as it suggests that stabilising yield hinges upon understanding and being able to manipulate the number of bunches that grapevines produce. In the context of crop forecasting the greatest effort should be given to an accurate assessment of bunch number. Inclusion of support information on bunch development, i.e. berries/bunch should further enhance the accuracy of the predicted yield.

Although the results of yield component analysis have not led to a model that can be used to predict and control yield, they have provided a basis for generating hypotheses and setting research priorities. Understanding the relationships between grape yield and factors in the previous season will improve with the aid of physiological research to identify critical periods during initiation and development. In the interim, we can at least identify the most important yield components to measure and control to manage seasonal yield variation intelligently and efficiently.

Physiological research

There was a diverse program of field and laboratory experimentation. As yield component analysis showed that bunches/vine was the major contributor to seasonal variation in vine yields. The research was heavily weighted toward understanding factors that determine bunch numbers and, to a lesser extent, factors that control bunch size.

The timing of inflorescence initiation was studied for the varieties Cabernet Sauvignon, Chardonnay and Shiraz. For Sunraysia, initiation and primary differentiation periods were determined for these 3 cultivars in the 1998/99 season. This is critical for determining treatments in future experiments and for developing models using weather data to model yield formation. Other results showed that the relationship between leaf area per shoot and the number of flowers per shoot was poor. This has implications for modelling yield development in grapevines. Unlike annual crops, such as wheat, using leaf area or dry matter production as a key driving variable to model yield development is likely to be unsuccessful. Rather, modelling should take into account effects of conditions during the previous season.

The experimental program testing the effects of conditions during budburst on yield components showed that conditions during floral initiation regulate both inflorescence and flower numbers. This may provide an opportunity to manipulate yield potential exists by actions during critical periods in the development of anlagen. For this potential to be realised, however, the critical periods need to be defined, important determining factors need to be identified, and commercially viable ways of controlling them need to be developed.

Other studies concentrated on budburst of unpruned vines, flowering and fruit set, fruit ripening and quality and the effects of mechanical thinning. The reader is referred to these sections for any implications and recommendations.

AUTHORS

Mr Peter Clingeleffer, CSIRO Merbein wrote sections 5.2 and 5.3 and contributed to sections 4.1, 7.1, 7.3, 7.7, 7.8 and 7.9.

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1 Background

During the 1996 vintage the Australian wine industry suffered problems associated with a general pattern of unexpectedly large deliveries of grapes to wineries. This followed a vintage during which deliveries were generally lower than expected. Coming at a time of rapid industry growth to meet increasing demand for Australian wine in export markets, these unforeseen fluctuations in grape supply had an adverse impact throughout the entire wine production and distribution chain. This focused the attention of the industry on its general inability to accurately forecast the production of particular classes of grapes at regional, vineyard and block levels. It also raised questions as to why large fluctuations in wine grape yield occur and how they might be controlled.

The industry has always been faced with year to year fluctuations in grape yields, and over the years there have been periods when research into yield formation processes and development of forecasting systems has been funded. Notably, CSIRO researchers at Merbein have made major contributions, and there is a long history of collaboration and exchange of information between the CSIRO and the Victorian Department of Agriculture (now Agriculture Victoria, part of the Department of Natural Resources and Environment (NRE)), particularly in the Murray Valley.

Against this background, a workshop was held at Attwood, Victoria, in June 1996. Participants included members of GWRDC, CRCV, CSIRO, NRE and CSU. Based on the priorities agreed upon at this meeting and broader industry consultation, the GWRDC facilitated the development of the project *Crop Development, Crop Estimation, and Crop Control to Secure Quality and Production of Major Wine Grape Varieties: A National Approach*.

2 Objectives

The major objectives of the project were to:

1. Review existing literature, unpublished results and anecdotal evidence on the physiological and environmental controls of crop development, particularly as they relate to bunch number, bunch size, bunch architecture and berry development

2. Adapt existing forecasting methods to accommodate modern vineyard management practices

3. Utilise historical data sets to provide base line data on regional and seasonal impacts on crop potential and final yield for the major wine grape varieties

4. Integrate data obtained in the vineyard with statistical information on vineyard area and vine management to forecast district yield of a given variety

5. Undertake physiological studies to enhance control of crop development and crop estimation, and secure quality and production of major wine grape varieties in the various climatic regions of Australia

The sections of this report address each objective in turn.

3 Review and Position Statement

Environmental and Physiological Control of Crop Development in Grapevines

3.1 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. A quantitative analysis (Martin, Urbanski and Dunn, unpublished data) has demonstrated substantial economic and social benefits of just being able to improve our ability to forecast yield. Recognising these and other, arguably more substantial benefits that would flow from an improved ability to reduce variations in yield and quality, GWRDC, Agriculture Victoria and CSIRO agreed to fund the collaborative project *Crop Development, Crop Estimation and Crop Control to Secure Quality and Production of Major Wine Grape Varieties: A National Approach* which began in mid 1997. One of the major objectives of the project was to prepare a position statement that would review existing literature, unpublished results and anecdotal evidence on the physiological and environmental controls of crop development, particularly as they relate to bunch number, size, architecture and berry development. The major objectives of the position statement were to:

- Contribute to the development of improved methods for forecasting
- Provide a sound basis upon which to make recommendations for vineyard management to stabilise yield and quality, both spatially within a season and from season-to-season.
- Define a sensible program of physiological research for the overall program

The position statement comprises 3 major sections. The first of these (Section 3.2) is devoted to a description of temporal and spatial variation in yield and its components. Sections 3.3 and 3.4 are devoted to flower formation and fruit set. Finally, in section 3.5, an attempt is made to synthesise the information reviewed in previous sections within the context of evaluating options for stabilising yield and quality in wine grapes.

3.2 Spatial and Temporal Variation in Vineyard Yields

3.2.1 Introduction

Variations in grape yield and composition occur from season-to-season, across sites, between regions, within individual vines and between berries within an individual bunch. Here we consider spatial and temporal variation in yield, discuss *variation* and *stability* in biological and manufacturing systems and point to implications for further research with a particular emphasis on management systems to better stabilise yield and quality.

3.2.2 Temporal (Seasonal) Variation

Seasonal fluctuations in grapevine yields may be considerable. In any season yield may be affected by a combination of weather, pests, diseases and cultural intervention. Generally, individual vineyard blocks form management units to which many management actions (eg. pruning, weed control, harvesting) are homogenously applied. Figure 3.2.1 presents examples of seasonal variation for two such vineyard blocks, one being a spur-pruned Chardonnay block and the other a minimal-pruned Cabernet Sauvignon block.

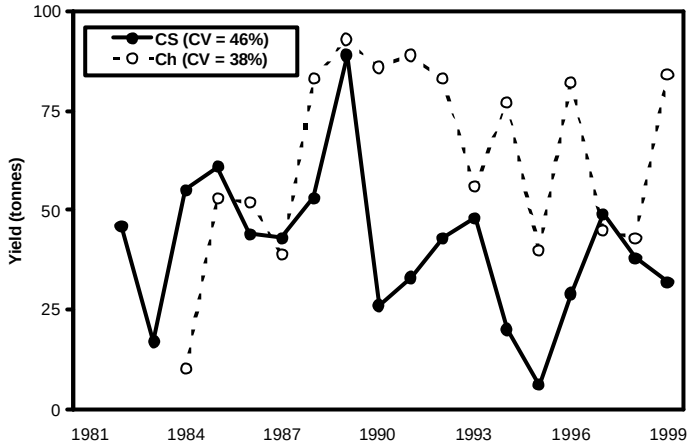


Figure 3.2.1 Harvest yields (tonnes) for a minimally-pruned (from 1987) Cabernet Sauvignon block (4.04 ha) and a spur-pruned Chardonnay block (4.84 ha) between 1982 and 1989.

A simple measure of yield variability is the coefficient of variation (CV). For 'normal' 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 these blocks are 46% and 38% for the Cabernet Sauvignon and Chardonnay respectively (Figure 3.2.1). This level of variation is fairly typical across the industry but large in comparison with many other agricultural systems. For instance, in the years 1971-1983 CVs for dryland wheat farming ranged from 14% to 23% and were lower still (< 10%) in humid and irrigated regions (Hazell 1989). A major explanation for such large differences between wheat farming and viticulture is that wheat, in contrast to the perennial grapevine, is an annual crop. It completes its life cycle over a much shorter period of time and, thus, is under the influence of environmental conditions for a shorter period of time. In grapevines the reproductive phase generally spans 18 months, and yield in the current season is under the influence of conditions during the previous season and, in some case, even the season before that (May 1987).

Also, in wheat and other crops (eg. cotton and sunflower) there is a strong linear relationship between intercepted light and net photosynthesis, which, in turn, exerts a strong control over yield. Such relationships are not so obvious in grapevines where developing buds are sensitive to shading in overly vigorous canopies.

Data presented in Figure 3.2.1 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 now 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 weight/berry

The first step in understanding the causes of variation is to quantify its sources (see Section 5). We have approached this using a range of medium- and long-term yield data sets for a wide collection of varieties grown over a diverse range of climates (from cool to warm). Yield component analysis has consistently demonstrated that the parameter bunches/vine explains 60-70% of the seasonal variation in vine yield. Yield fluctuations are less sensitive to berries/bunch (ca. 30%)and less sensitive again to berry size (ca. 10%) This is important as it suggests 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 (see Section 5.1.3).

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.

Statistical studies (Baldwin 1964, Alleweldt 1963), growth cabinet studies (Buttrose 1974a) and field experimentation (May and Antcliff 1963, May 1965) have shown that inflorescence formation in grapevines is highly sensitive to light and temperature conditions during critical stages of reproductive development in the previous season. Water stress can promote (Smart *et al.* 1974) or depress (Buttrose 1974b) inflorescence formation and it is difficult to separate the direct effects of water stress on reducing inflorescence formation from any indirect effects on canopy characteristics that may improve the microclimate (light) around latent buds. Nutrition also affects inflorescence formation (Mullins *et al.* 1992). However, in well-managed vineyards water and nutrients are adequately supplied to vines. To summarise, grapevines have a long reproductive phase that begins in one season and is not completed until the next. During this time there is a set of critical events that determine potential yield and its realisation. These events are highly sensitive to light and temperature (see Section 3.3.4).

3.2.3 Spatial Variation

Figure 3.2.2 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 explain much of the variation in yield (Figure 3.2.3).

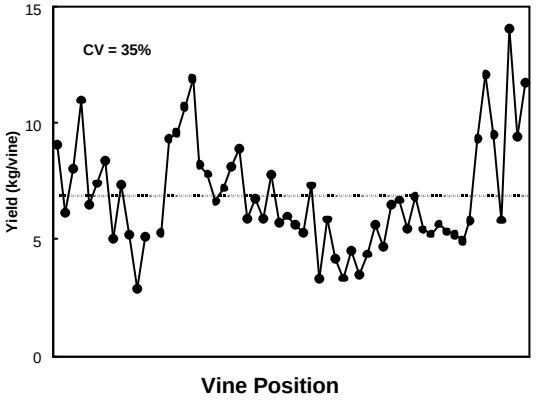


Figure 3.2.2 Individual yields at harvest (1999) for a row of 13-year-old spur-pruned Cabernet Sauvignon vines at Dookie, central Victoria. The dashed vine represents average vine yield.

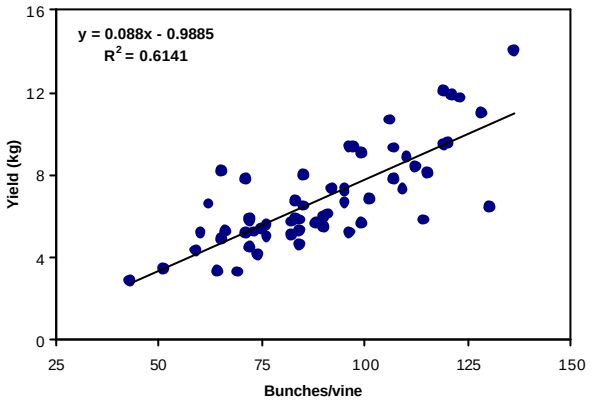


Figure 3.2.3 The relationship between harvest yield and bunch number for 60, 13-year-old spur-pruned Cabernet Sauvignon vines at Dookie, central Victoria.

Further 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.

3.2.4 The Relationship between Temporal and Spatial Variation

Grapevines are perennial plants that begin to form reproductive structures in the previous season. Thus, reproductive behaviour is affected by conditions and management in the previous season as well as by conditions and management during the current season. Some in fact suggest that grapevines follow a three-year cycle. The arguments for this are based on Rives and Lafon (1972) and have been presented by May (1987). We won't reiterate them here, but just point to the complexity of yield formation in long-lived perennial plants that are heavily modified (through the removal of wood) each winter. Given such complexity, it is pertinent to investigate the nature of the link between temporal and spatial variation. For instance, do vines, which yield low in comparison to other vines, continue to do so in subsequent seasons? The answer to this question has important implications for forecasting yield as well as for the development and application of techniques to manage seasonal variation. There have been few studies addressing this specific question. Figure 3.2.4 shows individual vine yields over a four-year period for Cabernet Sauvignon grafted onto two rootstocks at a cool climate site and Pinot Noir on Schwarzmann rootstocks at another cool climate site. In most cases, higher yielding vines in one season yielded higher in subsequent seasons. However, this was not always so.

Obviously, whether the relative ranking of yield changes from one season to the next depends on the particular reasons for yield differences in the first place. Irrespective of the reasons, lack of association between spatial and temporal yields may present problems for those attempting to stabilise yields in the following season based on observations of the spatial distribution of yield in the current season. It will be of considerable interest to observe relationships between temporal and spatial yield variation on some of the detailed spatial distribution maps emerging from precision viticulture.

It is also important to consider stability when evaluating vine performance in both breeding trials and management systems. For instance, Clingeleffer (1984, Figures 1&3) presents 6 to 8 years of yield data for unpruned, pruned and minimal pruned sultana vines. Although the substantially higher yields from the unpruned and minimal pruned vines foreshadowed a shift toward minimal pruning in many viticultural regions, it is instructive to also look at the seasonal yield patterns. Yields of unpruned vines appear to be more variable and seem to exhibit biennial bearing. In this instance, and in the absence of any means for controlling the increased variation, the choice of management system becomes an economic one based on the following factors: increased yields, the cost of increased variation (to the grower and the winery), lower costs of production and any likely effects on fruit quality including any increased risk of disease due to delayed ripening of higher yielding vines.

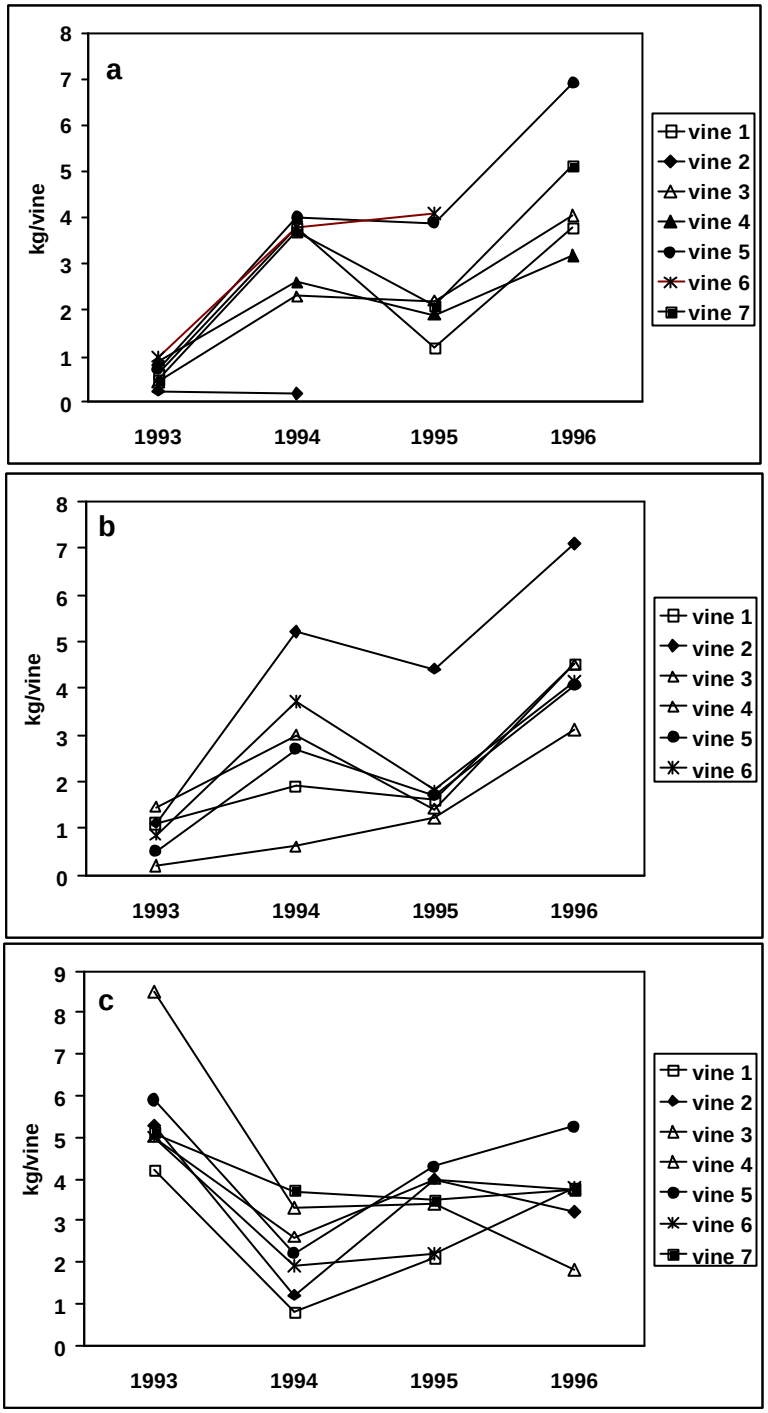


Figure 3.2.4 Individual vine yields for (a) Cabernet Sauvignon on Schwarzmann rootstocks at Warramate, Gruyere, (b) Cabernet Sauvignon on K32 rootstocks at Warramate and (c) Pinot Noir on Schwarzmann rootstocks at Kings Creek Vineyard, Bittern.

3.3 Formation of Inflorescences

3.3.1 Introduction

Grapevines, like most other spring-flowering perennials, commence 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. During winter these dormant buds are covered by a protective layer of hairs and enclosed within a scale. In the following season, flowers are formed during a short period spanning bud burst. The formation of inflorescence primordia (flower buds) determines the potential number of bunches that the vine will carry while the number of flowers formed on an inflorescence primordium determines the potential number of berries that may be set on that bunch. Hence, gaining an improved understanding of the physiology of flower formation remains a pursuit of considerable economic importance as well as one of intellectual interest.

Flower formation in grapevines follows three well-defined steps: 1. Anlagen, or uncommitted primordia, are formed in the apices of latent buds on shoots of the current season, 2. These specialised meristematic structures may differentiate inflorescence primordia, and 3. Individual flowers are formed on inflorescence primordia (Perold 1927, Barnard 1932, Barnard and Thomas 1933). For grapevines grown in temperate climates, steps 1 and 2 are usually completed during the previous season. Individual flowers, on the other hand, are not formed until during bud burst in the current season. (Barnard 1932, Synder 1933, Winkler and Shemsettin, 1937, Srinivasan and Mullins 1981, Scholefield and Ward 1975). The reproductive biology of grapevines has been reviewed from a variety of aspects. For instance, Pratt (1971) presented a detailed and comprehensive review of the reproductive anatomy of grapes while Buttrose (1974a) reviewed what was known about the effect of climatic factors (mainly light and temperature) on inflorescence initiation. Most recently, Srinivasan and Mullins (1981) reviewed the physiology of flowering in grapevines placing particular emphasis on the controlling role of phytohormones. However, there is a need to revisit flower formation with the aim of synthesising these and other, often disparate, treatments of the subject. For each step of flower formation in turn, we will review our state of knowledge on its control with particular emphasis on the effects of the environment and viticultural management. Then, we will point to areas that we believe warrant further attention within the context of the current research and development environment.

3.3.2 Bud Anatomy

The morphology of the grapevine shoot system and the anatomical origin of its inflorescences have been described in detail (see Barnard 1932, Barnard and Thomas 1933, May 1964, Pratt 1974, Mullins *et al*. 1992).

Three types (orders) of buds develop on young shoots in the spring: (i) the lateral (prompt) bud, (ii) the primary latent bud and (iii) secondary latent buds (often referred to secondary and tertiary buds). Initially, these buds are subtended by a common scale and give the appearance of being just one bud in the axil of the foliage shoot. In viticulture, this compound bud is referred to as the 'eye'. It contains axillary buds of the second (the primary latent bud) and third orders (secondary latent buds) with regard to the lateral shoot.

Lateral (prompt) bud

The first bud formed arises in the axil of the foliage leaf soon after it expands (Pratt 1974). This bud is often referred to as the prompt bud as it grows out in the season in which it is formed, producing the summer lateral shoot. These shoots are usually small and do not normally lignify. Although commonly less fruitful than primary shoots, most viticulturists would be familiar with the phenomenon of the 'second crop', comprising bunches carried on these summer lateral shoots. Clusters on these shoots present problems as they flower, set fruit and mature later than the rest of the crop.

A major difference between bunches formed on laterals and bunches formed within primary and secondary latent buds is that bunches formed on laterals are initiated, differentiate flowers and ripen all during the one season. Coombe (1980) to investigate the effects of time of flowering and competition on berry development exploited this difference. However, to or knowledge the appreciably shorter development time is yet to be exploited to investigate initiation and differentiation in grapevines.

Primary latent bud

The first leaf of the summer lateral is much reduced and referred to as a prophyll. The next bud to form, the primary latent bud is formed axillary to this prophyll. Primary latent buds give rise to primary shoots in the following season. These comprise the vine's vegetative growth as well as carrying the crop. The primary latent bud grows slowly during spring, developing 6 to 10 leaf primordia and up to three inflorescence primordia before entering dormancy (Mullins *et al*. 1992). However, shoots that carry four or even five clusters can be observed in vineyards (Figure 3.3.1).



Figure 3.3.1 A Cabernet Sauvignon shoot collected after fruit set from Barooga in the 1999/2000 season. Five bunches are clearly visible at node positions 1, 2, 4, 5 and 11.

Secondary latent buds

The apex of the primary latent bud will differentiate two basal prophylls, often more, before forming leaf primordia. Secondary latent buds are formed in the axils of the first two basal prophylls. These do not normally go on to form shoots in the following season except where there is some damage to the primary latent bud prior to budburst (eg. primary bud-axis necrosis or mite damage) or when the primary shoot itself is damaged after budburst by frost or hail, for example. When they do form shoots their plane of phyllotaxy departs by about 90º from that of primary shoots. According to Pratt (1974), shoots formed from secondary latent buds (first secondary latent bud to form) usually bear inflorescences, whereas shoots that develop from tertiary (second secondary latent bud to form) buds tend to bear none. On the other hand, Mullins et al. (1992) stated that these buds remain small and seldom contain inflorescence primordia. Such an apparent contradiction may reflect varietal differences in the material studied.

In the course of our own studies on Cabernet Sauvignon, Chardonnay and Shiraz, we have observed inflorescences on many secondary shoots. It is not uncommon to see both secondary shoots bursting and carrying two bunches each. Although our data would allow us to compare 'fruitfulness' of secondary and primary shoots we are yet to analyse it within this context. Dry (2000) observed that for Shiraz in 1984/5 that shoots from node positions 2 to 5 were less fruitful than shoots from node positions 6 to 9 (1.45 bunches/shoot versus 1.70 bunches/shoot). The shoots from lower nodes also had a higher ratio of secondary to primary shoots (0.80 versus 0.11). Dry suggests that although the low fertility of basal nodes is often attributed to a poor light environment in the renewal zone an alternative explanation would be that these nodes have a higher incidence of primary bud-axis necrosis (PBN, discussed later). The observed lower number of bunches would then be accounted for by a greater proportion of secondary shoots bursting, which are known to be less fruitful than primary shoots.

3.3.3 Morphogenesis of Inflorescences and Flowers

Flower formation in grapevines involves a long multi-step process. The first visible sign of the evocation of flowering is the initiation, during spring, by the apical meristem of an extra-lateral meristematic structure called the 'anlage'. The anlage, a term introduced by Barnard (1932) first forms a bract primordia, then divides into an 'inner' and 'outer' arm. The inner arm, and often the outer arm, may differentiate branch initials before the bud enters dormancy. After dormancy, and during budburst of the following season, further branching takes place terminating in the formation of individual flowers. Branches usually terminate with three flowers. In Shiraz, however, branches terminate in five flowers. Overall, the process determines potential yield. First, by exerting a

coarse control over potential bunch number and then by exerting a finer control over flowers per bunch (bunch size).

Anlagen initiation takes place in basal buds around the time of flowering and progresses up the shoot. Anlagen may become tendrils (as is the case with all anlagen formed on actively growing shoots), inflorescences, shoots (rare) or even transitional forms between all three. Studies in controlled-environment growth cabinets (Buttrose 1974a) and in the field (Lavee *et al.* 1967) have demonstrated that 'floral' induction occurs well before the initiation of anlagen. For the cultivars Muscat of Alexandria and Sultana the time interval is 20 d and 18 d, respectively. It remains intriguing that the meristem would be sensitive to floral stimuli well before the appearance of anlage. It may be that conditions during this stage of development affect the competence (size or status) of the meristem to respond to floral stimuli.

Light microscope (Barnard 1932, Barnard and Thomas 1933) and scanning electron microscope studies (Srinivasan and Mullins 1981) of developing latent buds demonstrate that anlagen which undergo extensive branching prior to dormancy form inflorescences while those that possess only two or three branches form tendrils. This would suggest that the extent of branching prior to dormancy controls potential inflorescence development. There is no evidence to challenge the long-held opinion of Barnard and Thomas (1933) that "the extent of the growth of an inflorescence during this period (mid-August to budburst) is largely dependent upon the stage of development it had reached at the end of the previous season (prior to dormancy)". Thus, quantitatively, flowering seems to be irreversibly evoked during the early stages of ontogeny.

Tendrils and Inflorescences are considered to be homologous structures (Morrison 1991) as they are derived from the same meristematic structure, it is possible to convert one structure to another (Srinivasan and Mullins 1981) and intermediate forms are common in the vineyard. Evidence for growth substances playing a controlling role in flower formation is strong. Srinivasan and Mullins (1979, 1980) demonstrated that the repeated exogenous application of cytokinin to shoot apices induced inflorescence formation in the place of tendril formation. Thus, cytokinins are probably involved in the early differentiation of anlagen. Interestingly, applying cytokinins to young tendrils also transformed them into inflorescences. That young tendrils are still able to form flowers indicates that they may be modified inflorescence primordia, which are being inhibited from differentiating floral meristems. Also, isolated tendrils cultured *in vitro* with cytokinins underwent repeated branching and grew into inflorescences and inflorescence-like structures (Srinivasan and Mullins 1978). The exogenous application of gibberellins, on the other hand, turned inflorescences into tendrils and tendril-like structures (Mullins 1968). Culturing excised inflorescence primordia of Pinot Noir and Chardonnay with gibberellin alone led to the formation of shoots and tendrils (Yahyaoui, Barbier and Bessis 1998). Interestingly, application of the growth retardant chlormequat inhibits anlagen formation but promotes the formation of inflorescence primordia from anlagen (Mullins *et al.* 1992).

These results led Srinivasan and Mullins (1981) to propose a simple model for the transition of the vegetative apex to an inflorescence based on variations in endogenous cytokinins, gibberellins and inhibitors whose effect is mimicked by synthetic growth retardants such as chlormequat.

During budburst inflorescence primordia differentiate floral parts in the order sepals, petals, stamens and pistils. Detailed descriptions of the organogenesis floral parts of can be found in Pratt (1971) Scholefield and Ward (1975) and Srinivasan and Mullins (1981). Scholefield and Ward (1975) present an excellent set of scanning electron micrographs detailing the time course of developmental effects for Sultana. To the best of our knowledge these were the first of their kind for grapevines. Other micrographs for other cvs have been published since (eg. Shiraz, Srinivasan and Mullins 1981).

3.3.4 Environmental Effects

Temperature

High temperatures promote inflorescence formation in grapevines. This has been demonstrated in controlled-environment studies (Buttrose 1969a,b,c) and in field studies that have correlated temperature conditions during bud development with the subsequent formation of flower clusters (Alleweldt 1963, Baldwin 1964) or flowers (Palma and Jackson 1981) in the following season.

Cultivars differ in temperature requirements for inflorescence primordia formation (Buttrose 1970a, Srinivasan and Mullins 1981) and these differences seem to reflect differences in the climates of geographical origin. For instance, the 'cooler climate' cultivar Riesling will initiate inflorescence primordia at 20°C while the 'warmer

climate' Muscat of Alexandria requires a temperature of at least 25°C (Buttrose 1970a) for initiation. Irrespective of the differences between cultivars, however, the temperatures required for maximum inflorescence primordia formation are higher than the temperature required for maximum dry matter production (Buttrose 1968). Thus, the mechanisms by which temperature controls dry matter production may differ from those that control inflorescence primordia formation.

Effects of temperature on induction and initiation

A perennial problem with field experiments that attempt to elucidate plant responses to environmental variables is that environmental variables are often confounded. For instance, high temperature coincides with a high number of sunshine hours or cloudiness tends to increase relative humidity. In an attempt to separate the effects of temperature and light on inflorescence primordia formation from each other as well as from other environmental factors Buttrose (1969a,b,c, 1970a) conducted a series of studies in controlled-environment growth cabinets. By dissecting latent buds 13 weeks after budburst on small potted vines, he was able to show that temperature significantly affected the formation of inflorescence primordia. For the cultivar Muscat of Alexandria, latent buds on vines growing at 20°C formed no inflorescence primordia while buds on vines growing at the optimum temperature of 35°C averaged 1.6 inflorescence primordia (Buttrose 1969a). By changing temperature conditions during development, he was able to deduce that the period of optimum sensitivity to induction was some 3 weeks prior to the initiation of anlagen (Buttrose 1969b, 1974a). Sensitivity to temperature was negligible before the separation of the node from the apex maximum at the time the node was separating from the apex and then progressively declined becoming negligible when the node was about 10 positions below the apex. A pulse of only 4 hrs (day or night) of high temperature was required to maximise inflorescence primordia formation.

Thus, the induction of the vegetative apex to differentiate an inflorescence occurs long before the first visible signs of its formation. The strong relationship between size of basal leaf primordia and inflorescence number and size (May 1964, Buttrose 1970b) led Buttrose (1974a) to speculate that it is the way in which basal leaf primordia develop that influences floral induction. He suggested that basal leaf primordia must be of a certain size and adequately illuminated for the maximum development of inflorescence primordia. Thornley (1975), discussing floral transition in general, suggested that changes in the size of the vegetative apex could lead to reproductive growth.

Palma and Jackson (1981) described a highly significant ($P < 0.01$) correlation between temperature on the day when the node was 3 node positions below the apex and the average number of flowers on that shoot in the following seasons for the cultivars Chasselas Doré, Pinot Noir and White Reisling. Although, they did not report the number of clusters per shoot, they suggest that their results provide support for a very early, very specific effect of temperature on inflorescence primordia formation. It may be, however, that by regressing <u>mean</u> flowers/shoot on temperature that they unjustifiably remove a large amount of variation in the data with subsequent interpretations being misleading. To illustrate this we will refer to some of our data. Figure 3.3.2 presents mean flowers per cluster and daily mean air and soil temperatures on the day of budburst (reproduced from Dunn and Martin 2000). A fitted regression of mean flowers per cluster on, for instance, daily mean soil temperature (the data presented in Figure 3.3.2) would have yielded an r^2 value of 0.77. In the above example the misleading interpretation would be that variations in mean daily soil temperature explain 77% of the observed variation in flowers per cluster. This is clearly not the case. When the full set of data (300 flower clusters) is included, flowers per cluster was only weakly correlated with daily mean soil temperature on the day of budburst (Adjusted $r^2 = 3.6\%$) although this correlation was highly significant ($P < 0.001$) (see Dunn and Martin 2000, Figure 4).

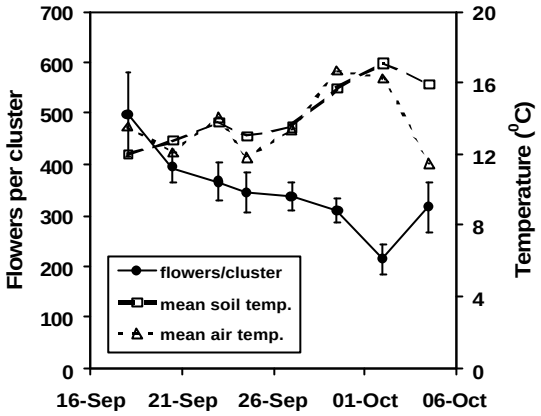


Figure 3.3.2 Daily mean soil and air temperature and flowers per cluster (± s.e.) during the period of budburst in *Vitis vinifera* var. Cabernet Sauvignon at Dookie in central Victoria (reproduced with permission from Dunn and Martin 2000).

It is difficult, however, to reconcile optimum temperatures for inflorescence primordia formation defined by controlled-environment studies (Buttrose 1974a) with field observations. For example, the optimum temperature for inflorescence primordia formation in the cultivar Shiraz is 30°C (Buttrose 1970) and if the period of maximum sensitivity to temperature is as the node is just separating from the apex then this would coincide with budburst for spur-pruned vines. In the Yarra Valley at this time of year four hours of continuous 30°C+ during a 24 hour period seems unlikely. However, spur-pruned Shiraz vines produce many two-cluster shoots. It is likely that grapevine buds experience higher than ambient temperatures during the day. A theoretical analysis of the energy balance of apple buds and blossoms coupled with actual measurements (Landsberg *et al.* 1974) showed that apple bud temperatures could be up to 5°C higher than ambient temperatures on clear sunny days.

Effects of Temperature on Anlagen Differentiation (branching) Prior to Dormancy

Baldwin (1964) described a significant ($P < 0.01$) relationship between percentage of fruitful buds (those containing an inflorescence primordia) at nodes position 4, 9 and 14 on dormant canes of Sultana and hours of bright sunshine and daily maximum temperatures above 29°C in a 20 d period in the previous November (r^2 = 75%). In contrast to the very early period of optimum temperature sensitivity defined by Buttrose (1970a, 1974a), this period is much later. In fact, primary branching of anlagen would be taking place (Srinivasan and Mullins 1981, Swanepoel and Archer, 1988). Certainly, Srinivasan and Mullins (1981) reckoned that the control of inflorescence formation in grapevines 'hinged' on the control of branching of anlagen. It is possible, therefore, that while the induction of anlagen is dependent on temperatures at an earlier stage, their potential to become inflorescences is influenced by light and temperature conditions during the early branching stage. Cytokinins, which are known to regulate reproduction generally (Kinet *et al.* 1993), may be important regulators of this process. They are known to act as a mitotic stimulus, decrease cell membrane permeability and promote branching and are mainly synthesised in root tips. Warm temperatures in the root zone at this time may increase cytokinin synthesis and transport and, thereby, promote the branching of inflorescence primordia.

Smit (1970) also attempted to explain large fluctuations in regional fruitfulness of Sultana in Upington, South Africa from 1957 to 1968. Bud fruitfulness was assessed by microscopic examination. In contrast to Baldwin, he found no significant correlation between the duration of bright sunshine hours during differentiation and bud fruitfulness and suggested that in Upington, which receives about 1.5 hours more bright sunshine hours than Sunraysia where Baldwin's studies were done, bright sunshine hours did limit flower differentiation. Similarly, attempts to correlate mean monthly maximum temperatures during November and December with mean fruitfulness were unsuccessful. Rather, the best correlation that Smit could find was between cold duration during the period twelve to fourteen months before flower differentiation. Such a finding is difficult to explain in terms of our understanding of floral biology in grapevines.

Effects of Temperature on Anlagen Differentiation (branching) During Budburst

Those few studies that relate conditions during budburst to inflorescence development have all used small, modified plants or cuttings grown in glasshouses or growth cabinets. In one study, Pouget (1981) subjected small, experimental vines (cvs Cabernet Sauvignon and Merlot) to 12°C and 25°C during budburst.

Substantially more flowers were formed on inflorescences of the vines held at 12°C (130% more for Cabernet Sauvignon and 29% more for Merlot). However, this was offset by an increased number of bunches per shoot (from 1.32 to 1.72 in Cabernet Sauvignon and from 1.73 to 2.25 in Merlot) at the higher temperature. Ezzili (1993) confirmed Pouget's observation that lower temperatures during budburst increased the number of flowers per inflorescence for two other *Vitis vinifera* varieties, namely Cardinal and Alicante Grenache.

Kliewer (1975) studied the effects of soil temperature on budburst in an effort to explain poor and often patchy budburst in cooler grape growing regions in California. He exposed the roots of 3-year-old Cabernet Sauvignon vines, grown in pots and pruned to two 10-node canes, to temperatures ranging from 11ºC to 35ºC while keeping air temperature constant at 20ºC. Although he did not assess flower number, he reported that increased root temperatures substantially (60.2% across the entire temperature range) and significantly reduced the number of berries per bunch. Together, these studies suggest that temperature, probably in the root zone, may exert partial control over inflorescence differentiation at budburst.

Pouget (1981) speculated that the effect of temperature on flower number was due to its effect on the growth of the developing shoot in relationship to inflorescence differentiation. Higher temperatures, he suggested, lead to the rapid growth of vegetative organs of the developing shoot which increases the 'speed' of budburst and, consequently, fewer flowers are formed. Lower temperatures, on the other hand, slow the growth of vegetative organs, which slows the 'speed' of budburst allowing inflorescence differentiation to occur over a longer period of time. Although there is often a strong correlation between changes in plastochron and flowering, it is generally considered not be a causative relationship. May (1987) proposed an alternative hypothesis, suggesting a role for cytokinins, which are promoted at higher temperatures. He proposed that higher temperatures cause a 'cytokinin enhanced' enlargement of the early produced flowers which, in turn, inhibit the formation of other flowers.

By delaying pruning, Dunn and Martin (2000) were able to expose bursting shoots of 13-year-old Cabernet Sauvignon vines to a range of temperature conditions in the field. Unfortunately, the weighted average air and soil temperatures to which the 2 populations of bursting shoots (earlier and later pruning) were exposed differed by only 1.6°C and 0.5°C, respectively. However, they showed that there were highly significant ($P < 0.05$) but very weak ($r^2 = 4\%$) associations between daily mean soil and maximum air temperatures and flowers per cluster. As temperature gradually increased over time, however, it was not possible to separate any potential effect of temperature from any effects of time itself. In any case, as budburst is a process that is mainly under the control of temperature, it is difficult to envisage practical techniques that would lead to large temperature differences during budburst in the vineyard. In any case, any increase in flower number may be offset by a decrease in bunch number (Pouget 1981) and/or poorer budburst (Kliewer 1975). Of perhaps more importance was that the position of the cluster relative to other clusters (ie. upper, lower or only) explained more than 26% of the variation in flowers per cluster (Dunn and Martin 2000). Furthermore, mean flowers per cluster was significantly ($P < 0.05$) and substantially (97%) higher on two-cluster shoots than single cluster shoots suggesting that conditions during the previous spring that favour the initiation and/or differentiation of uncommitted primordia also pre-condition clusters to have more flowers.

Effects of Temperature on the Formation of Floral Parts

Low temperatures during development lead to high levels of pollen sterility in grapevines (Staudt Kassrawi 1972). In other plants pollen development can be damaged by unfavourable environmental conditions such as temperature (high and low), inadequate light, water stress and nutrition (Laser and Lersten 1972, Iwao 1983, Saini *et al*. 1984, Hormaza and Herro 1992). It may be that these factors are also important determinants of pollen viability in grapevines

Light

Light affects vegetative production directly as well as patterns of plant development. Plants respond to changes in spectral composition ('light quality'), radiant energy ('light quantity') and the periodicity (day length) of light.

Shading reduces the formation of inflorescence primordia in grapevines. This has been demonstrated through shading vines as well as individual buds in the field (May and Antcliff 1963, May 1965, Hopping 1977, Perez and Kliewer 1990) and in controlled-environment studies (Buttrose 1974a). In growth cabinet studies, both the number and size of inflorescence primordia increased with increasing light intensity (Buttrose 1969a) while increasing photosynthetic photon flux densities (PPFD) increased berries per bunch in the following season (Morgan *et al.* 1985). In the field, vertical shoots are more fruitful than horizontal shoots (May 1966) and

natural shade profiles within canopies have been related to reduced node fertility (May *et al*. 1976, Smart *et al*. 1982a, b). Although Dry (2000) suggested that Kliewer *et al*. (1989) showed no effect of shoot orientation on fruitfulness a closer examination of the paper reveals that the experiment was restricted to investigating vegetative and reproductive development in the current year and that fruitfulness was not measured. For Sultana, the effect of light appears to be one of quantity rather than quantity as R:FR does not significantly affect inflorescence primordia formation (May 1965). Similarly Morgan *et al*. (1985) showed that altering R:FR ratios did not significantly ($P>0.05$) affect node fertility of Muller Thurgau grapevines. However, these authors suggested that although there was no significant effect ($P>0.05$) of reducing R:FR ratios on node fertility there was a consistent trend for reductions in node fertility indicating a quantitative role for phytochrome in the control of flowering.

The timing of maximum sensitivity has been studied for Sultana. Shading (70% shade) had its greatest effect over a 4-week period during late spring (May and Antcliff 1963). Earlier and later shading did not significantly reduce the number of inflorescence. Shading for the first 2 weeks or the last 2 weeks of the sensitive period did not reduce inflorescence numbers either. It may be that uncommitted primordia remain sensitive to light intensity for a period longer than 2 weeks. Also, shading buds directly, rather than the subtending leaves, was shown to reduce inflorescence formation (May 1965).

As with responses to temperature, the intensity of light required for optimum inflorescence primordia formation varies between cultivars and species. Sultana requires more than 30% full sunlight for maximum inflorescence primordia formation, Riesling requires just 10% full sunlight and node fertility of Muller Thurgua was reduced at PPFD one-third or less of full sunlight (Morgan *et al*. 1985).. Although grapevines have evolved in forest habitats they are restricted to the outer, more sunlit areas of canopies. Thus, it is not surprising that their leaves display none of the typical photosynthetic characteristics of shade tolerant plants (Kriedemann 1968), such as low light saturation of photosynthesis.

Although inflorescence induction in *Vitis vinifera* cultivars is not sensitive to photoperiod, long days, in comparison to short days, increased the number of inflorescence primordia per bud for some cultivars (Buttrose 1969b, Buttrose 1974).

Light and Primary-Axis Bud Necrosis

Low light levels have also been implicated in primary bud-axis necrosis (PBN), a condition which may lead to reduced fertility and lower yield. This condition was first reported by Berstein (1973, printed in Hebrew and cited in Lavee *et al*. 1981) who reported that the grapevines Dattier de Beirout and Queen of Vineyard were among the most sensitive cultivars and that lower buds were more affected than buds higher up the cane. Other susceptible varieties include Sultana, Flame Seedless, Riesling and Shiraz. PBN incidence is highest at basal nodes (Lavee *et al*. 1981, Dry and Coombe 1994) and the condition has been linked to canopy shading (Perez and Kliewer 1990), high shoot vigour (Lavee *et al*. 1981, Dry and Coombe 1994) and high levels of soil nitrogen (Kliewer *et al*. 1994). The promotive effects of exogenous applications of gibberellic acid (Ziv *et al*. 1992) on PBN, which also increase vegetative vigour in grapevines (Weaver and McCune 1961), suggest a causal role for endogenous gibberellin levels (Lavee 1987).

Morrison and Iodi (1990) investigated the development of PBN in Thompson Seedless grapevines and provided a detailed histological description of the disorder. When primary buds died earlier in the season accessory buds expanded to fill the space. However, when primary buds died later in the season accessory buds remained small. Therefore it might be that the timing of necroses is important in terms of 'bursting potential'. They also found that although shading was correlated with PBN in susceptible vineyards neither shading or GA application could induce necrosis in a vineyard with low incidence of the disorder. The timing of GA application may be important though. Ziv *et al*. (1981) showed that GA only increased bud necrosis if it was applied before or soon after bloom, applications made well after bloom were ineffective. Morrison and Iodi sprayed 9 and 17 days after bloom, which may have been outside the sensitive period.

Dry and Coombe (1994) reported that in Australia the most sensitive cvs were Shiraz (among the seeded) and Sultana (among the unseeded). Incidence of the disorder was lower in Australia compared to Israel, Japan, Chile and USA. At a vineyard level PBN was correlated with vineyard vigour and at a shoot level PBN was correlated with indices of shoot vigour (cane diameter, total number of lateral shoots, % nodes with lateral shoots). In an experiment (Dry and Coombe 1994), shoot thinning (65% removal 10 days after flowering) substantially increased PBN (16% to 65%) despite a significant improvement in the light environment. Thus, the effect of increased vigour of shoot thinned vines seemed to outweigh any positive effect of improving the light

environment around basal buds. Like Morrison and Iodi (1990), Dry and Coombe (1994) suggest that "shading is not a major cause of PBN and that any association between shading and PBN is an indirect consequence of the poor light environment within the canopies of vigorous vines". Further work is required to quantify the effects of PBN on vineyard productivity.

Other Factors

Water stress can also reduce inflorescence formation in latent buds. Controlled-environment studies have shown that the number and size of inflorescence primordia are reduced by water stress (Buttrose 1974b). In certain instances, however, mild water stress can improve inflorescence primordia development (Smart *et al.* 1974). It may be that mild water stress limits vegetative growth during initiation leading to a better-lit canopy and improving initiation and differentiation of anlagen. There are reports of frost, hail and water logging reducing inflorescence primordia formation (May 1961).

Cultural Factors

Some of the preceding sections have emphasised the important influence of light and temperature during critical periods in the previous season on flower formation in grapevines. Of these two, it is more difficult to modify temperature within grapevine canopies. Thus, it is not surprising that cultural methods to modify or enhance fruitfulness have concentrated on improving the light environment. Dry (2000) recently reviewed this area.

Although there have been many experiments on the effect of trellis and training systems on vine yield, many of these have not measured yield components so it is difficult to determine whether budburst, shoots vine, bunches per shoot or bunches per node are affected (Dry 2000). From the research done though, it seems that only when the canopy is divided is there an increase in node fertility. This is generally attributed to improving the light environment within the canopy (Dry 2000). Although there is still some debate as to whether improvements are due to the light incident on the bud itself or the subtending leaf blade. Also, the height of the renewal zone strongly influences yield (May *et al.* 1976). Yield differences can be substantial (Shaulis and Smart 1974, May *et al.* 1976) and are strongly related to light intensity measured in the fruiting zone (Smart *et al.* 1990). The yield components budburst, bunches per shoot, berries per bunch and weight per berry are all affected explaining the substantial yield improvements, which may be as high as threefold.

There have been many studies on leaf removal in the fruiting zone but by and large these have concentrated on effects on fruit development and fruit composition in the current season. Fortunately some researchers have extended these studies to include measurements of yield components in the following season. Dry (2000) in reviewing these studies pointed to equivocal results suggesting that "vine response is variable, ranging from nil effect to a positive effect on fruitfulness in the following season". On one hand, Howell *et al.* (1994) and Zoecklein *et al.* (1992) demonstrated no effect of shoot removal on fruitfulness (bunches per shoot) in the following season for cvs Pinot Noir, Riesling and Chardonnay. While, on the other hand, Kliewer and Smart (1989) showed that leaf removal had a positive effect on fruitfulness in the following season for Sauvignon Blanc. Although the effects on bunches per shot were less important than those on budburst (increased shoots per node) and flower number (increased flowers per cluster). However, when these papers are examined more closely important differences emerge. For instance, the timing of defoliation differed. In the experiments reported by Howell *et al.* (1994) and Zoecklein *et al.* (1992) leaves were removed mid way between set and veraison and 2 to 3 weeks after bloom respectively. While in the experiment reported in Kliewer and Smart (1989) leaves were removed at fruit set. We know from May and Antcliff (1963) that the timing of shading for affecting fruitfulness is critical. They found only if shade was applied during a 4-week period in late spring (roughly coinciding with flowering) was fruitfulness reduced. It is likely that in the experiments of Howell *et al.* (1994) and Zoecklein *et al.* (1992) leaves were removed after this period. Also, the vines were pruned to 2- to 5-bud spurs or short 7-node canes. The experiments described in Antcliff and May (1963) were done on much longer canes. We know that flower differentiation begins in the basal nodes and continues distally up the cane (Swanepoel and Archer, 1988), thus the critical period for these lower nodes is likely to be earlier again.

Shoot thinning can improve yield (Shaulis and May 1971, Shaulis 1982). Shoot thinning (appox 50%) had a small but significant effect on bunch numbers per shoot for Riesling (Reynolds *et al.* 1994) and removing 8 to 10 leaves from the crown reduced PBN in Sultana (Perez and Kliewer 1990). However, severe shoot thinning (65%) increased PBN (Dry and Coombe 1994). Thus, it seems that the severity of thinning is important in determining the balance between an improved light environment within the canopy and any detrimental effects of increased vigour. Also, like leaf removal, the timing of shoot thinning in relation to the initiation and differentiation of anlagen is likely to determine any effects on fruitfulness in the following season.

3.3.5 Genetic Control of Flower Formation

Obvious differences in the distribution (on shoots) and number of inflorescences exist between genotypes. As discussed earlier (Section 3.3.3), tendrils and inflorescences are closely related. They derive from the same 'uncommitted primordia', intermediate forms are common in the vineyard and the transition from tendril to inflorescence and *vice versa* can be induced through the exogenous application of plant hormones. Boss and Thomas (2000) suggest that the close relationship between tendrils and inflorescences indicate a control step at the gene level, which controls the differentiation of anlagen down one or the other pathway. In the plants *Arabidopsis* and *Antirrhinum* models that describe the genetic control of flower formation have been constructed. These models incorporate a complex set of regulatory processes involved in the transition of shoot meristem > inflorescence meristem > indeterminate floral meristem > determinate floral meristem (Ma 1998). Ma (1998) suggests that these models will inevitably increase in complexity through the identification of many other genes that must be involved but are yet to be uncovered for various reasons.

The environmental responses of flowering differ markedly between these plants and grapevines. For instance, *Arabidopsis* is long day plant while grapevines seem to be insensitive to day length. There are also differences in responses to exogenous applications of hormones. Gibberellins induce early flowering in *Arabidopsis* but inhibit aspects of flower formation in grapevines. Furthermore, our understanding of the genes which modify/regulate inflorescence formation in grapevines is very rudimentary (Boss and Thomas 2000). Despite this, looking for *Arabidopsis* gene homologues that direct anlagen initiation and further development is obviously a potentially fruitful line of investigation.

3.4 Flowering and Fruit Set

This stage of sexual reproduction, where a proportion of flowers will successfully set and become berries, is a key determinant of yield. The nature and timing of the processes that occur during flowering and fertilisation are briefly described. Experiments investigating effects of the environmental conditions of light and temperature and plant nutrition are reviewed with particular reference to any regional effects on the malformation or dysfunction of flowers. Evidence for the view that fruit set is strongly influenced by inter-organ competition with rapidly growing shoot tips or other reproductive structures is reviewed. This includes the many studies on the effects of exogenously applied plant growth substances.

Fruit set is a term that is used to describe the transformation of flowers into fruit (Mullins et al. 1992). It covers a set of distinct biological processes that are affected by environmental and plant conditions in different ways. Fruit set for grapevines can range from 0 to 40% but commonly is between 20 and 30%. However, even under the most favourable conditions (ideal conditions for pollination and fertilisation and reducing the number of competing sinks) it has not been possible to raise this above 65% in Cabernet Sauvignon (Mullins et al. 1992). It seems that many flowers are wasted. Although industry would obviously benefit from being able to stabilise fruit set and, in particular, avoid seasons when fruit set is low, the benefits of being able to increase fruit set to even 50% are dubious. Unless bunch framework enlarges in proportion with the increased number of berries, the resultant more tightly packed bunches would be subject to an increased risk of disease. The increased clumping of fruit in the fruiting zone may also lead to other grape 'quality' problems.

Pollen Release

Most authors suggest that that calyptra opening is controlled by temperature alone. Below 15^{o}C few flowers open but as temperature reaches 18-20^{o}C flower opening intensifies (Winkler et al. 1974). However, if temperature is kept constant an endogenous rhythm prevails with flowers opening over a two-hour period between 0600 and 0800 hrs and again between 1400 and 1600 hrs. Cold or wet weather can lead to incomplete calyptra opening. This 'abnormal' opening can greatly reduce fruit set (Winkler et al. 1974). Once the calyptra is 'thrown' off the stamens move away from the pistil and anthers rapidly dehisce. Like calyptra opening, anther dehiscence is influenced by temperature. However, as the mechanism involves the outer wall drying out and tearing, any conditions that lead to high humidity such as rain or a sudden drop in temperature will delay anther opening.

Poor Fruit set

Poor fruit set, where much less than the normal 20 per cent of flowers develop into berries, can occur in all varieties. Some cultivars (eg. Merlot) are more sensitive than others are especially in cool climates. The

phenomenon is most often blamed on cold weather at or around flowering. It is clear that low temperatures as well as high temperatures decrease fruit set (Buttrose and Hale 1973, May 1992; Ebadi et al. 1995, Delas et al. 1991, Zapata et al 1999). Low root temperatures may also led to poor fruit set and small berries (Kubota et al. 1985).

A special case of poor fruit set is called millerandage or hen and chickens. At harvest, each bunch contains large (hens) and small (chickens) berries that ripen unevenly. Certain cvs, and clones, such as Merlot and Chardonnay especially when own-rooted, appear to be particularly susceptible to millerandage. The factors causing this disorder may be similar to those causing poor fruit set, but are possibly more severe, or occur at a critical time in the development of the flower or berry.

Several factors or combinations of factors have been linked with poor fruit set and/or millerandage, but these are not all well defined (Bessis et al. 2000). Poor fruit set may be due to (i) flowers not being completely fertilised leading to early abscission,(ii) insufficient nutrition (especially boron and/or zinc) leading to abscission of ovaries soon after fertilisation, (iii) insufficient or excess hormones preventing the activation of the abscission layer, (iv) insufficient carbohydrates stored over winter inhibiting the normal development of flowers, (v) seedless berries with less than adequate hormones for partitioning carbohydrate to berry growth and development, (vi) growing shoots or expanding leaves competing with flowers or berries for photosynthate, (vii) phloem damage preventing the translocation of phloem sap into berries (Coombe, 1962; May 1992; Ebadi et al. 1995; McCarthy and Coombe 1999; Bessis et al. 2000).

Low temperatures interfere with the differentiation of flower primordia, leading to defective reproductive structures and fewer flowers per bud, and poor fruit set (Ebadi et al. 1995). Even when set was normal in cold weather, ovules tended to be defective, with less germinating pollen and reduced growth of pollen tubes (May 1992). This led to fewer seeds per berry and small berries. A well-defined abscission layer develops at the base of the pedicel of the berry, and if stimulated causes the berry to drop (Mullins et al. 1992). Ethylene (stimulated or inhibited by pre-cursors) appears to control the activation of the abscission layer, and hence abscission of the berry (Bessis et al. 2000).

The timing of any detrimental weather events is likely to be important. After the onset of flowering, a cluster of flowers develops into a bunch of berries, with some berries developing ahead of others. Over the whole bunch this process may take longer than two weeks and the wing always develops later than the rest of the bunch and often any other bunch on the shoot weeks (personal observation). Bunches that have set before a sudden drop in temperature may escape damage, and develop into normal berries, whereas others in the cluster may not produce viable pollen to fertilise the ovules. If small and large berries are mixed through the bunch, phloem to individual berries may be blocked. If large berries develop at the proximal end of the bunch, and small berries develop at the distal end, a) the phloem in the rachis may be blocked, or b) there may be insufficient photosynthate, nutrition and hormones for all berries.

The amount of carbohydrates or nutrients (especially boron) is critical for developing clusters. Hence growers may also increase fruit set by removing or tipping young leaves which compete with the developing clusters (Mullins et al. 1992). The application of plant hormones, which are thought to affect partitioning of organic nutrients, increases fruit set (Coombe 1973). It may be that that carbohydrate stored over winter in stressed vines decreases quickly below critical concentrations needed for proper development of flowers. Also nitrogen applied late in the growing season usually leads to a flush of root and shoot growth, with less carbohydrate being stored over winter. This may also lead to decreased fruit set.

The development of seeds within the berry depends on the weather, the site, clone, boron nutrition, water supply at and after flowering and severity of pruning (Hardie and Aggenbach 1996). Berries with few or no seeds are usually small, and ripen later than do large berries with more seeds (Skirvin and Hull 1972). The seed coat produces hormones, which affect fruit set through the effects on partitioning of organic nutrients of normal berries (Fougère-Rifot et al. 1995). Hormones applied to green berries at about 2 weeks before harvest caused a callus-like layer to develop between the pedicel and skin which delayed the drop of berries (Mullins et al. 1992).

Low temperature, boron stress and water stress can all affect fruit set. However, it is not known whether these factors operate directly on flowers or berries, or indirectly by affecting other plant processes or the partitioning of vegetative growth. Furthermore, the timing of maximum sensitivity of development stages has not been well described. Most of the experiments on the effects of low temperature on the development of flowers and on fruit set have involved subjecting the whole plant to low temperature. To better understand the mechanisms of development involved, we need to study the individual effects of temperature on the anatomical changes in flower clusters, roots and the canopy.

3.5 General Conclusions

This section summarises and synthesises information from the foregoing sections and presents a set of priorities for future physiological research in the context of developing improved methods for crop forecasting and stabilising yield

Quantifying variation is a necessary first step toward understanding it. The project has collected baseline data on the nature and extent of variation in commonly assessed yield components and compositional characters at all levels within vineyards. Some of this data has been used to design sensible sampling strategies for improved yield forecasting. However, we believe that there is a need for continued investment in research and development of rapid and accurate methods for assessing crop load and berry composition. In other fields this is commonplace. For instance, satellite imaging is used for forest inventory. Nevertheless, using remote-sensing systems to assess crop loads in viticulture, whether from satellites or horizontally along rows presents particular challenges. Satellite imaging is capable of delineating areas of high vigour from lower vigour areas. But we know that there may be no correlation between yield and canopy vigour, and in dense overly vigorous canopies yield may be reduced in the current season and in the following season. Another problem is that in many vine management systems fruit is generally restricted to a narrow fruiting zone. This may be advantageous for harvesting but the clumping of fruit (bunches obscuring other bunches) becomes a problem when attempting to image crop load. Similarly, leaves may obscure fruit. However, one can envisage an air blower exposing fruit immediately preceding image capture by, for instance, a digital video camera.

The overlap between the results presented in our project and current research into yield mapping (Precision Agriculture) is obvious and worthy of some discussion. PA describes a system of site-specific management that enables producers to more effectively match production inputs (eg. fertiliser, water, pest control chemicals) to small scale spatial variations in factors that determine yield and crop quality (East and Dempsey 1998). It links detailed spatial information on crop yield and quality with intensive sampling of the potential underlying causal factors, such as soil or plant properties, to provide a manager with objective information on which to base decisions. It is conceivable that the application of PA to viticulture will lead to some fairly immediate and substantial benefits, eg. using PA to identify and ameliorate areas under attack by pathogens or being able to identify when yield is being limited by an identifiable cause such as soil pH. Also, the use of grape 'quality' sensors attached to harvesters would allow batches of grapes that vary in quality to be separately harvested and processed.

Stabilising temporal variation in yield and quality, however, is likely to be more difficult. The inputs required to reduce variation would be expected to be more complex than, say, the addition of nutrients for the following season. In the absence of any obvious nutritional or water availability limits to yield, bunch or shoot removal appear to be the simplest and most powerful ways to control crop during the current season. Data presented in Section 5 illustrate an important point. A comparison of seasonal yield variation patterns from 1957 to 1972 for same variety on different rootstocks with different varieties on same rootstock at Wahgunyah in North Eastern Victoria is presented. Unlike variety, the choice of rootstock exerted little control of the seasonal variation patterns. An obvious interpretation is that seasonal differences in the reproductive biology of the grapevine are more responsive to the environment above the ground than the soil environment. Also, given the obvious influence of light and temperature in the previous season on yield (see Section 3.3.4), improved canopy management during critical stage of the previous season will also be important. Nevertheless, irrespective of how one might stabilise yield any methods will necessarily rely on accurate estimates of crop potential and on monitoring of crop development during the season.

This project has concentrated, in the main, on understanding (and forecasting) the development of yield. Further strategic research needs to be undertaken into the inherent processes that affect grape composition, including vigour, vegetation: fruit balances, carbohydrate economy, edaphic factors, conditions during maturation, canopy microclimate and soil and water management. There is a need for simple tools to assist grape growers make viticultural decisions that will enhance and stabilise grape quality. The development of these tools needs to be based on a better understanding of the determinants of compositional quality and how these can be controlled through vineyard cultural practices such as timing and severity of pruning, canopy management, irrigation practices, nutrition and adjusting crop load.

Variation is unavoidable and characterises biological systems in particular. Some variation may even be desirable. With this in mind it is also important to define how much can be tolerated. Business management approaches to defining and managing variation may be usefully applied to this problem (see Section 5.1). Bramley and Proffitt (1999) explore the application of 'process control' thinking in other manufacturing systems

to growing grapes. In other systems it is possible to exert a level of control over processes "because the manufacturer has a good understanding of the relationship between inputs to the processes and outputs". Examples of inputs that viticulturists have control over are listed as water, pesticide, fertiliser and other management. While weather and soil types are seen as "things that we can measure but cannot control". In vineyards, however, we would argue that nutrition, water availability and pest and disease prevention are, in the main, understood and well managed. It is undeniable that seasonal variation in weather exerts (the) major influence over yield and quality. While detailed spatial map of yields are potentially very useful we won't realise this potential until we assemble a better understanding of the interaction between management and weather during critical stages of reproduction. Gaining this is made more challenging by our lack of detailed, quantitative knowledge about the influence of conditions in the previous season on yield in the current season for wine grapes.

Flower formation in grapevines is a complex and, in many ways, a poorly understood process. The complexity of the process is increased by the imposition of dormancy between the ontogenetic development of anlagen and the formation of individual flowers at budburst. However, the picture that emerges is one of where the reproductive behaviour of the plant is characterised by astonishing plasticity. The critical stages appear to be induction, initiation and early differentiation and budburst. Despite the large amount of work done, the responses to environmental and cultural factors of these critical stages remains poorly understood.

As a general rule, it seems that a combination of adequate light and exposure to high temperatures are required for maximum inflorescence initiation and differentiation in grapevines. However, a problem with many experiments is that the response variable that tends to be measured is bunches per shoot. We know that aside from any effects of initiation (and differentiation) that bunches per shoot can be modified by temperatures at budburst (Pouget 1981) and also by the types of shoots that burst (ie. ratio of primary shoots to secondary shoots).

There are now many lines of evidence that point to the importance of conditions (including temperature and light) leading up to the initiation and differentiation of anlagen in determining yield. These include the growth cabinet studies of Buttrose, empirical field studies of Baldwin, some of the field experimentation of Antcliff, May and others, our analyses of the contribution of various yield components to temporal variations in yield (Section 2) and the recent finding (Dunn and Martin 2000) that conditions which are conducive to initiation of anlagen also seem to pre-dispose inflorescences to form more flowers (bunch size). Therefore, there is an urgent need to describe the time-course of induction and initiation for our major wine grape varieties in a range of climatic regions and to link these processes to well defined phenological stages. This information is also required for the sensible imposition of treatments in experiments and for the testing the usefulness of weather data for predicting yields potential or, retrospectively, to understand previous patterns of seasonal yield variation.

If conditions preceding and during floral initiation simultaneously promote both inflorescence and flower numbers, then an excellent opportunity to manipulate yield potential exists. It may be possible to manipulate both inflorescence number and flowers per inflorescence by actions prior to or during critical periods of the development of anlagen. For this potential to be realised, these critical periods need to be defined, the most important determining factors need to be identified, and commercially viable ways of controlling them need to be developed. This is a field of research and development that has the potential to deliver very large benefits to the grape and wine industries with regard to both predicting and controlling crop development.

Bud burst also represents a critical time. Temperature can modify bunch numbers and, perhaps less importantly, flower numbers. The type of shoots that burst and the % budburst can also exert a powerful effect over bunch numbers. Also, for spur pruned vineyards this is the time when induction of inflorescence primordia for the next season's crop takes place

The relative importance of branching prior to dormancy compared to differentiation during budburst in controlling potential inflorescence size and flower numbers is not well understood. This related area might also represent a fertile field of applied research.

Section 4 shows that yield forecasts can be significantly improved by (i) having an accurate knowledge of block dimensions, (ii) employing adequate sampling techniques to estimate bunch number and (iii) improving the prediction of final bunch weight. Solutions for improving the first two have been provided by this project and if implemented will save the Industry a substantial amount of money each year (see Section 4.2.6). However, they will only improve forecasts so much. Further improvement relies on a better prediction of final bunch weight. This has proved difficult and 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. Preliminary research (Dunn and Martin, data not presented) has shown that branch numbers (primary branches on rachis), whether measured after budburst, around veraison or before harvest usually explains between 60 to 70% of the variation in flower number and berry number at harvest. This estimate of bunch weight is an obvious improvement on using historical averages. It is simple to measure and looks promising as an early indicator of bunch weight. An added advantages of branch number as a predictor is that it would lend itself to rapid spatial analysis techniques already being used or under development. More research is required establish its reliability as an indicator from season to season, within and between varieties and across a range of regional climates and management systems.

3.6 References

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4 Crop Forecasting

At various stages during each season, wineries ask grape growers to provide forecasts of yield. Differences between expected grape intake and actual delivery can lead to a chain reaction of problems spreading throughout the entire process of wine production and distribution. The ability to accurately forecast wine grape yields is essential for efficient harvest organisation, regional pricing negotiations, crusher intake scheduling, tank space allocation for vintage, investment in new winery capital equipment and the development of marketing strategies for both domestic and export markets.

In many grape-growing districts in Australia, there are legends of growers who have a "knack" of making accurate forecasts. However, these are exceptional individuals. The majority find it difficult to forecast production as accurately as wineries would like, even in established blocks that they have worked with for decades. Furthermore, the subjective "knack" of forecasting accurately is difficult to impart to new industry trainees. Consequently there is a need for an objective method that can be used generally to produce more accurate forecasts.

The CSIRO and Agriculture Victoria addressed this need in a project funded by the Grape and Wine Research and Development Corporation, entitled Crop Development, Crop Estimation, and Crop Control to Secure Quality and Production of Major Wine Grape Varieties: A National Approach. The project tested and refined a method for forecasting grape production, originally proposed by Dr Peter May of the CSIRO, in a broad range of conditions throughout Victoria, South Australia and New South Wales during the three seasons from 1997/98 to 1999/2000. Inaccuracy in forecasts is often due to some simple, avoidable factors. Growers often simply guess likely production based on a subjective "eyeballing" of a block and knowledge of its past production. Alternatively, where growers use an objective method, they often use unreliable numbers in their calculations. Grower beliefs about the size of their blocks can be inaccurate. Finally, sampling procedures are commonly inadequate.

In the Sunraysia during the 1950s, 1960s and early 1970s the CSIRO and the Victorian Department of Agriculture routinely sampled canes in Sultana and Doradillo blocks during winter dormancy, dissected buds and assessed their 'fruitfulness' (ie. presence or absence of inflorescence primordia) (Peter May, Ross Wall, Douglas Kneen, Reginald Johns personal communication). The results of these assessments were used by the Australian Wine and Brandy Board for planning allocations of varietal tonnages to brandy production and by growers to decide how many canes of Sultana to retain at winter pruning. The assessment procedure required microscopes and skilled personnel, so it was not considered to be one that growers might contemplate using for themselves. However, researchers speculated that growers could potentially 'force' dormant buds to burst early in the winter, assess bud fruitfulness by counting visible inflorescences, and prune accordingly. In the development of the project reported on here, it was recognised that this technique could potentially be developed for growers to make an early forecast of crop potential and as a basis for crop control by winter pruning. Consequently the potential of the technique of forcing single-node cuttings during winter dormancy was assessed in complementary programs of research at Mildura and Tatura.

For forecasting after budburst, however, May (1972) proposed a system based on (i) bunch counts made 4-6 weeks after budburst and (ii) berry counts made after fruit set. Another forecasts can be made close to harvest by destructively sampling vines or segments of vines. This forecast is important for intake scheduling.

Two teams worked on the testing and improving May's protocol: 1. CSIRO/NRE Irymple in Mildura - sampling from sites in the Sunraysia and at Coonawarra and 2. NRE Tatura at Tatura sampling from sites throughout Victoria, excluding the Mallee (Greater Victoria). They worked in close consultation and shared results and experience at regular project meetings and by correspondence. However, due to geographical separation and differences between the regions they studied and serviced, this part of the report is presented in two parts, *viz.*: Crop forecasting (Sunraysia and Coonawarra) and Crop forecasting (Greater Victoria). The project team believes that the results, taken as a whole provide an excellent basis for the industry nationally due to the wide spectrum of conditions tested, ranging from high-cropping, minimally-pruned vineyards in very hot, dry areas to low-cropping, elaborately canopy-managed vineyards in cool, high-rainfall areas.

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 summarised in a booklet issued by the Victorian and Murray Valley Wine Grape Growers Council (VMWGGC) (see Appendices). Experiences with its use in the Sunraysia and Coonawarra are described in section 4.1. At the time of its development and

dissemination to growers in the Sunraysia at the beginning of the 97/98 season, System 1 constituted a definition of current best practice and provided a framework for further research and development.

The Agriculture Victoria viticultural team at Tatura commenced work on crop forecasting at the beginning of the 1997/98 season. Its initial aim was to test the CSIRO/MVGGIDC protocol in vineyards in Victoria (excluding the Mallee). In the course of doing this, it identified some potential improvements to the system, tested them during the 97/98, 98/99 and 99/00 seasons and developed a revised protocol.

Work by each team reflected priorities and schedules of grower organisations in their respective regional constituencies, but the project team as a whole maintained a national perspective. The Merbein/Irymple team developed System 1 early in the project and extended it as an alternative to subjective grower estimation and worked with MVGGIDC and Sunraysia TAFE to produce a kit for growers in the Murray Valley. Their research program was based on measuring crop yield components in 40 vineyard blocks in the Sunraysia and Coonawarra, where they sought to identify possible predictors of yield at various stages of growth and development. The Tatura team focussed more on research and development of techniques that might improve the performance of System 1, and developed and delivered a training system for the grapecheque program in Victoria. They Measured crop components in 31 study blocks throughout Greater Victoria in 97/98 and in 16 study blocks on a north-south climatic transect in 98/99 and 99/00. At end of project had developed System 2.

In this report the CSIRO/MVWGGIDC protocol will be referred to as 'System 1' and the revised protocol will be referred to as 'System 2'.

4.1 Crop Forecasting (Sunraysia and Coonawarra)

4.1.1 Introductory Technical Information

In the planning and design phase of this project, there was a clear division between the low input methods of vineyard management (minimal and mechanical pruning) and the intensively managed vineyards in the cooler regions (see section 4.2). The project team located at Merbein and Irymple (both in Victoria) focussed on the viticultural practices associated with the typical wine grape production practices in the Sunraysia and compared and contrasted those to a cooler region (Coonawarra) which utilised similar vineyard management practices.

The aims were to:

1. Monitor yield components at each stage of crop development in the varieties Chardonnay, Shiraz and Cabernet Sauvignon and relate the measurements to the final yield.
2. Identify possible predictors of yield at various stages of growth and development.

4.1.2 Definitions

SNC = Single Node Cuttings
MBC = Merbein Bunch Count
BDF = Bunch Difference Factor

4.1.3 Research Methodology

Experimental Sites

The experimental sites consisted of 40 commercial vineyards growing *Vitis vinifera* L. varieties Chardonnay, Shiraz and Cabernet Sauvignon. 28 vineyards (11 Chardonnay, 9 Shiraz and 8 Cabernet Sauvignon) were located within a 40km radius of Mildura (Sunraysia), Victoria, Australia (142^{o}08'E, 34^{o}12'S) and 12 vineyards (4 Chardonnay, 4 Shiraz and 4 Cabernet Sauvignon) within a 10km radius of Coonawarra, South Australia, Australia (140^{o}50'E, 37^{o}22'S) (Table 4.1.1).

The long-term average annual rainfall for Mildura is 275mm, the mean January temperature (MJT) is 23.3^{o}C with a October to April temperature variability index of 46.9 and the heat sum between October to April is 1,753 degree days (base temperature10^{o}C) (Gladstone, 1992). The soils in Sunraysia typically range from Coomealla sands to Merbein clay (Northcote, 1979). The long-term average annual rainfall for Coonawarra is 628mm, the MJT is 19.3^{o}C with a October to April temperature variability index of 45.3 and the heat sum between October to April is 1,337 degree days (base temperature 10^{o}C) (Gladstone, 1992). The soils in Coonawarra are typically red Terra Rossa (Northcote, 1979).

Planting and vine management details for each site are outlined in Table 4.1.2 and Table 4.1.3. A range of different clones were examined within each variety, however, clonal differences were not examined during this experiment.

Table 4.1.1 Participating growers

Participating Grower	Address	Variety
	Sunraysia	
Bate Bros.	P.O. Box 56 Sunnycliffs VIC, 3494	Ca
Beringer Blass Ltd	Box 396 Merbein, VIC, 3505	Ch
Binbilla Nominees	P.O. Box 331 Mildura, VIC, 3502	Ch,Sh
B. Ferry	P.O. Box 144 Coomealla, NSW, 2717	Ch,Sh
S. Freckleton	Swamp Rd Karadoc, VIC, 3494	Ca
E. Lindsay	P.O. Box 740 Merbein, VIC, 3505	Ca,Ch
Mildura Agricultural Contractors	PMB 30 Red Cliffs, VIC, 3496	Ca,Ch,Sh
L. Phillips	P.O. Box 2008 Mildura, VIC, 3501	Sh
W. Reyne	Paschendale Ave Merbein, VIC, 3505	Sh
Russell Horticultural Services	P.O. Box 469 Nangiloc, VIC, 3494	Ch
P. Walmsley	Dickeson Rd Nangiloc, VIC, 3494	Ca
R. Wells	P.O. Box 168 Merbein, VIC, 3505	Ch
Wingara Wine Group	Kulkyne Way Iraak, VIC, 3496	Ch
Zil Zie Estate	P.O. Box 1141 Red Cliffs, VIC, 3496	Ca,Ch,Sh
	Coonawarra	
Southcorp Wines Pty Ltd	c/o Coonawarra Post Office Coonawarra, SA, 5263	Ca
Beringer Blass Ltd	P.O. Box 21 Coonawarra, SA, 5263	Ca, Ch, Sh

Ca = Cabernet Sauvignon
Ch = Chardonnay
Sh = Shiraz

Table 4.1.2 Assessment year and vine planting details of trial sites in the Sunraysia.

Variety	Site	Year assessed	Year planted	Area (ha)	Total Vines	Vine space (m)	Row space (m)	Trellis
Cabernet S.	Av1OR	1998-2000	1972	1.74	2837	1.83	3.35	Vert
Cabernet S.	Av2OR	1998-2000	1972	2.55	4163	1.83	3.35	Vert
Cabernet S.	BatOR	1998-2000	1978	1.54	2375	1.83	3.55	Tee
Cabernet S.	FreRS	1998-2000	1993	3.14	4872	2.15	3.00	Vert
Cabernet S.	LinRS	1998-2000	1992	1.03	1252	2.45	3.35	Tee
Cabernet S.	WalORAll	1998-2000	1989	2.35	3264	2.15	3.35	Vert
Cabernet S.	WalORMore	1998	1989	0.98	1360	2.15	3.35	Vert
Cabernet S.	WalORMore	1999	1989	1.96	2720	2.15	3.35	Vert
Cabernet S.	WalORLess	1998	1989	0.98	1360	2.15	3.35	Vert
Cabernet S.	WalORLess	1999	1989	0.39	544	2.15	3.35	Vert
Cabernet S.	WalORSide	1998	1989	0.39	544	2.15	3.35	Vert
Cabernet S.	ZilORF4Box	1998	1989	3.20	4920	1.83	3.55	Vert
Cabernet S.	ZilORF4Side	1998	1989	3.41	5248	1.83	3.55	Vert
Cabernet S.	ZilORF4Side	1999	1989	6.07	9348	1.83	3.55	Vert
Cabernet S.	ZilORF4Side	2000	1989	6.61	10168	1.83	3.55	Vert
Cabernet S.	ZilORF4Min	1999	1989	0.53	820	1.83	3.55	Vert
Cabernet S.	ZilORF4All	1998-2000	1989	6.13	10168	1.80	3.35	Vert
Cabernet S.	ZilORF9Side	1998	1989	3.43	5280	1.83	3.55	Vert
Cabernet S.	ZilORF9Side	1999	1989	7.12	10956	1.83	3.55	Vert
Cabernet S.	ZilORF9Side	2000	1989	7.55	11616	1.83	3.55	Vert
Cabernet S.	ZilORF9Min	1998	1989	4.12	6336	1.83	3.55	Vert
Cabernet S.	ZilORF9Min	1999	1989	0.43	660	1.83	3.55	Vert
Cabernet S.	ZilORF9All	1998-2000	1989	7.12	11616	1.83	3.35	Vert
Chardonnay	AgcRS	1998-2000	1987&89	4.35	5304	2.45	3.35	Vert
Chardonnay	Al8RS	1998-2000	1982	1.20	1960	1.83	3.35	Vert
Chardonnay	CcoBO	1998-2000	1983	10.27	17110	2.00	3.00	Vert
Chardonnay	FerOR	1998-2000	1993	1.67	3641	1.83	2.50	Vert
Chardonnay	FerRS	1998-2000	1993	2.76	4019	2.75	2.50	Vert
Chardonnay	LinRS	1998-2000	1992	2.39	2916	2.45	3.35	Tee
Chardonnay	MilRS	1998-2000	1992	0.92	1210	2.45	3.10	Vert
Chardonnay	RusRS	1998-2000	1987	2.79	4556	1.83	3.35	Vert
Chardonnay	WelRS	1998-2000	1988	1.89	2600	2.50	2.90	Vert
Chardonnay	WinOR	1998-2000	1982	7.04	11480	1.83	3.35	Vert
Chardonnay	ZilORF2	1998-2000	1987	27.55	44936	1.83	3.35	Vert
Shiraz	BinORSw	1998-1999	1970	2.49	4060	1.83	3.35	Vert
Shiraz	CcoORCon	1998-1999	1975	3.59	6235	1.83	3.15	Vert
Shiraz	CcoORCon	2000	1975	3.13	5434	1.83	3.15	Vert
Shiraz	CcoORRem	2000	1975	0.41	715	1.83	3.15	Vert
Shiraz	FerOR	1998-2000	1991	1.37	2730	1.83	2.75	Vert
Shiraz	HurOR	1998	1970	1.21	1980	1.83	3.35	Tee
Shiraz	HurOR	1999	1970	0.66	1188	1.83	3.05	Tee
Shiraz	HurOR	2000	1970	0.40	792	1.83	2.75	Tee
Shiraz	PhiOR	1998-2000	1958	2.17	4320	1.83	2.75	Tee
Shiraz	ReyORMin	1998	1989	1.05	2080	1.83	2.75	Vert
Shiraz	ReyORMin	1999	1989	2.09	4160	1.83	2.75	Vert
Shiraz	ReyORMin	2000	1989	2.09	4160	1.83	2.75	Vert
Shiraz	ReyORBox	1998	1989	1.28	2080	1.83	3.35	Vert
Shiraz	ReyORAll	1998-2000	1989	2.55	4160	1.83	3.35	Vert
Shiraz	WfiOR	1998-2000	1970	1.19	1936	1.83	3.35	Vert
Shiraz	ZilORB4Hed	1998	1989	1.94	3168	1.83	3.35	Vert
Shiraz	ZilORB4Hed	1999-2000	1989	4.05	6600	1.83	3.35	Vert
Shiraz	ZilB4ORMin	1998	1989	2.10	3432	1.83	3.35	Vert
Shiraz	ZilB4ORAll	1998-2000	1989	4.05	6600	1.83	3.35	Vert
Shiraz	ZilB8ORHed	1999	1991	15.38	25080	1.83	3.35	Vert
Shiraz	ZilB8ORHed	2000	1991	16.18	26400	1.83	3.35	Vert
Shiraz	ZilB8ORMin	1999	1991	0.81	1320	1.83	3.35	Vert
Shiraz	ZilB8ORAll	1999-2000	1991	16.18	26400	1.83	3.35	Vert

Table 4.1.3 Assessment year and vine planting details of trial sites in Coonawarra

Variety	Site	Year assessed	Year planted	Area (ha)	Total Vines	Vine space (m)	Row space (m)	Trellis
Coonawarra								
Cabernet S.	BerHedOR	1998-2000	1988	9.08	16512	2.00	2.75	Vert
Cabernet S.	BerMinOR	1998-2000	1971	12.94	21100	1.83	3.35	Vert
Cabernet S.	SouHedOR	1998-2000	1971	24.84	30270	2.45	3.35	Vert
Cabernet S.	SouMinOR	1998-2000	1971	0.60	735	2.45	3.35	Vert
Chardonnay	GraHedOR	1999-2000	1989	9.24	16800	2.00	2.75	Vert
Chardonnay	LynHedOR	1999-2000	1988	7.94	14430	2.00	2.75	Vert
Chardonnay	McBHedOR	1999-2000	1987	6.68	13275	1.83	2.75	Vert
Chardonnay	SmiHedOR	1999-2000	1985	2.09	4960	1.53	2.75	Vert
Shiraz	MunHedOR	1998-2000	1968	8.79	18841	1.53	3.05	Vert
Shiraz	MunMinOR	1998-2000	1968	0.74	1589	1.53	3.05	Vert
Shiraz	OdeMinLoOR	1998-2000	1970	0.36	775	1.53	3.05	Vert
Shiraz	OdeMinShOR	1998-2000	1970	0.36	775	1.53	3.05	Vert

Forced Single Node Cuttings

A modified method for producing single node cuttings was used in this study, this was similar to those methods used by May and Antcliff (1973). Briefly, during winter (June) of 1997 and 1998, 20 randomly selected one year old fruiting canes were collected from each experimental vineyard in Sunraysia and Coonawarra. Canes were stored in sealed plastic bags with 200mL of water, at 4^{o}C, until required. Each cane was dipped in 2.5% (v/v) Dormax® (active constituent - Hydrogen Cyanimide 600g/L) for 5 seconds and the cane cut approximately 3-5mm above each node position along the cane, to give anywhere between 1-15 single node cuttings per cane. The base of each single node cutting was planted into trays (20cm x 30cm x 7cm) containing steam sterilised river sand. In 1997/98 cuttings were propagated in an old insulated cool room located at CSIRO Plant Industry, Horticulture Unit, Merbein, Victoria. The insulated room was maintained at 27^{o}C (+/- 5^{o}C) during the day and 15^{o}C (+/- 5^{o}C) during the night, under 'Growtube' fluorescent lights and watered once a day by hand at 9:00am. In 1998/99 and 1999/2000 propagation was conducted under glasshouse conditions of 27^{o}C (+/- 5^{o}C) during the day and 15^{o}C (+/- 5^{o}C) during the night. Watering was conducted using misting sprays 3 times a day at 9:00am, 12:00pm and 6:00pm for 5 minutes each time. Bud burst (E-L stage 4, Coombe, 1995) occurred approximately 10-14 days after planting. Bunch number and node position were recorded on each cutting 14 days after bud burst. At this stage, the growing shoot on each cutting was approximately 10-100mm long.

Merbein Bunch Count Method

The Merbein Bunch Count Method (Antcliff *et al.*, 1972) was conducted on shoots arising in a 20cm transect. Ten randomly selected vines were sampled in each experimental vineyard, in both Sunraysia and Coonawarra. This was conducted approximately one month after budburst. Using this method nodes/vine, shoots/vine, fruitful nodes/vine, bunches/vine and percentage bud burst could be calculated from this data. The average bunch number per node position was also recorded for comparison with Single Node Cutting results.

Flower number

Average flower number per cluster was calculated by randomly collecting 100 individual clusters from each experimental vineyard, just prior to cap fall. A rapid method of determining flower number per cluster was developed using a multilinear relationship between cluster dry weight and cluster length (R^2=0.80-0.97). This relationship was established at each experimental site using 20 extra clusters, which were collected at the same time as the other clusters.

Berry number assessment

Average berry number per bunch was calculated by randomly sampling 100 individual bunches from each experimental vineyard, when berries were approximately pea-sized. Each bunch was frozen and stored at –18°C prior to counting. Individual berries were separated by braking apart each individual bunch, passing them over a 3mm sieve a berries which did not pass though were counted by using a automatic berry counter developed by CSIRO Plant Industry. The percentage fruit set was calculated by expressing the ratio of average berry number per bunch with the average flower number per cluster and expressing this as a percentage.

Harvest Assessment

Harvest samples were collected during the week prior to harvest. 10 randomly selected vines were hand picked (trunk to trunk) and the fruit weight, bunch number, and length of vine picked were recorded for each vine. A randomly pre-allocated 20cm transect was removed from each harvested vine and taken back to the laboratory. From this transect sample, bunch weight and bunch number were recorded. 10 bunches were randomly sub sampled and the berries from each of these 10 bunches removed. A 100 random berry sub sample was collected and average berry weight recorded. The 100 berry sample was crushed using an electric juicer and total soluble solids (°Brix) recorded using an Atago digital refractometer, pH and titratable acidity (TA) were also recorded using a Metrohm autotitrator.

Statistical Analysis

Analysis of single node cutting data and Merbein bunch count data was conducted in Systat version 7.0, using a program written by Dr Karl Sommer. This program calculated mean bunch number per node position, percentage bud burst per node position and node number per vine, shoots per vine, fruitful shoots per vine and bunch number per vine. SNC, MBC, Flower number, Berry number and harvest data were all analysed using Microsoft excel. All graphical data was presented in Sigmaplot version 4.0.

The generation of a yield estimate at all stages of growth except for the pre-harvest assessment requires utilising some estimate of %bud burst, average bunch weight or average berry weight. This will be outlined and discussed in each of the following sections.

4.1.4 Results and Discussion

The following sub-section represent a summary of the research conducted in both the Sunraysia and Coonawarra regions during the 1996/97 (limited sites in Sunraysia only), 1997/98, 1998/99 and 1999/2000 growing seasons. Table 4.1.1 contains a list of all the names, addresses of collaborating growers and varieties used during the life of the project. The in-kind support of these growers to the 'crop forecasting' project is acknowledged and was greatly appreciated. The vineyard details, which includes variety, year planted, area, total number of vines, year of assessment, trellis type, pruning method and row and vine spacing is summarised in Table 4.1.2 and Table 4.1.3. In some of the vineyards assessed, the year of assessment and the area of the vineyard may have changed on an annual basis because of the change in pruning/canopy management. This table includes a summary of vineyard information for both the Sunraysia and Coonawarra experimental vineyards.

Dormancy Assessment (SNC)

The use of forced single node cuttings (SNC) to examine bud fruitfulness has been described previously by May and Antcliff (1973). SNC's are a relatively cheap and easy method of monitoring the fruitfulness of individual buds along the cane. Figure 4.1.1 shows a typical SNC 14 days after actual bud burst.



Figure 4.1.1 A typical forced single node cutting 14 days after budburst

The integer type nature of the data collected from SNC assessments (ie. 0, 1, 2 or 3) and the inherent variability in the data (coefficient of variation [%CV]=80-120%) made it hard to get meaningful numbers on an individual vineyard basis. However, when the data was combined on a regional basis for each variety, the data was useful for examining the regional and seasonal trends in dormant bud fruitfulness (Figure 4.1.2).

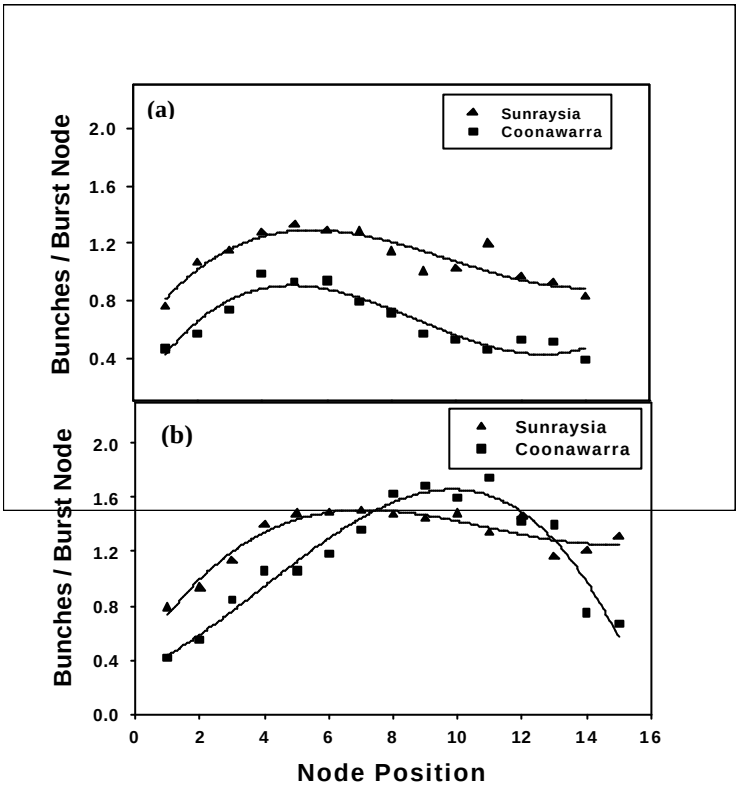


Figure 4.1.2 Mean bunches per node position for Cabernet Sauvignon in the Sunraysia and Coonawarra in (a) 1997 and (b) 1998 determined by forcing single node cuttings during dormancy.
(n=4 sites x 20 canes per site)

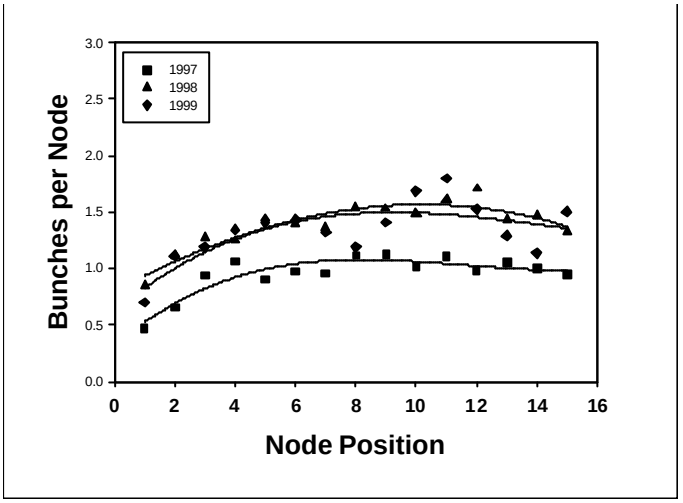


Figure 4.1.3 Seasonal differences in the average number of bunches per burst node for node numbers 1-15 in Sunraysia grown Chardonnay (1997, 1998 and 1999)

The effectiveness of SNC bud fruitfulness assessments for crop forecasting purposes is limited by a lack of knowledge about the buds which will actually burst. In both minimal pruned and mechanical pruned vineyards one can expect anywhere between 40-80% of the buds to burst (Appendices, Tables 1-4). However, the data may be useful for crop estimate purposes when comparing between seasons (Figure 4.1.3).

Here the ratio of current seasons predictor (mean bunches per burst node) can be expressed as a ratio against the previous seasons predictor, ie.

$$\text{Yield estimate} = \frac{\text{Mean SNC bunches/burst node Year 2}}{\text{Mean SNC bunches/burst node Year 1}} \times \text{Yield in Year 1}$$

or;

$$\text{Yield estimate} = \frac{\text{Mean SNC bunches/burst node in current year}}{\text{Mean SNC bunches/burst node in previous years}} \times \text{Mean Vineyard yield}$$

The trouble with using this method of estimating yield on an individual vineyard basis was the inherent variability within an individual vineyard. When this information was used for generating a regional estimate in the Sunraysia on a variety basis, using the ratio method of prediction an overestimate of approximately 15-28% was produced (Table 4.1.1). There was no real improvement in the estimate between the 1999 and 2000 seasons. Therefore the usefulness of this SNC data to assist in the generation of regional estimates may be limited.

A comparison of fruitfulness assessments at both the SNC and Merbein Bunch Count (MBC) stage of development was conducted by comparing the mean number of bunches per burst node at each experimental vineyard. In Sunraysia Shiraz and Cabernet Sauvignon, a good relationship between the mean number of bunches per burst node at both stages was observed, with similar bunch numbers observed at both stages (Figure 4.1.4 and Figure 4.1.5). However, in Sunraysia Chardonnay, while there was generally a good relationship between bunch numbers observed at SNC and MBC stages of development, fewer bunches were observed in spring (Figure 4.1.6). This makes it hard to make accurate yield assessments in Chardonnay during dormancy if only a proportion of the bunches are being observed in spring (MBC assessment).

Table 4.1.4 The mean number of bunches per burst node in SNC's, average yield per vine, the predicted yield using the ratio method and the percentage difference between predicted and actual yield for Chardonnay, Shiraz and Cabernet Sauvignon grown in Sunraysia during the 1998, 1999 and 2000 seasons.

Variety	1998 Mean SNC bun per burst node	1998 Mean Yield Kg/vine	1999 Mean SNC bun per burst node	1999 Mean Yield Kg/vine	1999 Predicted	1999 % Diff	2000 Mean SNC bun per burst node	2000 Mean Yield Kg/vine	2000 Predicted	2000 % Diff
Chardonnay	0.907	22.9	1.143	23.5	28.9	22.8	1.133	17.0	25.6	50.8
Shiraz	0.697	16.2	0.750	15.0	17.4	16.2	1.163	13.7	25.1	83.0
Cab. Sauv.	0.861	15.6	1.106	16.9	20.0	18.6	0.934	13.2	15.4	16.9

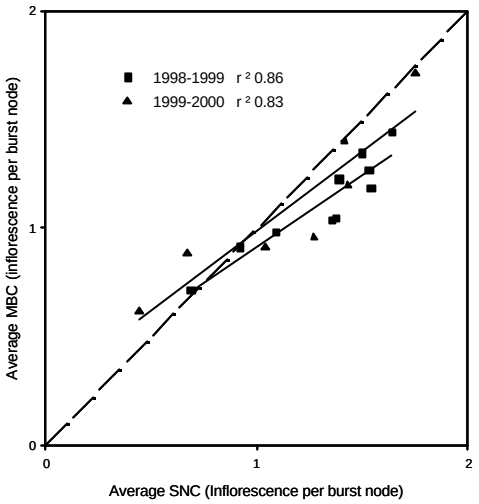


Figure 4.1.4 Sunraysia Shiraz SNC average number of bunches perburst node versus MBC average number of bunches per burst node.

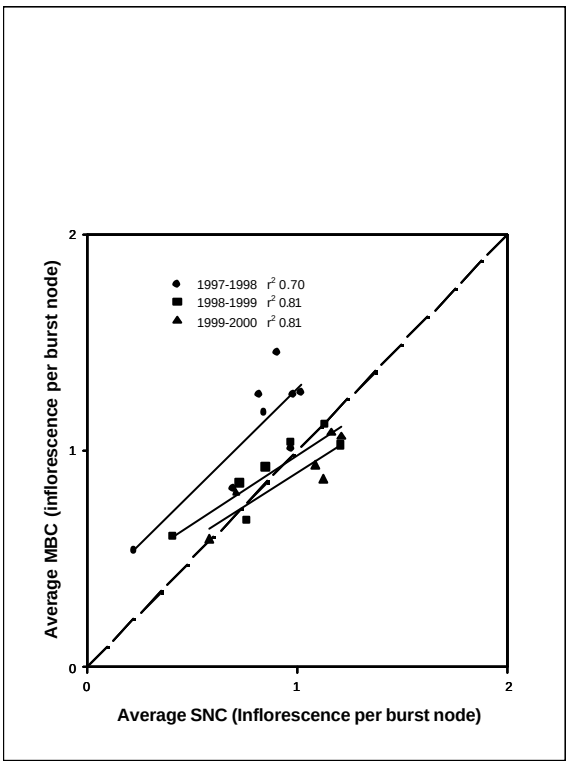


Figure 4.1.5 Sunraysia Cabernet Sauvignon SNC average number of bunches per burst node versus MBC average number of bunches per burst node.

In summarising this section on dormancy assessments, given the highly variable nature of the data collected using SNC (usual %CV is 80-120%), much higher cane numbers per vineyard need to be assessed (ie in the order of 114-256) to give any numbers which will give a reasonable level of confidence (95%) and an acceptable level of error (ie 15%). Given that each cane may generally possess 8-17 individual nodes, this means that a total of approximately 912-4352 SNC would need to be assessed per vineyard. This is only really for Shiraz and Cabernet Sauvignon, because of the bunch loss phenomenon observed in Chardonnay (which varied depending on the season in which it was examined). While an accurate estimate may be possible at this stage, the time, resources and effort required to produce this estimate may not be commercially practical to industry.

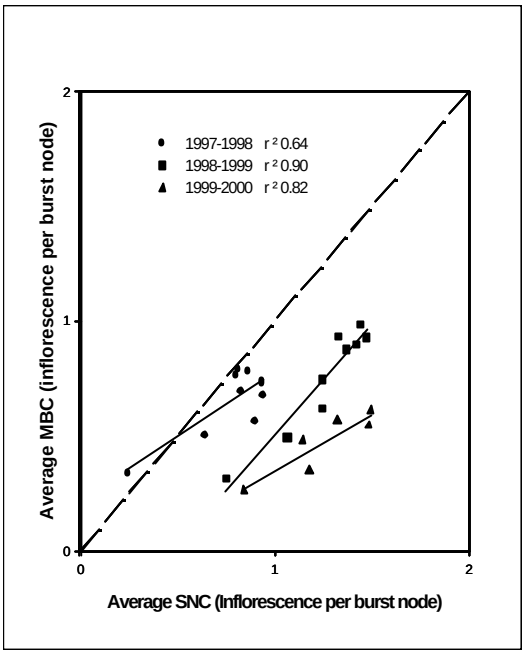


Figure 4.1.6 Sunraysia Chardonnay SNC average number of bunches per burst node versus MBC average number of bunches per burst node.

Spring Assessment (MBC)

The assessment of bunch numbers after bud burst is usually conducted 4-6 weeks after bud burst. The Merbein Bunch Count (MBC) method was developed by Antcliff *et al*. (1972) and utilised because it provides an assessment of the number of bunches per vine, and information on total node number, percentage bud burst, number of shoots, number of fruitful shoots and the percentage fruitful nodes.

In examining the MBC bunch count data initially, discrepancies between MBC bunch count data and pre-harvest bunch count data were consistently observed. This MBC bunch count information has been summarised (Appendices Tables 1-4). Table 1 contains the Sunraysia Chardonnay MBC data, Table 4 contains the Sunraysia Shiraz MBC data, Table 3 contains the Sunraysia Cabernet Sauvignon MBC data and Table 4 contains the combined Coonawarra Chardonnay, Shiraz and Cabernet Sauvignon data. These tables contain information on percentage bud burst at each site, MBC average bunch number per vine, pre-harvest average bunch number per vine, a probability of a significant difference using paired *t*-test and a calculated bunch difference factor (BDF). The bunch difference factor was calculated by expressing the average number of bunches observed at MBC stage of development as a ratio to the average number of bunches observed just prior to harvest.

As mentioned in the previous sub-section on SNC assessments, the percentage bud burst across the minimally and mechanically pruned vineyards generally ranged between 40 and 80%. On vineyards where both pruning treatments had been established and vineyard management system was similar, a higher percentage bud burst was observed in the mechanically hedged vines, as expected. However, this general comparison could not be made between different sites where vineyard management techniques varied, Both pruning systems did show similar ranges in values for the percentage of bud burst (Appendices Tables 1, 2, 3 and 4).

There was also a significant seasonal variation in percentage bud burst on each vineyard (Table 4.1.5). The reasons for this variation in percentage bud burst are not well known, but it does make attempting crop prediction at bud dormancy (SNC) much more difficult and unreliable.

Table 4.1.5 Seasonal differences in the percentage bud burst of Hedged Cabernet Sauvignon (Site ZilORF9Side) in 1998, 1999 and 2000.

Year	% Bud Burst
1998	77.0
1999	60.4
2000	72.4

Initially, when developing crop forecasting methodology, it was assumed that the number of bunches observed during spring MBC assessments would be that same or similar to the numbers observed at harvest. It wasn't until significant differences in bunch numbers were being observed between MBC and pre-harvest bunch number assessments that a different approach needed to be considered (Appendices Tables 1-4). In Sunraysia, the number of bunches counted during spring (MBC assessment) may have been significantly higher or lower than that observed at harvest. In the Coonawarra, significant differences were also observed in bunch number assessments at both stages of development. However, in Coonawarra there was mainly a significant loss in the number of bunches between spring assessment and pre-harvest assessment (Appendices Table 4). Where a significant difference in the number of bunches was observed between MBC and pre-harvest assessment a Bunch Difference Factor (BDF) was been calculated (Appendices Tables 1-4). This is calculated simply as a ratio of MBC average bunch number per vine to pre-harvest average bunch numbers per vine, ie

$$\text{BDF} = \frac{\text{MBC average bunch number per vine}}{\text{Pre-harvest average bunch number per vine}}$$

This BDF ratio ranged from 0.40 – 1.74 across vineyards in both Sunraysia and Coonawarra. In Coonawarra, all of the significant reductions in bunch numbers between MBC and pre-harvest assessments occurred during the 1999 vintage (Appendices Table 4). In fact, in Coonawarra, where there were significant losses in bunch numbers between MBC and pre-harvest assessments, the average BDF was 0.74 for Chardonnay, 0.90 for Shiraz and 0.76 for Cabernet Sauvignon (Appendices Table 4). In these particular Coonawarra sites, only an average of 74, 90 and 76% of bunches observed during spring were actually present and counted for at harvest in Chardonnay, Shiraz and Cabernet Sauvignon respectively (Appendices Table 4).

The percentage coefficient of variation (%CV) for MBC bunch number per vine was always higher (average between 43 and 60%) than that observed for pre-harvest bunch number per vine (average between 21 and 34%) (Appendices Tables 1-4). This higher variability in bunch number counts may be attributed to the fact that only 20cm transects were assessed at the MBC stage of assessment compared to whole vines at harvest.

To generate a yield estimate using the MBC data, the following formula was used;

$$\text{Yield (T)} = \frac{\text{Av. MBC bunches/vine x total vines/vineyard x average bunch weight (g)}}{1{,}000{,}000}$$

Using this formula, an estimate of yield per vineyard may be obtained during spring. To apply this formula, the average bunch weight data is generally obtained from historical data. Where historical bunch weight data is not available data from similar varieties, regions and vineyard management system may be used as a 'best guess'. To remove this ambiguity, we attempted to make an estimate of yield based on knowledge of the actual pre-harvest bunch weight. Also, no bunch difference factor (BDF) was used in this calculation, because there were no consistent trends in BDF on a regional or seasonal basis. A summary of crop forecasting at the MBC stage of crop development can be seen in Appendices (Tables 5 - 8). These tables report the average bunch number information determined at MBC assessments, the pre-harvest average bunch weight, the yield estimate obtained at MBC and the percentage difference in the estimate from the actual yield. On some sites, the estimate has been out by as much as 293% (Appendices Table 8). However, when the average difference between estimated and reported yield is examined we generally noticed that we were overestimating on average by 27-37% in Sunraysia (Appendices Tables 5 - 7). However, if you looked at absolute differences in yield (correcting for positive and negative values) we are generally on average by 36-46% Appendices Tables 5 - 7). This error in the estimated yield is most probably coming from the differences observed in bunch numbers between MBC and pre-harvest yield assessments. Also, because the vineyards are mechanically harvested, a lower harvest efficiency would be expected. As expected, the yield estimate obtained just prior to harvest was generally more accurate than that obtained at MBC stage of crop development (Appendices Tables 5 - 8).

Flowering Assessment (Flower Numbers)

Flowering and fruit-set is an important stage in the cycle of yield development. It is where the vine decides on the potential number of berries to take through until harvest. The assessment of flower numbers per cluster was conducted just prior to cap fall (<1 week prior to flowering). Previous work by Cour and Bousquet (1981)

demonstrated a good relationship (R^2=0.8) between pollen number counts and yield. It was thought that this might indicate that a relationship between flower number and yield might exist and therefore be useful as a predictor of yield.

The assessment of flower numbers is a difficult and time-consuming process. The project team examined many different ways of assessing flower number per cluster. This involved examining relationships between measurable factors such as inflorescence length, flower numbers on the 1st and 3rd branch of the inflorescence and total cluster dry weight. Generally, good relationships were observed between all of the above factors and total flower number per inflorescence, except for flower numbers on the 1st branch of the inflorescence (Figure 4.1.7).

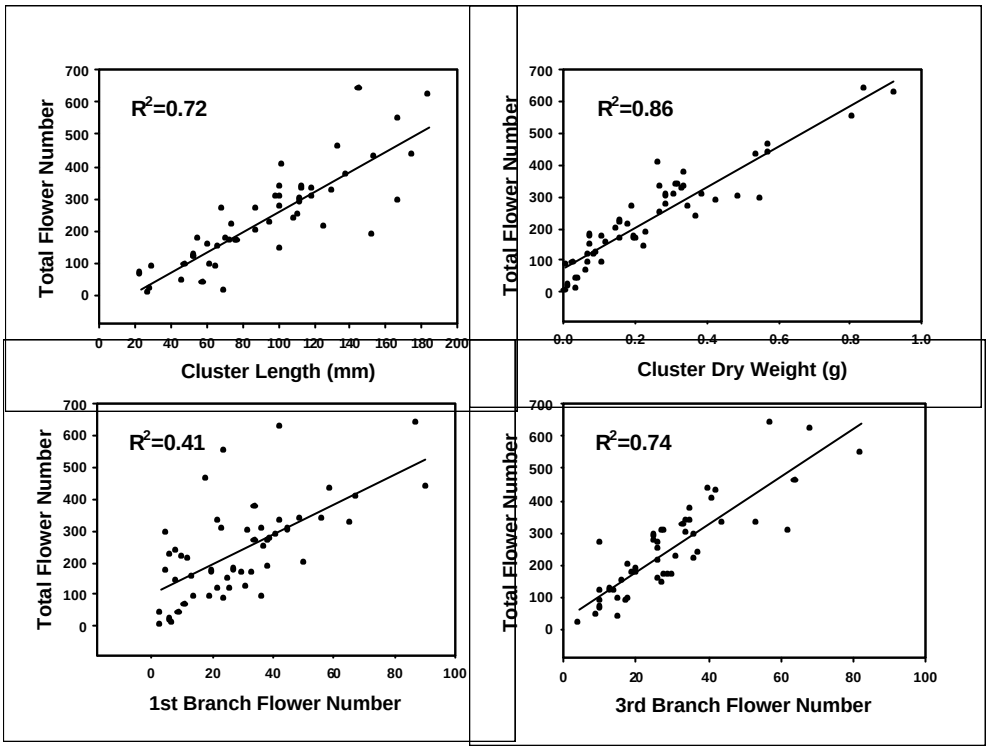


Figure 4.1.7 The relationship between cluster length, cluster dry weight and the number of flowers on the 1st and 3rd branch of the cluster to total number of flowers per cluster in Sunraysia grown Cabernet Sauvignon assessed 1 week prior to flowering.

Generally, a reasonable relationship between flower number per vine and yield per vine was observed across all varieties in (Table 4.1.6).

Table 4.1.6 Correlations (coefficient of determination, *r* – values) between yield per vine and MBC per vine, flower number per vine and berry number per vine in Sunraysia Chardonnay, Shiraz and Cabernet Sauvignon. This table includes data from different seasons and across different vineyard management systems.

Variety	MBC Bunch count	Flower number per vine	Berry Number
Chardonnay	0.73	0.64	0.68
Shiraz	0.51	0.55	0.77
Cabernet Sauvignon	0.45	0.62	0.84

While an assessment of flower number per cluster may be a slightly better predictor of yield in Shiraz and Cabernet Sauvignon than MBC, it was actually not a better predictor of yield in Chardonnay. Given the costly nature of generating yield estimates from assessments of flower numbers, it is unlikely that this would be used as a predictor of yield on a commercial basis.

Post-Fruit Set Assessment (Berry Numbers)

May (1972) reported that berry number per hectare was found to be the best predictor of yield. Berry number is a good predictor because it accounts for differences in both bunch number and berry number per bunch.

In our project, the number of berries per bunch were assessed at two different stages of development, 1) 'pea size' and 2) just prior to harvest. This was done to determine if there was any loss in berry number between post-set and pre-harvest assessments. Data was then tested statistically using a t-test to determine if there were any significant differences between the different stages of crop development. Analysis of the data revealed that there were some significant differences in berry numbers per bunch observed between the two different stages of development (Appendices Tables 9, 10, 11 and 12). Generally, there was a loss of berries per bunch between post-set and pre-harvest assessments (Appendices Tables 9, 10, 11 and 12). In Sunraysia Chardonnay, up to 36% of the berries may have been lost between post-set and pre-harvest assessments, with an average of 17% loss across all sites (Appendices Table 9). In Shiraz and Cabernet Sauvignon grown in Sunraysia there was generally not as many berries lost between post-set and pre harvest assessments (Appendices Tables 10 and 11). While, in one Shiraz site in Sunraysia (ReyORMin) a significant increase in berry numbers per bunch was observed, this was atypical (Appendices Table 10). In Coonawarra, significant differences in the number of berries was observed between post-set and pre-harvest assessments (Appendices Table 12). Generally, there could have been a significant loss or gain of berries per bunch in Chardonnay, Shiraz and Cabernet Sauvignon (Appendices Table 12). Because bunches were collected for all three varieties in Coonawarra at the same time, the assessment of berry numbers per bunch post fruit-set may have been just a little premature for both Shiraz and Cabernet Sauvignon (Appendices Table 12). This was confirmed by the counting of all 'full sized' and 'shot' berries at both stages of development (data not shown).

To account for this difference observed in berry number per bunch these two stages of crop development a 'berry difference or loss' factor could be used. In most cases there was a significant loss in the number of berries per bunch between post-fruit set assessment and pre-harvest assessments. However, there were some cases where a significant gain in the number of berries per bunch was observed. Sampling factors contributing to this phenomenon require investigation.

Using an assessment of berry number per bunch it is possible to make a yield prediction using the following formula;

$$\text{Yield (T)} = \frac{\text{Total number vines/vineyard x bunches/vine x berries/bunch x berry weight (g)}}{1{,}000{,}000}$$

Using a bunch number assessment post-set, this method of yield estimation did result in an improved estimate in all varieties grown in Sunraysia (Tables 9, 10 and 11). In general the average estimate was between 8.3 and 24.8% overestimated. When this was expressed in absolute terms this method of yield estimation resulted in errors of between 17 and 33% in all varieties assessed in Sunraysia. However, using this method of estimating yield in Coonawarra vineyards generally resulted in poor yield estimates, which ranged from 33 and 104% overestimates (Appendices Table 8). This error in estimating yield was may be partially attributed to the large differences in the number of berries per bunch observed between post-set and pre-harvest assessments (Appendices Table 12). While this method of crop estimation has worked well in Sunraysia vineyards, the errors using this method are not surprising considering the multiplication of the number of berries per vineyard (very large number) by an estimate of average harvest berry weight. Also, calculating the number of berries per vineyard (very large number) and then multiplying it by an estimate of harvest berry weight means that small changes in berry weight can result in massive differences in a yield estimate using this approach. The use of berry numbers in the ratio method of yield estimation does result in average errors of between –47 –and 53% across both Sunraysia and Coonawarra (Appendices Table 13). The variable nature of the ratio method does not give users any more confidence in producing an accurate yield estimate (Appendices Table 13). This may be due to the over-simplistic nature of this formula not to take account of the factors which can result in changes in berry weight. However, berry number does correlate well with final yield and is still one of the most important yield assessments stages of crop development across all varieties and regions (Appendices Tables 15 and 16).

The main obstacle to yield estimation at both the MBC and post fruit set stage of crop development is knowing the bunch weight or berry weight to use in the algorithm. In examining many other yield components, the component that correlates the best with pre-harvest bunch weight is the number of berries per bunch and also the pre harvest berry weight (Appendices Tables 14 and 17).

Pre-Harvest Assessments

Previous sub-sections of this crop forecasting chapter have examined the assessment of yield component data at various stages of crop development and its associated value as a predictor of cropping level. This section aims to deal with the assessment of yield just prior to the actual harvest date. The assessment of yield at this stage is ideal because all the critical growth stages of crop development have occurred (bud burst, fruit-set, berry growth etc). However, the full potential of this estimate, in terms of grower and winery planning, may be not realised because of its proximity to the actual harvest date.

In theory, the assessment of yield per vine close to harvest (within a week), should provide a good estimate of actual vineyard yield. The yield estimate was calculated using the following equation;

$$\text{Yield estimate (T)} = \frac{\text{average yield/vine (kg)} \times \text{total number of vines/vineyard}}{1{,}000}$$

Generally, a more improved estimate of yield was obtained at this pre-harvest stage of assessment compared to MBC assessment (Appendices Tables 5 - 8). The yield assessment was compared to the reported yield and a percentage difference determined. Across different varieties, regions and seasons, the average percentage difference between the pre-harvest estimated yield and the reported yield was 15-29% overestimated. This overestimated figure may be due to harvest efficiency, because all vineyards being assessed by this project in Sunraysia and Coonawarra were machine-harvested. When you looked at absolute differences in yield (correcting for positive and negative values) we are generally overestimating by between 19 and 36%. However, it must also be noted that some vineyards may have been up to 101% overestimated and 31% underestimated in yield, even at this stage close to actual harvest (Appendices Tables 5 - 8). The reason for this again lies with the inherent variable nature of yield within the vineyards. The number of samples required to give estimates of mean yield within high confidence and acceptable error limits was much higher (generally 20-40 vines need to be assessed).

The use of the ratio method (May 1972) was also tested. Here the historical yield and predictor (bunch number or berry number) data are compared against each other using the following calculations;

$$\text{Yield estimate} = \frac{\text{Mean bunches/vine Year 2}}{\text{Mean bunches/vine Year 1}} \times \text{Yield in Year 1}$$

or;

$$\text{Yield estimate} = \frac{\text{Mean bunches/vine in current year}}{\text{Mean bunches/vine in previous years}} \times \text{Mean vineyard yield}$$

These calculations can only be applied in the second year of using a crop forecasting system. The first formula is applied in year 2 and the second formula is applied in the third and following years.

In applying these formula to yield predictions, we found that they could have more error associated with them in the first year of using them in comparison with using the previous method of estimating yield by picking, counting and weighing bunches just prior to harvest (Appendices Table 13). However, in the third year the percentage difference compared to the actual yield became quite low in comparison to using the formula in the first year, except for Sunraysia Shiraz (Appendices Table 13). This indicated that the use of the ratio method in calculating an estimate of cropping potential becomes very useful with time (> 3 years). The important things to remember are that accurate assessments of bunch or berry numbers are still required for this formula to work well and a dramatic change in vineyard management practice can upset the dynamics of this simple relationship. It doesn't take into account that bunch weight and berry weight vary between seasons in relation to bunch number and other environmental and cultural factors.

Finally, examining the data for Sunraysia the following relationships were observed when examining pre-harvest yield component information;

Chardonnay (all seasons)

1) Yield/vine = 6.0 + 0.04(bunch number/vine) $R^2 = 0.87$
2) Yield/vine = -4.15 + 0.05(bunch number/vine) + 0.11(berries/bunch) $R^2 = 0.89$
3) Yield/vine = -21.5 + 0.05(bunch number/vine) + 0.13(berries/bunch) + 14.9(berry weight) $R^2 = 0.95$

Shiraz (all seasons)

1) Yield/vine = 5.43 + 0.28(bunch number/vine) $R^2 = 0.53$
2) Yield/vine = -3.83 + 0.03(bunch number/vine) + 0.14(berries/bunch) $R^2 = 0.71$
3) Yield/vine = -10.4 + 0.03(bunch number/vine) + 0.12(berries/bunch) + 8.8 (berry weight) $R^2 = 0.71$

Cabernet Sauvignon (all seasons)

1) Yield/vine = 6.5 + 0.03(bunch number/vine) $R^2 = 0.40$
2) Yield/vine = -4.74 +0.05(bunch number/vine) + 0.15(berries/bunch) $R^2 = 0.50$
3) Yield/vine = -27.1 + 0.05(bunch number/vine) + 0.18(berries/bunch) + 20.5 (berry weight) $R^2 = 0.52$

These relationships show large differences in crop development across seasons and growers. They also identify key yield components which should be targeted for crop prediction. In the case of Chardonnay, bunch number alone accounted for 87% of the yield variation between seasons and growers. Although significant, inclusion of berries per bunch did not give a substantial improvement in accounting for Chardonnay yield variability. However inclusion of berry weight, enhanced the overall accuracy, such that the model accounted for 95% of the yield variation across growers and seasons. Similarly, for Shiraz, bunch number accounted for 53% of the yield variation across growers and seasons. There was a substantial improvement when berries per bunch was included, accounting for 71% of yield variation. However, berry weight was not a significant factor in the model. In the case of Cabernet Sauvignon, bunch numbers accounted for 40% of the yield variation between seasons and growers. Inclusion of berries per bunch and berry weight, which were not significant, did not improve the model.

From a crop prediction perspective these models results that an accurate estimate of bunch number is required for the three varieties. In the case of Chardonnay inclusion of berry weight values should enhance the accuracy of the prediction. For Shiraz an accurate estimate of berries per bunch will enhance the estimate based on bunch number. For Cabernet Sauvignon careful monitoring of all yield components both from season to season and for individual growers will be necessary because there were no consistent trends.

4.1.5 Implications and Recommendations

The experiences and results obtained during the three years of the "crop development, crop estimation and crop control to secure quality and production of Australia's major wine grape varieties: a national approach" have been invaluable to the development of a robust and reliable quantitative crop forecasting system. The major 'lessons' learnt during the past three years of the project can fall under the following sub-headings of; visual versus quantitative crop forecasting, knowing your vineyard, variation and forecasting accuracy, yield components and their changing nature, changing of vineyard management and regional crop forecasting.

Visual versus quantitative crop forecasting

Historically, most growers, winery liaison officers and winemakers have adopted a 'visual' approach to estimating the current seasons yield at different stages of development. While some people have been successful in using this method, there have been many examples of failure to accurately estimate cropping levels. In 1997, a survey of Chardonnay vineyards in the Sunraysia region was undertaken, where the grower was asked to estimate visually the yield of their vineyard. In the same year, a quantitative system of crop estimation was employed to compare with this visual estimate (Figure 4.1.8).

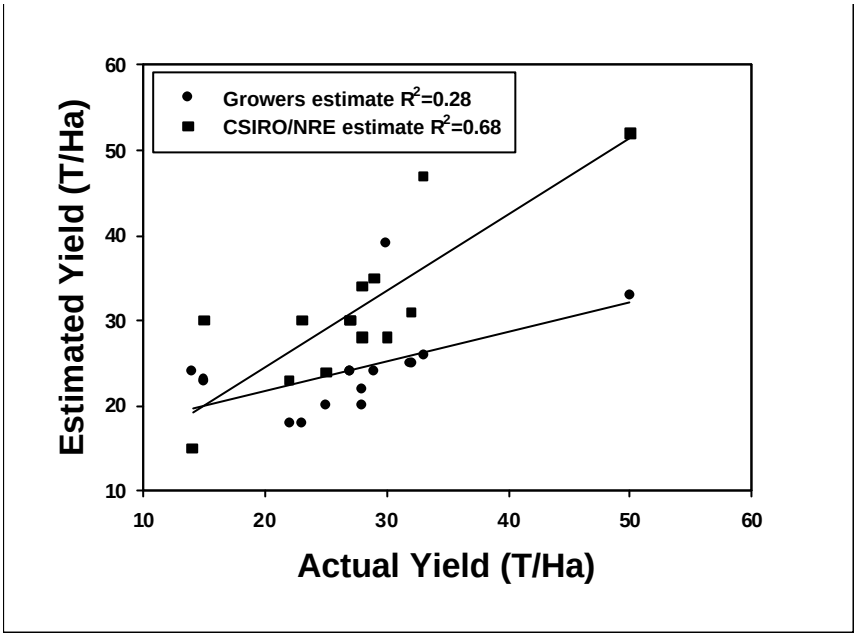


Figure 4.1.8 The comparison between the growers visual estimate (R^2=0.28) and the CSIRO/NRE estimate (R^2=0.68) and the actual vineyard yield (T/Ha). Results are for Sunraysia Chardonnay in the 1997 season.

Figure 4.1.8 highlights that the grower tends to predict close to the average and not to the extremes of production. This tendency to forecast close to average yields is naturally conservative.

Knowing your vineyard

During the first year of this research project, major discrepancies between actual production and forecasted production were observed in some of the experimental sites. This was a major concern for the crop forecasting project team. It wasn't until detailed vineyard surveys were conducted on each experimental/monitoring site that the problem was uncovered. Until then, the information about the vineyard planting details was obtained verbally from the grower. When the row spacing, vine spacing, planted area and total vine numbers were rechecked by conducting a detailed vineyard survey, major discrepancies between the growers information and actual planted information was observed. Often the area of the vineyard was under or over-estimated by between 20-30%. Many growers often include the 'headlands' in giving total area figure. We often double checked our vine counting methods with the SunLIS (Sunraysia regional GIS database) orthophotos to ensure our area calculations were correct.

Not only area there many legal implications in the buying and selling of real estate with vineyard area not correctly determined, but it is also a major source of error in any crop forecasting system. It is essential that the vineyard details, including row spacing, vine spacing, number of rows, number of vines in each row, the total number of vines in the vineyard and the total planted area (post-post) be determined/known accurately.

Variation and forecasting accuracy

The key to improving any quantitative crop forecasting system is having some knowledge of the variability in the vineyard (spatial and temporal variability). This means that appropriate sampling strategies can be designed and employed to deliver an estimate of a yield component within certain confidence and error limits. Given the large nature of variation in yield (%CV 20-80) and yield components (%CV 40-120) and the variable nature of variation itself, the need to understand and measure variation and sample appropriately on a vineyard by vineyard basis is essential. In most of the initial work, which was conducted at CSIRO Plant Industry and NRE – Mildura, 10 vines were assessed. This was selected as a level which growers would adopt. The assessment of 10 vines for the determination of average number of bunches per vine was, in hindsight, was low in terms of the numbers required to achieve a reliable and robust estimate of bunch number per vine for individual vineyards. The use of the sample numbers formu la;

$$n = \frac{t^2 \times CV^2}{PE^2}$$

Where: n = number of samples required, t = the t value from Students t tables, CV = the percentage coefficient of variation, PE = percentage error of from the mean for the desired estimate

The use of this formula allows for a sampling strategy to be utilised which can help deliver an estimate of a yield component within certain confidence and error limits. This is fully discussed in the Crop Forecasting (Greater Victoria) chapter (4.2).

Yield components and their changing nature

Initially at the commencement of this project, the rationale for experimentation was basically to obtain an estimate of a particular yield component and apply the appropriate equation using some basic some assumptions and produce a yield estimate. However, detailed analysis of crop development data revealed that this may be a little too simplistic.

In examining bud fruitfulness of Chardonnay, the number of bunches observed in spring was actually lower than that number observed during dormancy (SNC) assessments (Figure 4.1.6). While it was not observed in either Shiraz or Cabernet Sauvignon, this makes crop estimation at dormancy much harder for Chardonnay when some 'bunch loss factor' may need to be applied to take account of this variance. However, the differences observed in Chardonnay between dormancy and spring bunch number assessments appear to be quite seasonal (Figure 6), making the use of a 'bunch loss factor' difficult to apply without an understanding of the factors causing this phenomenon.

Secondly, the number of bunches observed in spring may have been significantly higher or lower than that observed just prior to harvest in all varieties and regions (Appendices Table 1 - 4). This loss or gain of bunches between MBC and harvest puzzled the project team for some time. The gain of bunches may have come about by some buds still bursting well after most other buds have already burst. For this reason it is recommended that bunch number assessment be conducted at least 5-6 weeks after the initial buds have burst. Alternatively, bunches are lost through factors such as pests and disease, bunch necrosis, shoot trimming etc. Given that bunch numbers may still vary between MBC and pre-harvest assessments, a 'bunch difference factor' (BDF) may need to be applied to account for this loss or gain of bunches during this time. In general, Coonawarra tended to have much higher BDF values (bunches gained between MBC and harvest) than Sunraysia (Appendices Table 1 - 4). Again a better understanding of the factors controlling these factors is more desirable for improving yield prediction.

Thirdly, the number of berries per bunch may have also changed between the 'pea size' stage of growth and just prior to harvest. This makes using the berry number method of predicting yield more difficult when berries are generally disappearing (Appendices Table 1 - 4). Again the use of a 'berry loss or difference factor' may help to account for yield components when balancing the budget, but at the end of the day a better understanding of the factors controlling these variables is more desirable.

Lastly, berry growth can also make life complicated when attempting to accurately forecast vine yield. This is particularly important in the variety Shiraz, where berry shrivel is a natural phenomenon. In some of the vineyards we monitored on a regular basis, berries could loose between 5 and 35% of their weight during the final four weeks leading up until harvest (Figure 4.1.9). In some of the Shiraz vineyards that there is a crop loss of approximately 1% per day, where berry shrivel has been severe. This indicated that harvest date also becomes important for yield prediction. While berry shrivel is most noticeable in Shiraz, it does occur to a lesser degree in both Chardonnay and Cabernet Sauvignon (Figure 4.1.9).

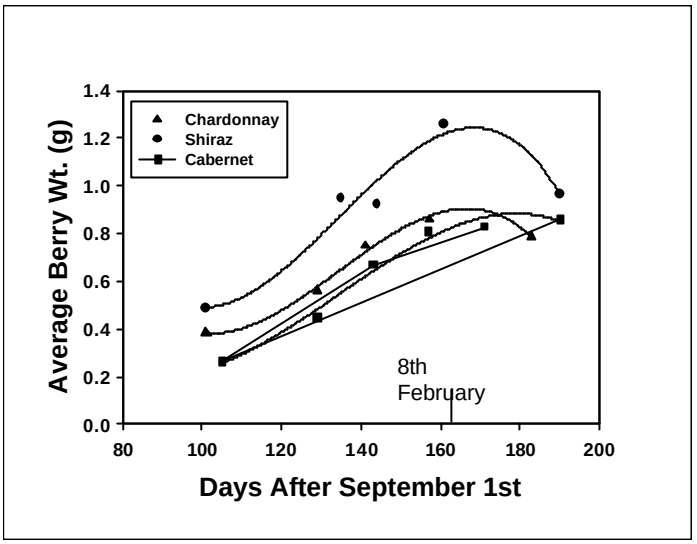


Figure 4.1.9 The change in average berry weight for Chardonnay, Shiraz and Cabernet Sauvignon in Sunraysia during the 1998 season.

Changing vineyard management systems

In the wine industry, growers are always looking for new ways of improving quality and/or profitability. As new cultural methods or technologies become available, growers may adopt these in search for either a time saving or an improved bottom line. The net effect of all this is that very few vineyards are actually maintaining a constant system of vineyard management. The implications for crop forecasting are obvious when considering that historical information is essential for the generation of the yield estimate. Therefore it is important to know the implications of the change in the vineyard management on the yield components.

Regional crop forecasting

While in some cases the accurate forecasting of yield on an individual vineyard basis may be suffice, the generation of a regional forecast is also extremely important. Regional estimates are required for knowing the tank storage capacity required for the current vintage, knowing if more space is required or if grapes need to be sourced from other regions to meet the shortfall in production. The problems with generating a regional estimate have been using accurate variety by area information to generate the regional estimate, especially when the area of young non-bearing and not fully bearing vines has increased exponentially over the last couple of years. Only a few of the larger wine grape growing regions (>50,000T) have actually done the surveys to give accurate information on the area by variety. Not only is it important to know this information accurately it is important to keep it updated on a regular basis.

To generate a reliable regional estimate it is essential to understand the level of variation that might exist between different sites within that region. While vineyard management system can have a huge effect on the final yield, comparing vineyards on a per metre of canopy basis (rather that on a per vine basis) can help reduce this variability. In our experience in the Murrumbidgee Irrigation Area (MIA), the assessment of at least 20 individual vineyards per variety can help to generate a accurate and reliable regional estimate for that variety.

Using historical bunch and berry weight data

To generate a yield estimate a quantitative assessment of either bunch or berry numbers can be made at various stages of crop development. The next step is to use an algorithm that utilises the known and quantitatively assessed data combined with an estimate of average bunch or berry weight. This is the real shortcoming of any

crop forecasting system at present. A lot of time and resources can be devoted to the determination of accurate bunch or berry number assessment, but unless a accurate harvest bunch weight or berry weight can be used in the yield calculation, the estimate will always contain more error.

This has been especially evident when trying to get growers involved with the crop forecasting system. To generate an estimate in year 1 you need to provide the growers with an estimate of the bunch or berry weight for that particular variety. After the first year the grower at least has some historical information of both bunch and berry weight data obtained off their particular vineyard. However, the variance observed between different growers and even between seasons (within the same vineyard) made this very difficult to reliably predict bunch and berry weight information for growers. One of the most important areas for future research is the development of systems that allow for accurate prediction of bunch weight and berry weight within a particular growing season.

4.1.6 References

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4.2 Crop Forecasting (Greater Victoria)

4.2.1 Introductory Technical Information

The Agriculture Victoria team at Tatura commenced work on crop forecasting at the beginning of the 97/98 season. The team's initial aim was to test System 1 in vineyards in Greater Victoria. The methods and formulae used in System 1 are described in detail in Crop Forecasting (Sunraysia and Coonawarra). To recap, System 1 specified a method to make forecasts at three stages during the season of growth preceding the vintage to be forecast. For cane or spur pruned vineyards, which are the norm in Greater Victoria, the formulae used to produce forecasts at the three stages were:

Stage 1 – One month after budburst

Weight/block = Vines/block x bunches/vine x weight/bunch

Stage 2 – After fruit set

Weight/block = Vines/block x bunches/vine x berries/bunch x weight/berry

Stage 3 – One week before harvest

Weight/block = Vines/block x weight/vine

Each of the components of these formulae can be classified as either a constant, an estimate of a mean derived from a sample of measurements of objects actually present in the vineyard, or a prediction of a mean at harvest (Table 4.2.1).

Table 4.2.1. Classification of yield components at the three crop forecasting stages specified in System 1 for cane and spur pruned vineyards.

Component type	Stage 1	Stage 2	Stage 3
Constant	vines/block	vines/block	vines/block
Estimate of mean (by sampling)	bunches/vine	bunches/vine berries/bunch	weight/vine
Prediction of mean	weight/bunch	weight/berry	-

There are two general factors that can affect the accuracy of forecasts:

1. The reliability of the methods used to produce the numerical inputs to each formula
2. The structures of the forecasting formulae

This suggested a need for four general lines of research and development to be pursued:

1. Development of a reliable block survey system
2. Development and improvement of measurement techniques
3. Development and improvement of prediction techniques
4. Identification of components that, if included in formulae, would improve forecasts

These lines of research and development were pursued during the 97/98, 98/99 and 99/00 seasons. The outcome was System 2, which formed the basis for a crop forecasting kit that was disseminated to growers towards the end of the project and in the period between its end and the completion of this report. This is available in manual or computerised versions.

In addition, the potential of the technique of forcing single-node cuttings during winter dormancy as a forecasting tool was evaluated.

4.2.2 Definitions

Segment

In System 1 a 'transect' was defined as a 20 cm wide cross-section or 'slice' of a vine row. In our sections of this report we use the term 'segment' rather than 'transect' to refer to the 'slice' of vine row in which measurements are made. We felt that the term 'transect' had an established meaning in biological research that differed from the meaning intended within the context of grape crop forecasting. 'Transect' means a line across an area, as in the following definition: "Line of belt of vegetation selected for charting plants; designed to study changes in composition of vegetation across a particular area" (The Penguin Dictionary of Biology). We preferred the term 'segment' because we felt that it more accurately conveyed the meaning intended. 'Segment' has been defined as: "one of the parts into which anything naturally separates or is naturally divided; a division or section" (The Macquarie Concise Dictionary, 1988) and synonyms include section, part, division, portion, component, element, piece, fraction, fragment, length, and slice (Urdang, 1991).

Coefficient of Doubt and Tolerance of Doubt

The formulae used for forecasting grape crops require the input of estimates of means derived from a sample of a limited number (n) of measurements made in a vineyard. Conventionally, the variation within a sample is described by a standard deviation (s), which is the square root of the sample variance. The variation of different samples can be compared using a Coefficient of Variation (CV), which is the ratio of the standard deviation to the mean expressed as a percentage. The error around the estimate of the sample mean is conventionally described by a standard error (s.e.) of the mean, which is calculated using the formula $s/\sqrt{n}$. The reliability of the sample mean as an estimator of the true population mean is described by a 95% confidence interval, which is calculated using the formula $t_{(p,d.f.)} \times s.e.$, where t is an appropriate value from Student's t-distribution, p is the probability that the true population mean will lie outside the confidence interval and d.f. are n-1 degrees of freedom.

Wolpert and Vilas (1992) used the term 'Percentage Error' to describe the ratio of the confidence interval to the mean expressed as a percentage, which can enable comparison of the reliability of sample means as estimators of true population means. The concept is analogous to the Coefficient of Variation, in that both are denominated by the mean. We have some reservations about using the term 'Percentage Error'. Following the precedent established by the conventional and widely-used term 'Coefficient of Variation', the formula used to calculate 'Percentage Error' would suggest that it could be called 'Coefficient of Error'. However, given that the Coefficient of Variation is derived from a division of the standard deviation by the mean, a claim on the term 'Coefficient of Error' could be made for a quantity obtained by a division of the standard error by the mean. A division of the 95% confidence interval by the mean might, in accordance with precedent, be called a 'Coefficient of Confidence'. However, the use of such a term could induce some puzzlement. One might reasonably assume that an increasing quantity for a Coefficient of Confidence would describe increasing confidence in the sample mean as an estimator of the true population mean. However, an increasing ratio of the 95% confidence interval to the mean would actually mean that the reliability of the sample mean as an estimator of the true population mean is deceasing. Rather than describing confidence, such a coefficient describes some concept that we feel is best named 'doubt'. Therefore, we propose that the term 'Coefficient of Doubt' should be used to refer to the ratio of the 95% confidence interval to the mean expressed as a percentage. We have adopted this proposal in this report. The derivation of this concept is summarised in Table 4.2.2.

Table 4.2.2. Summary of existing and proposed terms for coefficients describing the ratio of a standard deviation, standard error and 95% confidence interval to a mean.

Statistic	Symbol	Formula	Term for ratio of statistic to the mean
Standard deviation	s	$\sqrt{}$ variance	Coefficient of Variation
Standard error	s.e.	$s / \sqrt{n}$	Coefficient of Error?
95% confidence interval	-	$t_{(0.05,n-1)} \times s.e.$	Coefficient of Doubt

4.2.3 Research Methodology

Analysis of grower forecasting behaviour and performance

Data were obtained from a Victorian winery, which crushed 11,600 tonnes in the 2000 vintage. The winery nominated an experienced grower to represent growers in general and provided records of his forecast and actual deliveries per variety for the vintages from 1996 to 1999. The winery also provided records of forecast and actual deliveries for all their growers in the 2000 vintage. There were 204 forecasts, aggregated at a grower x variety level, from 63 growers for 41 varieties. The forecasts were given to the winery during January and the grapes were received from early February until late April. Various aspects of forecasting behaviour were analysed using standard statistical methods.

Measurement of yield components

Yield components were measured at the stages defined in Table 4.2.3 in the 97/98, 98/99 and 99/00 seasons in selected blocks of Cabernet Sauvignon, Chardonnay and Shiraz. For brevity, the codes shown in Table 4.2.4 are used to refer to these varieties in this report. The selected blocks were located in representative commercial vineyards throughout Victoria (Figure 4.2.1,
Table 4.2.5, Table 4.2.6).

Table 4.2.3. Stages at which yield components were measured within each season.

Stage	Timing
0	During winter dormancy
1	About a month after budburst
2	About a month after fruit set
3	In the week before harvest

Table 4.2.4. Codes used to identify the varieties studied.

Variety	Code
Cabernet Sauvignon	Ca
Chardonnay	Ch
Shiraz	Sh

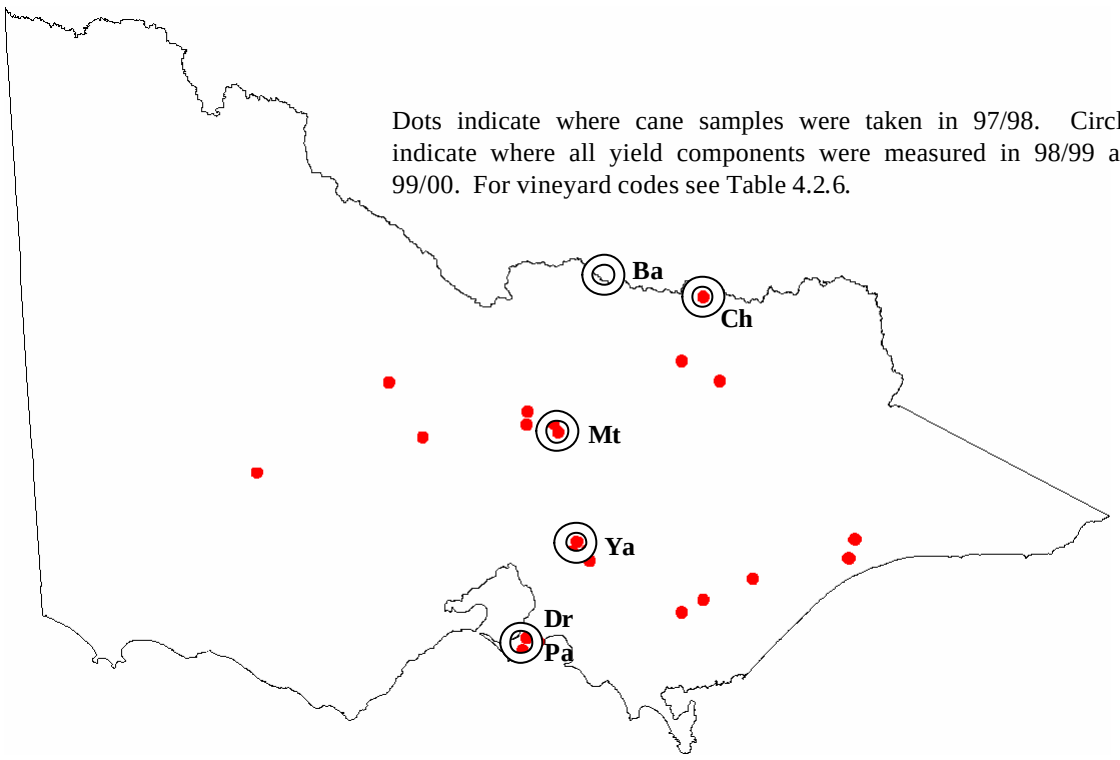


Figure 4.2.1 Locations of vineyards in Victoria in which samples were taken for measurement of yield components in the 97/98, 98/99 and 99/00 seasons.

Table 4.2.5. Details of vineyards in which yield components were measured in 97/98 only.

Vineyard	Owner	Address	Varieties
Baileys	Hilton, Ron & Ken Bailey	Merriang South Rd, Merriang 3737	Ca, Ch, Sh
Blackjack	Blackjack Wines Pty Ltd	Calder Highway, Harcourt 3453	Ca, Sh
Briarston	Southcorp Wines Pty Ltd	Briarty Rd, Gruyere 3770	Ca, Ch
Brown Brothers Milawa	Brown Bothers Milawa Vineyard Pty Ltd	Milawa 3678	Ca, Sh
Chateau Tahbilk	Tahbilk Pty Ltd	Tabilk 3608	Ca, Ch, Sh
Coalville	Mair's Wines	RMB 4750, Moe South Rd, Moe, 3825	Ca
Lusatia Park	Shelmerdine Vineyards Pty Ltd	Owens Rd, Woori Yallock, 3139.	Ca
Mitchelton	Mitchelton Wines Pty Ltd	Mitchellstown 3608	Ca, Sh
Narkoojee	Harry & Val Friend	RMB 1110, Francis Rd, Glengarry 3854	Ca
Nicholson River	Ken Eckersley	Liddell's Rd, Nicholson 3882	Ca, Ch
Plunketts Whitegate	Warrumbungle Pty Ltd	Tarcombe Rd Tarcombe 3664	Ca, Sh
Red Hill Estate	Sir Peter Derham	53 Red Hill – Shoreham Rd, Red Hill South 3937	Ch
Sarsfield Heights	Susanne Rutschmann, Peter Albrecht	RMB 8759, Sarsfield 3875	Ca, Sh
Seppelts Great Western	Southcorp Wines Pty Ltd	Moyston Rd, Great Western 3377	Ca, Ch, Sh
Stoniers	Stonier Yuill Hamson & Limb Pty Ltd	362 Frankston-Flinders Rd, Merricks, 3196.	Ca
Wa-de-Lock	Graeme Little	Stratford Rd, Maffra, 3860	Ca
Water Wheel	Peter Cumming	Raywood Rd Bridgewater-on-Loddon 3516	Ca, Sh

Table 4.2.6. Details of vineyards in which yield components were measured in 97/98 - 99/00.

Code	Vineyard	Owner	Address	Varieties
Ba	Tarn Pirr and Windarra	Southcorp Wines	Barooga-Mulwala Rd, Barooga, 3644	Ca, Ch, Sh
Ch	Lakeside	Peter Chambers	Moodemere Rd, Rutherglen 3685	Ca, Ch, Sh
Dr	Dromana Estate	Zummer Pty Ltd	Harrisons Rd, Dromana 3936	Ca[1], Ch[1]
Mt	Mt Helen	Mildara-Blass, Norman Brothers	Upton Rd Tarcombe 3664	Ca, Ch, Sh
Pa	Paringa Estate	Lindsay McCall	44 Paringa Rd, Red Hill South, 3937	Ca[2], Ch[2], Sh
Ya	Yarra Ridge	Mildara-Blass	Glenview Rd, Yarra Glen, 3775	Ca, Ch

[1]Not measured in 97/98. [2]Not measured in 98/99 and 99/00.

Climatic profiles for each of the vineyards in which yield components were measured in 98/99 and 99/00 are presented in Figure 4.2.2 to Figure 4.2.6 and Table 4.2.7.

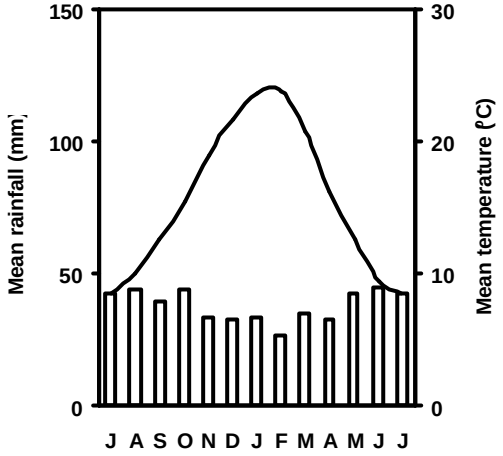


Figure 4.2.2. Seasonal patterns of rainfall and temperature at Tocumwal.

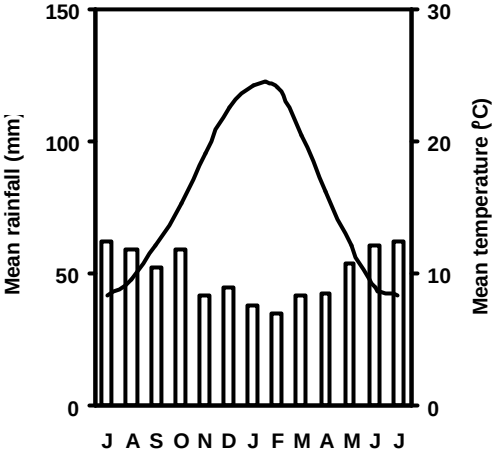


Figure 4.2.3. Seasonal patterns of rainfall and temperature at Rutherglen.

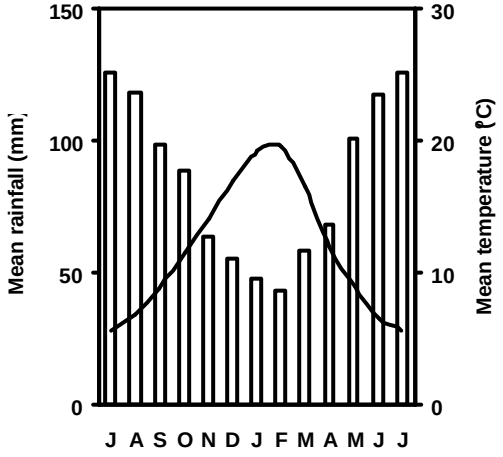


Figure 4.2.4. Seasonal patterns of rainfall and temperature at Strathbogie.

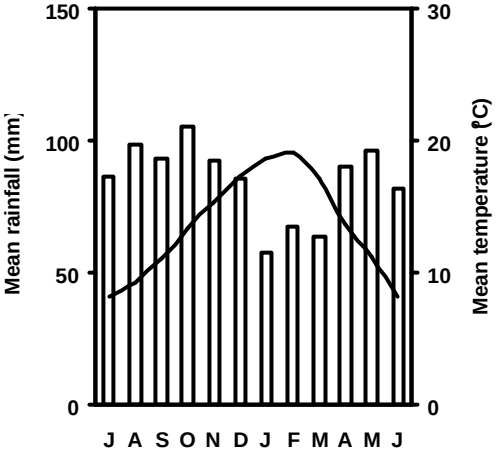


Figure 4.2.5. Seasonal patterns of rainfall and temperature at Healesville.

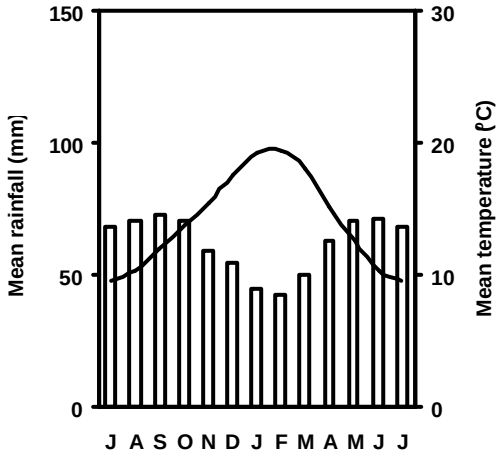


Figure 4.2.6. Seasonal patterns of rainfall and temperature at Mornington.

In Figure 4.2.2 to Figure 4.2.6 the line represents mean monthly temperature and the columns represent mean monthly rainfall.

Table 4.2.7. Bureau of Meteorology stations representing climates of vineyards in Greater Victoria studied in 98/99 and 99/00, with Mean January Temperatures (MJT) and Growing Degree Days (GDD).

Vyd	Station	MJT	GDD
Ba	Tocumwal	23.7	2140
Ch	Rutherglen	24.2	2179
Mt	Strathbogie	19.2	1199
Ya	Healesville	18.6	1345
Dr, Pa	Mornington	19.2	1474

For vineyard identities see Table 4.2.6. GDD were calculated in °C with a base temperature of 10°C for October to April inclusive.

1997/98 season

At Stage 0 in 1997, 1 cane was sampled from each of 10 vines that were selected capriciously within each of the blocks in Table 4.2.5. These vines were tagged and their row-vine address within the block was recorded. The canes were stored in plastic bags containing some water at approximately 4°C. The nodes on each cane were numbered in ascending acropetal order and the lowest 14 were divided into single-node cuttings. Each single node cutting was placed vertically with the wood below the bud in moist sand. Each bud was painted with a solution of Dormex. The cuttings were held constantly at 20°C under NEC Biolux BR fluorescent tubes. Each cutting was monitored daily for budburst, which was defined as the time when the serrated edge of a leaf was first visible. This corresponds with modified Eichorn and Lorenz stage 04 (Coombe 1995). Each cutting was measured 14 days after budburst. The measurements were: cutting length, cutting diameter, shoot length, shoot diameter, number of bunches, and the fresh weight of each bunch. Statistics were calculated for each block, particularly mean shoots/node and bunches/node for each node position along the cane.

At Stage 1 in 1997, a modified Merbein Bunch Count (based on Antcliff et al 1972) was done for each vine from which canes were sampled at Stage 0 in 22 of the 42 blocks from which cane samples were taken. Statistics for each block were calculated, particularly mean bunches/vine.

At Stage 2 in 1998 Ca, Ch and Sh blocks at two vineyards were studied intensively. The vineyards were Paringa Estate, in a cool climate at Red Hill on the Mornington Peninsula, and Chambers near Rutherglen, with a growing degree day sum approximately midway between Red Hill and Mildura, where the CSIRO / Agriculture Victoria team were conducting a parallel research program. In each block 30 vines were selected randomly. A counting frame with vertical cords spaced at 20 cm intervals was suspended parallel to the row direction from a foliage wire near the top of the canopy. The first cord was aligned with the vine trunk. One of the halves of the vine extending away from the trunk along the row was selected randomly and spanned by the rest of the counting frame. All the bunches at any height in each segment between the vertical cords were counted and statistics were calculated for a range of multiples of 20 cm. In addition, a segment was selected randomly from within each half vine. At 20 of the vines a position within the segment was selected randomly and the nearest bunch was removed. At the remaining 10 vines all the bunches within the segment were removed. The bunches were placed in sealed plastic bags in the vineyard and frozen. Later the berries were removed from each bunch and counted using various manual and mechanical techniques. Statistics were calculated and the estimates of mean berries/bunch obtained from individual bunch samples and whole segment samples were compared.

At Stage 3 in 1998 the 10 vines that were measured in each block at Stage 1 were picked. The bunches picked from each vine were counted and weighed, and 1 bunch was randomly sampled from each vine for later analysis. In the 6 blocks that were intensively studied at Stage 2, in addition to the 10 vines measured at Stage 1, 20 more of the vines not sampled at Stage 2 were selected randomly. The bunches on each of the 30 vines were picked, counted and weighed as in the other blocks. From the 10 vines measured at Stage 2 and 10 of the other vines a single bunch was sampled randomly. From the remaining 10 vines 10 bunches were sampled randomly. In addition 3 blocks (Ca, Ch and Sh) in the Southcorp vineyards at Barooga were measured. In each of these blocks 20 vines were selected randomly. The bunches on each vine were picked, counted and weighed as in the other blocks. From 10 of these vines a single bunch was sampled randomly. From the remaining 10 vines 10 bunches were sampled randomly. Each sampled bunch was placed in a plastic bag in the vineyard and stored in a refrigerator. Within a week each bunch was weighed and its berries were removed, counted and weighed. Compositional analyses were also undertaken. Statistics for each block were calculated including mean weight/vine, bunches/vine, weight/bunch, berries/bunch and weight/berry.

1998/99 season

At Stage 0 in 1998 canes were sampled from the blocks identified in Table 4.2.6. In each block 20 vines and a position within each vine were selected randomly. The cane with its base nearest to each position was removed and stored as in 97/98. For each block 15 of the 20 sampled canes were selected randomly and set as in 97/98, except that they were held at 27°C rather than 20°C. The number of bunches on each shoot was measured 14 days after budburst and means of shoots/node and bunches/node were calculated for each node position.

For all measurements after budburst in 1998 in both the 98/99 and 99/00 seasons a new set of sampling locations within each block was selected at each Stage. In each case the 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) (modified from Wolpert and Vilas, 1992). Coefficients of Variation were derived from previous measurements.

The standard Tolerance of Doubt was 15%. A 95% level of confidence was sought, and it was considered sufficient to assume that t=2.

At Stage 1 in 1998, in each block measured at Stage 0, vines and a position within each vine were selected randomly (BSS derived from 97/98 CVs). A 60 cm wide segment frame (Figure 4.2.7) was placed at each selected position. All the bunches at any height within the canopy and within the vertical cords of the frame were counted. A bunch was counted only if the base of its stalk was between the cords. A bunch was defined as a stalk with one or more flowers on it. Mean bunches/segment was calculated for each block. In addition, Merbein Bunch Counts were done on 10 of the vines selected for segment bunch counts in a subset of blocks, and statistics were calculated as in 97/98.

At Stage 2 in 1999, vines and spots within each vine were selected as at Stage 1 (BSS derived from 97/98 CVs). At 10 locations 10 bunches were removed. At the remaining locations a single bunch was removed. All bunches were stored and measured as in 97/98.

At Stage 3 in 1999, vines and spots within each vine were selected as at Stages 1 and 2 (BSS derived from CVs in 97/98 and 98/99). A single bunch was sampled at each location within each block. At a subset of these locations a segment frame was placed, bunches in the segment were counted as they were picked and the fruit from the segment was weighed. From 10 of the segments 10 bunches were sampled. The sampled bunches were stored and measured as at Stage 3 in 1998.

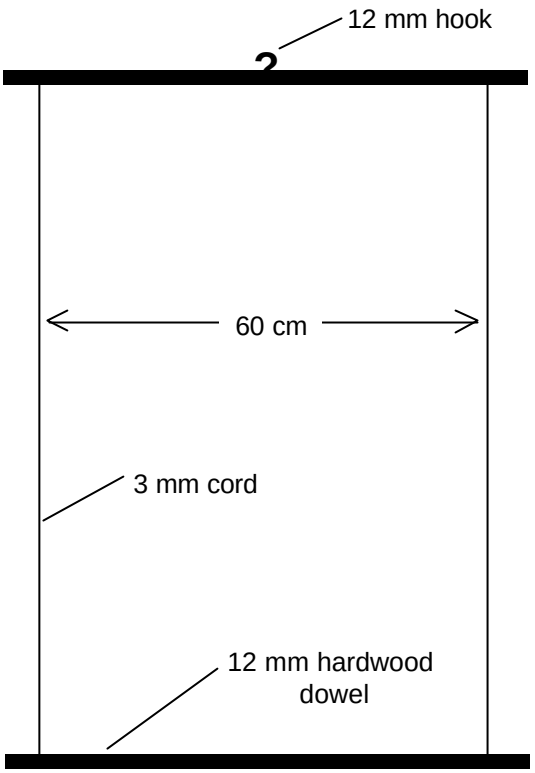


Figure 4.2.7 Segment frame used at Stages 1 and 3 in the 98/99 and 99/00 seasons.

From flowering until harvest in 98/99, 20 bunches were sampled at weekly intervals in the Ya Ch, Dr Ca and Dr Ch blocks. The bunches were selected as at Stage 2. The volume of each bunch was measured *in situ* by displacement, then it was removed for measurements of the volume, dimensions, fresh weight and dry weight of the berries and rachis in the laboratory. From veraison the soluble solid concentration of the juice from each bunch was measured with a refractometer. Patterns of bunch development over time were charted and analysed, with a view to predicting bunch size at harvest.

1999/2000 season

At Stage 0 in 1999, 40 canes were selected randomly from each of the blocks studied in 98/99. Of these 20 were randomly selected. The compound buds (eyes) at the lower 14 nodes of these canes were dissected under a microscope. The condition of each true bud within each 'eye' was assessed and the number of visible inflorescence primordia in each true bud was counted. Statistics for each block were calculated, particularly predictions of shoots/node and bunches/node.

All measurements at Stages 1 and 3 in 99/00 were made as in 98/99. The measurement process was the same at Stage 2 except that an attempt was made to synchronise sampling with the onset of veraison in each block and weight/bunch was measured in addition to berries/bunch.

Block surveys

For each block studied in 98/99 and 99/00 the following information was obtained: identification numbers of the rows in the block, the number of vines in each row, row spacing, vine spacing. The growers provided any available information and research staff also surveyed the block.

Forecasts

In 97/98 no forecasts were attempted except at Stage 3, when the System 1 formula were used.

In 98/99, forecasts were made at Stages 1, 2 and 3 for the blocks in Table 4.2.6, based on measurements of components in the current season and means derived from measurements made at Stage 3 in 97/98. A Harvest Efficiency Factor was added to the System 1 formulae (see Detailed Results).

In 99/00, forecasts were made at Stages 1, 2 and 3 for the same blocks as in 98/99, based on measurements of components in the current season and means of components measured at Stage 3 in 97/98 and 98/99. A Bunch Gain Factor and a Berry Loss Factor were added to the formulae used in 98/99, and alternative methods of forecasting at Stage 2 and 3 were added (see Detailed Results). The system developed by the end of 99/00 was also used to make revised forecasts for 98/99.

Evaluations of performance

The performances of System 1 and System 2 were assessed by comparing the forecasts made for each block at each stage with records of actual deliveries provided by the growers. In each case the absolute difference between the forecast and actual delivery was calculated and expressed as a percentage of the actual delivery. For each System the mean difference and the mean absolute difference over all blocks were calculated for each stage in 98/99 and 99/00.

Analysis of sources of inaccuracy

Statistical methods were developed to test for significant differences between predicted values of yield components at harvest and the actual values. Three general classes of test were discriminated:

Detection of a difference between the sample mean of a yield component at Stage 1 or 2 and the sample mean of the same yield component at Stage 3

Cases: a sample mean of bunches/segment at Stage 1 compared with Stage 3, a sample mean of berries/bunch at Stage 2 compared with Stage 3. A two-sample t-test, with a significance level of $p=0.05$, was used to detect a significant difference between a Stage 1 or 2 sample mean and a Stage 3 sample mean. If the means were significantly different the actual value at harvest was considered to be different from the predicted value.

Detection of a difference between a guess at the value of a yield component at harvest (usually based on historical records) and the actual value

Cases: a prediction of harvest weight/bunch at Stage 1 compared with a sample mean of weight/bunch at Stage 3, a prediction of harvest weight/berry compared with a sample mean of weight/berry at Stage 3, a prediction of Harvest Efficiency Factor (see Detailed Results) at Stages 1 and 2 compared with the ratio of actual delivery to the estimate of fruit present in a block at Stage 3. If a predicted value was outside the 95% confidence interval of a Stage 3 sample mean, then the actual value at harvest was considered to be different from the predicted value.

Detection of a difference between a guess at the ratio of the value of a yield component at an earlier stage to its value at harvest and the actual ratio

Cases: a prediction of a Bunch Gain Factor compared with an actual Bunch Gain Factor, a prediction of a Berry Loss Factor compared with an actual Berry Loss Factor, a prediction of a Weight Gain Factor compared with an actual Weight Gain Factor (for explanations of these factors, see Detailed Results). If a predicted value was outside the 95% confidence interval of a ratio of a sample mean at Stage 1 or 2 to a sample mean at Stage 3, then the actual ratio was considered to be different from the predicted value.

The data used to make forecasts at each Stage for each block were analysed to detect incidences of these sources of inaccuracy in 98/99 and 99/00.

4.2.4 Detailed Results

Analysis of grower forecasting behaviour

The sum of all the forecasts made by the representative grower in each year remained close to the mean production of the vineyard for the 1996-99 vintages (Figure 4.2.8). The sum of his forecasts over the four vintages was only 7% less than the sum of the actual vineyard production. However, the sum of the absolute differences between each forecast and actual delivery was 1,052 tonnes (Table 4.2.8). The annual mean absolute difference ranged from 25% to 40% of actual production and the grand mean for the four years was 33%. This suggested that the representative grower had a good feeling for the mean long term behaviour of his vineyard but had difficulty forecasting the direction and scale of the annual deviations of each varietal block.

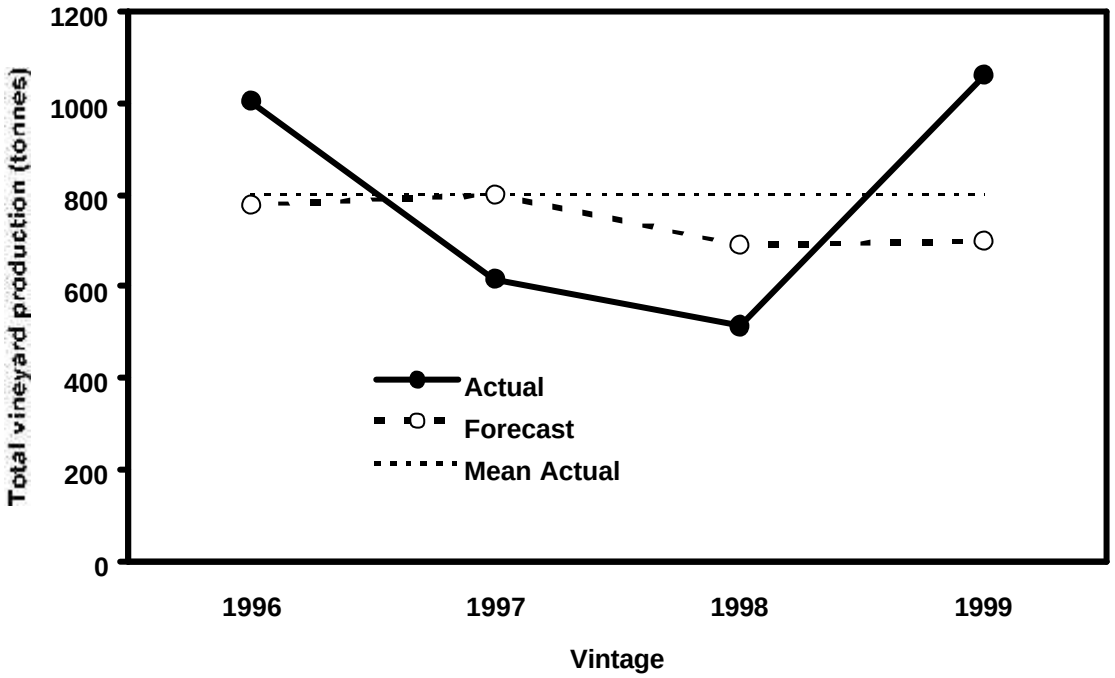


Figure 4.2.8. Actual and forecast production from a vineyard over a four year period.

Table 4.2.8. Summary of a typical grower's forecasting performance over four years.

	Vintage				
	1996	**1997**	**1998**	**1999**	**Total for 4 years**
Total actual vineyard production (t)	1005	616	514	1062	3197
Sum of absolute differences per forecast (t)	250	218	207	377	1052
Mean absolute difference (% of actual)	25	35	40	35	33

On a year by year, block by block basis, the grower did not vary his estimates sufficiently from the mean. This resulted in a consistent overestimation of production in low-cropping years and a larger underestimation in high-cropping years (Figure 4.2.9). Our conclusion that his forecasting performance was inhibited by failure to forecast the direction and scale of the annual deviations of each varietal block was further supported by the observation that his performance was worse in blocks where production was more variable over time (Figure 4.2.10).

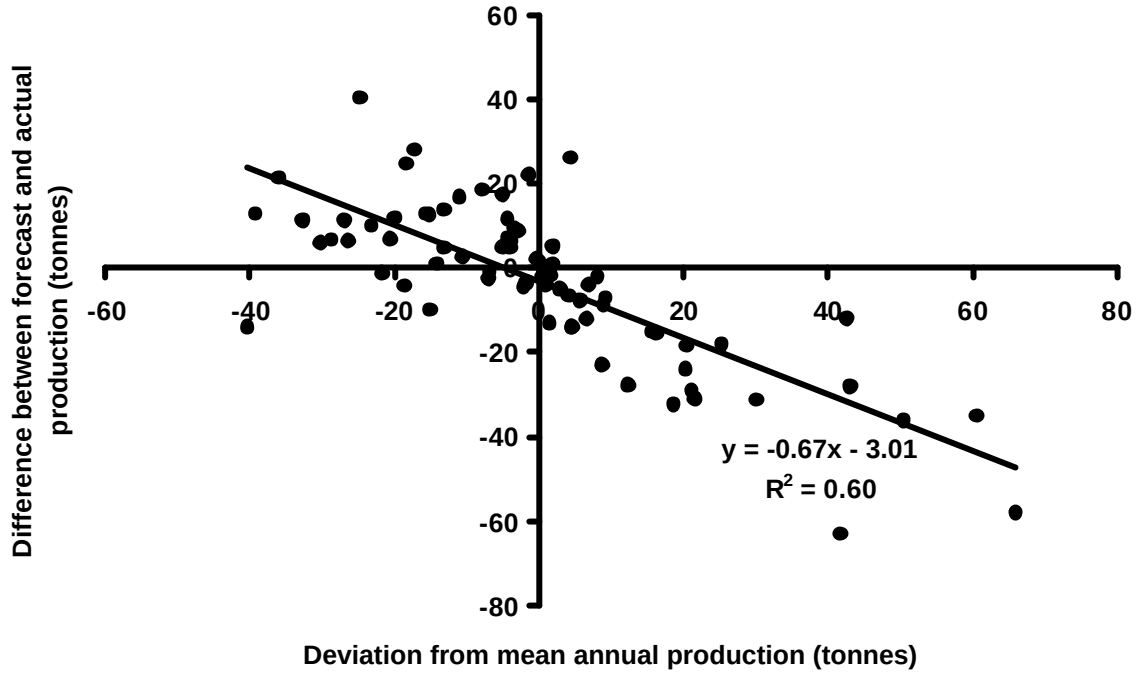


Figure 4.2.9. Relationship of difference between forecast and actual production to actual annual deviation.

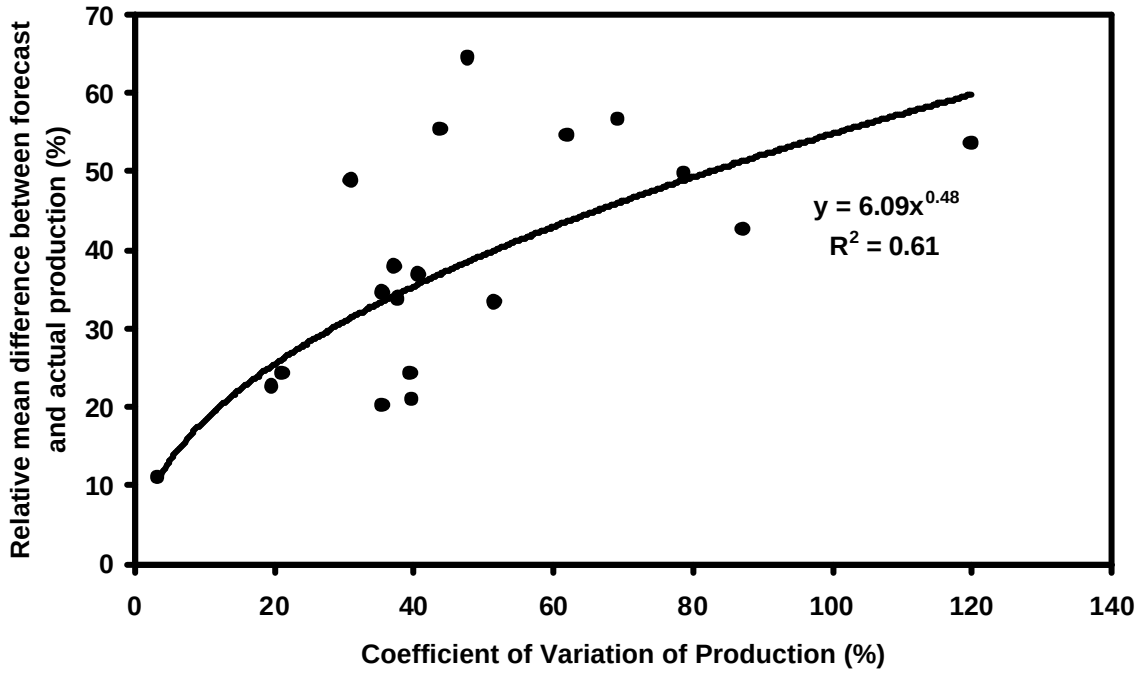


Figure 4.2.10. Relationship of forecasting performance to block variability over time.

Performance of growers in the 2000 vintage

A statistical survey of the forecasting methods used by growers was not attempted, but the winery from which performance data was obtained for the 2000 vintage indicated that the most common method is reference to historical means with adjustment based on subjective assessment by visual inspection. This was confirmed by *ad hoc* interviews of growers over the life of the project.

The sum of all the forecasts provided to the winery was only 6% more than the sum of the actual deliveries (Table 4.2.9). However, the sum of the absolute differences was 2,433 tonnes, and the mean proportional absolute difference was 33% of the total actual delivery.

Of all the forecasts provided to the winery, 81% were less than 45% out (Figure 4.2.11). However, the proportional absolute differences of the remaining 19% ranged from 46% to 228%. The mean absolute difference was greater than the median (Table 4.2.9), indicating that a minority of very inaccurate forecasts had a disproportionately large influence on overall performance.

Table 4.2.9. Summary of forecasting performance of growers for a winery in the 2000 vintage.

Number of growers	63
Number of varieties	41
Number of forecasts	204
Total actual delivery (t)	11,604
Total forecast delivery (t)	12,247
Aggregate difference (t)	643
Proportional difference (% of actual)	6
Sum of absolute differences (t)	2,433
Mean absolute difference (% of actual)	33
Median absolute diff. (% of actual)	21

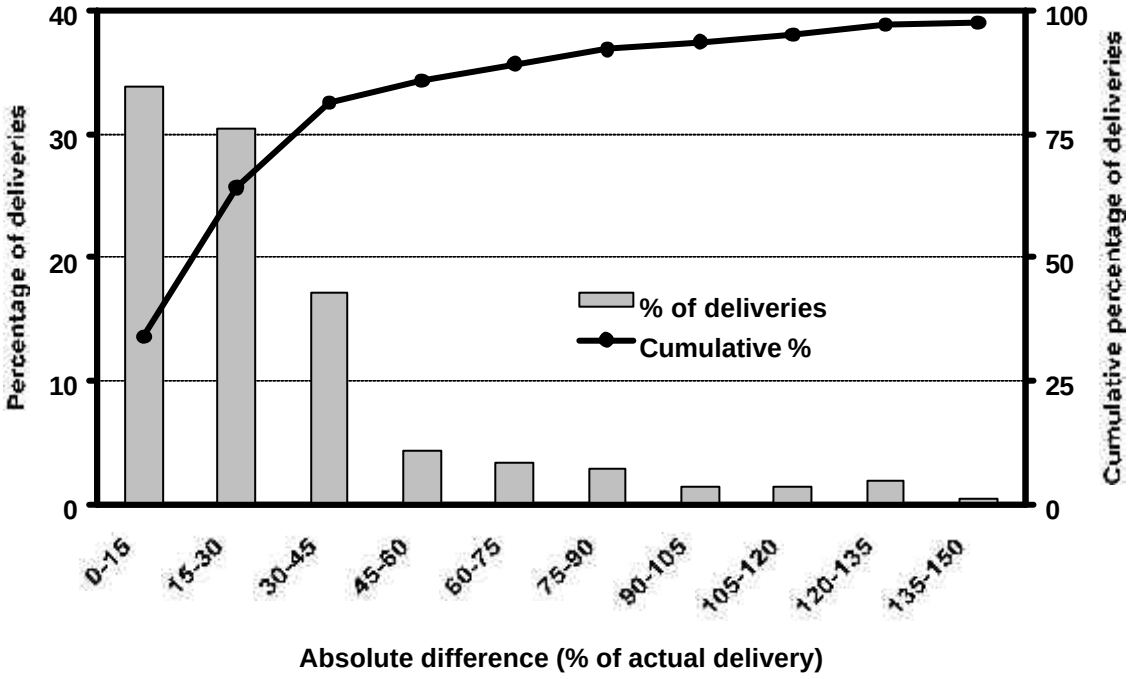


Figure 4.2.11. Distribution of absolute differences between 199 forecast and actual deliveries to a Victorian winery in the 2000 vintage (excluding 5 absolute differences greater than 150%).

Records of the forecasts supplied to the winery were available for 2000 only, and the representative vineyard manager left after 1999, so a direct comparison was not possible. However, according to the winery, his method of forecasting was typical of their growers in general. Also, the mean absolute difference that the growers achieved in 2000 was the same as the vineyard manager achieved from 1996 to 1999 (33%). Consequently we concluded that his behaviour and performance could indeed be regarded as representing a typical grower, and that currently in Victoria the difference between forecast and actual delivery to wineries is in the order of ±33% of the actual delivery.

Factors that affect accuracy and efficiency of measurement-based forecasting

The essential difference between the forecasting systems evaluated in this report and the forecasting methods commonly used by growers at present is that the former are based on objective measurements of crop components in the season leading up to the delivery to the winery, rather than reference to historical means with adjustments based on subjective visual assessment. In principle, objective measurement-based systems should avoid a tendency to underestimate annual deviations from the mean production of blocks of vines. Therefore, the Industry could expect a general improvement in the performance of forecasters if measurement-based systems were to be broadly adopted. However, forecasts produced by measurement-based systems can never be perfectly accurate because they are dependant on formulae and measurement techniques that incorporate some error. In order to develop and continually improve a forecasting system that can be adopted with confidence by the Industry it is necessary to understand the factors that determine its performance. In this section, results are presented that highlight factors that we found had important effects on the accuracy of measurement-based forecasts during the 3-year experimental period.

Knowledge of block

In many cases the information provided by growers came from their memories. Where there were written records, they were often sketchy and sometimes incorrect. Measurement-based forecasting relies on the accuracy of such records. In the sample of 14 blocks that we studied we detected a number of instances where grower beliefs or records were inaccurate or non-existent (Table 4.2.10).

Table 4.2.10. Summary of grower knowledge of blocks studied in 98/99 and 99/00.

Vineyard	Variety	Rows in block	Vines in Each row	Row spacing	Vine spacing	Block area
Barooga	Cabernet S.	✓	×	✓	✓	?
	Chardonnay	✓	×	✓	✓	?
	Shiraz	✓	×	✓	✓	?
Chambers	Cabernet S.	✓	✓	✓	✓	✓
	Chardonnay	✓	✓	✓	✓	✓
	Shiraz	✓	✓	✓	✓	✓
Dromana Estate	Cabernet S.	✓	×	✓	✓	×
	Chardonnay	✓	×	✓	✓	?
Mt Helen	Cabernet S.	×	×	✓	✓	×
	Chardonnay	✓	×	✓	✓	×
	Shiraz	×	×	✓	✓	×
Paringa Estate	Shiraz	✓	×	✓	✓	?
Yarra Ridge	Cabernet	✓	×	✓	✓	×
	Chardonnay	✓	×	✓	✓	×

✓ known and accurate. × not known or inaccurate. ? Grower knowledge uncertain.

It is understandable that growers may not have accurate knowledge or records of factors particular to crop forecasting that they had no need to know previously. However, beliefs about some quite fundamental pieces of information were sometimes surprisingly inaccurate, with potentially important implications. For example, misinformation about which rows are in a block could lead to harvesting mix ups. Where records of the area of a block are inaccurate, estimates of unit yield could be incorrect, perhaps leading to erroneous conclusions about the relationship between yield and compositional quality.

Variation, doubt and sample size

It would be impractical to measure the entire population of bunches or berries in vineyard blocks. Consequently, a sample mean is used in forecasting calculations. The reliability of a sample mean as an estimator of the true population mean is described by its Coefficient of Doubt (CD, see Definitions).

The CD is dependant on the intrinsic variation of the measurements and the sample size. Variation is determined by the population, and cannot be controlled by the forecaster, but the forecaster can reduce the CD (and improve the reliability of forecasts) by increasing the sample size (Figure 4.2.12, which assumes CV=44%). However, increasing sample sizes increases the cost of sampling. At some point the extra cost of increased sample size may outweigh the extra benefit, so it would be desirable to be able to calculate a Best Sample Size (BSS). This can be done using the formula $BSS = t^2 (CV^2 / TD^2)$, where 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 CD that will be tolerated) (modified from Wolpert and Vilas, 1992). In practice it is usually sufficient to assume that t=2.

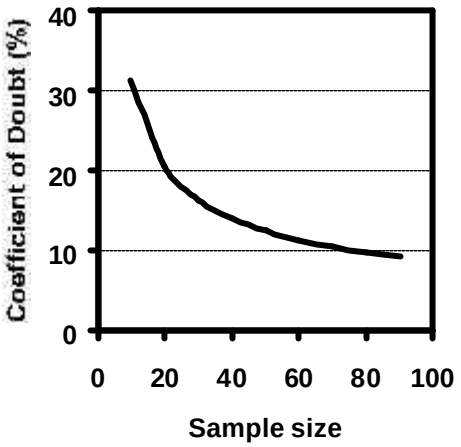


Figure 4.2.12. Example of the effect of sample size on Coefficient of Doubt.

CVs for all components measured in all blocks studied are tabulated in the Appendices. CVs varied with yield component, block and season. Indicative values are summarised in Table 4.2.11and Dunn and Martin (1998). There was no relationship between the CVs of any of the yield components that we measured and block size (e.g. see Figure 4.2.13). Consequently, BSS did not increase with block size.

Table 4.2.11. Indicative Coefficients of Variation for selected yield components measured at a range of sites in Victoria from 1997/1998 to 1999/2000.

		Coefficient of Variation (%)		
Yield component	**Stage**	**Low**	**Medium**	**High**
Bunches/segment	After budburst	20	35	50
Berries/bunch	After fruit set	40	55	65
Weight/segment	Near harvest	30	40	65

Grape intake officers and winemakers typically express a desire to achieve a 5% Tolerance of Doubt. An implication of this is that hundreds of measurements would be required at common levels of variation (Figure 4.2.14). We decided that a more realistic TD would be 15%, and we adopted this standard for calculating BSSs. If a 15% Tolerance of Doubt were to be adopted broadly throughout the industry, in theory the average difference between all the means estimated from samples and the true population means would be approximately 5% (because $t_{(p=0.05)} \approx 3 \times t_{(p=0.50)}$).

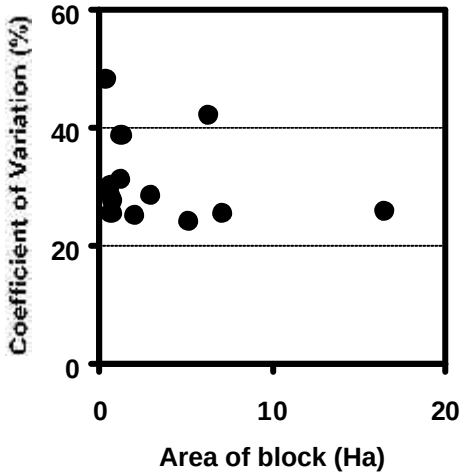


Figure 4.2.13. Relationship of Coefficient of Variation of bunches per 60 cm segment of row at harvest in 1998/99 to block size.

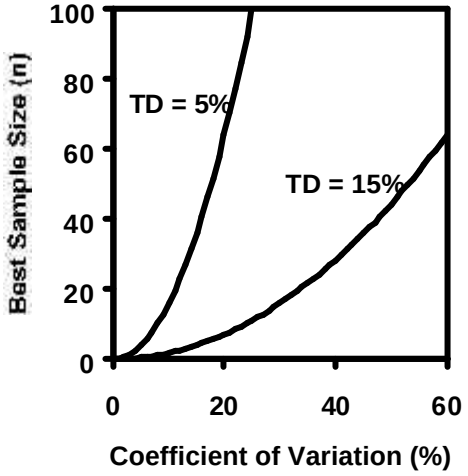


Figure 4.2.14. Effect of Coefficient of Variation on Best Sample Size to meet two specifications of Tolerance of Doubt (TD).

Segment size

One objective of the national project was to adapt existing forecasting methods to accommodate modern vineyard management practices. The existing method described by May (1971,1972) relied on counting bunches per vine. The CSIRO team at Merbein recognised that counting bunches on minimally or mechanically pruned vines would be difficult and time-consuming. Their solution was the development of a 20 cm wide 'transect ladder' that could be laid over a vine canopy to provide boundaries within which to count bunches. This was an important innovation. Counting in smaller segments saves forecasters time and aggravation, thus removing a barrier to adoption of measurement-based forecasting. However, the technique was not recommended for cane or spur pruned vines, where all the bunches on the whole vine were still to be counted.

In other fields of research it has been recognised that the size of the sample unit influences the reliability and budgetary efficiency of the process of estimating a sample mean. For example, Hendrickx et al (1994) found that an increase in tensiometer cup size reduced the variability of soil water tension measurements, with implications for the number of measurements required to estimate the mean with a tolerable degree of error. According to Hendrickx et al (1994), measurements of sample units smaller than the Representative Elementary Volume (REV), a concept discussed by Bear (1972), are often characterised by high variation and the means calculated from them may not be reliable. Measuring sample units larger than the REV does not produce additional information or reduce variation further, thus increasing costs without additional benefit. This gave rise to questions as to whether 20 cm was the optimum length for a segment and whether it was necessary to count all the bunches on whole vines in cane or spur pruned vineyards.

We found that increasing the segment length decreased the CV of counts of bunches/segment (e.g. Figure 4.2.15). Consequently, the Best Sample Size decreased with increasing segment length (See Variation, doubt and sample size). The time needed to travel between sampling locations within a block and to set up to count is practically independent of segment length. However, counting time is proportional to segment length. As a result of these counteracting effects, the time required to count bunches in each block was generally at a minimum when the segment length was 60 cm (Figure 4.2.16). Consequently the standard segment length we used in the 98/99 and 99/00 seasons was 60 cm.

Counting 60 cm segments also diminished the tedium and difficulty of the bunch counting and picking tasks. Miscounting is a potential source of error. Even well-trained and dedicated personnel find it surprisingly easy to miscount when repeatedly counting hundreds of bunches. On small vines with low numbers of bunches per unit length, counting whole vines may not result in more human error, but as bunch numbers increase into the hundreds, the risk of human error increases.

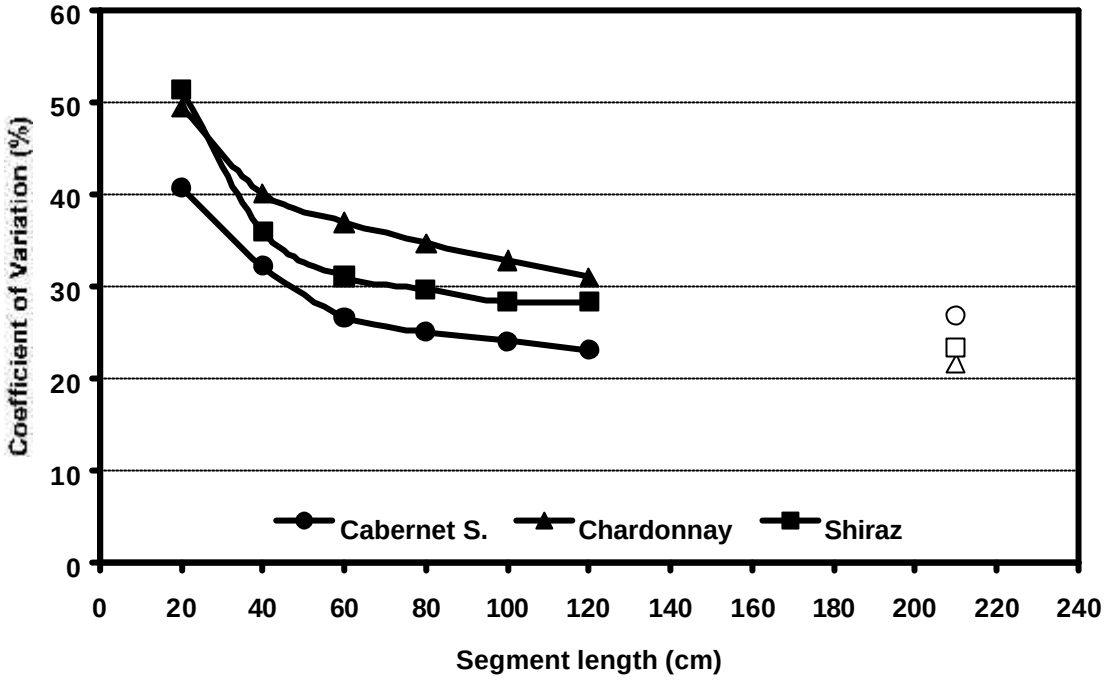


Figure 4.2.15. Effect of segment length on coefficient of variation of counts of bunches per segment in three varietal blocks in Chambers vineyard in 97/98.

The closed symbols relate to measurements made after fruit set in segments of varying length. The open symbols relate to measurements made shortly before harvest in whole vines.

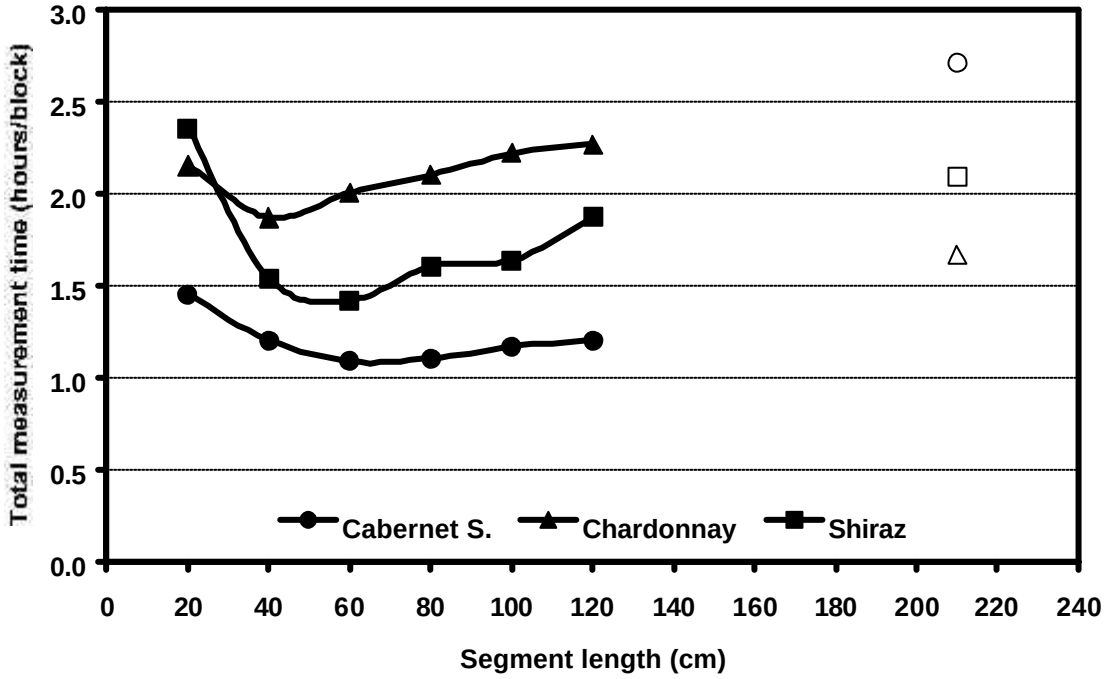


Figure 4.2.16. Effect of segment length on total time required to count bunches in three varietal blocks in Chambers vineyard in 97/98.
Calculations assumed a travel and set up time of 2 minutes per sampling location and a counting rate of 5 minutes per metre of row.

Sampling bias

As emphasised above, the accuracy of crop forecasts depends on the accuracy of estimates of yield components, which are derived from samples. To derive an accurate estimate of the true population mean from a sample mean, the sample must represent the population without bias. Bias may be introduced if particular types of sampling unit are favoured by a sampling system. Unbiased sampling ensures that every sampling unit has an equal chance of being selected.

The generally-accepted standard statistical method of avoiding bias is to sample randomly. However, the so-called 'random' sampling practised in many vineyards throughout Australia is in fact subject to human bias. The nature of this bias can be seen clearly in Figure 4.2.17, which shows the locations selected in a triangular-shaped block by a person who was simply asked to take 10 samples 'at random'. The person concentrated on a relatively small area in the block that may not have been representative of it as a whole, and there was a strong pattern in their sampling.

One method that is commonly used in vineyards to try to overcome human bias is to specify some sort of systematic sampling. For example, it may be specified that the measurement should be made at regular row and vine intervals (Figure 4.2.18). This may ensure that bias due to human factors is avoided and it can achieve an even coverage of the block, but it can introduce other biases. For example, the sampling interval could coincide with a yield pattern in the block associated with such factors as post or sprinkler placement.

Systematic bias can be avoided by random selection of locations. The method for doing this that was specified in System 1 was to randomly select rows in the block, then randomly select vines within those rows (using random number tables). This method avoids human and systematic bias and is unbiased in blocks where the number of vines in each row is the same, but in other blocks it gives vines in shorter rows a greater chance of being selected. This may not be readily apparent with a small sample size (e.g. Figure 4.2.19), but is obvious when sample sizes are larger (e.g. Figure 4.2.20). This is a form of systematic bias.

All of the aforementioned biases can be avoided by the use of completely random sampling. For example, if we wanted to select a sample of vines to measure in a block, we could assign a serial number to each one, select as many vines as we need, then work out where they are in the block. This would be the generally accepted statistical ideal, but it is theoretically possible (although extremely improbable) that this method would result in a sample in one small region of the block. Some chance clustering of locations can be seen in Figure 4.2.21.

To overcome all of the potential biases outlined above, we developed a system of stratified random sampling for use in vineyard blocks. Vine 'spaces' (including missing and weak vines) within the block are numbered in a sequence defined first by the row number and then by the vine number within the row, as if the block is one long row. Then the 'long row' is divided into sections of equal length, the number of sections being determined by the sample size. Vines are randomly selected within each of these sections. The 'address' of each vine can then be computed from the row and vine numbers associated with its serial number. This method prevents human and systematic biases and constrains the locations to be distributed evenly throughout the block (e.g. Figure 4.2.22).

Having selected a particular vine 'space' without bias, there is still a need to select a spot to place a counting frame or to select a bunch or a berry. It would be impractical to use a truly random method to give every bunch or berry in the block an equal chance of being selected, because it would not be economic to ascertain how many bunches or berries are in the block and the precise address of each. However, each vine 'space' has an allocation for a number of arms of equal length. Consequently, the method we used was to randomly select an arm 'space' and then a 'spot' within it. The centre of the segment frame was placed in line with an imaginary cross-sectional plane intersecting the row at the selected spot. When sampling bunches, the bunch with the base of its stalk nearest to the plane was selected. This method incorporates a slight bias to bunches in sparser parts of the vine, but overcomes human bias. We found that it is nearly impossible to select a single berry within a bunch in a vineyard without any bias. There is a strong bias to bigger, more coloured berries on the outside of the bunch, and it is difficult to gain access to berries near the central axis. Consequently we determined weight/berry in the laboratory using whole bunch samples.

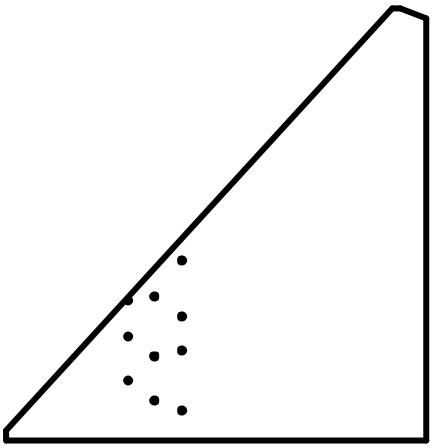


Figure 4.2.17. Human sampling.

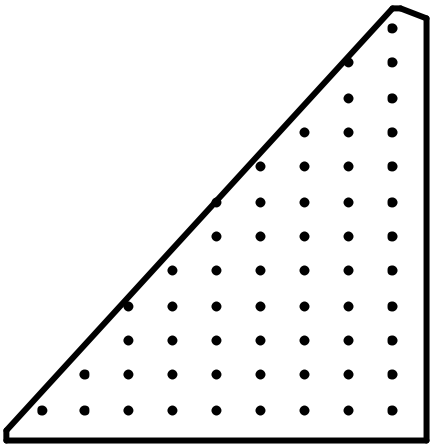


Figure 4.2.18. Systematic sampling.

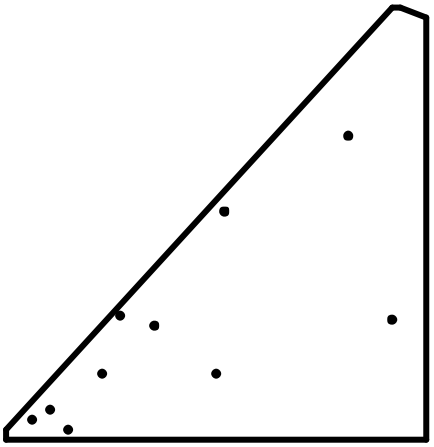


Figure 4.2.19. Random row, vine sampling (10).

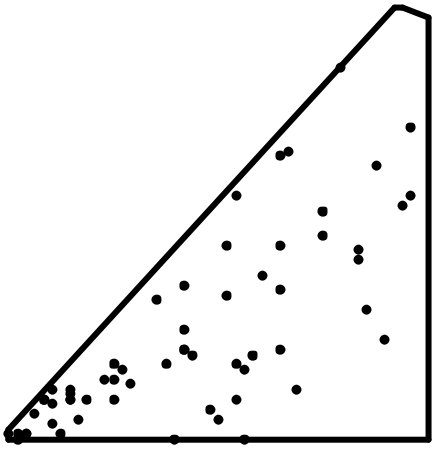


Figure 4.2.20. Random row, vine sampling (60).

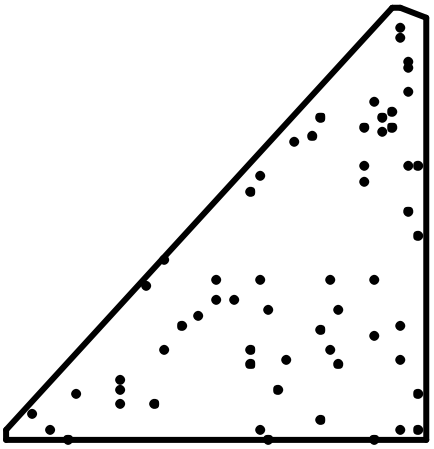


Figure 4.2.21. Completely random sampling.

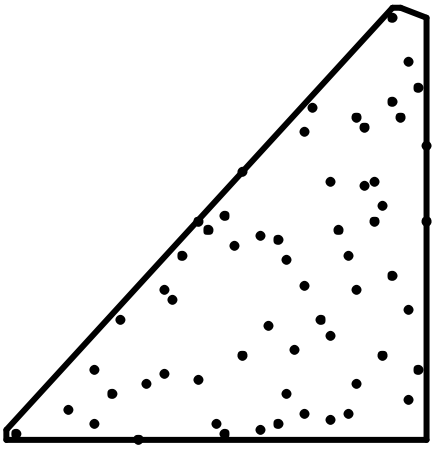


Figure 4.2.22. Stratified random sampling.

Definition of a bunch

The choice of definition of a bunch has some practical implications that can affect the accuracy of forecasts. From a physiological perspective, tendrils and bunches are homologous organs, distinguished by the presence or absence of flowers or berries. For operational purposes, there are a number of definitions in current use that exclude bunches below an arbitrary size threshold. For example, Antcliff et al (1972) specified that a bunch "must carry at least 5 – 10 berries depending on cultivar, or 4 times that no. of florets". This definition is broadly used in the Sunraysia, but researchers in other parts of Victoria have traditionally excluded bunches with less than 5 berries. We decided to distinguish a bunch from a tendril if it had one or more flowers or berries on it, on physiological grounds. However, from an operational perspective, we also found it easier and quicker to decide whether to select a bunch when the 'one berry' definition was applied. It also removed some variation due to differences in the subjective judgments applied by sampling personnel.

In some cases the choice of a '10 berry' definition can result in an underestimate of bunches/segment (Table 4.2.12). This has little effect on an estimate of weight/segment, and hence weight/block, because a large number of small bunches only contribute a small amount of weight. However, mean weight/bunch can be overestimated. When comparing data it would be important to ensure that a consistent definition was used.

Table 4.2.12. Effect of excluding bunches with less than 10 berries on estimates of yield components.

Error	%
Underestimate of bunches/segment	16.7
Underestimate of weight/segment	1.4
Overestimate of mean weight/bunch	18.3

(Block: DE Ca 99/00)

The application of a consistent definition is also important with respect to 'second crop' (i.e. bunches that form on lateral shoots in the current season). These bunches usually contribute to mechanically harvested loads, but are often excluded from hand-picked loads. In some cases, a choice of definition that includes or excludes them could significantly affect a forecast.

Definition of a berry

It may be assumed that a forecaster knows what a flower or a berry looks like. However, bunches in some blocks may have up to four classes of berries present, viz.:

1. 'Normal' berries
2. Raisins – individual berries which have desiccated but which have not abscised
3. 'Chickens' (as distinct from normal 'hens'), which usually do not have a viable seed - at veraison these are about 3 to 4 mm diameter, average about 0.2 g and stay green for longer
4. 'Shot' berries, which have a diameter of about 1 mm and remain tiny, green and hard until harvest

Raisins are relatively light, so if they are present in large enough numbers they can lower the estimate of mean berry weight appreciably. 'Shot' berries and 'chickens' tend to fall off before harvest, so there may be reasons not to count them at an earlier stage. In sites where there was a noticeable incidence of non-normal berries we counted and weighed them separately. However, sometimes there is a gradation between 'hens' and chickens' that makes it hard to distinguish between them.

Bunch gain

In the forecasting formulae of System 1 it is assumed that an estimate of mean bunches/segment at Stage 1 predicts actual bunches/segment at harvest. However, bunches may be gained if they appear after the time of counting at Stage 1 or if a 'second crop' develops on summer laterals. Bunches can also be lost due to factors such as hail damage, bunch stem necrosis, severe Downy Mildew, or deliberate removal for crop control purposes. Estimates of mean bunches/segment derived from samples at Stage 1 and Stage 3 (near harvest) may also differ simply due to chance (sampling error). Over the three year duration of the project, in cases where bunches were not thinned, there was a general tendency for more bunches to be counted at Stage 3 than at Stage 1 (Table 4.2.13).

Table 4.2.13. Comparison of mean bunches per 60 cm segment at Stage 1 and Stage 3 in blocks in Victoria over 3 seasons.

Year	Vyd	Var	Bu/seg		
			Stg. 1	Stg. 3	t-test p
97/98	Ch	Ca	23.66	24.74	0.657
		Ch	21.24	23.54	0.219
		Sh	14.85	17.51	0.064
	Pa	Sh	33.52	37.12	0.274
	Ya	Ca	18.87	25.87	0.000 ***
		Ch	16.47	19.60	0.036 *
98/99	Ba	Ca	37.70	61.17	0.000 ***
		Ch	31.53	42.65	0.003 **
		Sh	12.75	18.24	0.001 **
	Ch	Ca	27.27	39.17	0.001 ***
		Ch	26.20	25.55	0.814
		Sh	23.15	29.40	0.004 **
	Dr	Ca			
		Ch	13.00	15.20	0.091
	Mt	Ca	22.73	37.63	0.000 ***
		Sh	13.90	26.43	0.000 ***
	Pa	Sh	22.40	21.85	0.840
	Ya	Ca	24.30	20.45	0.046 *
		Ch	29.25	38.35	0.001 ***
99/00	Ba	Ca	11.67	16.06	0.012 *
		Ch	36.22	40.82	0.116
		Sh	24.44	28.05	0.078
	Ch	Ca	19.13	28.82	0.000 ***
		Ch	22.80	24.37	0.394
		Sh	16.20	24.81	0.004 **
	Dr	Ca			
		Ch	18.73	17.77	0.612
	Mt	Ca	23.33	27.20	0.129
		Ch	12.75	18.87	0.001 ***
		Sh	12.75	13.34	0.646
	Pa	Sh	25.53	25.05	0.756
	Ya	Ca	17.80	21.08	0.085
		Ch	37.40	36.40	0.651

Thus there is a case for including a ***bunch gain factor*** in forecasting formulae. We define this as the ratio of bunches/segment at Stage 3 to bunches/segment at Stage 1. When making a forecast at Stage 1, an allowance for potential bunch gain may be made by multiplying an estimate of mean bunches/segment at Stage 1 by a Bunch Gain Factor. It can also be used to adjust for expected bunch thinning, in which case its value would be less than 1.

The use of a Bunch Gain Factor would require some quantification of its mean value for each block over a number of seasons. We have measured it in our study blocks for only 2 or 3 seasons. More would be better. In some blocks its value can vary considerably from season to season (Table 4.2.14), so records of one previous year are not a good guide for the current year. In general, however, bunch gain is only moderately variable from year to year, so there is a prospect that historical records may provide a reasonable guide.

Table 4.2.14. Variation of Bunch Gain Factor (BGF) in blocks in Victoria, 97/98 - 99/00.

Vyd	Var	Years	BGF	s	CV (%)
Ba	Ca	2	1.50	0.174	12
	Ch	2	1.24	0.159	13
	Sh	2	1.29	0.200	16
Ch	Ca	3	1.33	0.248	19
	Ch	3	1.05	0.068	7
	Sh	3	1.33	0.183	14
Dr	Ca				
	Ch	2	1.06	0.156	15
Mt	Ca	2	1.41	0.346	25
	Sh	2	1.47	0.605	41
Pa	Sh	3	1.02	0.075	7
Ya	Ca	3	1.13	0.269	24
	Ch	3	1.16	0.171	15
Mean		2.5	1.25	0.221	17

Berry loss

It might be assumed that an estimate of mean berries/bunch at Stage 2 would predict actual berries/bunch at harvest. However, in 97/98 there were significantly fewer berries/bunch at Stage 3 than at Stage 2 in five of the six blocks measured (Table 4.2.15). In 98/99, in three of the blocks studied, berries/bunch decreased from fertilisation to harvest, while the berries that remained grew fairly steadily (Figure 4.2.23, Figure 4.2.24, Figure 4.2.25). Consequently, bunches sampled at Stage 2 had more berries than bunches sampled at Stage 3.

Table 4.2.15. Comparison of berries/bunch at Stages 2 and 3 in the 97/98 season.

Vyd	Var	Berries/bunch		
		Stg 2	Stg 3	t-test p
Ch	Ca	167	109	0.000 ***
	Ch	126	96	0.024 *
	Sh	118	104	0.186
Pa	Ca	203	105	0.000 ***
	Ch	203	156	0.014 *
	Sh	167	88	0.000 ***

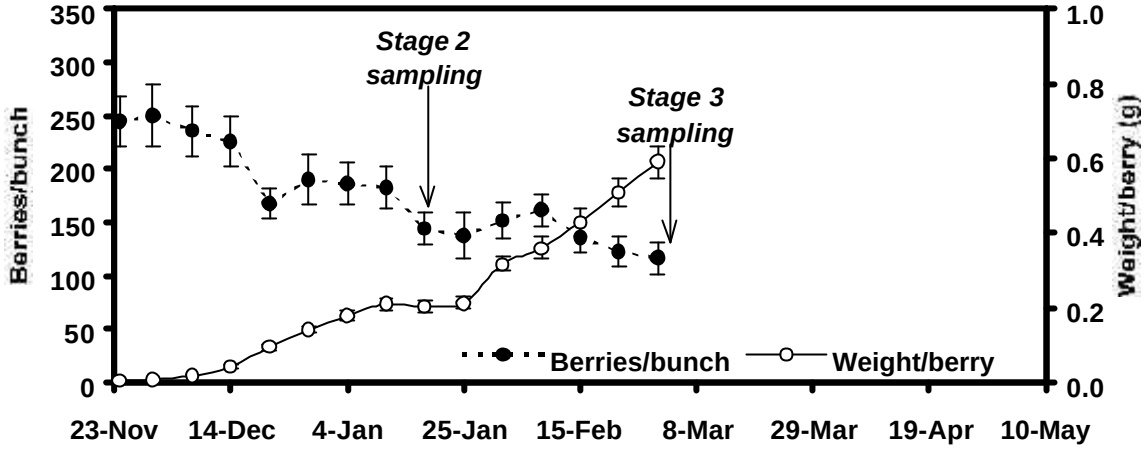


Figure 4.2.23 Bunch sampling times relative to seasonal patterns of berry loss and berry growth, Yarra Ridge Chardonnay, 98/99.

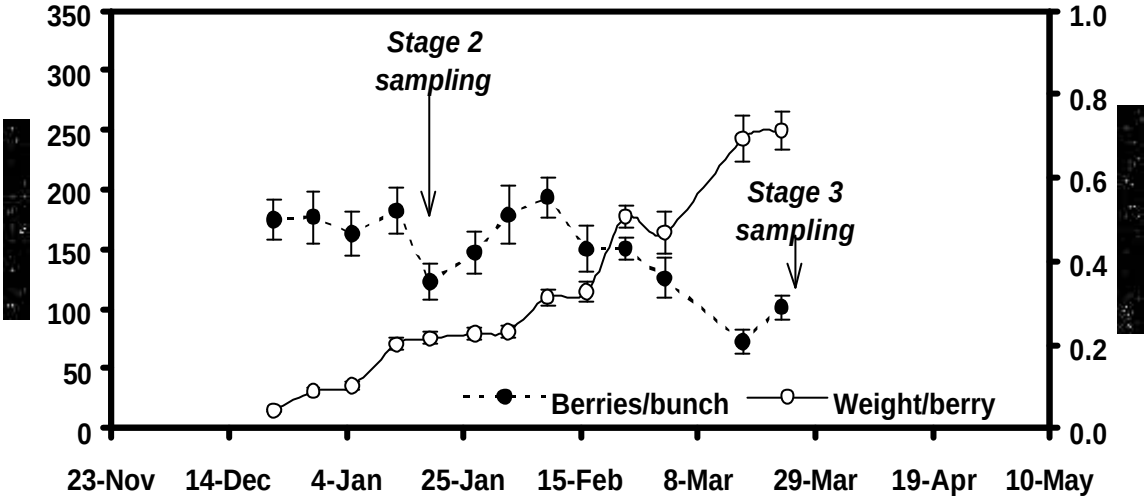


Figure 4.2.24 Bunch sampling times relative to seasonal patterns of berry loss and berry growth, Dromana Estate Chardonnay, 98/99.

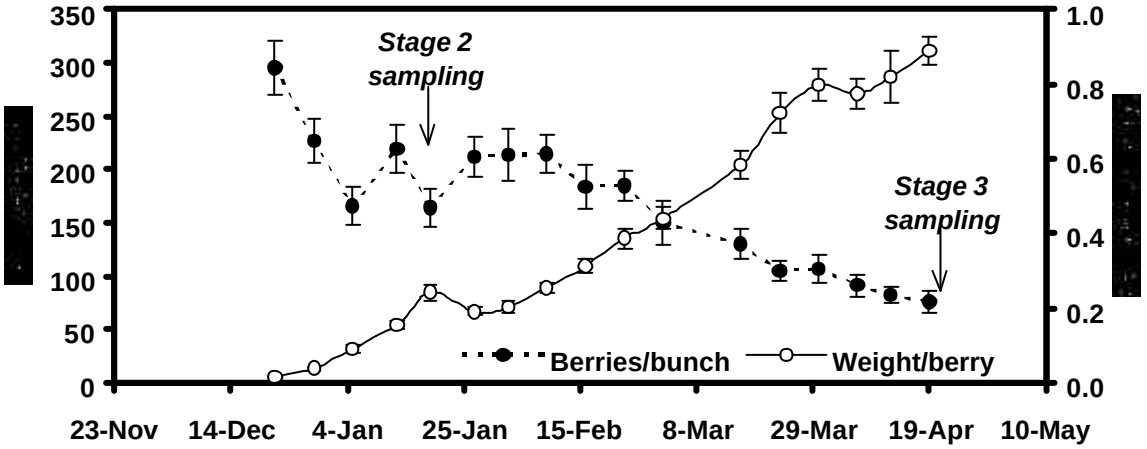


Figure 4.2.25 Bunch sampling times relative to seasonal patterns of berry loss and berry growth, Dromana Estate Cabernet Sauvignon, 98/99.
The bars indicate standard errors of the mean (n=20).

In 98/99 there were fewer berries/bunch at Stage 3 than at Stage 2 in the three blocks noted above when all berries were counted, but there was no significant difference between means of 'normal' berries/bunch (see Definition of a berry) (Table 4.2.16). However, in 99/00, even when only counts of normal berries/bunch were used at Stage 2, there were significantly more berries/bunch at Stage 2 than at Stage 3 in 5 of the 16 blocks studied (Table 4.2.17).

Table 4.2.16. Comparison of mean berries/bunch at Stages 2 and 3 in blocks in Victoria in 98/99 using two different criteria for inclusion of berries to count.

		All berries/bunch				Normal berries/bunch			
Vineyard	**Variety**	**Stage 2**	**Stage 3**	**t-test p**		**Stage 2**	**Stage 3**	**t-test p**	
Barooga	Cabernet S.	84	98	0.133	ns	84	92	0.383	ns
	Chardonnay	101	103	0.865	ns	101	100	0.886	ns
	Shiraz	90	90	0.949	ns	89	90	0.940	ns
Chambers	Cabernet S.	93	111	0.154	ns	93	111	0.165	ns
	Chardonnay	122	115	0.700	ns	122	104	0.297	ns
	Shiraz	103	102	0.983	ns	103	102	0.953	ns
Dromana Estate	Cabernet S.	139	81	0.001	***	82	77	0.628	ns
	Chardonnay	126	81	0.000	***	49	58	0.237	ns
Mt Helen	Cabernet S.	83	91	0.482	ns	73	91	0.083	ns
	Shiraz	72	87	0.088	ns	72	84	0.146	ns
Paringa Estate	Shiraz	51	45	0.344	ns	41	42	0.854	ns
Yarra Ridge	Cabernet S.	87	90	0.823	ns	59	74	0.066	ns
	Chardonnay	156	113	0.019	*	71	65	0.542	ns

Thus there is a case for including a ***berry loss factor*** in forecasting formulae. We define this as the ratio of berries/bunch at Stage 3 to berries/bunch at Stage 2. The use of a berry loss factor would require some quantification of its mean value for each block over a number of seasons. We have measured it in our study blocks for only 2 or 3 seasons. More would be better. In some blocks its value can vary considerably from season to season (Table 4.2.18), so records of one previous year are not a good guide for the current year. In general, however, berry loss is only moderately variable from year to year, so there is a prospect that historical records may provide a reasonable guide.

Table 4.2.17. Comparison of mean berries/bunch at Stages 2 and 3 in blocks in Victoria in 99/00 (normal berries only).

		Berries/bunch		
Vyd	**Var**	**Stg 2**	**Stg 3**	**t-test p**
Ba	Ca1	113	91	0.098
	Ca2	147	124	0.126
	Ch	105	96	0.335
	Sh	91	75	0.051
Ch	Ca	92	79	0.154
	Ch	117	100	0.108
	Sh	82	74	0.288
Dr	Ca	82	80	0.800
	Ch	78	79	0.838
Mt	Ca1	138	99	0.002 **
	Ca2	82	64	0.026 *
	Ch	94	76	0.021 *
	Sh	66	48	0.014 *
Pa	Sh	72	61	0.178
Ya	Ca	76	48	0.000 ***
	Ch	85	84	0.907

Table 4.2.18. Seasonal variation of Berry Loss Factors in blocks in Victoria, 97/98 to 99/00.

Vyd	**Var**	**Years**	**Mean**	**s**	**CV (%)**
Ba	Ca	2	0.95	0.20	22
	Ch	2	0.95	0.05	5
	Sh	2	0.91	0.13	14
Ch	Ca	3	0.90	0.27	30
	Ch	3	0.82	0.05	6
	Sh	3	0.92	0.06	7
Dr	Ca	2	0.96	0.02	3
	Ch	2	1.10	0.12	11
Mt	Ca	2	0.98	0.38	38
	Sh	2	0.95	0.31	32
Pa	Sh	3	0.80	0.25	31
Ya	Ca	2	0.95	0.44	47
	Ch	2	0.95	0.05	5
Mean		2.3	0.93	0.18	19

Prediction of harvest bunch weight from historical records

At Stage 1, mean weight/segment at harvest can be forecast using the formula:

$$weight/segment_{(harvest)} = bunches/segment_{(stage\ 1)} \times bunch\ gain \times weight/bunch_{(harvest)}$$

At Stage 1 harvest weight/bunch has yet to be determined and must be predicted in some way. At present, growers who use some form of measurement-based forecasting refer either to winery-supplied tables of mean weight/bunch per variety or their own records.

Over the three years of the project, weight/bunch varied little in some blocks, but varied considerably in others (Figure 4.2.26, Figure 4.2.27, Figure 4.2.28). In general, seasonal variation was greater in Chardonnay and Shiraz blocks than in Cabernet Sauvignon blocks, but variation in some Chardonnay and Shiraz blocks was similar to the Cabernet Sauvignon blocks (e.g. Chardonnay at Barooga and Yarra Ridge and Shiraz at Barooga). This variation is a source of doubt in Stage 1 forecasting calculations that rely on predictions from historical records and is quantified in Table 4.2.19 and Table 4.2.20.

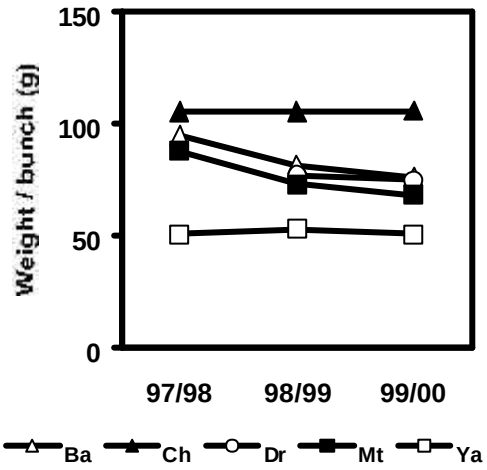


Figure 4.2.26. Mean weight/bunch at harvest in Cabernet Sauv. blocks over three seasons.

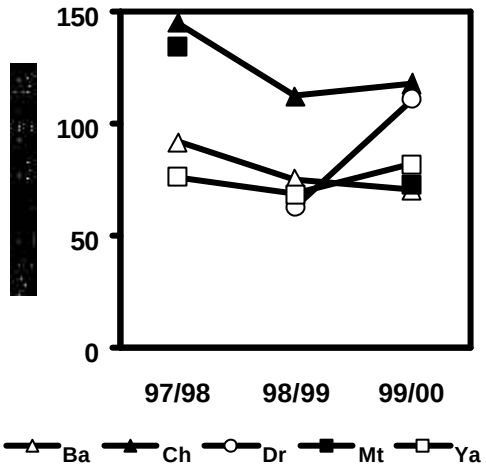


Figure 4.2.27. Mean weight/bunch at harvest in Chardonnay blocks over three seasons.

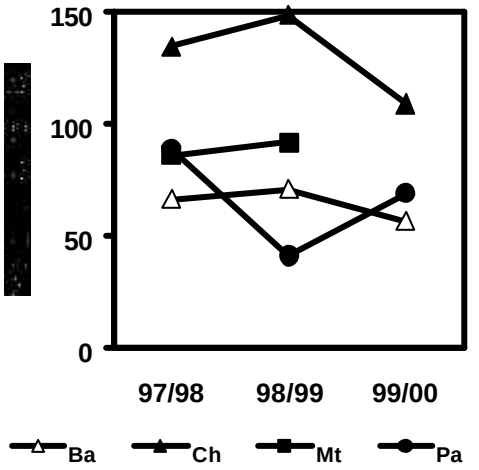


Figure 4.2.28. Mean weight/bunch at harvest in Shiraz blocks over three seasons.

Mean weight/bunch for each block in each season was calculated from measurements of weight/segment and bunches/segment at Stage 3.

For identities of vineyards, see Research Methodology.

Table 4.2.19. Seasonal variation of mean weight/bunch (g) derived from weights of bunches that were sampled individually at Stage 3.

Vyd	Var	Years	Mean	s	CV(%)
Ba	Ca1	3	96	6.3	6.6
	Ca2	1	135		
	Ch	3	83	5.4	6.5
	Sh	3	64	9.4	14.5
Ch	Ca	3	119	3.9	3.2
	Ch	3	122	10.9	8.9
	Sh	3	131	17.6	13.5
Dr	Ca	2	79	1.4	1.8
	Ch	2	83	32.3	38.9
Mt	Ca1	3	83	4.7	5.6
	Ca2	1	54		
	Ch	2	136	63.8	47.1
	Sh	3	78	19.8	25.3
Pa	Sh	3	70	23.9	34.2
Ya	Ca	3	65	21.1	32.7
	Ch	3	82	11.8	14.3

Table 4.2.20. Seasonal variation of mean weight/bunch (g) derived from (weight/segment) / (bunches/segment) at Stage 3.

Vyd	Var	Years	Mean	s	CV(%)
Ba	Ca1	3	84	9.5	11.3
	Ca2	1	105		
	Ch	3	79	11.1	14.1
	Sh	3	64	7.4	11.4
Ch	Ca	3	105	0.2	0.2
	Ch	3	125	17.5	14.0
	Sh	3	130	20.0	15.4
Dr	Ca	2	76	1.3	1.8
	Ch	2	86	34.0	39.3
Mt	Ca1	3	76	10.3	13.6
	Ca2	1	44		
	Ch	2	103	43.4	42.0
	Sh	2	89	4.2	4.7
Pa	Sh	3	66	24.0	36.3
Ya	Ca	3	51	1.3	2.5
	Ch	3	75	6.7	8.9

Statistics are numbers of seasons of measurement (n), and Means, standard deviations (s) and Coefficients of Variation (CV) of seasonal means.

Mean weight/bunch at Stage 3 can be calculated from weights of individually-sampled bunches or by dividing weight/segment by bunches/segment. The estimate derived from whole segments is probably more reliable because it is based on a larger total sample of bunches. We found that the estimate derived from individually-sampled bunches was generally higher than the estimate derived from picks of 60 cm segments (Figure 4.2.29). Across the range of blocks we studied there was a constant overestimate of approximately 10g. This suggested that samplers tend to miss smaller bunches when sampling individual bunches, but not when picking all the bunches in a segment.

Consideration of this statistical evidence and anecdotal observations led us to conclude that there is a general tendency to overestimate weight/bunch throughout the industry, both in research and in practice. This may not be a source of bias in research experiments when the objective is to compare effects on a relative basis. However, in forecasting the objective is to estimate the absolute value of weight/bunch.

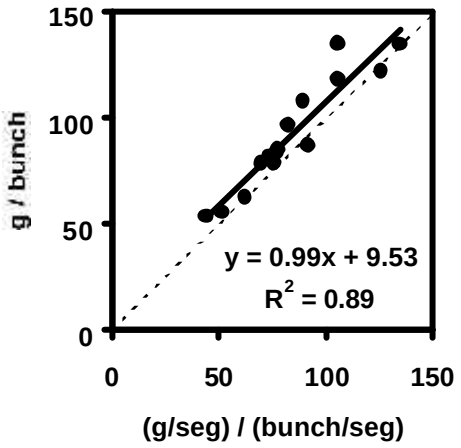


Figure 4.2.29. Relationship of mean weight/bunch determined by sampling individual bunches (g/bunch) to mean weight/bunch determined by sampling segments and dividing weight/segment by bunches/segment ((g/seg) / (bunch/seg)) for blocks in Victoria, 97/98 - 99/00.

At Stage 2, after berries have set, the estimate of harvest bunch weight can be adjusted by either counting berries/bunch and multiplying by a predicted berry loss factor and weight/berry or weighing bunches and multiplying by a weight gain factor

Prediction of harvest berry weight from historical records

At Stage 2, mean weight/bunch at harvest can be forecast using the formula:

$$weight/bunch_{(harvest)} = berries/bunch_{(stage\ 2)} \times berry\ loss \times weight/berry_{(harvest)}$$

At Stage 2 harvest weight/berry has yet to be determined and must be predicted in some way. At present, growers who use some form of measurement-based forecasting refer either to winery-supplied tables of mean weight/berry per variety or their own records.

There was relatively little seasonal variation in mean weight/berry in most blocks, with some minor exceptions (Figure 4.2.30, Figure 4.2.31, Figure 4.2.32 and Table 4.2.21). Consequently, a mean of previous seasons should be a reliable predictor of harvest weight/berry. We developed techniques to predict harvest weight/berry from growth curves, but this achieved little compared with using historical means.

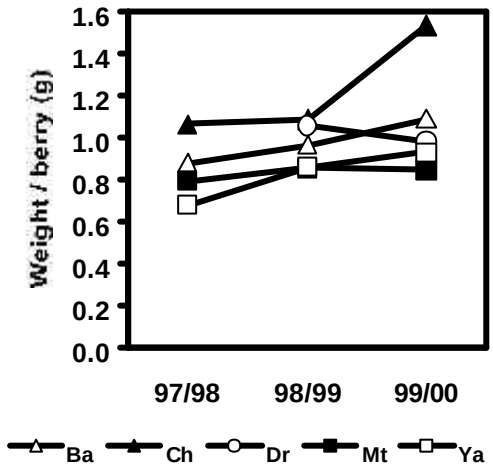


Figure 4.2.30. Mean Stage 3 weight/berry in Cabernet Sauv. blocks over three seasons.

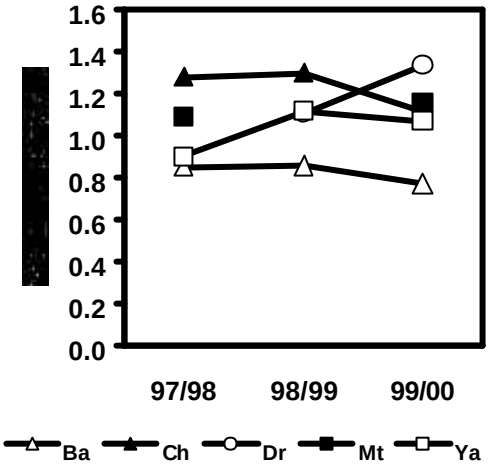


Figure 4.2.31. Mean Stage 3 weight/berry in Chardonnay blocks over three seasons.

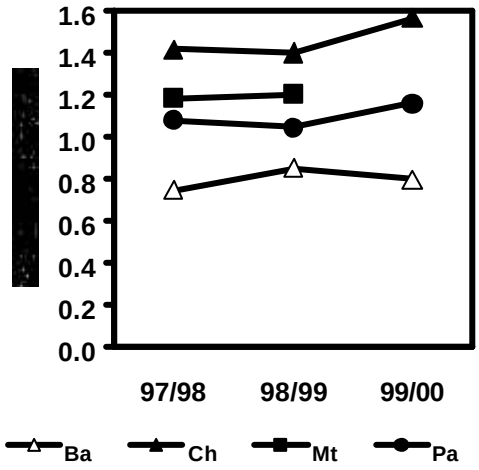


Figure 4.2.32. Mean Stage 3 weight/berry in Shiraz blocks over three seasons.

For identities of vineyards, see Research Methodology.

Table 4.2.21. Seasonal variation of mean weight/berry (g) at Stage 3.

Vyd	Var	Years	Mean	s	CV(%)
Ba	Ca 1	3	0.97	0.11	10.9
	Ca 2	1	1.11		
	Ch	3	0.82	0.05	5.8
	Sh	3	0.80	0.05	6.6
Ch	Ca	3	1.23	0.26	21.5
	Ch	3	1.23	0.10	8.4
	Sh	3	1.46	0.09	6.3
Dr	Ca	2	1.02	0.05	5.2
	Ch	2	1.22	0.16	13.2
Mt	Ca 1	3	0.83	0.03	3.9
	Ca 2	1	0.85		
	Ch	2	1.12	0.05	4.3
	Sh	3	1.21	0.04	3.1
Pa	Sh	3	1.09	0.06	5.3
Ya	Ca	3	0.82	0.13	15.9
	Ch	3	1.03	0.11	11.0

Harvest efficiency

In principle, a reliable estimate of the amount of fruit that can potentially be harvested from a block can be made immediately before harvest, because there is no time for weight to be gained or lost. However, wineries seek forecasts of expected delivery and losses of weight can occur during harvest and transport. For example, machine harvesting leaves stalks behind and can miss bunches near posts or outside the range of beaters. Fruit and juice is lost during transfers to bins, and evaporative losses from bins occur in the vineyard, during transport and at the winery. In the absence of an allowance for these losses, forecasts consistently overestimate delivered weight/block at Stage 3 by approximately 10% (e.g. Figure 4.2.33). Thus there is a case for inclusion of a ***Harvest Efficiency Factor*** (HEF) in crop forecasting formulae used at all forecasting stages. When appropriate HEFs derived from experience in previous seasons are included they can improve forecasts in the current season (Figure 4.2.34 cf Figure 4.2.33). The appropriate HEF will vary depending on the harvesting conditions that apply in each block (Table 4.2.22). The actual HEF for each block can be estimated by calculating the ratio of the delivered weight to the weight of grapes present in a block at Stage 3. Values for HEFs determined this way vary from block to block and season to season (Table 4.2.23).

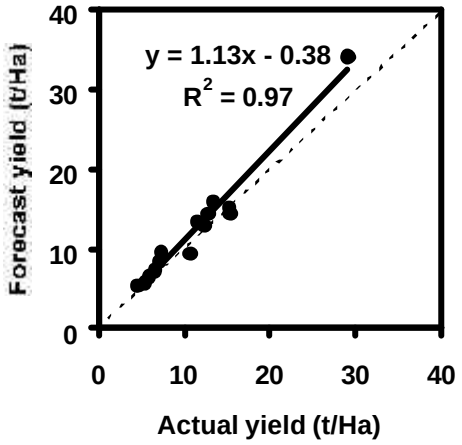


Figure 4.2.33. Relationship of forecasts at Stage 3 to actual yields in blocks in Victoria in 99/00 with no harvest efficiency factors.

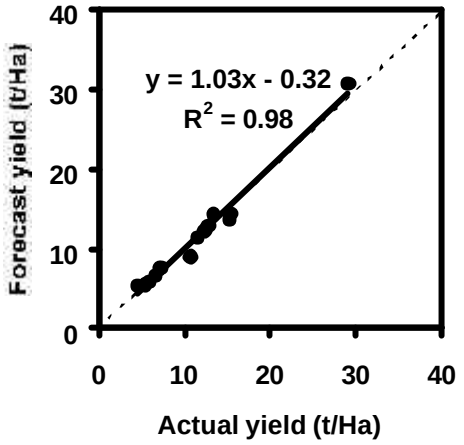


Figure 4.2.34. Relationship of forecasts at Stage 3 to actual yields in blocks in Victoria in 99/00 with harvest efficiency factors.

Table 4.2.22. Indicative Harvest Efficiency Factor (HEF) for particular harvesting conditions.

Harvesting conditions	HEF
Meticulous hand harvesting close to the winery	1.00
Hand harvesting with transfer to a distant winery	0.95
Very efficient machine harvesting with small transport losses	0.90
Relatively inefficient machine harvesting with transport losses	0.85

Table 4.2.23. Variation of Harvest Efficiency Factors in blocks in Victoria, 97/98 - 99/00.

Vyd	var	Years	Mean	s	CV (%)
Ba	Ca	3	0.92	0.13	14
	Ch	3	0.96	0.13	14
	Sh	3	0.74	0.18	24
Ch	Ca	3	0.93	0.10	11
	Ch	3	0.96	0.08	9
	Sh	2	0.81	0.07	9
DE	Ca	1	0.94		
	Ch	1	0.96		
MH	Ca	2	0.80	0.15	19
	Sh	2	0.81	0.15	18
PE	Sh	2	0.95	0.26	27
YR	Ca	2	1.03	0.24	24
	Ch	2	1.04	0.04	4
Mean		2.2	0.91	0.14	16

Quantification of reliability of forecasts

No measurement-based forecast can be 100% accurate, because there are errors surrounding all the numbers used to calculate it. Forecasters can only estimate the ***most likely production*** from a block, which is a product of a number of yield components. For example, an estimate of most likely production could be made at Stage 2 using a formula with six components: *Most likely production = segments/block x bunches/segment x bunch gain x berries/bunch x berry loss x weight/berry x harvest efficiency.* Segments/block is a constant with no error, but a 95% confidence interval (and hence a Coefficient of Doubt) can be defined for the estimates of the other five components, because they are all based on either sampling or some sort of subjective guessing process.

As with a single sample, it would be desirable to define a Coefficient of Doubt for the product of the components, in order to quantify the reliability of the forecast. This can be derived from the variance of the product of sample means (Table 4.2.24). As the number of sample means in a formula increases so does the Coefficient of Doubt (Figure 4.2.35).

Table 4.2.24. Formulae for calculating variances of means for multiple components in a crop forecasting formula.

Components	Product of means (P)	Variance of means (Vm)
1	M_1	V_1/n_1
2	M_2P_1	$M_2^2Vm_1 + P_1^2V_2/n_2$
3	M_3P_2	$M_3^2Vm_2 + P_2^2V_3/n_3$
4	M_4P_3	$M_4^2Vm_3 + P_3^2V_4/n_4$
5	M_5P_4	$M_5^2Vm_4 + P_4^2V_5/n_5$
6	M_6P_5	$M_6^2Vm_5 + P_5^2V_6/n_6$

Sample variance = V. Sample size = n.
Standard error of means (se) = $\sqrt{Vm}$.
Coefficient of Doubt = t x se / P x 100.

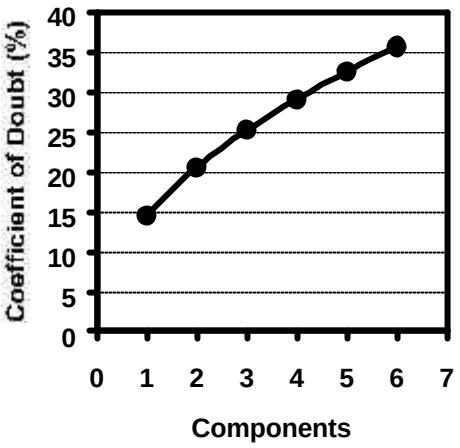


Figure 4.2.35. Relationship of cumulative Coefficient of Doubt to the number of components in a forecasting formula.
Assumptions: The estimate of the mean for each component is derived from a sample with a Coefficient of Variation of 40% and a sample size of 30.

For example, in a block with generally low variability, the Coefficient of Doubt would be approximately 37% (Table 4.2.25). Over many blocks of this type and many years, this would mean that the average difference between forecast and actual production would be approximately 13% (the mean absolute difference will be approximately one third of the Coefficient of Doubt, because $t_{(p=0.05)} \approx 3 \times t_{(p=0.50)}$, see Variation, doubt and sample size). For more variable blocks, the CD and the mean absolute difference would be larger (e.g. CD ≈ 88% and mean abs. diff. ≈ 30% in Table 4.2.26.

After measurement bias has been eliminated and all known factors have been included in crop forecasting formulae, the only way to achieve further improvement would be to increase sample sizes and refine predictions from historical records. Estimates of bunches/segment at Stage 1, berries/bunch at Stage 2 and weight/segment at Stage 3 are derived from sampling in the current season. Consequently, a forecaster can reduce the CD for these components by tolerating less doubt when sampling. However, estimates of bunch gain, berry loss, weight/berry and harvest efficiency are determined not only by sample sizes used in previous seasons but by seasonal variation.

We have predicted the effect of adopting different standards of Tolerance of Doubt in a hypothetical average block, using the mean of all blocks over the three seasons studied for each yield component. A decrease in TD from 25% to 15% would increase sample sizes to a moderate degree, but a further decrease in TD to 5% would result in a requirement for hundreds of segments and bunches to be sampled per block (Table 4.2.27). Decreasing TD from 25% to 5% would decrease the mean absolute difference by approximately 4% at each forecasting Stage. However, a lower limit of approximately 20% at Stages 1 and 2 and approximately 10% at Stage 3 would be imposed by basing predictions on historical means, which incorporate seasonal variability.

Table 4.2.25. Contribution of factors in a crop forecasting formula to the Coefficient of Doubt (CD) of their product for a block with generally low measurement and seasonal variability.

Yield component	Value	CV (%)	Sample size	Cum. CD (%)
Mean bunches/segment	24	31	20	14.5
Bunch gain factor	1.05	7	1	20.6
Mean berries/bunch	99	55	60	24.2
Berry loss factor	0.82	6	1	27.0
Mean grams/berry	1.23	8	1	31.3
Harvest efficiency factor	0.9	10	1	37.1
Mean kg/segment	2.26			37.1

Table 4.2.26. Contribution of factors in a crop forecasting formula to the Coefficient of Doubt (CD) of their product for a block with moderate measurement and seasonal variability.

Yield component	Value	CV (%)	Sample size	Cum. CD (%)
Mean bunches/segment	23	30	20	14.0
Bunch gain factor	1.33	19	1	42.2
Mean berries/bunch	105	58	60	42.8
Berry loss factor	0.9	30	1	73.5
Mean grams/berry	1.23	22	1	85.5
Harvest efficiency factor	0.9	10	1	87.8
Mean kg/segment	3.20			87.8

Table 4.2.27. Predicted mean absolute difference between forecast and actual production for sampling regimes governed by different Tolerance of Doubt (TD) at three forecasting stages.

	Sample size			Mean absolute difference (%)		
TD (%)	Stg.1 segments	Stg. 2 bunches	Stg. 3 segments	Stage 1	Stage 2	Stage 3
5	144	400	256	19	21	11
10	36	100	64	19	22	11
15	16	44	28	20	23	12
20	9	25	16	21	24	13
25	6	16	10	23	25	14

Assumptions:

Component	Value	CV(%)	Sample size (n)
Stage 1 estimate of bunches/segment	22	30	Determined by Tolerance of Doubt
Stage 2 estimate of berries/bunch	100	50	Determined by Tolerance of Doubt
Stage 3 estimate of weight/segment	2.37	40	Determined by Tolerance of Doubt
Predicted bunch gain factor	1.25	17	1
Predicted weight/bunch	86	15	1
Predicted harvest efficiency factor	0.91	16	1
Predicted berry loss factor	0.93	19	1
Predicted weight/berry	1.07	9	1
Predicted harvest efficiency factor	0.91	16	1

Summary of factors that affect the accuracy and efficiency of forecasts

The accuracy and efficiency of the forecasting process depends on accurate knowledge of block dimensions, measurement and sampling methods that are adequate, efficient and unbiased, and the extent to which predictions can be made from historical records. In short, a forecast is only as good as the numbers that go into it. Including factors such as bunch gain, berry loss and harvest efficiency in formulae can improve the accuracy of forecasts. However, the current reliance on historical means as predictors of values that have yet to be determined at the time of making a forecast imposes a limit on the mean absolute difference between forecast and actual production that would be achievable across the industry as a whole, because of the intrinsic variability of grape production systems.

Improvements incorporated into System 2

An improved system designed for use by crop forecasters was developed during the 99/00 season, incorporating features that addressed the issues highlighted in ***Factors that affect accuracy and efficiency of measurement-based forecasting***. By the end of the project this system had been developed in prototype paper-based and computer-based forms. The paper-based system included a set of forms and a step-by step manual, designed to be delivered with a hands-on training course. The computer-based system was distilled into a Microsoft Excel Workbook, which was designed to produce forecasts for one block in one season. Revised versions of the paper-based system and a disc containing copies of the Excel Workbook, including exercises and examples, are included in the Appendices. The key features of the system, referred to here as System 2, are summarised below.

Autonomy of growers
System 2 is designed to be used by a skilled viticulturist without external support. The documentation is thorough and the equipment is relatively cheap and simple to use. A computer is not necessary, but the computer-based system is a lot quicker and less tedious to use.

Application to any block
System 2 can be used in any block, regardless of its age or patchiness.

Systematised block and vine survey methods
A set of forms and instructions is supplied to ensure that necessary information about the structure of a block and the vines in it is obtained correctly.

Facility to use any segment size
Any segment length can be used, provided that the same length is used all season in a block. A 20 cm segment, whole vines or panels can still be used but a 60 cm segment is recommended.

Method for determining best sample size and checking if sampling was adequate
When setting up sampling forms, sample size can be tailored to each block. This removes limits on the precision of estimations and the cost-effectiveness of sampling. An easy way to calculate Best Sample Size from a Coefficient of Variation and a Tolerance of Doubt is provided. Initial sample sizes are suggested for cases where no historical data are available. After measurements are made using the estimated best sample size, data is entered into a worksheet or calculations are made on a form and the best sample size is calculated from the actual data. If the sample size was too small, the number of extra measurements needed is calculated.

Unbiased sampling system for use at any stage
The same method is used for all measurements at all stages to ensure that a segment frame is placed or a bunch is picked without bias. For each segment or bunch, a Row-Vine 'address', an arm of the vine and a spot on the arm is specified on a form that is produced prior to sampling in the block. Instructions are provided that specify how to place a segment frame or sample a bunch.

Tighter specification of bunch counting and sampling techniques
Instructions are provided that specify how to identify bunches and decide whether a particular bunch should be selected. The time of Stage 1 has been changed to six weeks after budburst.

Tighter specification of berry counting techniques
Instructions are provided that specify how to decide which berries should be counted at Stage 2 and 3.

Addition of procedure to measure crop components near harvest
Procedures are included to ensure that bunches/segment, weight/bunch and berries/bunch are measured at Stage 3. This provides data for analysing causes of unsatisfactory performance and predicting yield components in subsequent seasons. These procedures are independent of forecasting at Stage 3, but are designed to be integrated with forecasting procedures if they are used.

Addition of bunch gain, berry loss and harvest efficiency factors to forecasting formulae
In System 2, the revised formulae for forecasting at each stage are:

Stage 1 – Six weeks after budburst
weight/block = segments/block x bunches/segment x bunch gain x weight/bunch x harvest efficiency

Stage 2 – After fruit set
In the Stage 1 formula, substitute: weight/bunch = berries/bunch x berry loss x weight/berry

Stage 3 – One week before harvest
weight/block = segments/block x weight/segment x harvest efficiency

Addition of alternative method of forecasting at Stage 2 from bunch weights
An alternative method of forecasting at Stage 2 would be to weigh bunches at some specified time or stage of phenological development and then multiply the estimate of mean weight/bunch by a factor to predict weight/bunch at harvest. A method of this type is included in System 2. We have called it the 'Bunch Weighing Method' to distinguish it from the 'Berry Counting Method' adapted from System 1. Instructions are provided specifying that bunches should be sampled as for the Berry Counting Method, but at the onset of veraison, which is defined as the time when softening or colouring of the first few berries on each vine can be observed in a block. This is easy to detect and at this stage the majority of the berries will be in the slow-growth period preceding veraison, so some variation in sampling time from season to season will have less impact on mean weight/bunch than in the later stages of veraison, when the daily growth rate is higher.

The formula used to predict weight/bunch at harvest from weight/bunch at veraison is:

$\text{weight/bunch}_{(\text{harvest})} = \text{weight/bunch}_{(\text{veraison})} \times \text{weight gain}$.

This required the addition of a ***weight gain factor***, which we define as the ratio of the sample mean of weight/bunch near harvest (Stage 3) to the sample mean of weight/bunch near veraison (Stage 2).

Addition of method of forecasting near harvest using bunch count x bunch weight
Growers are often reluctant to pick segments in advance of harvest, which is necessary to make a forecast from weight/segment at Stage 3, because the picked fruit must either be added to a batch of fruit being harvested simultaneously, stored until the sampled block is harvested, or dumped. System 2 requires the measurement of bunches/segment and weight/bunch at Stage 3, which enables an estimate of weight/segment to be made and substituted in the Stage 3 formula above. We have called this the 'Bunch Counting and Weighing Method' to distinguish it from the 'Segment Picking Method' adapted from System 1.

The formula used to calculate weight/segment at Stage 3 is:

weight/segment = bunches/segment x weight/bunch

The Bunch Counting and Weighing Method makes use of data that must be collected for other purposes and is non-destructive. However, it is less reliable than the Segment Picking Method.

Addition of method to quantify doubt surrounding a forecast
System 2 allows the Coefficient of Variation and sample size of every yield component to be specified. This enables the calculation of 95% confidence limits and an overall Coefficient of Doubt for the estimate of most likely production from each block. Printouts not only include the estimate of most likely production from a block, but also a measure of the reliability (quality) of the forecast.

Addition of a continual improvement system
System 2 includes facilities for comparing forecasts made at each Stage during the season with the actual delivery from a block. For each forecast the difference between forecast and actual production is calculated, and a chart is produced that allows easy visual comparisons to be made. Causes of inaccuracy are detected and summarised simply, so that a forecaster can monitor and review the forecasting process and improve it over successive seasons.

Evaluation of performance of System 1 and System 2

Meaningful comparisons of forecasts made by the growers who managed the blocks we studied with the forecasts we produced using Systems 1 and 2 could not be made, because in a number of cases the growers used our forecasts and data. Consequently, the benchmark we used to assess the performance of Systems 1 and 2 was the mean absolute difference between forecast and actual production achieved by the representative grower from 1996 to 1999 and the representative group of 63 growers in 2000. This was 33% for forecasts provided in January, which would be equivalent to Stage 2.

The forecasts produced at each Stage for each study block in 98/99 and 99/00 and the inputs used to produce them are detailed in the Appendices. General approaches and assumptions are outlined in Research Methodology. The comparisons described here are limited to the 99/00 season.

In the 99/00 season, mean differences between forecasts calculated using System 1 and actual production were +6%, +21% and +11% of actual production at Stages 1, 2 and 3 respectively (Table 4.2.28). This indicates that System 1 tended to overestimate production. At the equivalent stages, the mean differences for System 2 were +11%, +1% and 0% respectively, indicating less bias except at Stage 1. The added Bunch Weighing method at Stage 2 underestimated production by 4% and the added Bunch Counting and Weighing method at Stage 3 overestimated production by 8%. Mean absolute differences at all stages were lower for System 2 than System 1, indicating a general reduction in the deviance of forecasts from actual delivery. Forecasts calculated using System 1 at Stage 2 were not as reliable as at Stage 1, whereas there was less bias and deviance in forecasts calculated using System 2 at Stage 2 than at Stage 1. Forecasts calculated using both Systems 1 and 2 were much more accurate at Stage 3, particularly those calculated using the Segment Picking Method of System 2. The performance of both System 1 and 2, as measured by the mean absolute difference between forecast and actual production, was better than the grower benchmark of ±33% at all forecasting stages.

Table 4.2.28. Mean differences and mean absolute differences between forecast and actual production (% of actual) achieved by Systems 1 and 2 in the 99/00 season.

		Mean difference (%)		Mean abs. diff. (%)	
Stage	**Method**	**System 1**	**System 2**	**System 1**	**System 2**
1	Bunch counting	+6	+11	±30	±27
2	Berry counting	+21	+1	±31	±23
	Bunch weighing		-4		±28
3	Bunch counting and weighing		+8		±11
	Segment picking	+11	0	±14	±6

(The mean absolute difference achieved by growers at Stage 2 was 33% of actual production)

A regression of forecasts of yield (t/Ha) made at Stage 1 using System 2 on actual yield indicated that the overestimation of production at Stage 1 was due mainly to an overestimation at lower yield levels (Figure 4.2.36). A similar regression for the Berry Counting method at Stage 2 revealed that the apparent lack of bias indicated by the mean difference between forecast and actual production (Table 4.2.28) was due to the counteracting effects of an overestimation of lower yields and an underestimation of higher yields (Figure 4.2.37). The Bunch Weighing method at Stage 2 eliminated this bias but was no more reliable (Figure 4.2.38). Both the Bunch Counting and Weighing method and the Segment Picking method consistently produced unbiased and very reliable forecasts at Stage 3 across the whole range of yields (Figure 4.2.39 and Figure 4.2.40)

In the 99/00 season the block of Cabernet Sauvignon at Barooga (Ba Ca) that had been studied in the two previous seasons was lightly pre-pruned during dormancy, but approximately a quarter of the block was not hand pruned afterwards. Consequently, much higher numbers of buds were retained in this part of the block than usual. Because of this drastic change, the block was split into two parts for the purpose of forecasting. The actual yield of the part of the block that was not hand-pruned (Ba Ca 2) was exceptionally high (29 cf. 4 – 15 t/Ha) and had an unacceptably high leverage in regression analyses. Consequently, it was excluded from the regressions shown in Figure 4.2.36 to Figure 4.2.40.

Figure 4.2.36 to Figure 4.2.40. Performance of System 2 in the 99/00 season as indicated by regressions of forecast on actual yield.

The diagonal dotted line indicates the 1:1 relationship.

These regressions exclude Ba Ca 2, because its yield (29 t/Ha) was unusually high and had an unacceptably high leverage.

The regression equation provides measures of bias in the method and the R^2 value provides a measure of reliability.

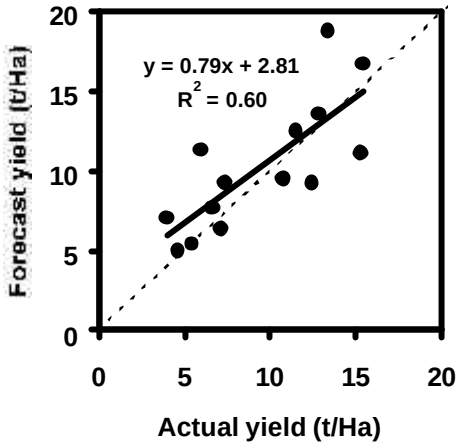


Figure 4.2.36. Performance at Stage 1 in 99/00.

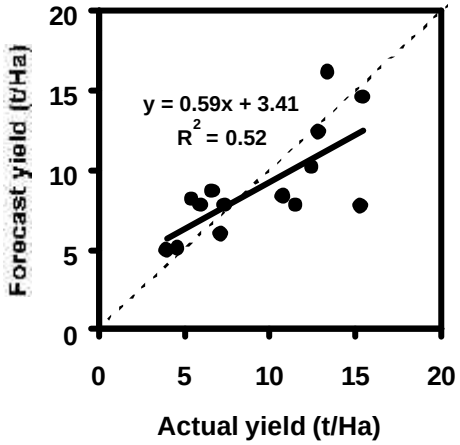


Figure 4.2.37. Performance of Berry Counting method at Stage 2 in 99/00.

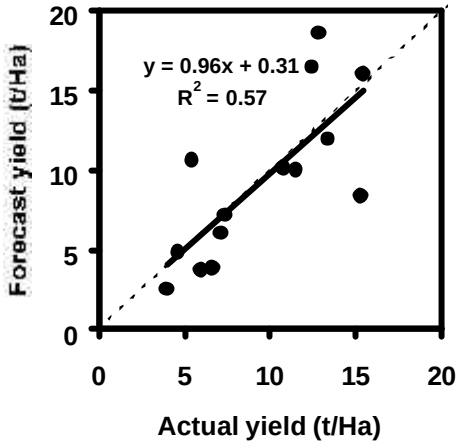


Figure 4.2.38. Performance of Bunch Weighing method at Stage 2 in 99/00.

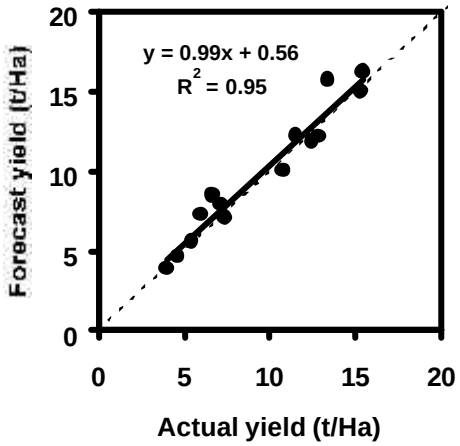


Figure 4.2.39. Performance of Bunch Counting and Weighing method at Stage 3 in 99/00.

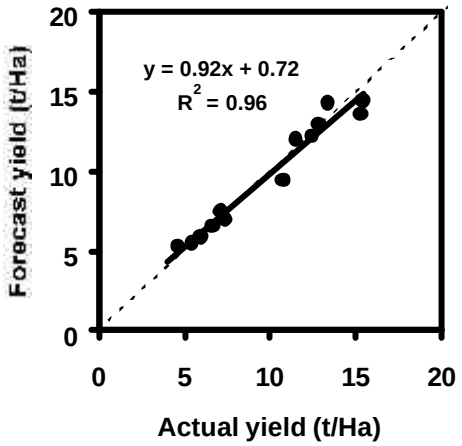


Figure 4.2.40. Performance of Segment Picking method at Stage 3 in 99/00.

Analysis of sources of error in System 2 forecasts

The Ba Ca 2 block that was excluded from the regressions presented above provides an example that can be used as a case study to illustrate the performance evaluation capabilities of the computer-based version of System 2.

The Excel Workbook at the core of the computer version of System 2 uses grower-friendly terminology to refer to the five different methods of forecasting supported (Table 4.2.29).

Table 4.2.29. Equivalent terms used to refer to forecasting methods supported by System 2.

Name of forecast type used in this report	Name in Excel Workbook
Stage 1 Bunch Counting method	6 weeks
Stage 2 Berry Counting method	Post set
Stage 2 Bunch Weighing method	Veraison
Stage 3 Segment Picking method	Harvest (1)
Stage 3 Bunch Counting and Weighing method	Harvest (2)

After all the data have been entered, all the forecasts have been made and the grapes have been delivered a forecaster can enter the actual production of a block and compare the forecasts to it. In the case of the Ba Ca 2 block in 99/00, production was underestimated by 45%, 32% and 19% at 6 weeks after budburst, after fruit set using the Berry Counting method and near veraison using the Bunch Weighing method respectively (Table 4.2.30). Near harvest the Segment Picking method overestimated production by a relatively small 6%, but the Bunch Weighing and Counting method produced a 38% overestimate.

Table 4.2.30. Example of a performance assessment provided by System 2.

Block Ba Ca 2

Season 99/00

Actual production 39.15 tonnes

Production forecasts

Stage	Production (tonnes)			Difference
6 wks after budburst	21.51	±	12.68	-45%
Post set	26.53	±	17.95	-32%
Veraison	31.61	±	20.54	-19%
Near harvest (1)	41.32	±	14.61	6%
Near harvest (2)	54.37	±	19.83	39%

Actual yield 29.13 tonnes/Ha

Yield forecasts

Stage	Yield (tonnes/Ha)		
6 wks after budburst	16.01	±	9.44
After fruit set	19.74	±	13.36
Veraison	23.52	±	15.28
Near harvest (1)	30.75	±	10.87
Near harvest (2)	40.46	±	14.76

The numbers in Table 4.2.30 are easier to digest and understand in the form of a chart (Figure 4.2.41). The error bars indicate the amount of doubt associated with each forecast, which is a result of sampling error and doubt surrounding predictions of yield components from historical records. In the case of the Ba Ca 2 block in 99/00 the differences between the four later forecasts and actual production may have been due to chance, because actual production was inside the 95% confidence interval for each of them. However, actual production was above the upper confidence limit for the forecast at 6 weeks, indicating that the underestimate was unlikely to be due to chance.

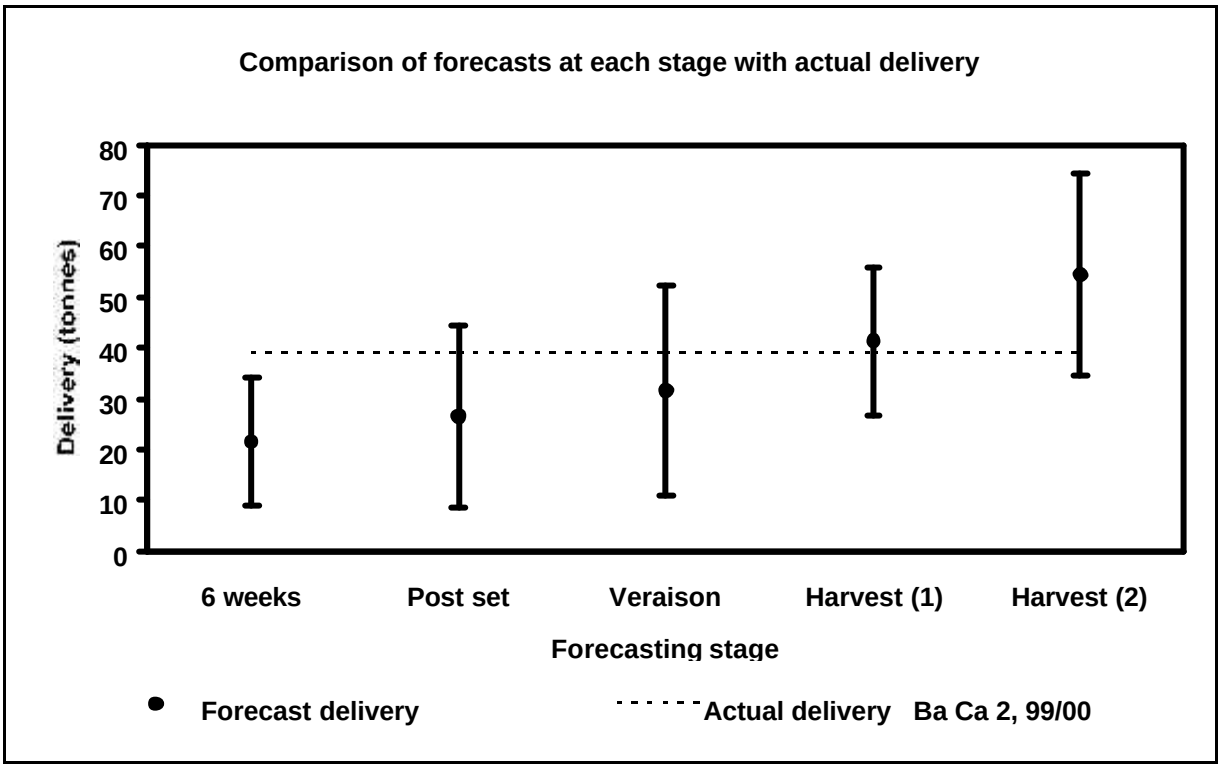


Figure 4.2.41. Example of a performance assessment chart produced by System 2.
The error bars indicate the 95% confidence intervals around the forecasts at each stage.

The reasons for this can be discerned by studying the example of the analysis of sources of forecasting error produced by the System 2 Excel Workbook (Table 4.2.31). Significantly more bunches/segment were counted near harvest than at 6 weeks after budburst. A 25% increase in bunches was allowed for by using a Bunch Gain Factor value of 1.25, but the actual Bunch Gain Factor was 1.82. In addition, it was predicted that the weight/bunch at harvest would be 78 g (recognising the changed conditions and using the mean weight/bunch for all Cabernet Sauvignon sites), but the actual harvest weight/bunch, as measured by dividing weight/segment by bunches/segment, was 105 g. Thus it may be concluded that the large size of the underestimate at 6 weeks was due to the multiplying of underestimates of bunch gain and weight/bunch. This was an unusual case. Much lighter pruning than usual resulted in many more bunches appearing after counting time at Stage 1 and much larger bunches being present at harvest than had been observed in the block in the previous two seasons. Meanwhile, in the rest of the block (Ba Ca 1), which had been hand-spur-pruned a little harder than usual, the bunch gain factor was 1.38 (cf. 1.25 predicted) and the actual weight/bunch was 94 g (cf. 88 g predicted).

These errors were not corrected at Stage 2 because the Stage 1 bunch counts and predictions of bunch gain were used again and the prediction of harvest weight/berry made after fruit set was a significant underestimate. It could not be said that significant berry loss occurred. There was also more weight gain from veraison to harvest than was expected (1.77 cf. 1.50 predicted).

The overestimate at harvest using the Bunch Counting and Weighing method could largely be accounted for by an overestimate of weight/bunch (135 cf. 105) rather than of bunches/segment. This was probably due to a bias towards sampling larger bunches among the many present.

Table 4.2.31. Example of an analysis of sources of forecasting error provided by System 2.

Block	Ba Ca 2
Season	99/00

How well was harvest bunches/segment predicted from bunch counts 6 wks after budburst?

Bunches per segment 6 weeks after budburst	32.83
Bunches per segment near harvest	59.75
Probability of difference being due to chance	0.000 (significantly different)
Predicted bunch gain factor	1.25
Actual bunch gain factor	1.82

How well was harvest weight/bunch predicted 6 wks after budburst?

Predicted mean bunch weight (g)	78

	Sampling bunches	**Picking segments**
Actual mean bunch weight before harvest (g)	135	105
Size of over (+) or under (-) estimate	-42%	-26%
Upper confidence limit	154	115
Lower confidence limit	116	96
Was under- or over-estimate significant?	**yes**	**yes**

How well was harvest berries/bunch predicted from post set berry counts?

Berries per bunch after fruit set	146.63
Berries per bunch before harvest	123.52
Probability of difference being due to chance	0.146 (not significantly different)
Predicted berry loss factor	1.00
Actual berry loss factor	0.84

How well was harvest weight/berry predicted post set?

Predicted mean weight per berry (g)	0.82
Actual mean weight per berry before harvest (g)	1.11
Size of over (+) or under (-) estimate	-26%
Upper confidence limit	1.16
Lower confidence limit	1.05
Was under- or over-estimate significant?	**yes**

How well was harvest weight/bunch predicted from veraison bunch weights?

Mean weight per bunch at veraison	76
Predicted weight gain factor	1.50
Mean weight per bunch predicted at veraison	115

	Sampling bunches	**Picking segments**
Actual mean bunch weight before harvest (g)	135	105
Size of over (+) or under (-) estimate	-15%	9%
Upper confidence limit	154	115
Lower confidence limit	116	96
Was under- or over-estimate significant?	**yes**	**no**
Actual weight gain factor	1.77	1.38

Potential further improvements

These results highlight an urgent need for reliable methods to predict yield components from measurements made in the current season, rather than historical records. To some extent, the need for a method to predict bunch gain could be made redundant simply by counting bunches again at Stage 2. While this would be more tedious than at Stage 1, it may still be worth it. However, methods to predict harvest weight/bunch from some measurement of inflorescences at Stage 1 or bunches in the early stages of development after fruit set would be particularly valuable.

Prediction of berries/bunch from counts of branches/bunch

The inflorescences of grapevines (referred to in this report as 'bunches') are fractal branching structures. A main axis carries primary side branches which are themselves 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) and can be very variable in form. Within a block of vines at any one time one may find many transitional forms of Branch 1, ranging from a bunch-like structure rivalling the main axis in size through smaller sizes to a presence as a tendril, or it may be missing all together. The size of the rest of the primary branches tends to decrease towards the apex of the bunch, giving grape bunches their familiar conical shape. At harvest larger bunches have more branches and more berries. At Stage 1 larger bunches have more branches and more flowers. May (1987 and 2000) analysed relationships of branches/bunch to flowers/bunch and berries/bunch for Pinot Noir in Burgundy and Chardonnay in South Australia and concluded that branches/bunch was not an adequate predictor for forecasting purposes. However, in an experiment conducted in a block of Cabernet Sauvignon at Dookie in 98/99, we found that branches/bunch predicted 68% of the variation in flowers/bunch (Figure 4.2.42). Typically, counts of flowers/bunch are not normally distributed and it is appropriate to apply a square root transformation to the data. When this was done, counts of branches/bunch predicted 74% of the variation in flowers/bunch (Figure 4.2.43).

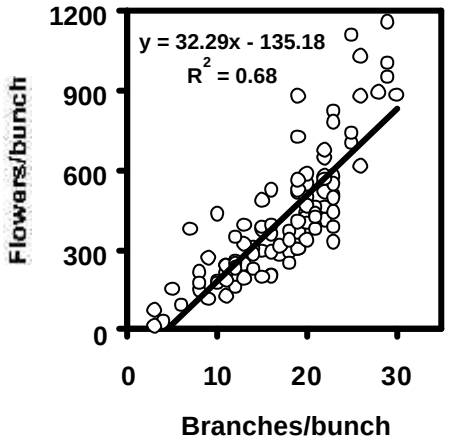


Figure 4.2.42. Relationship between flowers/bunch and branches/bunch in Cabernet Sauvignon at Dookie in 98/99.

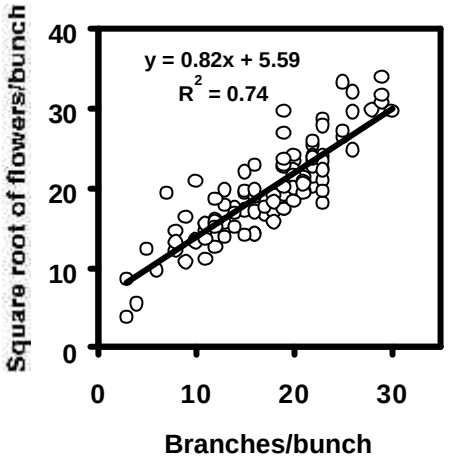


Figure 4.2.43. Relationship between the square root of flowers/bunch and branches/bunch in Cabernet Sauvignon at Dookie in 98/99.

There was a significant 14% decrease in the number of branches/bunch from the time when flowers were counted before flowering until the time when berries were counted after fruit set (Table 4.2.32). Thus, there could be a case for the inclusion of a ***branch loss factor*** in any forecasting formulae that may be developed to predict berries/bunch from counts of branches/bunch before flowering.

Table 4.2.32. Change in branches/bunch from before flowering to after fruit set in Cabernet Sauvignon at Dookie in 98/99.

Mean branches/bunch pre-flowering	17.77
Mean branches/bunch post-set	15.19
Two sample t-test p	<0.001
Branch Loss Factor	0.86

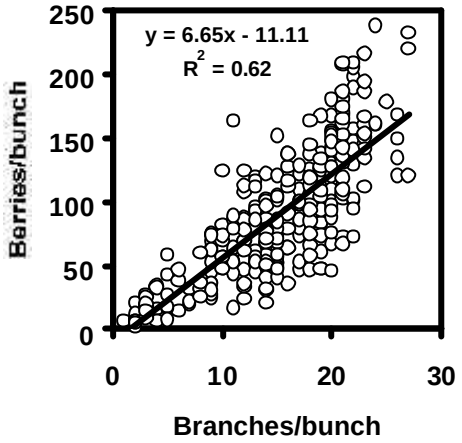


Figure 4.2.44. Relationship between berries/bunch and branches/bunch in Cabernet Sauvignon at Dookie in 98/99.

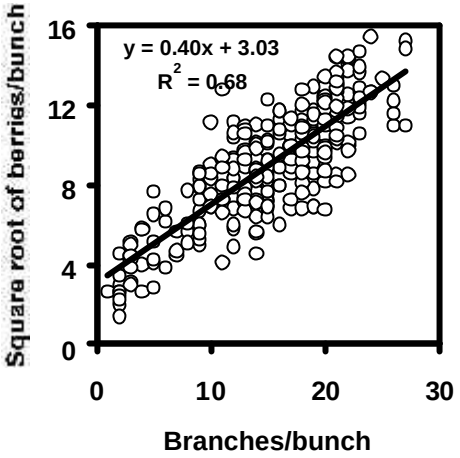


Figure 4.2.45. Relationship between the square root of berries/bunch and branches/bunch in Cabernet Sauvignon at Dookie in 98/99.

After fruit set, branches/bunch was not quite as good a predictor of berries/bunch as of flowers/bunch (Figure 4.2.44 cf. Figure 4.2.42), but it still predicted 68% of the variation in the square root of berries/bunch. The regression equations presented above include intercepts. For the purposes of forecasting, these could be omitted with only a small loss of predictive power. If this was done, berries/bunch could be predicted from counts of branches/bunch before flowering using the following formula:

berries/bunch = branches/bunch x branch loss x berries/branch

Berry loss from approximately a month after fruit set would also need to be considered. It is acknowledged that this method would still fail to predict approximately 30% of the variation in berries/bunch, but it may prove to be superior to the use of historical mean weight/bunch. It has the potential to detect large seasonal deviations of weight/bunch 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.

Prediction of weight/bunch from early in situ measurements of bunch volume

In theory it may be possible to predict weight/bunch at harvest from measurements of weight/bunch at an earlier stage. A number of approaches have been suggested at various times in the past. For example, May (Pers. Comm.) has explored the possibility of projecting an estimate of harvest weight/bunch from measurements made at two times during the first stage of bunch development after fertilisation. If harvest weight/bunch could be predicted from early measurements of bunch size it would be advantageous to be able to measure the developing bunches non-destructively and in situ. An displacement apparatus that could potentially be used for this purpose has been used to measure the volume of table grape bunches at a later stage of development (Islam et al, unpublished).

During the 98/99 season, we supervised a student project which investigated relationships between in situ measurements of volume/bunch and measurements of the volume, dimensions, fresh weight and dry weight of the berries and rachis in the laboratory, and which succeeded in developing a prototype of an improved displacement apparatus for in situ measurement of small bunches. The report on this project is appended (Hoogenraad, unpublished).

Forecasting during dormancy

Results of measurements of forced single node cuttings and dissected buds made during dormancy in the course of the project are included in a separate section of this report.

4.2.5 Discussion

Processes in wineries and throughout the product distribution chain are sensitive to differences between forecast and actual production at a vintage by vintage, variety by variety level. Therefore meaningful measures of the performance of a forecaster are the sums and means of the percentage differences and absolute differences between forecast and actual deliveries. The wine company that provided the forecast and delivery data that we analysed uses the mean absolute difference as a measure of the performance of its vineyard managers.

Our study of the forecasting behaviour of growers throughout Victoria has shown that generally they have a good feeling for the mean capability of their vineyards. Consequently, they take this as their starting point when they forecast the weight of grapes of a given type that they will deliver to a winery. Growers know that yields vary from season to season, and they usually adjust forecasts up or down from the long term mean. However, as a rule, they do not adjust by as much they need to.

The production of some vineyard blocks can be relatively constant from season to season. Consequently, growers who provide forecasts of deliveries from these blocks cannot go far wrong if they stay close to a long term mean. However, it is not unusual for the production of typical, well-managed blocks to deviate from the long term mean by ±40%. Growers rarely have the confidence to vary their forecasts by this much, so they tend to overestimate production in low-cropping seasons and underestimate it in high-cropping seasons.

In principle, this human bias can be eliminated by basing forecasts on objective measurements of factors in the vineyard that can indicate the behaviour of the grape production system. May (1971, 1972) recognised this and defined a protocol that provided the basis for the development of System 1 by the CSIRO team at Merbein in 1997. The formulae used in System 1 were based on the reasonable and generally-held assumption that the weight of grapes present in a block at harvest could be predicted by quantifying vines/block, bunches/vine, berries/bunch and weight/berry. It was reasonable to expect that forecasts would become more accurate at succeeding stages.

In practice, System 1 can detect the direction of deviations from long term mean production as early as Stage 1, because much of this deviation is due to bunches/vine, which are counted at this stage. However, the differences between the forecasts it produced for the blocks we studied and actual production were still relatively large (averaging in the order of ±30% at Stage 2). We found that this was due to the previously unsuspected phenomena of bunch gain and berry loss, the omission of an allowance for harvest inefficiencies, inadequate sample sizes, sampling bias, and a reliance on historical means as predictors of weight/bunch and weight/berry.

System 2 incorporates features that reduced the size of the differences between forecast and actual production for the blocks we studied. However, the mean absolute difference at Stage 2 in 99/00 remained above 20%. We have shown that, in theory, this could have been reduced further by specifying a smaller Tolerance of Doubt when calculating Best Sample Sizes. It is important to recognise that the performance of System 2 in 99/00 at the sites we studied was limited by the standard 15% Tolerance of Doubt that we used and a lack of historical data. The system itself is capable of much better performance. However, it would probably not be possible to achieve a mean absolute difference much less than 20% while so many components of the forecasting formulae are predicted from historical means.

System 2 incorporates a reliable block survey system, improved measurement techniques and new components in its formulae, but further improvement of prediction techniques is needed. At present the major sources of inaccuracy are inadequate prediction of bunch gain from Stage 1 to harvest, harvest weight/bunch at Stage 1, berry loss from Stage 2 to harvest and bunch weight gain from veraison to harvest. With the exception of bunch gain, all of these are related in some way to bunch development during the season, and there is a prospect that early measurements of bunches could be used to predict later development. These are the subject of continuing research.

At the end of the 99/00 season, System 2 was available to forecasters in paper-based and computer-based forms, supported by documentation, and some pilot training exercises had been run with grower groups. The main need at this stage was to facilitate further adoption.

4.2.6 Implications and Recommendations

When winery personnel are asked to define a tolerance for differences between forecast and actual deliveries they typically specify ±5%. If this is a limit, rather than a mean, then the target mean difference would be less than 5%. While it is possible that the blocks we studied were more difficult to forecast on average than across the industry at large, our results suggest that a target mean absolute difference of 5% would probably be impossible to achieve with existing technology in most circumstances. This would not be due to any fault of forecasters, but rather to the intrinsic unpredictability of grape production systems.

At first this news may seem disappointing. However, the biggest cause of such disappointment would be expectations that were probably never realistic. It would be better to focus on where the industry is now and the potential for improvement that would be achievable over the next few seasons using the relatively simple, low technology, counting and weighing processes of System 2.

Any disappointment might be evaporated by quantifying the financial value of an apparently small reduction in the mean absolute difference between all of the forecasts provided by growers to wineries throughout the industry. It is possible to provide numerous anecdotal examples of the financial impact of inaccurate forecasts. For example, in consultation with winemakers we have calculated that the cost of a style change forced by delivering 110 t of premium Shiraz when 80 t was forecast would be $22,500 to the winery. If the 40 t was scheduled to be delivered one day and 40 t on the next, but at the end of the first day the grower informed the winery that there was 70 t still to pick, and the winery decided to delay picking for a week, the cost to the grower due to weight loss could be $4,900. However, it is difficult to extrapolate from such anecdotes to the industry as a whole.

There is a simpler but coarser approach that can give us a rough estimate of the total cost of forecasting inaccuracy to the industry at present. If the total revenue of the industry is in the order of $2 billion per year, total expenditure is approximately 85% of revenue, approximately 10% of that expenditure is associated with establishing and maintaining systems to cope with seasonal variation of grape production, and 50% of that could be avoided if forecasts were 100% accurate, then the total cost of inaccurate forecasts would be $85 million per year. If the mean absolute difference between forecast and actual deliveries is 33%, then an improvement by 1% (e.g. to 32%) would save the industry approximately $2.5 million per year. If the industry as a whole adopted System 2 and reduced the mean absolute difference for all forecasts made in Australia from 33% to 22%, then the industry would be better off by approximately $28 million per year. Even if these figures are not very accurate, it is clear that a very large financial benefit would flow from an apparently small improvement in the accuracy of forecasts.

In any given region, some growers are legendary for their 'knack' of forecasting accurately. They personally may not benefit from using a measurement-based system. However, as we have seen, on average growers produce forecasts that are about 33% out, and it follows that the forecasting performance of approximately half of all growers would be worse. A subjective "knack" of forecasting accurately is difficult to impart to new industry trainees and may not be transferable to other conditions. What's needed is a set of documented procedures that can be taught and that, if followed, will assure a level of performance that can be measured.

Due to the unavoidable necessity of estimating true population means from sample means, an element of chance is introduced into the production of inputs to crop forecasting formulae, and hence into the production of forecasts. We have shown how 95% confidence limits can be determined for forecasts of most likely production. One implication of this is that there is a 5% chance that the actual delivery will be outside these limits. Put another way, even if a rigorous measurement-based forecasting system were to be used throughout the industry, the actual delivery would be outside the confidence limits for one in every twenty forecasts. Thus forecasting is to some extent a game of odds. It is quite possible that a superior forecasting system would produce a less accurate forecast than an inferior system in one block in one year, just by chance. However, over many blocks and seasons the superiority of a system would become apparent. Therefore, anyone comparing the performance of crop forecasting systems should do so across as many blocks as possible and preferably over a few seasons, as we have done.

There is a need to continue to measure blocks using standard techniques over many years to build up our knowledge of seasonal variability. Ideally, funding of research should allow continued measurement of at least some of the blocks we studied from 97/98 to 99/00. Due to a shift in research priorities we have not been able to continue these measurements in the 00/01 season. This is a pity, because more information would be useful to

assess the seasonal variability of both the well-known and newly-discovered yield components in the System 2 formulae.

It may be useful for the industry to regard forecasts as products in their own right, rather than confusing them with grape deliveries. This way of thinking leads to the following questions: How can a winery know how 'good' a forecast is? Who might produce the best quality forecasts? Who should pay for forecasts and how much are they worth?

Traditionally, forecasts have been provided to wineries in the form of one number, with no quantification of its reliability. As we have seen, the reliability of forecasts varies considerably from grower to grower, block to block and year to year. Everyone in the industry knows that there is some element of doubt surrounding each forecast due to the variability of the system they depend on. Given this, it is somewhat surprising that the nature and implications of this variation have not been given more attention. Ignoring its implications produces unrealistic expectations and conflict. This could be avoided if more people in the industry understood variation and knew how to measure it. System 2 provides procedures to do this and a method to quantify the doubt surrounding each estimate of most likely production from a block. Placing confidence limits around forecasts provides a measure of their quality to the customers of the forecasting process. So we would recommend that wineries seek and forecasters learn how to provide forecasts in the form of two numbers. For example, forecasts provided in January and a week before harvest for the Chardonnay block in Southcorp's vineyard at Barooga would be provided as 265 ± 167 tonnes and 236 ± 71 tonnes respectively. We would expect growers and grape intake planners to be somewhat shocked when confronted for the first time with a large zone of doubt like the one around the January forecast. Understandably, there may be a reluctance to provide or accept such a measure of reliability, but we would argue that it is realistic and that the industry would be better off knowing about it and considering its implications. It should be remembered, too, that it is more likely that the actual delivery would be nearer to the estimate of most likely production than the confidence limits, due to the bell-shaped nature of the probability distribution.

The accuracy (quality) of a forecast depends on the extent to which the formula used mirrors reality and the accuracy of the numbers used in the calculation. There is a strong pressure placed on system developers by growers to produce systems that are easy to implement. In the past, researchers, system developers, extension staff and technical personnel in the industry have shied away from proposing a system that involves 'too much' sampling or a requirement to understand statistics. This is understandable, because growers are 'hands on' people who are good at producing grapes but may not be particularly good at maintaining records or carrying out mathematical procedures. However, skill levels throughout the industry are increasing and technology is now available in the form of statistical calculators and computers that can greatly simplify and speed up the tasks of data management, calculation and reporting. A compromise that resulted in a forecasting system that is easy to implement but unreliable would be false economy, because the costs of implementation of a superior system are relatively small compared with the potential benefits. We wish to emphasise that System 2 is not particularly difficult to implement and does not contain luxurious elements insisted on by pedantic statisticians and 'ivory tower' research scientists.

At first sight, System 2 may appear to be complex. A survey of opinions in the industry and the literature published on the subject of crop forecasting reveals an understandable desire for a simple 'magic bullet' method or a gadget that can do the job. However, as with most things, we in the industry need to and in most cases do recognise that the grape production system is complex, dynamic and sensitive to many factors. Some of these contribute more to the seasonal variation of grape production than others and it makes sense to give them priority in a measurement process, but no single factor can predict yields very well. Consequently, it is reasonable to expect some complexity in a system designed to predict an aspect of its behaviour.

The accuracy of forecasts depends on the reliability of the numbers that go into them, so we need a process to assure the quality of these numbers. At present, growers who practice some form of measurement-based forecasting tend to use inadequate sample sizes, and hence tolerate more doubt than they realise. For example, where 10 vines per block are used to estimate mean bunches/vine in a block where the CV is 40%, the Coefficient of Doubt would be approximately 25%. Inadequate sampling is a key reason why forecasts are not as accurate as the industry would like at present. We cannot get around this, because of the intrinsic variability of vineyards and the accuracy that is needed to satisfy grape intake planners. If we duck the issue of sampling, a level of inaccuracy will be built into forecasts that will limit their reliability. No standard sample size can be specified for the industry. Adoption of a single standard would result in unreliable forecasts from more variable blocks and wasted sampling time in less variable blocks. Each of these would impose unnecessary costs on the

industry. The Coefficients of Variation and Best Sample Sizes should be determined for each component in each block.

At present growers often measure whole vines and, in some cases, whole 'panels' of vines between trellis posts. However, growers commonly use a sample size of 10 or sometimes 20 such units. Our results suggest that these growers are wasting time on counting excessively large units. They would be better off spending that time counting more, smaller segments, thus producing more reliable estimates of sample means at a lower cost. We have found that a segment length of 60 cm provides good all round results and sampling efficiencies. There is nothing magical about the 60 cm length. In some circumstances it may be more economic to use a different length.

The cost of running System 2 would be approximately $650 per block per year. This is an extra cost that wineries would be asking growers to bear, and would be a disincentive to adoption unless some form of compensation is provided to growers. Even if growers are not given an explicit incentive in the form of direct payment, it would be in their collective interest to adopt better forecasting systems, because some of the benefit to the industry as a whole would be distributed back to them. However, given that wineries stand to be much greater beneficiaries of improved forecasting methods than growers they might consider providing more direct financial signals or simply paying for forecasts. Wineries and growers would be well advised to consider the option of encouraging and supporting the establishment of professional forecasting services in their districts.

Another potential barrier to adoption is that, at first sight, System 2 may appear to require time and skills that growers feel they may not have. Some grasp of simple statistical principles and methods is needed. The dreaded 'statistics' is often avoided when considering the development of training programs for growers. However, it cannot be avoided all together in relation to crop forecasting. It is not necessary to put forecasters through a theoretical statistics course. We have tried to circumvent potential adoption problems by incorporating simple 'fill in the box' forms into System 2. With basic arithmetic skills and a calculator with statistical functions a secondary educated person can check sampling adequacy, produce a forecast and place an estimate of reliability around it. The computer system performs 'behind the scenes' calculations and produces printouts of forms, summary tables and performance charts.

In the period between the end of the project and the completion of this report a Training package as been developed and extended to 5 grapecheque groups and a group of growers supplying Beringer-Blass. This training program consists of a half-day session at Stages 1 and 2, and a 2 hour session at Stage 3 and after harvest. Thus an improved crop forecasting 'kit' is now available to the industry that caters for forecasters with and without computers. There is now a need to facilitate its adoption and to continue to improve the capabilities of the System.

4.2.7 References

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4.3 Forecasting Yield Potential During Dormancy

4.3.1 Introductory Technical Information

Node fertility, expressed as the number of inflorescences per node, is largely determined well before latent buds enter dormancy. If node fertility could be reliably estimated during dormancy managers could use this information as a guide for regulating yield through varying pruning regimes. It is important to understand, however, that the number of bunches per vine appearing after budburst (in spring) is also affected by budburst (ie. lower budburst means fewer bunches per vine) and any condition that may damage latent buds (eg. Primary Bud-Axis Necrosis (PBN) or bud mite). Also, there is some evidence that temperature conditions at budburst may directly affect the number of bunches per shoot (Pouget 1981). However, under the normal range of conditions encountered in vineyards this effect is likely to be small in comparison to the effect of budburst.

There are 2 methods used to estimate node fertility. The first is to dissect dormant latent buds. To use this method one requires a dissecting microscope and a detailed knowledge of bud anatomy in order to interpret and describe relatively small, translucent structures. The second method is to 'force' single-node cuttings to burst and, after an appropriate time (usually 2 weeks), count inflorescences on young shoots. May and Cellier (1973) used this technique to study annual variations in 'fruitfulness'. Recently, however, it has been used by industry to predict yield potential (eg. McMichael and Robinson 1998). To estimate bud fertility using this method one does not need a dissecting microscope or a detailed knowledge of bud anatomy. However, it is relatively labour intensive and one has to wait until a reasonable number of buds have burst and until shoots have elongated enough for all of the inflorescences to be counted. This may take up to 6 weeks. Furthermore, the temperature of the environment may lead to experimental artefacts as temperature itself is an important determinant of budburst and, perhaps, bunches per shoot (Pouget 1981).

This section of the report addresses two major questions associated with using forced single node cuttings to estimate yield potential: First, how reliable is the technique? Secondly, how important is the temperature of the environment in which cuttings are forced to burst?

4.3.2 Research Methodology

Reliability of the Technique

In 1997 one cane was sampled from each of 10 vines selected from 42 vineyard blocks. These vines were tagged and their row-vine address within the block was recorded. The canes were stored in plastic bags containing some water at approximately 4°C. The nodes on each cane were numbered in ascending acropetal order and the lowest 14 were divided into single-node cuttings. Each single node cutting was placed vertically with the wood below the bud in moist sand. Each bud was painted with a solution of Dormex and then forced by being held constantly at 20°C under NEC Biolux BR fluorescent tubes. Each cutting was monitored daily for budburst, which was defined as the time when the serrated edge of a leaf was first visible. This corresponds with modified Eichorn and Lorenz stage 04 (Coombe 1995). Each cutting was measured 14 days after budburst. The measurements were: cutting length, cutting diameter, shoot length, shoot diameter, number of bunches, and the fresh weight of each bunch. Statistics were calculated for each block, particularly mean shoots/node and bunches/node for each node position along the cane. A modified Merbein Bunch Count (based on Antcliff *et al.* 1972) was done 4-6 weeks after budburst for each vine from which canes were sampled in 22 of the 42 blocks sampled. Statistics for each block were calculated, particularly mean bunches/vine.

In 1998, 14 vineyard blocks were sampled (see Section 8). Twenty canes were randomly selected from each block and 15 of these were 'forced' to burst and monitored as above except that the temperature of the 'forcing' environment was set at 27^{o}C. As with 1997, a modified Merbein Bunch Count was done in each vineyard block on a set of randomly selected vines (not necessarily the same vines from which canes were collected) 4-6 weeks after budburst.

Temperature of the 'Forcing' Environment

As part of the 1997 collection (see above) eight extra canes were collected from three cvs (Shiraz, Cabernet Sauvignon and Chardonnay) at three vineyards *viz*. Chateau Tahbilk in the Goulburn Valley, Mount Helen in the Strathbogie Ranges and Lakeside at Rutherglen. These canes were 'set' as above in eight trays except that the

single nodes were randomly arranged within the trays. Two trays each were put into one of four environments: (1) A constant temperature room maintained at 20°C (CT 20°C), (2) a constant temperature room maintained at 27°C (CT 27°C), (3) a small growth cabinet incubator maintained at 20°C (GC 20°C) and (4) a small growth cabinet maintained at 27°C (GC 27°). Because the growth cabinets were much smaller than the constant temperature rooms and the cutting trays had to be well watered, relative humidity in the growth cabinets was higher and more variable (75-90%) than in the constant temperature rooms (45% and 60%). Each cutting was measured 14 days after budburst. Shoot length, the number of bunches per shoot and the node position of each bunch was recorded.

4.3.3 Detailed Results

Figure 4.3.1 shows the proportion of bursting nodes averaged across all 14 sites in 1998 for the three cvs Cabernet Sauvignon, Chardonnay and Shiraz. It illustrates an important feature of all of our experiments involving 'forced' single node cuttings. That is, the proportion of lower nodes (ie. nodes 1 to 3) bursting was invariably low.

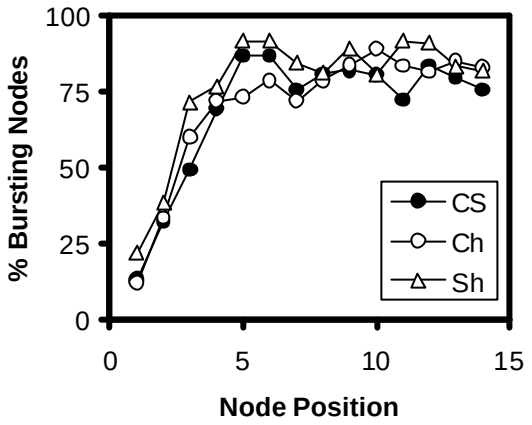


Figure 4.3.1 Percentage budburst of 'forced' single node cuttings of cvs Cabernet Sauvignon (CS), Chardonnay (Ch) and Shiraz (Sh) collected in 1998 from 14 sites across Victoria.

'Forced' single node cutting estimates of bunches per shoot are presented for burst shoots from Cabernet Sauvignon, Chardonnay and Shiraz collected from the same vineyard (Lakeside vineyard near Rutherglen) in 1998 (Figure 4.3.2). As these blocks were all spur pruned, estimates from only the lower nodes have been compared with 'actual' bunch counts made in the same blocks 4 - 6 weeks after budburst (Figure 4.3.3). The data indicates that the 'forced' single node cutting technique was a poor predictor of bunches per shoot, at least from lower nodes in these spur pruned vineyard blocks. This was true for most of our sites over 2 seasons (data not presented).

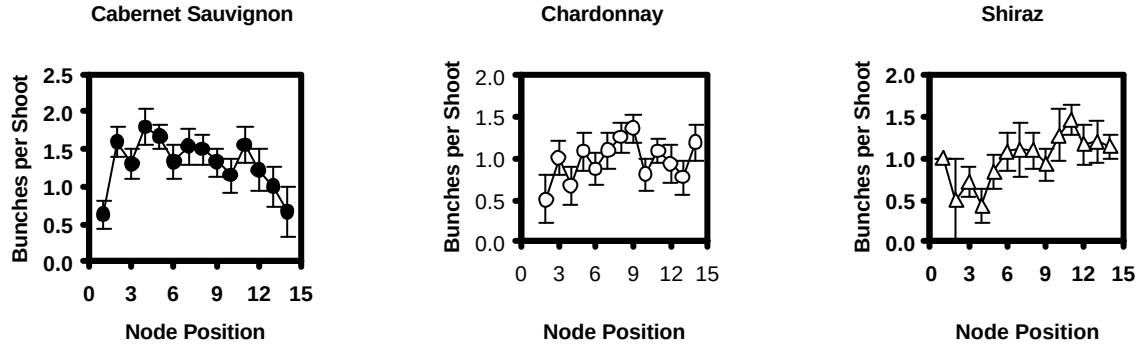


Figure 4.3.2 Bunches per shoot of 'forced' single node cuttings of Cabernet Sauvignon (a), Chardonnay (b) and Shiraz (c) collected from Lakeside vineyard (near Rutherglen) in 1998. Error bars shown are ± SE.

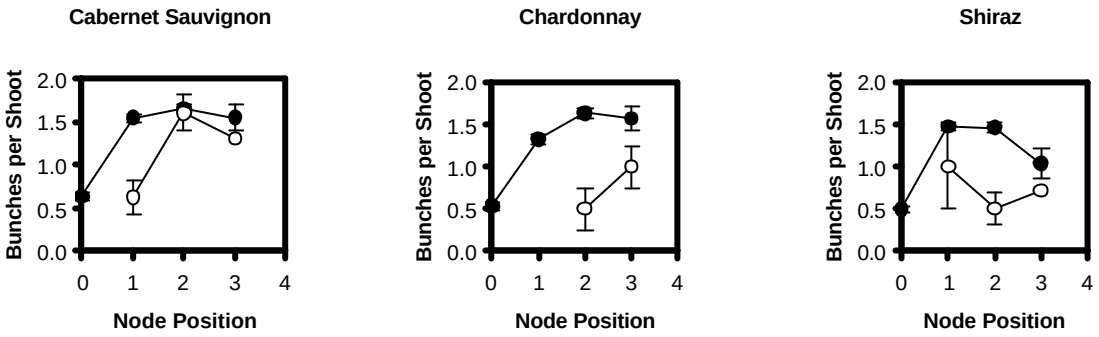


Figure 4.3.3 A comparison of 'forced' single cutting estimates of bunches per shoot (open circles) with 'actual' bunch counts (closed circles) made 4 - 6 weeks after budburst at Lakeside vineyard near Rutherglen in the 1998/99 season

Increasing the temperature of the 'forcing' environment increased budburst (Figure 4.3.4). There also seemed to be a positive interaction with relative humidity. The highest temperature and relative humidity environment (GC 27) showed the highest budburst. However, despite the positive effect of increased temperature on budburst, budburst from lower nodes was still relatively poor (Figure 4.3.5).

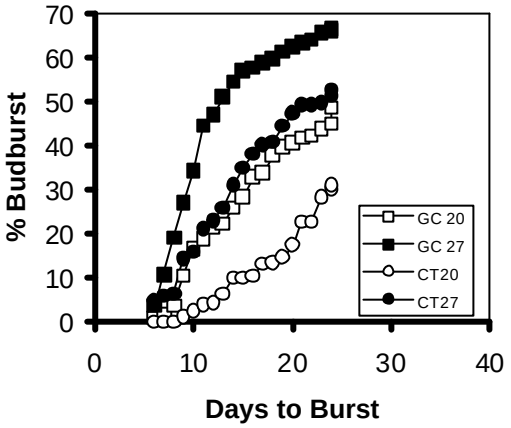


Figure 4.3.4 The effect of temperature on budburst of Cabernet Sauvignon single node cuttings.
Environments are: growth cabinet at 20°C (GC 20), growth cabinet at 27°C (GC 27), constant temperature room at 20°C (CT 20) and constant temperature room at 27°C (CT 27). Relative humidity in growth cabinets was higher than in constant temperature rooms (see text).

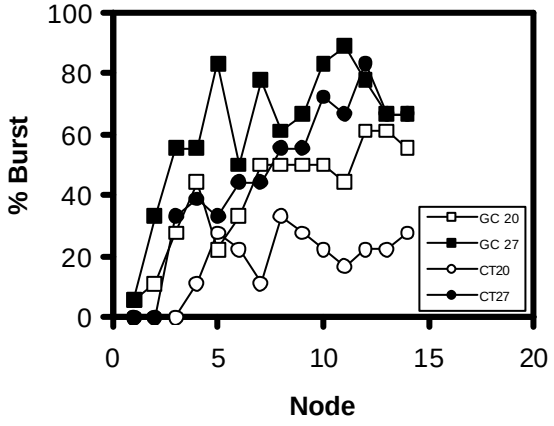


Figure 4.3.5 Effect of node position on percentage budburst of Cabernet Sauvignon single node cuttings.
Environments are: growth cabinet at 20°C (GC 20), growth cabinet at 27°C (GC 27), constant temperature room at 20°C (CT 20) and constant temperature room at 27°C (CT 27).

Increasing temperature of the bursting environment from 20°C to 27°C had no significant effect on the number of bunches per primary shoot (Figure 4.3.6).

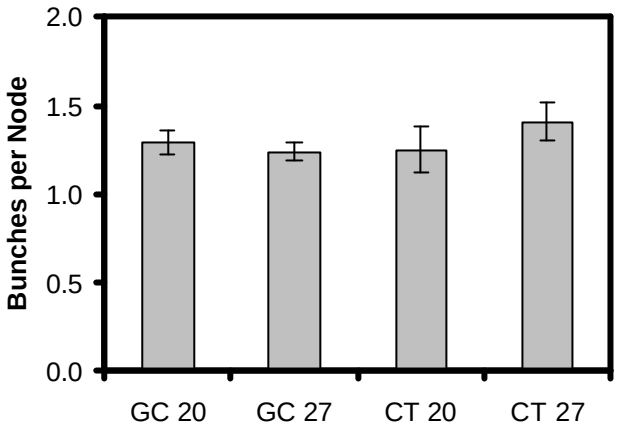


Figure 4.3.6 Effect of temperature on bunches per shoot of Cabernet Sauvignon single node cuttings
Environments are: growth cabinet at 20°C (GC 20), growth cabinet at 27°C (GC 27), constant temperature room at 20° C (CT 20) and constant temperature room at 27°C (CT 27).

4.3.4 Discussion

As budburst from lower nodes was consistently poor we cannot recommend forcing single node cuttings for use in spur pruned vineyards. McMichael and Robinson (1998) suggest that bursting from lower nodes can be improved if they are attached to older wood. However, we tried this with no noticeable improvement (data not presented). Although poor budburst from lower nodes is likely to be due, in part, to incidence of PBN this cannot explain the phenomenon entirely. Budburst from these nodes measured in the field was always higher. This problem was identified by May (1961) who made a full-scale comparison of the 'forcing growth' technique with bud dissection to estimate fruiting potential of the Sultana. To begin with May only set cuttings from node 3 and above. Furthermore, after four months any buds that had not burst were examined microscopically. Low budburst also has implications for the number of nodes that one would need to set to obtain a reliable estimate. Coefficents of variation (CVs) for this sort of data are at best around 40% but can range up to and above 80%. Thus, for node 1 where budburst is often less than 25%, to obtain a reliable estimate (assuming a CV of 40%, with a 95% confidence level and an allowable error of 15%) one would need to set more than 120 single node cuttings.

Aside from difficulties associated with budburst, the low predictive capacity of the technique (Figure 4.3.3) presents further problems. No doubt some of this is due to the low number of shoots that actually burst. Further research would be required to ascertain to what extent the problem is due to low sample size rather than the technique itself.

Pouget showed that higher temperature during budburst led to an increase in bunches per shoot. For Cabernet Sauvignon, bunches per shoot increased from 1.32 to 1.72 as temperature was increased from 12°C to 25°C. It is difficult to explain our results, which show no response to a temperature increase (20°0 to 27°C) imposed over the same time period for the same cultivar. It may be that there is a threshold at around 20°C and that above this threshold increasing temperature will not increase bunch formation. It is still possible however that by forcing cuttings to burst at 20°C one might be overestimating bunches per shoot as air temperature during budburst is likely to be much lower.

4.3.5 Implications and Recommendations

The project team cannot recommend the use of forced single node cuttings to estimate yield potential during dormancy, at least for spur pruned or tightly hedged vines. Although the technique does not require a dissecting microscope or a detailed knowledge of bud anatomy, it is relatively labour intensive and, in our opinion this time would be better spent acquiring the necessary skills and knowledge to dissect latent buds. Furthermore, difficulties associated with poor budburst from lower nodes and uncertainty surrounding any temperature effects render the technique even more problematic. Estimating bud fertility by microscopic dissection has the

advantage of being quick (at Tatura a skilled person can process approx. 15 buds per hour) and instantaneous. This means that information on node fertility is available soon after buds are collected. Variances around sample means can be calculated and if more buds need to be collected and dissected for a better prediction then this can be easily done. Another advantage of dissecting buds is that bud damage or the conditions which can lead to bud damage (eg. mite infestation) can be detected. Early results from project CSP\02 where indicate that if proper care is taken, and some simple rules are applied, bud dissection is a reliable method for estimating yield potential during dormancy. This research will be continued for a further 2 seasons to (i) test its usefulness across varieties, management systems and climates and (ii) develop appropriate sampling strategies and procedures.

4.3.6 References

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5 Analysis of Historical Data Sets

An objective of the project was to assess regional and seasonal impacts on crop potential and final yield using historical data sets, within the context of developing systems for forecasting and controlling seasonal fluctuation of wine grape yield. At the outset of the project a number of sets of long term yield and crop component data were reputed to exist in various research and commercial archives throughout Australia. It was anticipated that these could be collected and analysed to provide a base line for future research and development.

During the life of the project, the combined CSIRO Merbein and NRE Tatura team contacted current and retired researchers and commercial viticulturists in search of potentially useful historical data sets. In many cases, the reputation of the data sets exceeded their quality. In other cases, possessors of potentially useful data sets offered to provide them but did not deliver them. However, useful data sets were collected and analysed.

5.1 Analyses of Seasonal Yield Variation (Greater Victoria)

5.1.1 Introductory Technical Information

This section reports on analyses of data sets collected by the NRE team at Tatura. In seeking and analysing historical data sets, the primary aims of the team were:

- to assess the size of seasonal yield variation in a range of climates
- to identify the most important causes of yield variation
- to identify priorities for measurement and control of yield variation

5.1.2 Research Methodology

Ultimately the most useful sources for the NRE Tatura team were other NRE staff and a large Victorian winery (identity withheld for reasons of confidentiality). The data sets from the Victorian winery consisted of production totals for varieties within individual vineyards over the vintages from 1982 to 1998. These were analysed mainly with a view to quantifying the impact of variation in commercial vineyards and the potential application of statistical process control techniques to wine grape production. The NRE data sets were from a trial conducted at Wahgunyah from 1947 to 1972 and 12 other trials conducted at various locations throughout Victoria during the 1970s, 80s and 90s (Table 5.1.1). The duration of these latter trials ranged from 4 to 8 years. Typically, for each vine, the measurements made were weight/vine, bunches/vine and weight/berry, from which weight/bunch and berries/bunch were derived. In some cases nodes/vine and shoots/vine were also measured. Other miscellaneous data sets were collected but are not reported on here. Relationships between crop components, treatments and environmental factors were analysed using regression, analysis of variance and residual maximum likelihood methods.

Table 5.1.1. Department of Natural Resources and Environment data sets.

Vineyard	Location	Variety	Treatments	Duration
All Saints	Wahgunyah	Cabernet Sauvignon	Rootstocks	1983-87
All Saints	Wahgunyah	Chardonnay	Rootstocks	1982-87
All Saints	Wahgunyah	Shiraz	Rootstocks	1980-87
Baileys	Glenrowan	Brown Muscat	Rootstocks-virgin site	1983-87
Baileys	Glenrowan	Brown Muscat	Rootstocks-replant	1983-87
Bests	Great Western	Pinot Noir	Rootstocks	1993-97
Brown Brothers	Milawa	Brown Muscat	Rootstocks, trellises	1982-87
Dept. Agric.	Mid Area, Mildura	Muscat of Alexandria	Clones	1977-81
Dept. Agric.	Wahgunyah	8 varieties	Rootstocks	1947-72
Kings Creek	Bittern	Pinot Noir	Rootstocks	1993-96
Moorooduc Est.	Moorooduc	Cabernet Sauvignon	Rootstocks	1993-96
Mt Helen	Tarcombe	Pinot Noir	Pruning, irrig., crop	1995-99
Warramate	Gruyere	Cabernet Sauvignon	Rootstocks	1993-96

5.1.3 Detailed Results

In order to communicate our findings as simply as possible, we present the results of some relatively crude statistical analyses. More sophisticated analyses were conducted, but their presentation here is not necessary to support our conclusions. Furthermore, in this report we have attempted only a summary of the results of the analyses of all the data sets collected. Selected examples are used to highlight key findings. We intend to publish more detailed results in a series of journal articles. We welcome interested readers to contact us in the interim.

Size of seasonal variation in grape yields

By general industrial standards, the variation in the output of grape production systems is relatively large. For example, in an established block of Chardonnay that produced grapes for the Victorian winery, production varied between approximately 40 t and 100 t during the period from 5 to 16 years after planting (Figure 5.1.1). This is not unusual. For blocks in different regions throughout Victoria with an average yield of approximately 10-15 t/Ha, typically the coefficient of variation of yield over time is in the order of 30-40% and yields range by 10-13 t/Ha (e.g. Table 5.1.2).

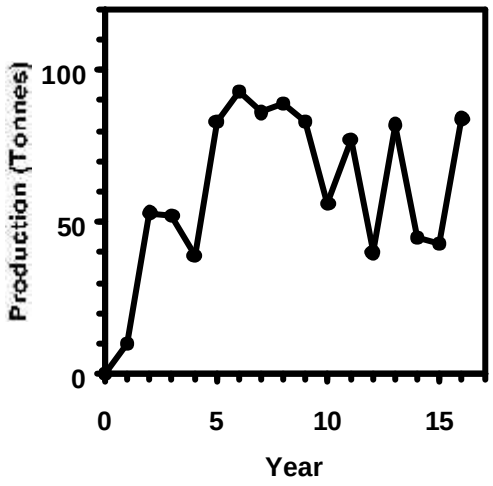


Figure 5.1.1. Production of a block of Chardonnay in a Victorian vineyard.

Analyses by the CSIRO Merbein team have shown that regional yields (t/Ha) increased steadily during the second half of the 20th Century. We did not detect a change in seasonal yield variation (as measured by coefficients of variation) in association with increasing yield. However, increased mean yield without a change in coefficient of variation resulted in an increase in the absolute size of yield fluctuations. For example, in one block of own-rooted Cabernet Sauvignon, improved management resulted not only in an increase of yields from approximately 50 t to 200 t but also in a subsequent fluctuation in production of approximately 70 t (Figure 5.1.2). In this particular case Phylloxera was then discovered in the block and production declined again, with an associated decrease in the scale of yield fluctuations.

Table 5.1.2. Measures of yield variation in four vineyard blocks in Victoria for the vintages from 1990 to 1999.

Block	Mean (t/Ha)	CV (%)	Range (t/Ha)
NE Chardonnay	14.15	29	10.12
KL Cabernet Sauv.	8.02	41	10.64
KL Semillon	10.42	37	13.85
KL Orange Muscat	13.09	28	11.44
Mean	11.42	34	11.51

NE = North East Victoria
KL = Kerang Lakes area

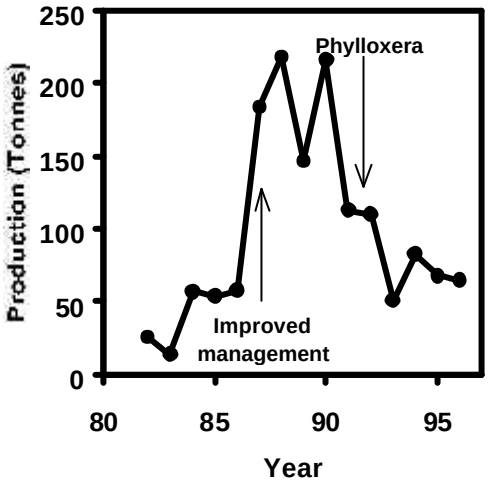


Figure 5.1.2. Impacts of improved management and Phylloxera on seasonal variation of production from a block of Cabernet Sauvignon in Victoria.

Causes of seasonal variation

The commercial data sets to which we had access mainly consisted of series of production totals (tonnes). In some cases, but not all, bearing areas were also available, so unit yields (tonnes/Ha) could be calculated. In addition to quantifying the size of variation in commercial blocks throughout Victoria (see above), these data sets enabled us to look for correlations between different blocks located throughout Victoria and empirical correlations with weather data. However, these data sets did not allow us to identify the yield forming mechanisms involved. The longest term data set available (8 variety x 8 rootstock trial, Dept. Agric., Wahgunyah) only included measurements of weight/plot, but its design enabled analysis of the relative effects of variety and rootstock, which we considered could assist in determining the relative importance of the shoot and root systems. The 12 other experimental data sets all contained yield component data. Each yield component is determined by a different set of physiological processes in both the season in which the crop is harvested and the previous season (Tassie and Freeman 1992) and these physiological processes are influenced by various environmental factors (see Review). Consequently, these data sets enabled us to search for the most important causes of seasonal yield variation.

Relative importance of scion and rootstock

At Wahgunyah from 1957 to 1972 the yields of Shiraz on the R99 rootstock varied between approximately 4 and 14 t/Ha (Figure 5.1.3). The yields of Shiraz on 8 different rootstocks tracked each other closely over the years (Figure 5.1.4). A given rootstock tended to produce consistently higher or lower yields than the other rootstocks, but the seasonal variability of the scion was not affected by different rootstocks. By contrast, there were pronounced differences in the seasonal variability of yields from 8 different scions on the R99 rootstock (Figure 5.1.5). We do not expect the reader to be surprised by this, given that the scion produces the crop, but it is a useful guiding observation because it locates the major source of seasonal yield variation in the aerial parts of the vine.

Relative importance of yield components

Typically, crop forecasting systems are based on calculation of future yield from estimates of its components, using a formula such as: *weight/vine = bunches/vine x berries/bunch x weight/berry*. When seeking to forecast yield, it would be efficient to devote more effort to the measurement of components in proportion to their relative contribution to seasonal variation. Similarly, there would be little point in devoting a great deal of time and effort to controlling a minor source of yield variation, while neglecting a major one. The relative importance of each yield component can be quantified by comparing the fractions of the seasonal variation in weight/vine accounted for by the seasonal variation of each yield component.

As an example we present results for Cabernet Sauvignon vines grafted on Schwarzmann rootstocks in a trial in the All Saints vineyard at Wahgunyah in North East Victoria. Yield components were measured in the five vintages from 1983 to 1987. Over the five seasons, weight/vine deviated from the mean by up to ±60%, and it deviated more than any of its components (Figure 5.1.6). Bunches/vine deviated by up to approximately ±40%. Berries/bunch deviated by up to approximately ±30%. Both bunches/vine and berries/bunch deviated in the same direction as weight/vine. Weight/berry deviated no more than ±10% and appeared to go in the other direction to the other components.

Nearly all (99%) of the seasonal variation in weight/vine could be accounted for by bunches/vine (Figure 5.1.7) while 85% of the variation could be explained by berries/bunch (Figure 5.1.8). By contrast, variation in weight/vine was not significantly correlated with variation in weight/berry (Figure 5.1.9). The greater deviation of weight/vine than its components appears to have been due to a simultaneous increase or decrease in bunches/vine and berries/bunch. There was a strong positive relationship between bunches/vine and weight/bunch (= berries/bunch x weight/berry) (Figure 5.1.10). This relationship is opposite to the compensating decrease in weight/bunch that commonly occurs when lighter pruning increases bunches/vine (e.g. see Tassie and Freeman 1992 p.71). There may have been some compensation by weight/berry but it was not significant.

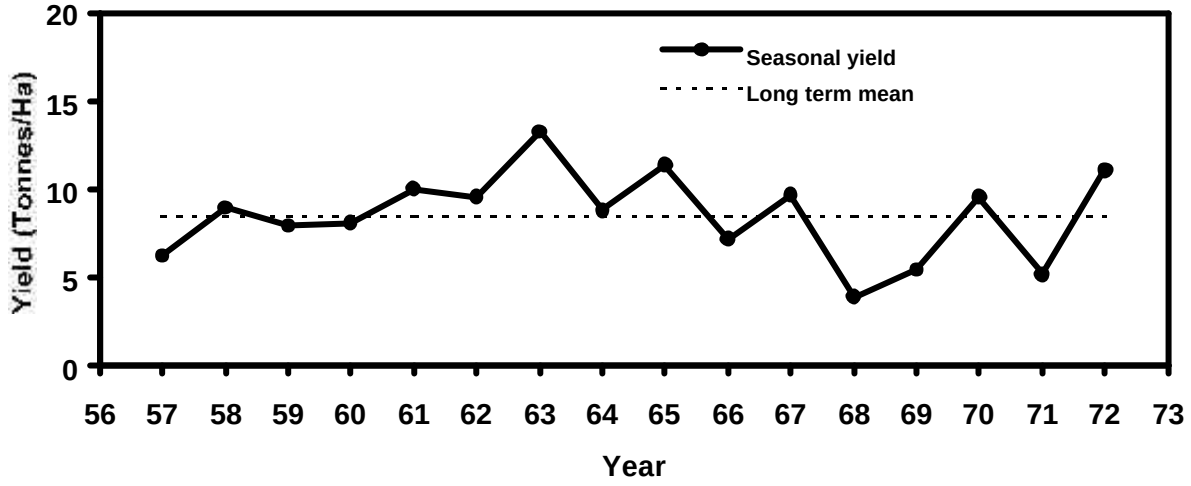


Figure 5.1.3. Seasonal variation in yield of Shiraz on R99 rootstocks at Wahgunyah.

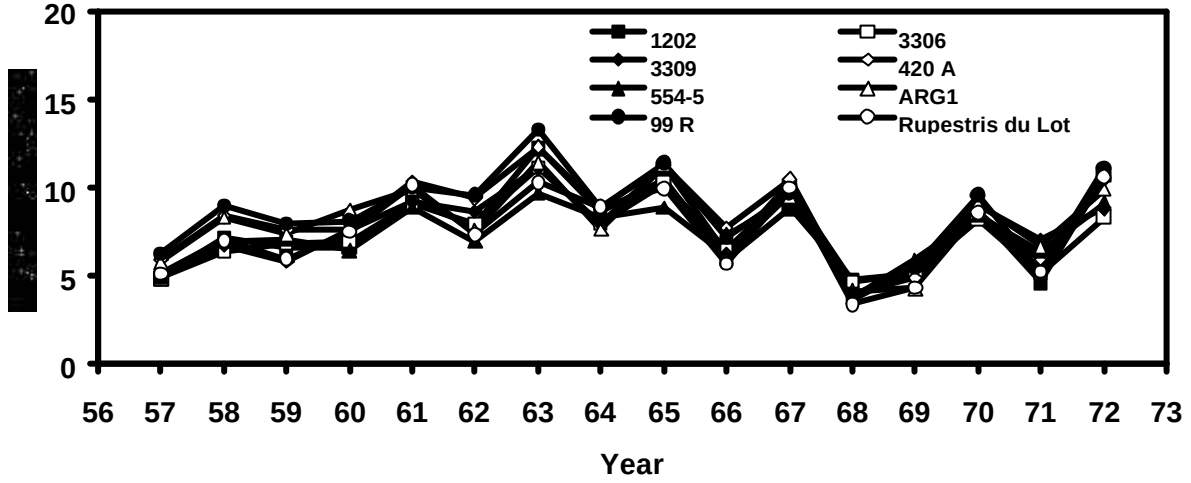


Figure 5.1.4. Seasonal variation in yield of Shiraz on 8 rootstocks at Wahgunyah.

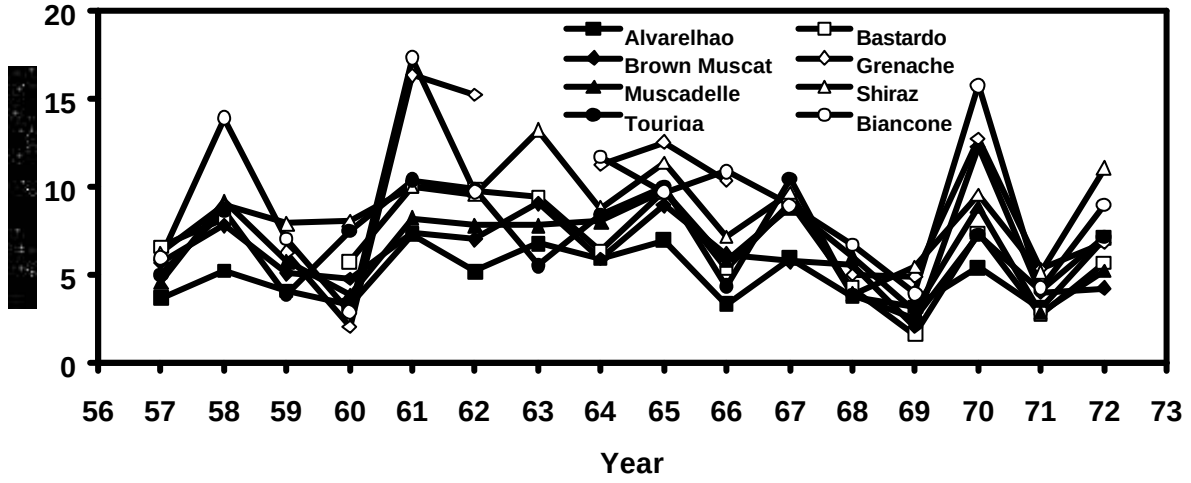


Figure 5.1.5. Seasonal variation in yield of 8 varieties on R99 rootstocks at Wahgunyah.

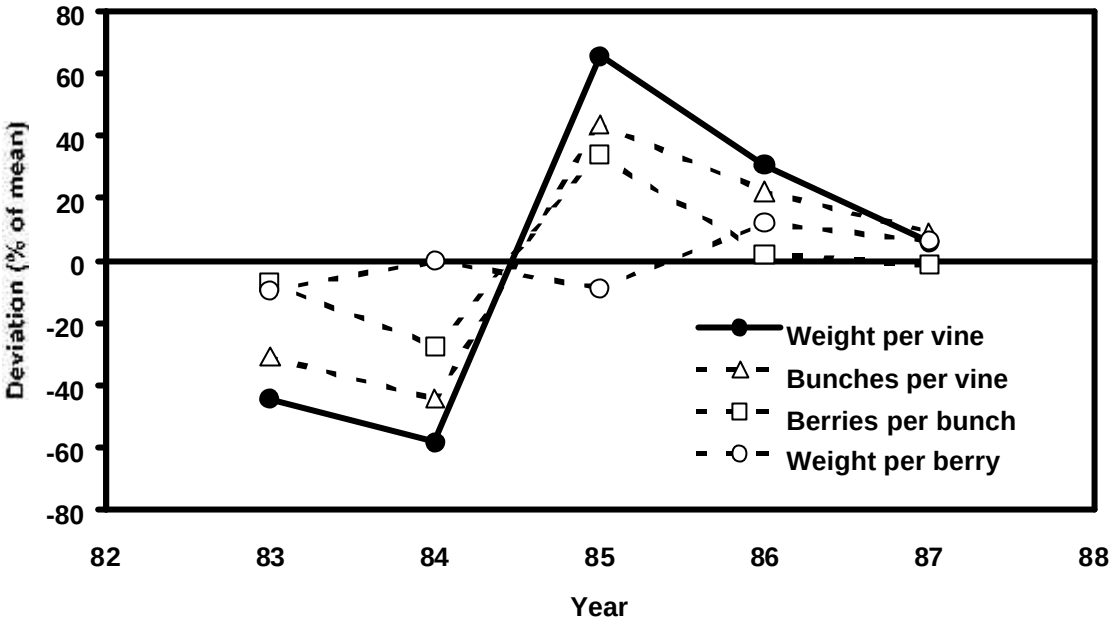


Figure 5.1.6. Annual deviations of yield components from the long term mean.

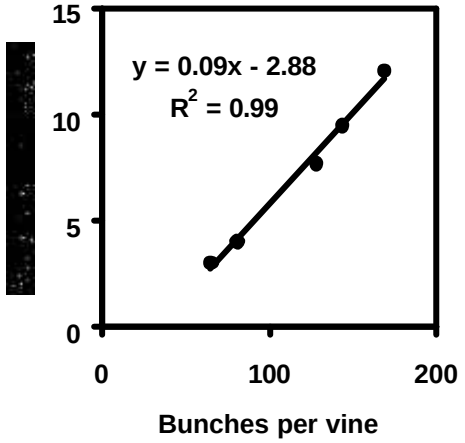


Figure 5.1.7. Relationship of annual mean weight/vine to bunches/vine.

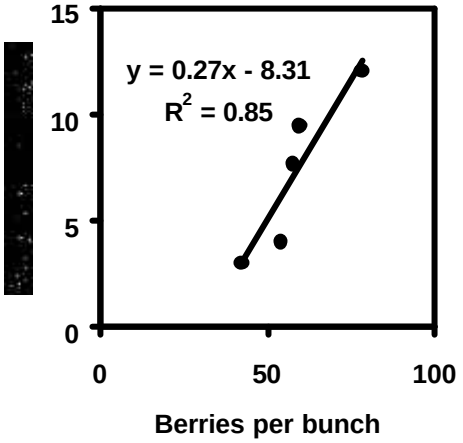


Figure 5.1.8. Relationship of annual mean weight/vine to berries/bunch.

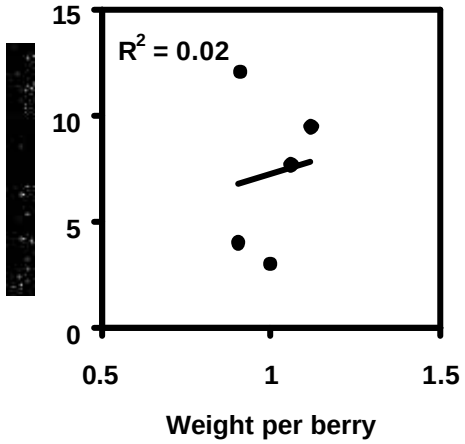


Figure 5.1.9. Relationship of annual mean weight/vine to weight/berry.

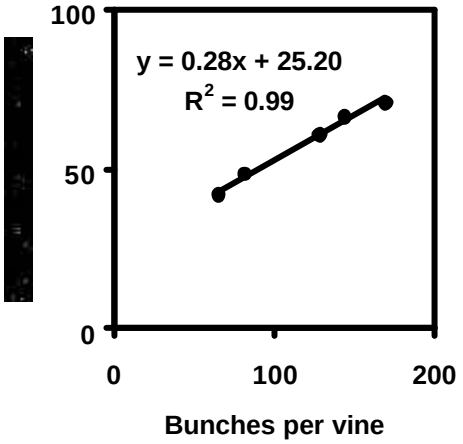


Figure 5.1.10. Relationship of annual mean weight/bunch to bunches/vine.

Figure 5.1.6 to Figure 5.1.10 were constructed from data for Cabernet Sauvignon on Schwarzmann at All Saints vineyard, Wahgunyah, 1983-87. Points represent means of 5 plot replicates.

In other data sets the relationship of seasonal variation in weight/vine to bunches/vine and berries/bunch was not as strong. For example, in a Shiraz rootstock trial in the same vineyard, bunches/vine was the only component significantly correlated with weight/vine, and the fraction of seasonal variation vine accounted for ranged from 39% to 80% for each rootstock (Table 5.1.3). However, the results for the Cabernet Sauvignon and Shiraz rootstock trials shared some general similarities. Seasonal variation in bunches/vine generally accounted for more of the seasonal variation than berries/bunch, which in turn accounted for more than weight/berry. Taking all the data sets as a whole, while the fraction of variation accounted for by the various yield components varied from location to location, the seasonal variation in weight/vine was consistently due mainly to variation in bunches/vine. This was true in all climates. Most of the remaining seasonal variation could be accounted for by berries/bunch, while there was little variation in weight/berry from season to season. In general, the fractions of variation accounted for by bunches/vine and berries/bunch were approximately 60% and 30% respectively. Theoretically, weight/berry should account for the remaining 10% of the variation, but the data sets we examined were not long enough to allow detection of a statistically significant correlation.

Table 5.1.3. Fractions of seasonal variation in weight/vine accounted for by seasonal variation in bunches/vine (bu/vi), berries/bunch (be/bu) and weight/berry (wt/be) for Shiraz on different rootstocks in a trial at All Saints vineyard, Wahgunyah, 1980-87.

	Variation accounted for (r^2)			Significance (p)		
Rootstock	**bu/vi**	**be/bu**	**wt/be**	**bu/vi**	**be/bu**	**wt/be**
110 Richter	0.39	0.31	0.19	0.096	0.253	0.390
5BB Kober	0.64	0.08	0.07	0.017	0.591	0.605
ARG1	0.59	0.05	0.16	0.025	0.666	0.439
Harmony	0.47	0.51	0.04	0.061	0.112	0.711
Own Roots	0.49	0.45	0.29	0.052	0.142	0.275
Rupestris Du Lot	0.61	0.06	0.13	0.021	0.632	0.489
S04	0.80	0.41	0.22	0.003	0.173	0.345
Schwarzmann	0.46	0.20	0.02	0.066	0.373	0.779
Teleki	0.61	0.00	0.01	0.021	0.953	0.822

Coefficients were determined by simple linear regression.

Where measurements of shoots/vine were made, the major source of seasonal variation in bunches/vine was bunches/shoot, rather than shoots/vine. For example, over the last 3 years of the trial for which results are presented in Table 5.1.3, bunches/shoot accounted for nearly all of the variation in bunches/vine for each rootstock, while the fraction of variation accounted for by shoots/vine was always lower and very variable (Table 5.1.4). Given that bunches/shoot is determined by the numbers of bunch primordia present in buds prior to dormancy (see Review), this suggested that the dominant source of seasonal variation in bunches/vine, and hence weight/vine, was in the previous seasons. Furthermore, the positive correlation between bunches/vine and berries/bunch may have been due to common factors in the prior seasons that promoted not only the number of bunch primordia per bud, but their potential to develop into larger bunches.

Table 5.1.4. Fraction of seasonal variation in bunches/vine accounted for by shoots/vine (sh/vi) and bunches/shoot (bu/sh) for Shiraz on various rootstocks in a trial at the All Saints vineyard, Wahgunyah, 1985-87.

	r^2	
Rootstock	**sh/vi**	**bu/sh**
5BB Kober	0.97	0.98
ARG1	0.00	1.00
Harmony	0.02	0.99
Own Roots	0.91	1.00
Rupestris Du Lot	0.43	0.96
S04	0.43	0.94
Schwarzmann	0.68	0.97
Teleki	0.50	0.83
All	0.67	0.97

Coefficients were determined by simple linear regression.

Environmental causes of seasonal variation

Seasonal patterns of yield in blocks of vines with apparently little in common other than being in Victoria at the same time sometimes exhibited startling similarities. For example, from 1990 to 1996, the yields of a block of Chardonnay in North East Victoria and a block of Orange Muscat in the Kerang Lakes area followed a very similar pattern and steadily converged (Figure 5.1.11). This suggested that the two blocks may have responded similarly to a common influence. It is unlikely that local factors such as hail, pests, diseases, frosts or vineyard management would have simultaneously affected the two blocks 300 km apart. It is far more likely that broad-scale climatic factors, such as sunshine and temperature affected both blocks. However, after 1996 the synchronisation appeared to break down. This suggested that after this time either the blocks were subject to different influences or they responded differently to the same influence. In theory it may be possible to isolate a climatic factor shared in the years from 1990 to 1996 (or one or two years earlier) but not in subsequent years.

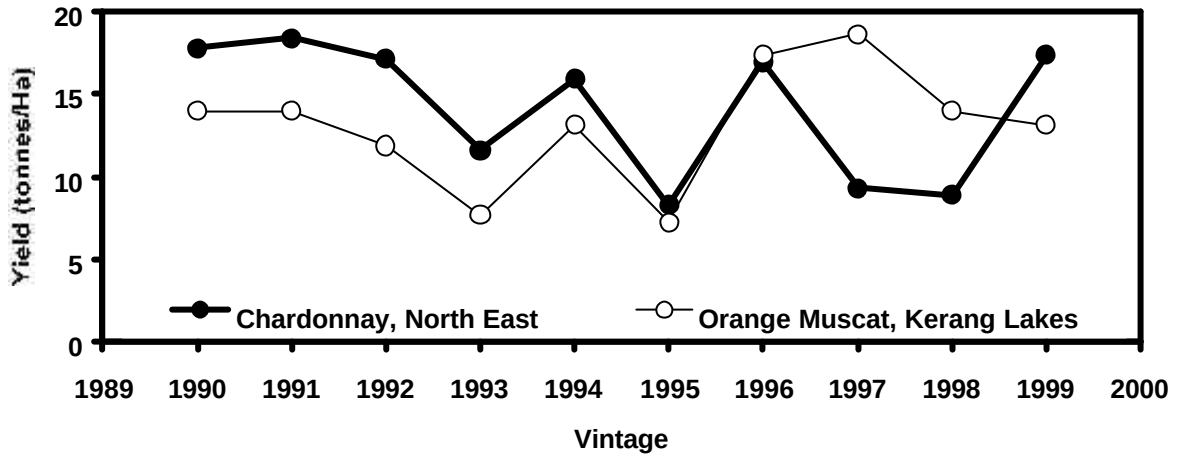


Figure 5.1.11. Yields of two blocks in regions of Victoria separated by 300 km.

Based on the priorities established by the Review and the results presented above, we conducted some targeted searches for correlations between yield, bunches/vine and weather data. In particular, we searched for relationships between yield components and temperatures in the previous season because of their theoretical importance and the availability of temperature records.

Buttrose (1974) concluded that higher temperatures favoured initiation of inflorescence primordia and that maximum sensitivity may be when the bud is separating from the shoot tip, decreasing over the next three weeks. Most of the trials that we analysed were spur-pruned (2 or 3 most basal buds retained), so the buds from which their crops arose would have separated from the tip soon after budburst in the previous season. No records of exact budburst dates were available, so we looked for correlations between temperature conditions in the month of budburst and yield components in the subsequent season. No significant correlations were detected.

Baldwin (1964) found that sunshine hours and maximum temperatures above 29°C in the 20 day period following flowering could account for 75% of the seasonal variation in the incidence of inflorescence primordia in Sultana buds from 1945 to 1962, and more variation could be accounted for by adjusting for local factors. Sunshine hour data was not available for meteorological stations near the sites of the trials from which the data sets were sourced, and records of exact flowering dates were not available. Consequently, our analyses were confined to regressions of yield components on temperatures in the month of flowering at various sites. No significant correlations were detected.

Till (1977) found some significant correlations between yield and rainfall in the Barossa Valley. Establishing even a weak relationship between yield and rainfall could be valuable because rainfall records are widely available, but we did not devote much time to looking for correlations between yield components and rainfall and no significant correlations were detected.

Chaos in the vineyard

Grapevine yields vary seasonally in an irregular manner that can formally be described as chaotic. According to Gleick (1987), "The modern study of chaos began with the creeping realization in the 1960s that quite simple mathematical equations could model systems every bit as violent as a waterfall. Tiny differences in input could quickly become overwhelming differences in output – a phenomenon given the name 'sensitivity to initial conditions'."

May (1976) described how a simple non-linear logistic difference equation can produce dramatically different patterns that mimic the dynamics of density-dependant populations that do not have overlapping generations. The equation was $x_{next} = rx(1-x)$, where x_{next} is next year's population, x is this year's population, r represents the rate of population growth and $1-x$ limits growth, since, as x increases, $1-x$ decreases. Population is expressed as a fraction between 0 and 1, with 0 representing extinction and 1 representing the carrying capacity. We were struck by apparent similarities between patterns of population growth produced by this equation and patterns of seasonal yield in vineyards, so we adapted the model to simulate the growth of yield from the time of planting.

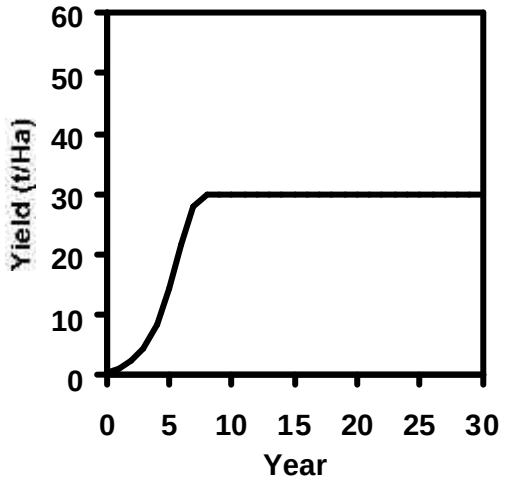


Figure 5.1.12. Prediction of constant yield by a logistic difference equation (r=2).

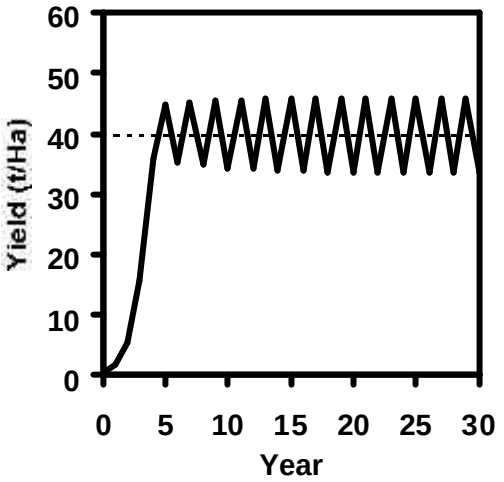


Figure 5.1.13. Prediction of biennial bearing by a logistic difference equation (r=3.1).

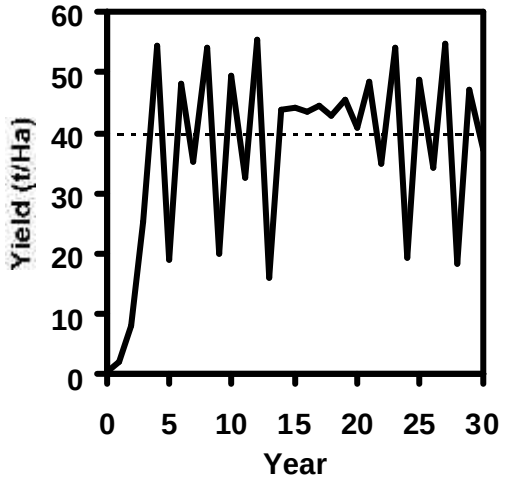


Figure 5.1.14. Prediction of chaotic bearing by a logistic difference equation (r=3.71).

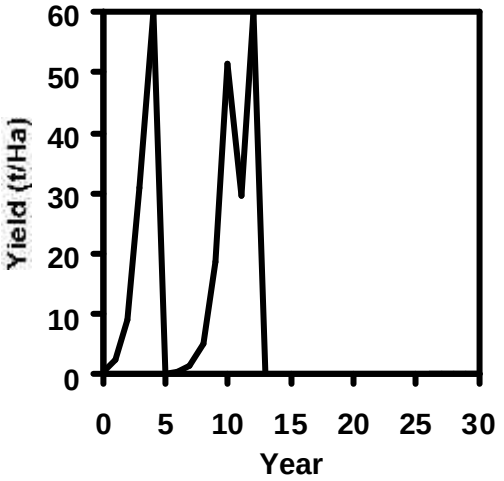


Figure 5.1.15. Prediction of a yield crash by a logistic difference equation (r=4.0033).

Figure 5.1.12 to Figure 5.1.15 were generated using the logistic difference equation $x_{next} = rx(1-x)$, such that $0 \leq x \leq 1$ and $x = 0.01$ in Year 0. Yield was then calculated as Yield = $60x$ (t/Ha). With a growth rate of r=2, the model predicted a conventional logistic growth pattern, stabilising at 30 t/Ha by Year 10 (Figure 5.1.12). When r was increased to 3.1 the model predicted a more rapid establishment phase followed by a regular biennial bearing oscillating around a mean of approximately 40 t/Ha (Figure 5.1.13). When r was increased to 3.71 the

model predicted an even more rapid establishment phase followed by large chaotic fluctuations around a similar long term mean of 40 t/Ha (Figure 5.1.14). When *r* was increased to just over 4, yield approached the yield limit very quickly, then fell close to 0 in the following year, then recovered chaotically and finally crashed to 0 (Figure 5.1.15).

The stable condition shown in Figure 5.1.12 is conventionally assumed in the framing of vineyard establishment budgets, but few people, if any, would seriously expect it to occur in actuality. Similarly, we are not aware of any yield data that would approximate the clock-like regularity of the biennial bearing pattern in Figure 5.1.13. The patterns of seasonal variation in grape yields seem to be most similar to the chaotic condition represented in Figure 5.1.14. There are some interesting features to this pattern. One is that there are periods characterised by alternating low and high yields, reminiscent to some extent of the pattern in Figure 5.1.3. Another is that, from Years 14 to 17, the model predicted a period of low variation. This is reminiscent of Years 5 to 9 in Figure 5.1.1.

The crash predicted by the model in Figure 5.1.15 occurred in the year after one in which yield slightly exceeded the carrying capacity. To translate from ecological to viticultural terms, the variable *x* in effect represents the density of the berry population in the vineyard (i.e. berries/Ha), given that weight/berry varies little from season to season (see above). Thus the model predicted that when the berry population density exceeded its carrying capacity, the result was extinction. This would equate to a circumstance where berries in the current season consume all of the 'food' (presumably photosynthate), leaving no reserves to support a crop in the next season. There is anecdotal evidence that this can occur at a single vine level. For example, numerous dead vines were observed dotted throughout a block of Tarrango near Tresco in the Kerang Lakes area of Victoria in the spring after a year in which a crop of approximately 60 t/Ha was harvested (Walpole, pers. comm.). At lower cropping levels the block was usually harvested when juice soluble solid concentration had increased to approximately 22°B, but in this instance the increase stopped at 18°B, possibly indicating that the demand for photosynthate by the berries exceeded the supply .

It is interesting that the same model that predicted constancy, biennality and chaos also predicted a crash simply by increasing *r* to 4.0033. The behaviour of yield was extremely sensitive to minute changes in *r* in this range. For example, with $r = 4.0032$ or 4.0034, the model predicted chaotic fluctuations continuing until a crash occurred in Year 33 or 147 respectively. The growth parameter *r* could be regarded as representing the rate of berry population growth at which a vineyard is driven by all the means viticulturists have available, including breeding, irrigation, fertilisation, canopy management, pest and disease control, etc. In a more sophisticated model, it could also be allowed to vary from season to season as a function of other factors, such as sunshine and temperature. Thus, it may be that by 'pushing' grape production systems to produce bigger and bigger crops viticulturists have increased the level of chaos in their seasonal bearing behaviour.

We are not suggesting that the particular equation used in the examples above would be appropriate for modelling the bearing behaviour of grapevines. In established blocks yields tend to decline over a few years before going into a more chaotic period (e.g. Figure 5.1.11), while the logistic difference equation predicts exponential increases followed by sudden drops (Figure 5.1.15). However, these results suggest that much of the apparent complexity of seasonal yield patterns could possibly be modelled if a simple function relating the size of this year's crop to the next could be defined.

Control of seasonal variation

Statistical Process Control

For over 70 years, manufacturing and service industries have used Statistical Process Control (SPC) to improve product reliability and reduce production costs. The success of many well-known multi-national companies is built on the use of SPC. In principle, the Australian wine industry could expect comparable benefits if SPC could be applied to grape production. In order to make a preliminary assessment of its applicability, we tried out a simple SPC method described by Wheeler (2000).

The data used to produce Figure 5.1.1 was used to construct a Process Behaviour Chart (Figure 5.1.16). Following the establishment phase, data for Years 5 to 9 was used to calculate mean production (solid line) and the Natural Process Limits (dashed lines). According to SPC principles, as long as a process operates consistently it will produce routine variation within its Natural Process Limits. This is regarded as 'noise' and it is considered that there would be no benefit in seeking an explanation for noise or reacting to it as if it were a signal. Changing the production system in reaction to noise is called 'tampering' and can unintentionally increase variation and costs.

Production fell below the Lower Natural Process Limit in Year 10 (Figure 5.1.16). In accordance with SPC principles, this should be regarded as a signal that something unusual had happened, and the appropriate response would be to seek an explanation and eliminate the specific cause. In Year 11, production recovered and lay within the Natural Process Limits. However, production fell below the Lower Natural Process Limit again in Years 12, 14 and 15. This would tell a vineyard manager that the drop in production in Year 10 was not a 'one-off', but the beginning of a longer-term change.

Relative to Years 5 to 9, the process had become unstable and unpredictable. The system had changed, so a new mean and new Natural Process Limits should be calculated (Figure 5.1.17). This would tell a manager that the new system is not as productive, on average, as the old one and that it causes more routine variation. The weight of grapes delivered to the winery each year would fluctuate more and be harder to forecast. If the manager wanted to improve the performance of the process, he would now know that he needed to change the system, rather than to ask for explanations each year.

It is reasonable to expect more variation in grape production than in manufacturing or service processes. However, this example shows that a way of thinking that is proven in these industries can be applied to grape production.

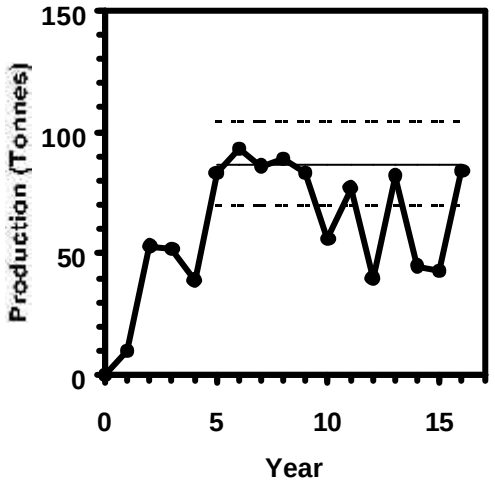


Figure 5.1.16. Process behaviour chart constructed from grape production data for a block of vines in Victoria.

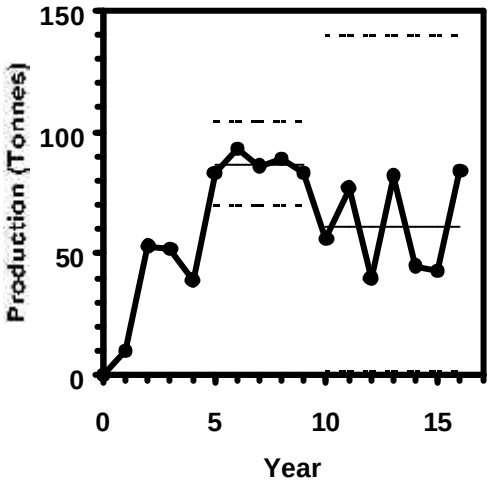


Figure 5.1.17. Process behaviour chart showing the effect of changing the grape production system.

Building quality into grape production processes

A key concept of Total Quality Management is that the quality of the product is determined by the quality of the process that produces it, and that quality should be 'built in' rather than 'inspected in' to a process (Walton 1989). In the case of grape production, a study of the variation in the output of grape production systems leads us to the view that the product of a block should not be regarded only as the particular batch of grapes that it produces in a given year but rather as all the batches it produces over the years. This is because the customer of the product is the winery, and wineries in general would benefit from having reliable sources of supply of their major raw material – grapes.

There are many inputs to the grape production process, and the data sets that we have analysed enable assessment of the effects of some of them, not only on mean yield over time, but also on its seasonal variability. While it is common to assess the relative benefits of a particular treatment in a research trial (e.g. variety, clone, rootstock, irrigation regime, pruning method, trellis type, etc.) by comparing mean yields over time, we are not aware of any examples where the effect of a treatment on seasonal yield variation has been considered.

By way of example, we consider here how seasonal variation might be considered in the selection of planting material, which is a key determinant of the long term performance of a block of vines. As we have seen, the yields of different varieties fluctuate more or less in response to the same conditions (Figure 5.1.5), and the seasonal variation of different varieties could be taken into account when planning to establish a vineyard block.

Furthermore, there is scope to select particular 'clone' of a variety. The choice of clone can be critical because the grower and his customers will be stuck with the consequences for the life of the block. Consequently, various trials have been conducted throughout Australia over the years to assess the suitability of clones for particular regions. The variability of yields produced by different clones can span a considerable range. For example, in a trial of 35 clones of Muscat of Alexandria (syn. Gordo) at Mildura from 1977 to 1981, the coefficient of variation of yield over the 5 years ranged from 26% to 42%. Interestingly, the higher yielding clones tended to be less seasonally variable (Figure 5.1.18). However, at a given level of mean long term yield there was a wide range of variability. If measures of seasonal variation were omitted from a report on the trial, it would be easy to build unnecessary seasonal variation into a grape production system by selecting a clone with the same long term yield but a higher seasonal variability.

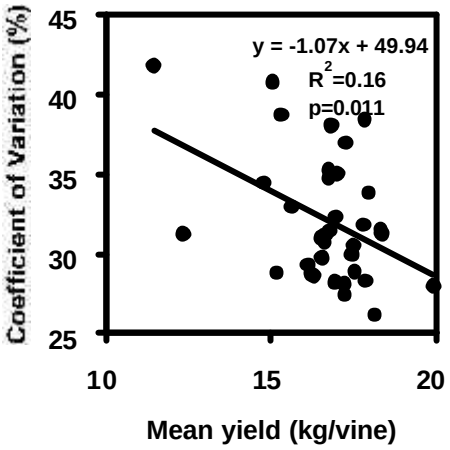


Figure 5.1.18. Relationship between mean yield and coefficient of variation of yield over 5 seasons from 1977 to 1981 in a trial of Muscat of Alexandria clones at Mildura.

Similar reasoning can be applied to other inputs to grape production systems, such as choice of rootstock, site selection, planting methods, early training techniques, trellis design, pruning methods, canopy management, design of irrigation systems, irrigation scheduling, fertilisation, pest and disease control, etc. These could all affect seasonal variation as well as mean yield.

5.1.4 Discussion

The process of collecting the data sets that we analysed was interesting in itself. Some reasonably long term records of production, aggregated at a vineyard x variety level, were provided by wineries. Some wine companies had measured crop components in their vineyards, but the methods used were not very consistent and the data sets were no longer than a few years. There may well be data sets that are superior to the ones that we analysed, but they have not been easy to obtain.

Obtaining data sets derived from research projects was not easy either. For example, we searched for the data that was known to have been collected and used by Jim Baldwin, interviewing a number of people along the way, including Dr Jim Hardie, who referred us to Dr John Considine. Tragically (from a number of points of view), it turned out that the data had been kept in boxes under Jim Baldwin's bed until he died and that they had been burned by Jim's wife in the back yard just before John arrived to ask if he could have them.

In the end, the most useful data sets were obtained from a source a few doors down the hallway from our offices at NRE Tatura, namely John Whiting (Senior Industry Development Officer – Viticulture). The 1947-72 data set from the Department of Agriculture vineyard at Wahgunyah was distinguished by its length and experimental design, but it did not contain crop component data. The other experimental data sets were not as long, but they did contain crop component data which has been particularly useful in probing the mechanisms at work in the formation of yield.

One striking feature of the results that we obtained from all of these data sets was the size and irregularity of grapevine yield throughout Victoria, despite diligent attempts by viticulturists to maintain a relatively constant level of management, or at least to avoid crop loss. If grape yields were constant, forecasting would be easy (this year = last year) and there would be no need to think about how to regulate them. If seasonal yield variation was cyclical, forecasting would not be very difficult either (e.g. if there was regular biennial bearing pattern then this year = two years ago). Other fruit crops, such as apples or pears, can exhibit robust biennial bearing patterns. In some of the wine grape data sets, biennial bearing appeared to become established in runs (e.g. from years 10 to 14 in Figure 5.1.1). In some cases these runs of biennial bearing were broken by an unexpectedly low crop, after which the biennial bearing pattern appeared to reverse phase (e.g. following Years 10 and 15 in Figure 5.1.1 and 1960 and 1969 in Figure 5.1.3). Cyclical patterns were not discerned in many of the data sets, but this may have been due to their shorter length. However, in most of the data sets, yield varied irregularly, and this is why it is difficult to forecast grape yields from historical records.

Traditionally, this irregular variation has been regarded as 'error' by research scientists and would be categorised as 'noise' by a process engineer. As Gleick (1987) has said, "The irregular side of nature, the discontinuous and erratic side … have been puzzles to science, or worse, monstrosities." and "Traditionally, when [scientists] saw complex results, they looked for complex causes".

In our search for the most important causes of seasonal yield variation, we have followed the traditional approach of reducing yield to its components and quantifying the amount of variation that can be explained by a particular component and the processes and influences to which it may be sensitive. This approach led us to the conclusion that most of the seasonal variation was due to variation in the number of bunches per vine, which previous research has established is determined by the number of inflorescence primordia per dormant bud. An unexpected finding was that in many cases the number of berries per bunch at harvest was positively correlated with bunches/vine. This suggested to us that both components may ultimately be sensitive to the extent of branching in inflorescence primordia before they enter organic dormancy in the previous season. If this is so, the most powerful predictors and controllers of yield variation would be in the season prior to the one in which yield potential is finally realised.

As concluded in the Review, the number of inflorescence primordia per bud and the size of these primordia should theoretically be related to weather in the previous season, but we have found no significant correlations to date. However, this may simply reflect a lack of appropriate data or a failure on our part to use the right analytical method. It would be possible to run many analyses and search for significant correlations between yield components and weather variables, but this would be time consuming and had not been done at the time of writing this report.

The results of our experimental application of the principles of chaos science are intriguing. Using conventional linear regression techniques, previous studies of factors that act in one season to determine yield in the next have found little, if any relationship between yields in successive seasons. By contrast, researchers such as Baldwin (1964) sometimes detected significant linear relationships between various driving weather variables and yield

components in the next season. In view of this, it may be tempting to dismiss as mere coincidence the similarity of seasonal grape yield patterns to the patterns produced by the simple logistic difference equation, which were produced by a feedback effect of one year's yield on the next. However, if the relationship between the yields in successive years is complex and non-linear, it would not be surprising if it was not detected by simple or multi-linear regression techniques.

The patterns of seasonal variation in grape yields would be regarded by chaos theorists as typical examples of the output of a complex, non-linear system, and their research has shown that the outputs of such systems are critically sensitive to initial conditions. Previous research (see Review) and the results presented above indicate that the initial conditions to which grape production systems may be sensitive are most likely to be related to the induction, initiation and differentiation of inflorescence primordia in the season before the one in which flowering and fruiting takes place. Conceivably, the yield output of a grape production system could be modelled relatively simply, but be sensitive to these early, small-scale physiological processes. This would not necessarily mean that we could predict a particular yield from a particular set of inputs, but we may be able to decide how predictable or not a particular grape production system might be.

These results are tantalising. The analyses of seasonal variation that we have conducted have not yielded a model that can be used to predict and control yield, but they have provided a basis for generating hypotheses and setting research priorities. The quest to understand and model the relationships between grape yield and factors in the previous season will continue. In the interim, we can at least identify the most important yield components to measure and control, and we can use quality management and statistical process control principles to manage seasonal yield variation intelligently and efficiently.

5.1.5 Implications and Recommendations

This project was funded because it was realised that grape yield variation is a root cause of many problems in the Australian Wine Industry. Wineries are essentially factories that are sensitive to the variability of inputs, and vineyards are agricultural systems characterised by a relatively high variability of output. The larger the variation in vineyard output, the bigger the negative impact on winery performance. In response to this variation, wineries have two general strategies available to them:

accept variation, attempt to forecast it, and plan accordingly
reduce variation so that it is easier to forecast and work with

In Australia during the 20th Century, much attention was paid to increasing yields by raising mean productivity and eliminating major sources of crop loss. Some of the main factors that contributed to this include selection of highly productive varieties and clones, elimination of viruses from planting material, use of pest-resistant and vigour-enhancing rootstocks, irrigation technology, fertilisation technology, chemical pest and disease control technologies and pruning, training and trellising to retain more buds per unit area (Possingham et al 1993, Clingeleffer et al 1999)

The general effect of this focus on productivity improvement without attention to the impacts of variation is summarised in Figure 5.1.19. Working with an unstable system, viticultural research and development has eliminated low yields and lifted the mean yield of grape production systems in Australia. However, this has magnified the absolute size of seasonal yield fluctuations and this, coupled with a tendency to plant vines in larger blocks, has increased the impact of seasonal variation on wineries. Consequently, while there is no evidence that seasonal yield variation has increased in relative terms, the industry has become more conscious of the problems caused by it and is asking what can be done to manage it.

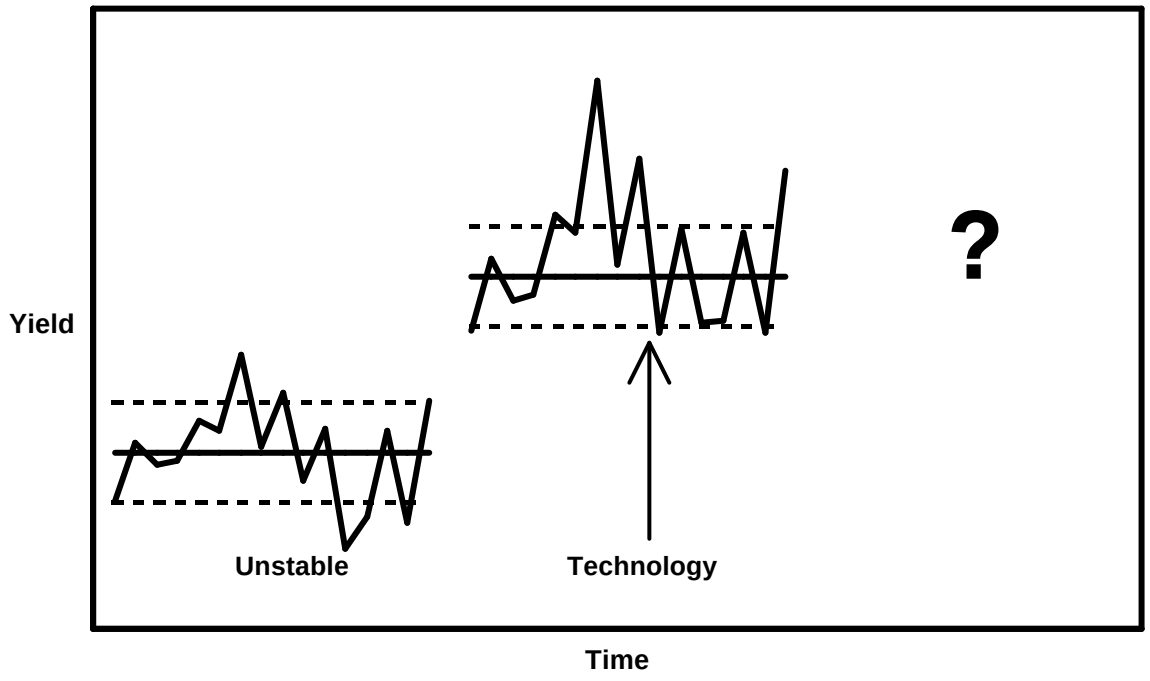


Figure 5.1.19. Historical pattern of technological development in Australian viticulture.

Fortunately, other industries have appreciated the value of managing variation for many years and have developed systematic procedures to improve variable processes. Measuring and controlling variation is a key component of the Quality Management Systems used by successful manufacturing and service organisations throughout the world, particularly in Japan (e.g. Toyota Motor Corporation). The recommended approach, applied to viticultural development, is summarised in Figure 5.1.20. The first step would be to use SPC methods to determine whether the process is stable or not (in this example the process is unstable). The next step would

be to stabilise the process by eliminating the causes of any exceptional variation. After this, the grape production system would be modified to make the process more capable, that is, yield variation would fluctuate within specification limits set by the winery. Only then, when variation has been controlled, would an attempt be made to improve the mean yield. And perhaps, sometime in the future, a radical new technology may make it possible to produce grapes at a high yield with minimal seasonal variation.

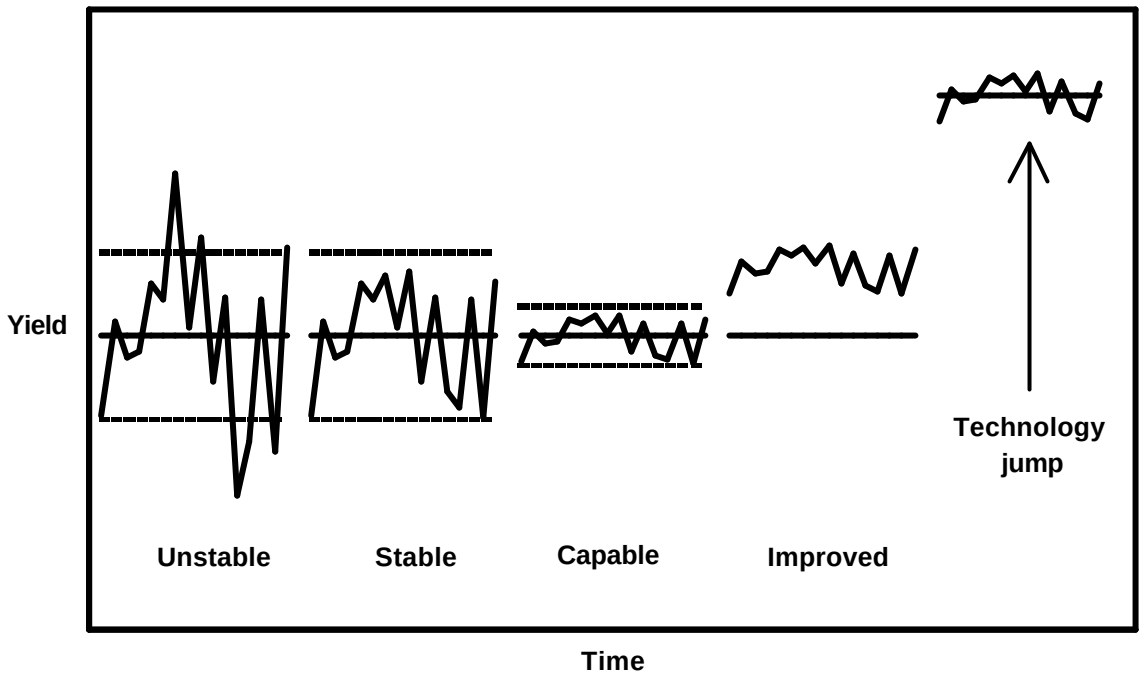


Figure 5.1.20. Recommended sequence of process improvement applied to viticulture.

Now, in the 21st Century, it may be time for the Australian wine industry to adapt and adopt this 70 year old philosophy. This would be in accord with the industry's planned shift from volume growth to value growth as stated in its 2025 Strategy.

In seeking to minimise yield variation, the industry should adopt the philosophy that quality has to be built in right from the start. It would be uneconomic to grow winegrapes indoors, and the industry can't control the weather, but it may be able to reduce the sensitivity of vine blocks to the weather by selecting and planting less sensitive genotypes.

More research is required to assess the effects of other inputs on seasonal yield variation, and all future research should consider and publish measures of the variation of treatment means over time, rather than merely the long term mean.

Meanwhile, in seeking to forecast or regulate the output of existing systems, our results suggest that a system should focus first on bunches/vine, adjust with berries/bunch and fine tune with weight/berry.

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5.2 Analysis of Seasonal Variation (Coonawarra)

5.2.1 Introductory Technical Information

This section reports on analyses of data sets collected by the CSIRO team at Merbein from two experiments conducted in the Coonawarra district.

5.2.2 Research Methodology

Minimal Pruned Coonawarra Shiraz managed under crop control stategies.

Yield component data from a long-term crop control study (1992-2001) with minimal pruned, Coonawarra Shiraz was analysed to identify variables contributing to within site and seasonal variation. The trial included three crop control treatments, ie. 'standard' minimal pruning, crop removal by mechanical skirting or mechanical thinning after fruit set (Clingeleffer 1992, Clingeleffer et al.2000). In the later case, it was noted that crop removal by mechanical thinning was associated with both berry thinning from bunches and loss of whole bunches.

Coonawarra Cabernet Sauvignon managed under different pruning regimes

Yield component data from a long-term study (1992-2000, collected by Karl Sommer) comparing cane, hedge and minimal pruning treatments for Coonawarra Cabernet Sauvignon were analysed to identify variables contributing to within site and seasonal variation. The three treatments represented both the traditional and low input mechanised approaches to vine management in the region. It should be noted that over the period there was a substantial decline in productivity of all treatments due to long-term effects of drought and changes in irrigation management practices aiming to impose higher levels of stress to enhance wine quality.

5.2.3 Results and Discussion

Minimal Pruned Coonawarra Shiraz managed under crop control strategies.

The table below provides a summary of the mean data of yield and the various yield components over the seasons. The range in component values for the standard treatment is also included to facilitate discussion of seasonal effects. Yield of both the crop control treatments was lower than the standard treatment due to the removal of bunches, and in the case of the thinning treatment development of smaller bunches due to berry removal. Both crop control treatments tended to produce slightly larger berries.

Over the seasons, there was almost a 3-fold difference in yield of the standard minimal pruning treatment. Contributing to this variability were the very large differences in bunch number (ie. 2.6-fold) and smaller differences in bunch and berry weight (ie. 38 and 33% respectively).

Table 5.2.1 Mean values of yield and its key components over 10 seasons, 1992-2001. The minimum and maximum value for each component across the seasons is also included for the standard treatment

Yield component	Standard	Skirted	Thinned	Min.	Max.
Yield (kg/vine)	9.5	8.0	6.8	4.1	11.8
Bunches/vine	246	201	205	121	320
Bunch weight (g)	38.2	39.1	32.0	33.7	46.5
Berry weight (g)	1.08	1.11	1.03	0.91	1.21
Berries/bunch	35.8	35.4	31.6	31.0	49.2

Correlation and multi-linear regression techniques were used to analysis the data to identify the key variables contributing to yield differences between seasons. Correlation coefficients (r) presented in the table below clearly show that the major determinant of yield was bunch number. Bunch weight, berry weight and berries per bunch were not significant contributors to seasonal yield variation of these treatments. In the case of the thinned treatment, there were significant correlations with yield and both bunch number and bunch weight, probably due to differences in severity of application of mechanical thinning, harvester type and machine set up.

Table 5.2.2 Correlations between mean yield and its various components for the 3 crop control over 10 years (1992-2001). Values presented in bold indicate significant correlations, P< 0.05.

	Standard	Skirted	Thinned
Bunches/vine	**.93**	**.92**	**.79**
Bunch weight	.44	.39	**.64**
Berry weight	.14	-.12	.21
Berries/bunch	.24	.38	.53

Multilinear regression techniques were applied to the mean data from each treatment across the seasons to develop models to describe relationships between yield and yield components over the seasons. The derived equations indicate for the standard and skirted treatments, 84% of seasonal yield variability can be accounted for by bunch number. Inclusion of berries per bunch and berry weight accounted for 92% and 98% of seasonal yield variability. In the case of the thinning treatment the equations identify that seasonal differences in berries per bunch and berry weight were also important factors in crop development.

standard

Y= 0.75 + 0.036 **bunno** $\mathbf{R^2 = .84}$

Y= -3.39 + 0.036 **bunno** + 0.12 **bepbun** $\mathbf{R^2 = .92}$

Y= -15.67 + 0.035 **bunno** + 0.22 **bepbun** + 8.08 **bewt** $\mathbf{R^2 = .98}$

skirted

Y= 0.75 + 0.035 **bunno** $\mathbf{R^2 = .83}$

Y= -2.55 + 0.034 **bunno** + 0.10 **bepbun** $\mathbf{R^2 = .93}$

Y= -12.0 + 0.035 **bunno** + 0.18 **bepbun** + 5.84 **bewt** $\mathbf{R^2 = .99}$

thinned

Y= 0.12 + 0.032 **bunno** $\mathbf{R^2 = .58}$

Y= -5.22 + 0.030 **bunno** + 0.18 **bepbun** $\mathbf{R^2 = .78}$

Y= -13.52 + 0.030 **bunno** + 0.22 **bepbun** + 6.78 **bewt** $\mathbf{R^2 = .98}$

Y	yield ($kgvine^{-1}$)
bunno	bunches/vine
bunwt	bunch weight (g)
bewt	berry weight (g)
bepbun	berries/bunch

Coonawarra Cabernet Sauvignon managed under different pruning regimes

Over the 10 seasons mean yields of the cane, hedged and minimal pruning treatments ranged from 4-14 t/ha, 4-14 t/ha, 6-19 t/ha respectively. Within each season, bunch number accounted for a significant proportion of the yield variability across replicates of both the hedging and minimal pruning treatments, ie on average 79% and 83% respectively. By contrast with cane pruning, bunch number accounted on average for 60% of the variability between replicates. For all treatments, berry number/vine accounted for most of the replicate variation in yield, ie. on average 91%, 93% and 82% for the hedge, minimal and cane pruning treatments. Overall all treatments, berry number/vine proved to be quite robust determinate of yield accounting on average for about 90% of the variability between replicates within a season.

Analysis of the mean data for each season was undertaken to identify the key contributors to seasonal variation in yield of each treatment. The results showed that differences in bunch number accounted for a significant proportion of the seasonal yield variation for all treatments, ie. 85%, 68% and 61% for the hedging, cane and minimal pruning treatments respectively. For all treatments, berry number per vine accounted for more than 90% of the variation in yield across seasons.

5.2.4 Implications and Recommendations

The results clearly have implications for crop forecasting in minimal pruned Coonawarra Shiraz. They indicate that the greatest effort should be given to an accurate assessment of bunch number. Inclusion of support information on bunch development, ie. berries/bunch should further enhance the accuracy of the predicted yield.

The results also have implications for crop forecasting in Coonawarra Cabernet Sauvignon. As with Shiraz they indicate that the greatest effort should be given to an accurate assessment of bunch number but that inclusion of support information on bunch development, ie. berries/bunch will enhance the accuracy of the predicted yield. Furthermore, the results indicate that differences in bunch development (ie. berries per bunch) is most likely to be a significant contributor to variation in replicate yield of cane pruned vines within a season, compared to hedging or minimal pruning. Hence different sampling strategies may be required to accurately provide a crop forecast for different pruning systems. Overall, the results indicate that an accurate estimate of berries per vine will provide a solid basis for crop prediction across all treatments and seasons.

5.3 Analysis of Long Term Trends in Regional Yields

5.3.1 Introductory Technical Information

The wine industry is often faced with year to year fluctuations in crop yields which can have significant impacts on grower returns and adverse effects on intake scheduling, storage requirements and marketing strategies for domestic and export markets. They may also have a negative impact on fruit quality caused by harvest at non-optimal maturity and delayed or incomplete ripening as a result of heavy crop loads, particularly in the cooler regions.

An accurate analysis of climatic effects on regional and varietal yields requires accurate historic data sets for vineyards where management conditions are known and reasonably consistent. The availability of such data is limited. Thus, yield data from the Australian Bureau of Statistics (ABS) was used to study long term production trends (Winegrape Crop Prediction and Management, P.R. Clingeleffer, K.J. Sommer, M. Krstic, G. Small and M. Welsh).

5.3.2 Research Methodology

The analyses were limited to three major winegrape varieties (Chardonnay, Cabernet Sauvignon and Shiraz) in three distinct and important climatic regions (Sunraysia/Riverland, Barrossa Valley, and Coonawarra/Padthaway).

5.3.3 Results and Discussion

Notable features from this analysis were:

- very large fluctuations in average yield from season to season in all regions and across all varieties with the low, intermediate and high yields in the Barrossa Valley, Coonawarra Padthaway and Sunraysia/Riverland respectively. Valid data for Chardonnay was available, only from 1980-97. Over the seasons, average annual Chardonnay yields ranged from 2-10 tha^{-1}, 4-15 tha^{-1} and 10-19 tha^{-1} in the three respective regions. For Cabernet Sauvignon, yields over almost thirty seasons (1969-97), ranged from 2-9 tha^{-1}, 3-12 tha^{-1} and 6-18 tha^{-1} for the three respective regions. Similarly, over the thirty seasons, Shiraz yields ranged from 4-10 tha^{-1}, 4-16 tha^{-1} and 9-18 tha^{-1} across the three respective regions.

- highly significant trends (R^2, 0.35 - 0.74) showing increased yield per hectare over time for the three varieties in all regions. These trends may be explained by increased yields as young vines matured and the adoption of improved management practices (eg. irrigation and light pruning techniques).

- inconsistent varietal yield responses within a region over the seasons. When yields were seasonally adjusted to account for the long term trends over time there was a close relationship between the performance of Cabernet Sauvignon and Shiraz in each region (R^2, 0.67-0.79). The performance of Chardonnay could be linked to the performance of the two red varieties in the Barossa Valley (R^2, 0.57, 0.48) but not in the other regions ($R^2 < 0.20$). Such a result with Chardonnay is not unexpected because of the earlier timing of phenological stages within a season compared to the red varieties.

- inconsistent seasonally adjusted yield responses of a variety between regions over the seasons. The yield of Chardonnay in Sunraysia/Riverland was not related to its performance in the Barossa Valley or in Coonawarra. However, there was weak but positive relationship ($R^2 = 0.27$) between the performance of Chardonnay in the Barossa Valley and Coonawarra/Padthaway. Regional yields of both the red varieties correlated between Sunraysia/Riverland and the Barossa Valley only ($R^2 = 0.41, 0.21$). These results indicate that climatic events within regions are largely responsible for the observed yield fluctuations rather than at a national level.

The influence of climatic factors, such as the El Nino (Southern Oscillation Index, SOI) on the seasonally adjusted yield, was also examined. Over the period from 1970, changes in the SOI accounted for 22%, 28% and 50% of the variation in annual rainfall in Sunraysia, Barossa Valley and Coonawarra respectively. However there was no significant relationship between either the SOI or annual rainfall and adjusted yield of all varieties tested in the three regions. While the SOI has been successfully used to account for the performance of rainfed,

annual crops such as wheat and peanuts the absence of a positive relationship with grapevine yield was not unexpected because:-

- of the short time span for which sufficient production data was available
- of large climatic variations within the regions
- the use of irrigation to augment the annual rainfall (*ie.* 300, 520 and 680 mm in Sunraysia, Barossa Valley and Coonawarra respectively)
- the development of a crop occurs over three seasons
- high rainfall, resulting from a positive SOI, may lower the potential crop due to effects on flowering and berry set, berry damage due to splitting and subsequent development of rots and moulds.
- varieties displayed different seasonal yield responses both within and between regions.

Closer scrutiny of the adjusted yield data suggested that a very negative SOI (*ie.* < -5) in the calendar year preceding the crop, may, in some instances result in below average yields due to combinations of adverse environmental conditions that impact on crop development. Such extreme conditions become manifest in the phenomenon of restricted spring growth which in the Sunraysia/Riverland region has been associated with the combination of below average soil temperatures, frequent frosts and below average winter rainfall. For example, Chardonnay yields were below average in all regions in 1983 and 1995. The incidence of frosts, many severe in Sunraysia in 1994 was double the normal average (*ie.* 52). Similarly the low yields of Chardonnay in the Barossa Valley and Coonawarra/Padthaway in 1988 were a result of a very severe frost in the preceding October. However, high Chardonnay yields were produced in Sunraysia /Riverland in other low SOI seasons. Shiraz in both the Barossa and Coonawarra/Padthaway and to a lesser degree Cabernet Sauvignon in Coonawarra/Padthaway almost always had low yields when the SOI was negative. These sporadic effects confirm the weak link between SOI and yield performance. Other factors related to temperature patterns between budburst and flowering as well as climatic and management factors on fruit set and bunch development are probably more important.

Because frosts appeared to be implicated in the above results the adjusted yield data was also analysed in relation to the number of frosts. In Coonawarra/Padthaway the number of frosts accounted for 9%,14% and 27% of the variation in adjusted yield of Chardonnay, Cabernet Sauvignon and Shiraz respectively over the seasons.

6 Forecasting Regional Yields

The crop forecasting project team has been actively involved with local regional groups in assisting in the establishment of regional wine grape crop forecasting systems.

Initially, work was conducted in Sunraysia with the Murray Valley Wine Grape Industry Development Committee (MVWIDC) in the establishment of a crop forecasting protocol (version 1 of the crop forecasting kit). Data was collected by individual growers and returned to the MVWIDC where data was compiled and summarised. Since the introduction of the crop forecasting system, growers in the Sunraysia region have become quite accurate. An example of this is Southcorp, a large wine company had underestimated their crop nationally by approximately 30% in the year 2000. When they did the regional analysis on the problem, they were only about 5% out in the Sunraysia region, while in the Coonawarra, they had underestimated the crop by 50%. This result lead us to believe that the adoption and use of objective crop forecasting systems had resulted in significant improvements in the accuracy of regional forecasts.

Further work in the Riverina (MIA) region with the Wine Grapes Marketing Board (WGMB) resulted in the development of a crop forecasting system which was extremely well structured and organised. They wanted to develop a system which improved there traditional visual assessment which was becoming quite unreliable (up to 20% error, or 30,000T). It involved the cooperation of 6 individual wineries, which assisted in the collection of forecasting data from specific regional sites. This data was then collated by the WGMB in Griffith and estimates calculated. Firstly, the adoption of this crop forecasting system has reduced the forecasting error from 20% to approximately 5-10% over the last 2 years of its use. This is critical for their regional pricing system and has assisted wineries immensely in ensuring that their processing and marketing capacity has been adequately determined.

The project team is currently working with many large wineries (Southcorp, Orlando-Wyndham, Beringer Blass etc) in assisting with the design and implementation of objective and reliable crop forecasting systems in the many different wine grape growing regions.

In summary, the development of objective crop forecasting systems has resulted in the widespread adoption of this technology. This has lead to much improved crop estimates being generated in those regions using these systems. Improved crop estimates assist the wine industry in many facets, including production, processing and marketing of wine.

7 Physiological Research

This section addresses objective 5: **to undertake physiological studies to enhance control of crop development and crop estimation, and secure quality and production of major wine grape varieties in the various climatic regions of Australia**. It summarises results from a program of research seeking to improve our understanding of the processes that control the formation of yield potential and its realisation in grapevines. It addresses important priorities for research identified by the review (Section 3) and an analysis of historical data sets (Section 5).

In its simplest form the yield of an individual grapevines can be described as:

bunches/vine x berries/bunch x berry size .

Yield component analysis (see Section 5) has consistently demonstrated that the component bunches/vine explains 60-70% of the variation in vine yields from season to season (Martin and Dunn, in preparation, Martin *et al*. 2000). Yield fluctuations are less sensitive to berries/bunch and less sensitive again to berry size. Hence, the program of research is heavily weighted toward understanding factors that determine bunch numbers and, to a lesser extent, factors that control bunch size.

Bunch Numbers

Sections 7.1 and 7.2 outline a set of anatomical studies investigating the timing of inflorescence initiation in the major wine grape varieties Cabernet Sauvignon, Chardonnay and Shiraz. Section 7.3 compares and contrasts the effect of climate on the 'fruitfulness' of Cabernet Sauvignon, Chardonnay and Shiraz across a broad climatic range. While section 7.4 describes a detailed field study exploring the environmental controls (during the previous season) on bunch number and size in Cabernet Sauvignon. While

Bunch Size

Section 7.5 explores the effects of conditions during budburst on the time-course of budburst, flower number, berry number, yield and fruit composition. Related to this is the extent to which pruning advances or retards budburst, which is examined in Section 7.6. Section 7.7 presents the results of detailed studies on flowering and fruit set in the Sunraysia and at Coonawarra.

Other Studies

Other sections investigate mechanical cop control (Section 7.8) and studies on ripening and quality (Section 7.9).

7.1 Timing and Control of Inflorescence Initiation (Sunraysia)

7.1.1 Introduction

Traditionally, most of the research on inflorescence initiation and development has been focussed on Sultana studies (Baldwin, 1964 & 1966, see chapter 4.3 of this report). His findings concluded that the sensitive stage of Sultana inflorescence initiation was between mid November and mid December (in Sunraysia). The best predictor of fruitfulness was a function of:

- Sum of daily max. temperatures between 27.8 and 32.2 ^{o}C, and
- Sunshine hours during a 20 day period from mid Nov - early Dec.

However, little work has been conducted into the varieties of Chardonnay, Shiraz and Cabernet Sauvignon. This experiment aimed to establish the timing of inflorescence initiation in these particular wine grape varieties. This was considered essential if relationships between climate and bud fruitfulness were to be established.

7.1.2 Materials and Methods

This experiment examined the varieties of Chardonnay, Shiraz and Cabernet Sauvignon and involved the weekly collection of buds from vineyards each of the vineyards around Merbein, Victoria. Dissected buds were removed from canes in 3 separate locations (base, middle and apex) and along the cane. Ten canes per a variety, per a vineyard were collected on a weekly basis and samples stored in both glycerol and Formalin Acetic acid Alcohol (FAA) solution.

Dr Peter May was engaged to teach us about bud dissection under the dissecting stereo microscope. The samples stored in glycerol were then dissected manually and stages of growth observed. The critical stage was observing when the buds went from the inductive to the differentiated phase. This was seen as the stage of bud initiation. Also, the development of the 2nd bunch in the bud was also monitored.

7.1.3 Results and Discussion

Dissection and analysis of buds was undertaken during the 1998/99 season (Figure 7.1.1). Results indicated that bud initiation was occurring much earlier in all the wine grape varieties being studied, especially Chardonnay. In Chardonnay, differentiation of anlage into bunch primordia was observed on the 1st of October (Figure 7.1.2). There was some evidence to suggest that this date may actually be earlier than this in Chardonnay, but samples were not collected prior to the 1st of September. Further differentiation was observed in Chardonnay buds until 11th November. The differentiation of the second bunches in the buds occurred at the latter dates.

In Shiraz, differentiation of anlage into bunch primordia was initially observed on the 14th of October, and the period of differentiation extended through until approximately the 9th of December (Figure 7.1.2). Again, the differentiation of the 2nd bunch was observed at the latter dates. This was a very broad period of differentiation in comparison to the other two varieties.

In Cabernet Sauvignon, differentiation of anlage into bunch primordia was initially observed on the 21st of October, and the period of differentiation extended through until approximately the 18th of November (Figure 7.1.2). Again, the differentiation of the 2nd bunch was observed at the latter dates.

7.1.4 Summary

Data presented here is the first work which has identified when inflorescence initiation in the wine grape varieties Chardonnay, Shiraz and Cabernet Sauvignon is occurring in the hot climate of Mildura. These dates differ significantly to that which has been published for Sultana (mid Nov – mid Dec), especially in the variety Chardonnay. In terms of grapevine phenology, the sensitive stage of bud initiation is most likely occurring around or just prior to flowering. It appears to occur in basal buds first and be slightly delayed towards the apex of the shoot.

This information is essential when attempting to establish links between climatic variables and fruitfulness. This was achieved in the variety Sultana by Baldwin (1964 & 1966), however, no research has been undertaken to examine the climatic drivers of bud fruitfulness.

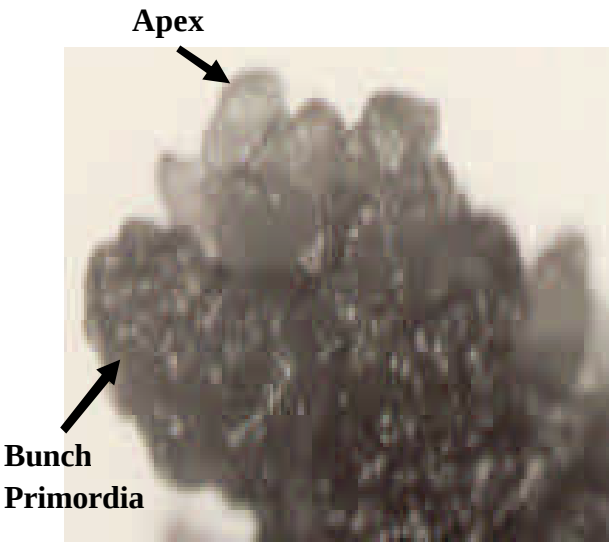


Figure 7.1.1 Photograph of a dissected Shiraz bud (collected 18th November) taken through a dissecting stereo-microscope (x60 magnification).

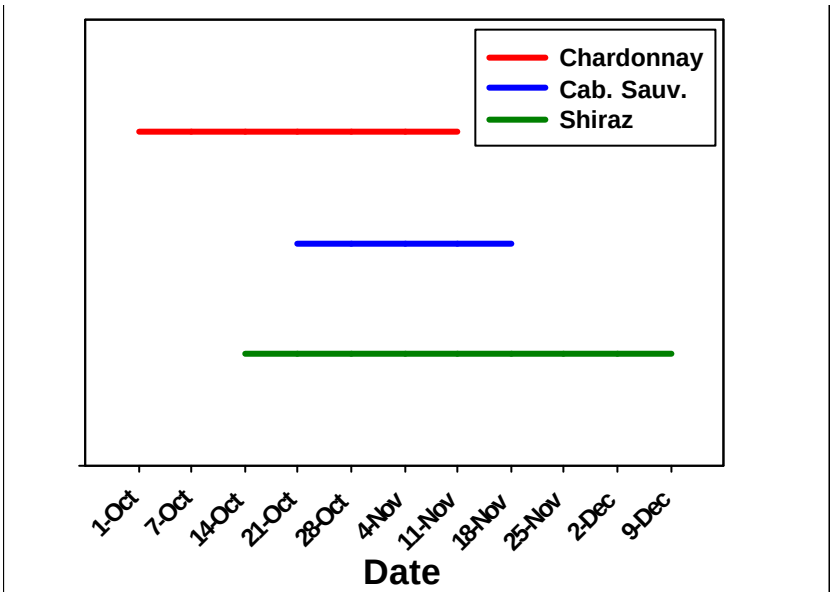


Figure 7.1.2 dates during 1998 season when inflorescence initiation in the varieties Chardonnay, Cabernet Sauvignon and Shiraz were occurring.

7.2 Timing and Control of Inflorescence Initiation (Greater Victoria)

7.2.1 Introductory Technical Information

Previous sections of this report (eg. see Section 3) have identified that there are a set of critical stages in the development of yield in grapevines: induction, initiation and early differentiation and budburst. Responses to environmental and cultural factors of reproduction at the early stages of yield formation (induction, initiation and early differentiation) remain, by and large, poorly understood. For instance, the relative importance of anlagen branching prior to dormancy compared to differentiation during budburst in controlling potential inflorescence size and flower numbers is not well known. Therefore, in seasons when bunches are either very big or very small it is difficult to know how much of this variation is due to fruit set and how much is due to early bunch development (either prior to dormancy or during budburst). This is partly because we lack detailed descriptions of the time-course of induction and initiation for our major wine grape varieties in a range of climatic regions. Without this information we cannot link processes to well defined phenological stages and better understand the effects of climate and management.

The main objectives of the experiment reported here were to: i) describe the time-course of fruit bud initiation (and 'pre-dormancy' differentiation) for Cabernet sauvignon vines grown in central Victoria, (ii) investigate any relationships between the development of inflorescences and grapevine phenology (eg. budburst, anthesis) and/or shoot development and (iii) investigate the effects of environmental factors and plant factors on the initiation and differentiation (pre-dormancy) of inflorescence primordia prior to dormancy (ie. to what extent is crop potential determined prior to dormancy and how important are environmental conditions during this time).

7.2.2 Research Methodology

Experimental Site

The experiment was established in a row of *Vitis vinifera* L. var. Cabernet Sauvignon (G9V3) described in Martin and Dunn (2000).

Experimental Design

The treatments imposed on the vines are detailed in Martin and Dunn (2000) and Dunn and Martin (2000) which are both attached to this report.

Measurements

Each Monday, Wednesday and Friday from 6th November 1998 until 16th December 1998 ten whole shoots were collected from the experiment: 5 from the 'early' pruning no dormex treatment and 5 from the 'late' pruning no dormex treatment. Shoots were randomly selected in advance and only taken from node positions 1 and 2 on primary shoots. Immediately after removal, each bud along the shoot was excised and placed into a labelled vial containing either FAA (50% Ethanol 90mL, glacial acetic acid 5mL and formalin [formaldehyde solution 37-40% w/v] 5mL) for the 'late' pruned treatment or glycerol (80%) for the 'early' pruned treatment. After buds were excised the shoots were placed into sealed plastic bags and transported back to the laboratory where buds were gently vacuum infiltrated for about 1 hr while the following shoot measurements were made:

- basal diameter
- shoot length
- internode length
- presence of lateral shoots
- leaf area of each leaf
- presence and position on clusters/bunches
- various cluster/bunch characteristics

Leaves stems and clusters/bunches were then dried (70^{o}C for 48 hr) and weighed separately.

7.2.3 Detailed Results, Discussion and Implications

It is our intention to undertake a full analysis of all buds collected. However, currently used histological and microscopic techniques are extremely time consuming and given the need to process many samples to obtain good quantitative data, not feasible. The samples are stable and will remain so for a number of years. In the meantime appropriate techniques are being developed. Despite this, some of interesting results have emerged.

Flowers and branches

The numbers of primary branches along the main axis (and the 'wing') were counted along with the total number of flowers on the inflorescence. Regression analysis of these data showed that branch number accounted for more than 70% of the variation in flower number per cluster (square root transformed, see Section 4.2.4, Figure 4.2.43). This relationship is stronger than that measured for Pinot Noir in Burgundy (R^2 = 52%) by May (1987) and those for Chardonnay in two vineyards near Adelaide (May 2000). However, the results presented here are supported by similar results relating berry number to branch number for cvs Chardonnay, Cabernet Sauvignon and Pinot Noir (unpublished data). Whilst R^2 values have generally fallen between 60 and 75%, there is some optimism that branch number may be a useful predictor of bunch size, at least in years where bunches are much bigger or smaller than usual. And after all these are the years that present industry with its greatest forecasting problems. Further work is required to determine how stable these relationships are from year to year and across climates. This work is being done as part of the GWRDC funded project CSP 00/2.

Flowers and Shoot Leaf Area

Figure 7.2.1 shows that the relationship between leaf area per shoot and the number of flowers per shoot is poor. This has implications for modelling yield development in grapevines. Unlike annual crops, such as wheat, using leaf area or dry matter production as a key driving variable to model yield development is likely to be unsuccessful. Rather, modelling should take into account effects of conditions during previous season.

Predicting Total Flower Number

May (1987) reported that for that the correlation between the flowers on branches 3+4 and the total number of flowers for over 100 Pinot Noir inflorescences in Burgundy explained more than 90 % of the variability. Our results for Cabernet Sauvignon at Dookie, although they explain less of the variation, show similarly strong correlations. Flowers on branches 3+4 explained 71% of the variation. This was improved by adding branch 2 (81%) and further improved when flower numbers were square root transformed (83%, see Figure 7.2.2). These correlations could be useful for forecasts based on flower numbers.

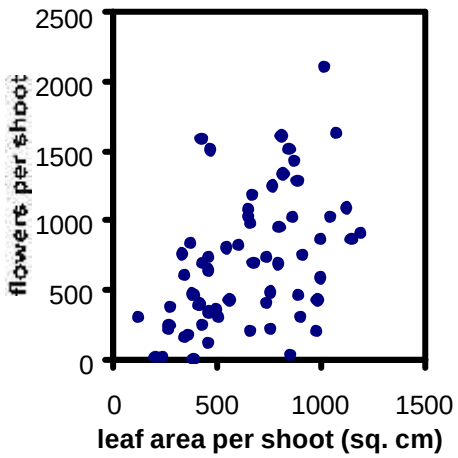


Figure 7.2.1 The association between leaf area per shoot and flowers per shoot for Cabernet Sauvignon growing at Dookie in Central Victoria during the 1998/99 season.

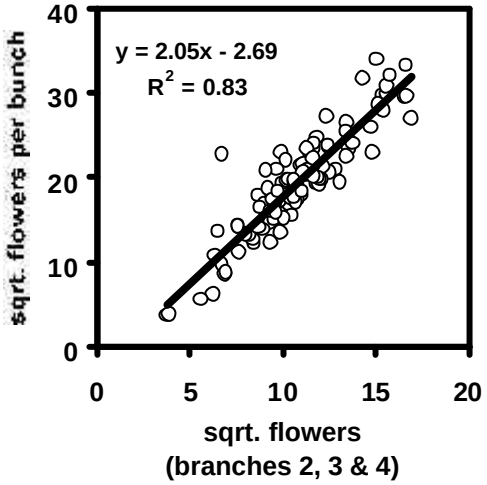


Figure 7.2.2 Regression of v(flowers per inflorescence) on v(flowers on branches 2+3+4) for Cabernet Sauvignon growing at Dookie in Central Victoria during the 1998/99 season.

7.2.4 References

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7.3 Climatic Effects on Fruitfulness

7.3.1 Introduction

The influence of climatic factors on bud fruitfulness was well studied by Baldwin (1964 & 1966) and Barnard (1932). This work was conducted in the variety Sultana, a variety which was historically known for its seasonal problems with fruitfulness. However, little or no research has examined the climatic effects on the fruitfulness of Australia's major wine grape varieties Chardonnay, Shiraz and Cabernet Sauvignon. The aim of this research was to examine the fruitfulness of two very different wine grape growing regions, Sunraysia (MJT=23.3^{o}C, classified hot irrigated growing region) and Coonawarra (MJT=19.3^{o}C, classified as a moderate growing region).

7.3.2 Materials and Methods

Experimental Sites

The experimental sites consisted of 43 commercial vineyards growing *Vitis vinifera* L. varieties Chardonnay, Shiraz and Cabernet Sauvignon. 31 vineyards (10 Chardonnay, 11 Shiraz and 10 Cabernet Sauvignon) were located within a 40km radius of Mildura (Sunraysia), Victoria, Australia (142^{o}08'E, 34^{o}12'S) and 12 vineyards (4 Chardonnay, 4 Shiraz and 4 Cabernet Sauvignon) within a 10km radius of Coonawarra, South Australia, Australia (140^{o}50'E, 37^{o}22'S). A range of different clones were examined within each variety, however, clonal differences were not examined during this experiment. Planting and vine management details for each site are outlined in Table 1. The long-term average annual rainfall for Mildura is 275mm, the mean January temperature (MJT) is 23.3^{o}C with a October to April temperature variability index of 46.9 and the heat sum between October to April is 1,753 degree days (base temperature10^{o}C) (Gladstone, 1992). The soils in Sunraysia typically range from Coomealla sands to Merbein clay (Northcote, 1979). The long-term average annual rainfall for Coonawarra is 628mm, the MJT is 19.3^{o}C with a October to April temperature variability index of 45.3 and the heat sum between October to April is 1,337 degree days (base temperature 10^{o}C) (Gladstone, 1992). The soils in Coonawarra are typically red Terra Rossa (Northcote, 1979).

Forced Single Node Cuttings

A modified method for producing single node cuttings was used in this study, this was similar to those methods used by Antcliff and May (1973). Briefly, during winter (June) of 1997 and 1998, 20 randomly selected one year old fruiting canes were collected from each experimental vineyard in Sunraysia and Coonawarra. Canes were stored in sealed plastic bags with 200mL of water, at 4^{o}C, until required. Each cane was dipped in 2.5% (v/v) Dormax® (active constituent - Hydrogen Cyanimide 600g/L) for 5 seconds and the cane cut approximately 3-5mm above each node position along the cane, to give anywhere between 1-15 single node cuttings per cane. The base of each single node cutting was planted into trays (20cm x 30cm x 7cm) containing steam sterilised river sand. Cuttings were propagated in a glasshouse located at CSIRO Plant Industry, Horticulture Unit, Merbein, Victoria. The glasshouse was maintained at 27^{o}C (+/- 5^{o}C) during the day and 15^{o}C (+/- 5^{o}C) during the night, under natural light conditions and misted 3 times a day (9:00am, 12:00pm and 6:00pm) for 5 minutes each time. Bud burst (E-L stage 4, Coombe, 1995) occurred approximately 10-14 days after planting. Bunch number and node position were recorded on each cutting 14 days after bud burst. At this stage, the growing shoot on each cutting was approximately 10-100mm long.

Merbein Bunch Count Method

The Merbein Bunch Count Method (Antcliff *et al.,* 1972) was conducted on 10 randomly selected 20cm transects in each experimental vineyard, in both Sunraysia and Coonawarra. This was conducted approximately one month after budburst. This method was used to assess nodes/vine, shoots/vine, fruitful nodes/vine, bunches/vine and percentage bud burst. The average bunch number per node position was also recorded for comparison with Single Node Cutting results. The definition of the term fruitfulness in this case will be number of bunches per burst bud.

7.3.3 Results and Discussion

The results of comparisons of regional and seasonal differences will only be conducted for the variety Cabernet Sauvignon. Examination of the forced single node cutting data indicated that Cabernet Sauvignon grown in Coonawarra had a significantly ($p<0.05$) lower fruit fruitfulness at all node positions in 1997 (Figure 7.3.1a). However, in 1998, although Coonawarra node positions 1 to 5 were significantly ($p<0.05$) lower in fruitfulness, node positions 6-14 did not differ significantly (Figure 7.3.1b). In 1997, although fruitfulness in Coonawarra was significantly ($p<0.05$) lower than that in the Sunraysia, they both displayed a similar trend at different node position along the cane. However, although in 1998 the basal fruitfulness of canes was significantly ($p<0.05$) lower that that of canes in Sunraysia, no significant difference in fruitfulness was observed between node positions 6 to 14.

Post-bud burst fruitfulness assessments indicated that Cabernet Sauvignon vines grown in the Coonawarra generally had a lower fruitfulness than that of vines grown in the Sunraysia (Figure 7.3.2). Analysis of the 1997 data indicated significantly ($p<0.05$) higher fruitfulness was observed in Sunraysia between node positions 5-14 (Figure 7.3.2a). In 1998, Coonawarra vines tended to be more fruitful than in 1997, however, they still possessed a significantly ($p<0.05$) lower bunch number per burst node at node positions 1,5,6,9 and 11 compared to that of 1998 Sunraysia vines (Figure 7.3.2b).

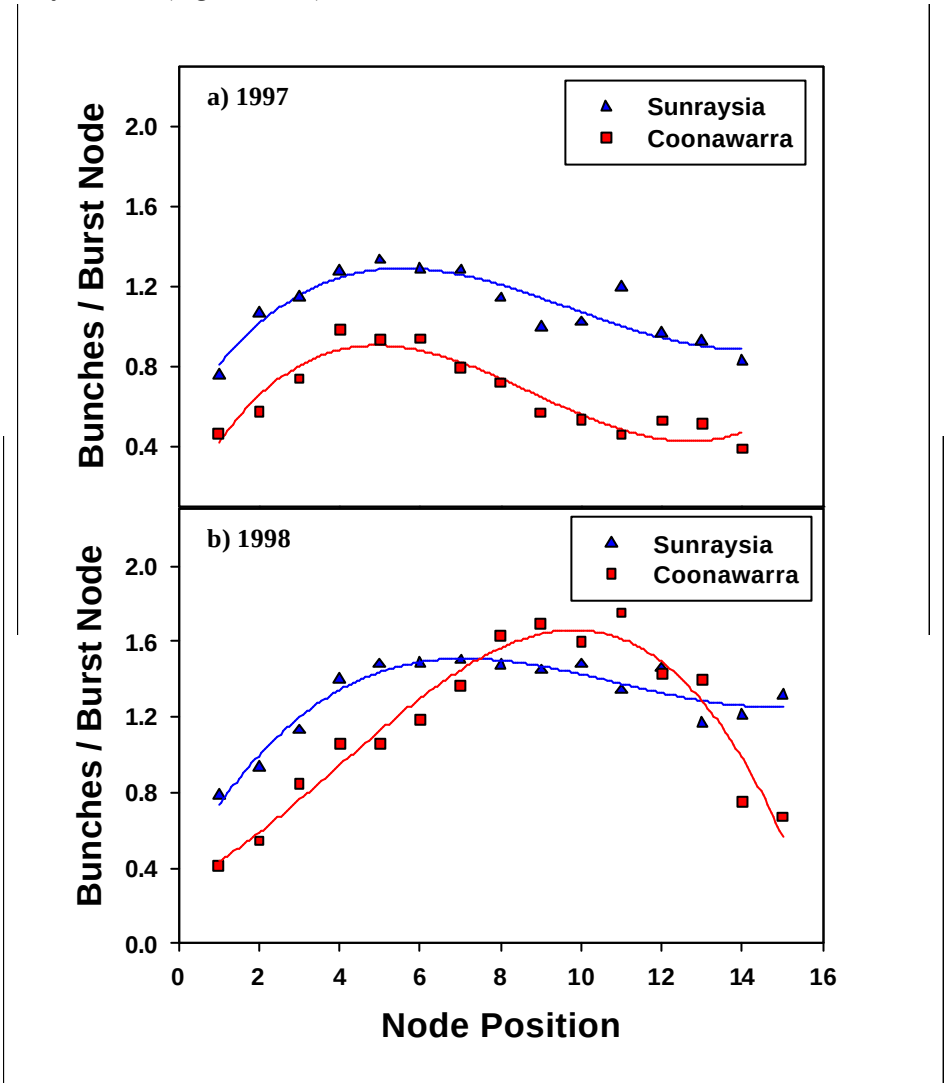


Figure 7.3.1 The average number of bunches per node position at bud dormancy for Cabernet Sauvignon in the Sunraysia and Coonawarra in a) 1997 and b) 1998.
Estimates were derived from measurements of forced single-node cuttings sampled from 10 sites in the Sunraysia and 4 sites in Coonawarra (20 canes per site)

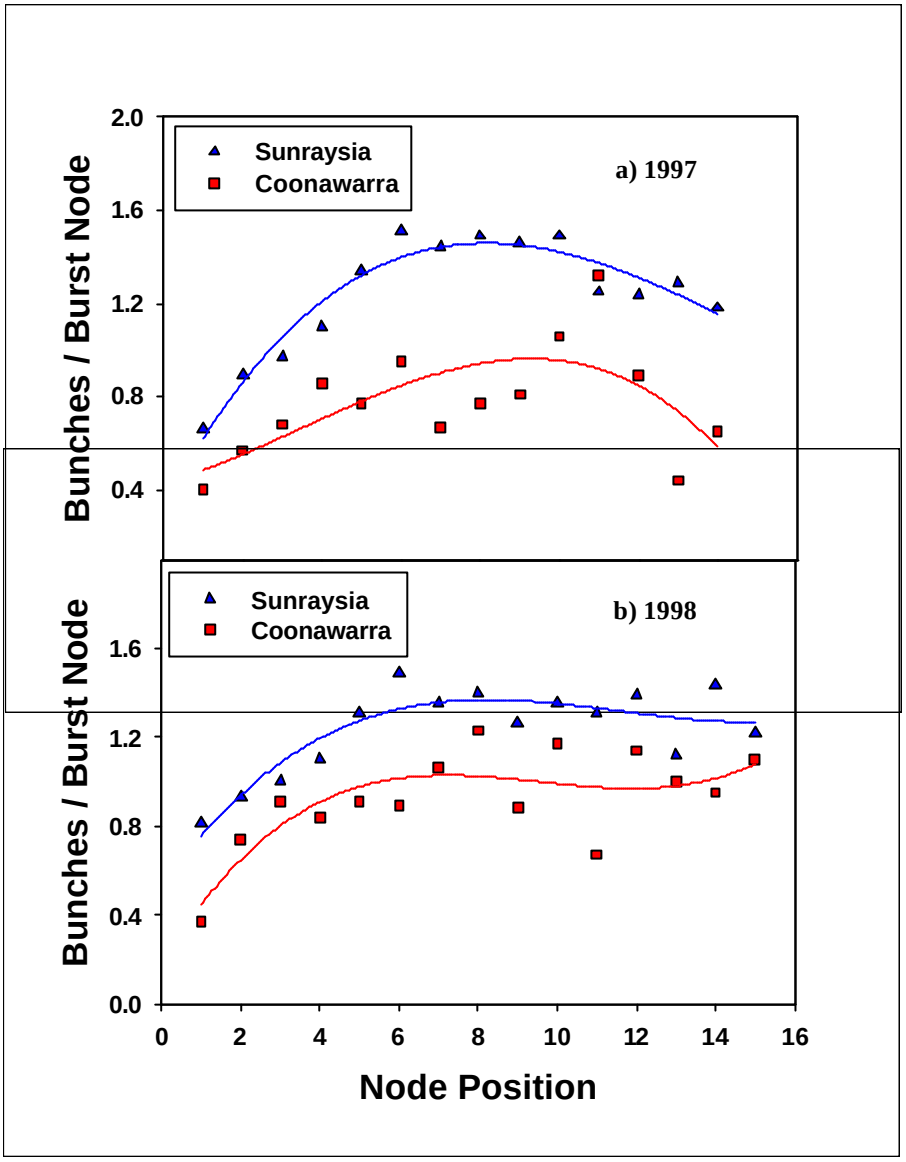


Figure 7.3.2 The average number of bunches per node position for Cabernet Sauvignon post bud burst in the Sunraysia and Coonawarra in a) 1997 and b) 1998.
Estimates were derived from Merbein bunch counts made at 10 sites in the Sunraysia and 4 sites in Coonawarra (10 x 20cm transects/site).

7.3.4 Summary

Climatic conditions can have a large influence on potential fruitfulness of wine grape varieties. The results indicated that wine grapes grown in cooler climates generally have a reduced fruitfulness in comparison to wine grapes grown in warmer climates, eg. Sunraysia. The management of potential vine fruitfulness in cooler climates is critical. In low fruitfulness seasons, pruning to two bud spurs may actually be removing most of the potential vine yield. In these climates cane pruning has advantages as a risk management tool to manage seasonal differences in fruitfulness.

7.4 Environmental Control of Bunch Numbers

7.4.1 Introductory Technical Information

Flower formation in grapevines involves a long multi-step process. The first visible sign of the evocation of flowering is the initiation, during spring, by the apical meristem of an extra-lateral meristematic structure called the 'anlage'. The anlage, a term introduced by Barnard (1932) first forms a bract primordia, then divides into an 'inner' and 'outer' arm. The inner arm, and often the outer arm, may differentiate branch initials before the bud enters dormancy. After dormancy, and during budburst of the following season, further branching takes place terminating in the formation of individual flowers. Overall, these processes determine potential yield. First, by exerting a coarse control over potential bunch number and then by exerting a finer control over flowers per bunch (bunch size).

Light microscope (Barnard 1932, Barnard and Thomas 1933) and scanning electron microscope studies (Srinivasan and Mullins 1981) of developing latent buds demonstrate that anlagen which undergo extensive branching prior to dormancy form inflorescences while those that possess only two or three branches form tendrils. Also, Barnard and Thomas (1933) recognised sometime ago that "the extent of the growth of an inflorescence during this period (mid-August to budburst) is largely dependent upon the stage of development it had reached at the end of the previous season (prior to dormancy)".

By dissecting latent buds 13 weeks after budburst on small potted vines grown in growth cabinets, Buttrose (1974) was able to show that temperature significantly affected the formation of inflorescence primordia. Furthermore, Buttrose (1969, 1974) deduced that the period of optimum sensitivity to induction was some 3 weeks prior to the initiation of anlagen (Buttrose 1969, 1974). Sensitivity to temperature was negligible before the separation of the node from the apex maximum at the time the node was separating from the apex and then progressively declined becoming negligible when the node was about 10 positions below the apex.

The timing of the temperature effect described by Buttrose (1974) in growth cabinet studies to disagrees with the field studies of Baldwin (1964). Baldwin (1964) described a significant ($P < 0.01$) relationship between percentage of fruitful buds (those containing an inflorescence primordia) at nodes position 4, 9 and 14 on dormant canes of Sultana and hours of bright sunshine and daily maximum temperatures above 29°C in a 20 d period in the previous November ($r^2 = 75\%$). The aim of the experiment reported here was to seek relationships between environmental conditions during critical stages of reproductive development in the previous season and bunch size and architecture of Cabernet Sauvignon vines growing in Central Victoria.

7.4.2 Research Methodology

Experimental Site

The experiment was established in a row of *Vitis vinifera* L. var. Cabernet Sauvignon (G9V3) vines, grafted onto Schwarzmann rootstocks, which were planted in 1986 in the Melbourne University vineyard at Dookie, Victoria, Australia (36° 23′S, 145° 25′E). The experimental site and vine management details are fully described in Martin and Dunn (2000). Air temperature and humidity, soil temperature, grass temperature, rainfall, wind-speed and solar radiation were measured at 15 minute intervals using an automated weather station located approximately 200m from the experimental site. Air temperature and humidity measurements were also recorded at 0900 h and 1500 h daily at The University of Melbourne Dookie College approximately 2 km from the experimental site.

Experimental Design

Four canes each from 60 vines were randomly selected for retention in the 1999/2000 season and 'arched' to promote budburst from the middle of the cane. All other shoots were pruned on 24th August 1999 and the pruning weights recorded for each vine. The retained canes were initially selected as shoots during the previous season for detailed assessments of, *inter alia*, growth (periodic measurements of node number and shoot length), anthesis, veraison, bunch characteristics (number, size, architecture, position and fruit composition) during the 1998/99 season (see Section 7.5).

Measurements - 1998/1999 Season

The experiment in 1998/1999 season tested the response of flower number to two pruning times and the application of hydrogen cyanamide (see Section 7.5). Thus, for each retained cane in the 1999/2000 season detailed records were recorded during the previous season:

- its date of budburst in the previous season
- a record of its growth and development during the previous season
- the number, size and position of inflorescences on that shoot in the previous season
- anthesis and veraison dates for any bunches
- bunch size and fruit composition at harvest
- whole vine yields and pruning weights

Measurements - 1999/2000 Season

Measurements made during the 1999/2000 season included:

- budburst
- shoot growth and development (including date of node separation)
- bunch numbers and bunch position
- bunch size at harvest
- bunch architecture and berry size
- fruit composition
- detailed meteorological measurements

7.4.3 Detailed Results

Data from this experiment are currently being analysed.

7.4.4 References

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Srinivasan, C. and Mullins, M.G. (1981) Physiology of flowering in the grapevine - A review. American Journal of Enology and Viticulture **32**, 47-63.

7.5 Influence of Temperature During Budburst on Inflorescence Differentiation

7.5.1 Introductory Technical Information

Grapevine yield can be expressed as the product of the number of berries present at harvest and their average size. Of the two, mean berry number is more variable than mean berry size - from bunch-to-bunch, from vine-to-vine and from season-to-season and, hence, berry number explains more of the vine-to-vine variation in yield. Berry number is determined by (i) the number of flowers present at anthesis, (ii) the proportion of these that set successfully and, (iii) the percentage of berries that remain attached until maturity. Well documented quantitative studies into inflorescence initiation in grapevines extends back to, at least, the 1930s, but less attention has been paid to subsequent differentiation and especially developmental events during budburst. Although the importance of conditions during budburst to the development of reproductive structures in other plants has been well established, this area of research remains poorly studied in the grapevine. Therefore, this study concentrates, in the first instance, on factors controlling flower number, the first of these important yield determinants.

Winter pruning is a common viticultural practice that may be carried out any time between leaf fall and budburst. It has been known for some time (Ravaz 1912) that delaying pruning can retard budburst for anything up to a few weeks. In the field study reported here, pruning time was varied in a population of 13-year-old *Vitis vinifera* L. var. Cabernet Sauvignon vines to extend the duration of budburst and, thereby, expose bursting shoots to a greater range of environmental conditions. Hydrogen Cyanamide, a known promoter of budburst was also applied in an attempt to advance budburst. We nominated temperature as a key driving variable for inflorescence differentiation and subsequent developmental events and sought relationships to flower number, budburst, fruit set and fruit composition.

7.5.2 Research Methodology

Experimental Site and Design

The experiment was established in a row of *Vitis vinifera* L. var. Cabernet Sauvignon (G9V3) vines, grafted onto Schwarzmann rootstocks, which were planted in 1986 in the Melbourne University vineyard at Dookie, Victoria, Australia (36° 23′S, 145° 25′E). The experimental site, vine management details and meteorological measurements are fully described in Martin and Dunn (2000).

Four treatments were imposed on 60 vines within a single row of 72 vines, *viz*.: 1. 'earlier' pruning, 2. 'earlier' pruning + hydrogen cyanamide, 3. 'later' pruning and 4. 'later' pruning + hydrogen cyanamide. 'Earlier-pruned' vines were pruned on 7th July 1998 and 'later-pruned' vines were pruned on 17th August 1998. The experimental design was a randomised block with nearest-neighbour balance, consisting of 5 blocks, 4 plots per block, and 3 contiguous vines per plot.

Measurements

The following measurements were made:

- Budburst (> 6, 500 nodes)
- Bunch numbers and position (772 shoots)
- Anthesis and Veraison (300 shoots)
- Bunch architecture (300 bunches)
- Flower number/weight (300 inflorescences)
- Berry number/weight (300 bunches)
- Fruit composition (pH, °Brix, titratable acidity, malic acid, tartaric acid, K)

For a complete description of the methodologies see Martin and Dunn (2000) and Dunn and Martin (2000)

Statistical Analysis

Analysis of Variance (ANOVA), regression analyses and Residual Maximum Likelihood (REML) analyses were performed using Genstat© 5 Release 4.1 (Lawes Agricultural Trust, 1997).

7.5.3 Results

Detailed results can be found in Dunn and Martin (2000) and Martin and Dunn (2000). Here we present a selection of these results.

Budburst

Relative to 'earlier' pruning, 'later' pruning delayed the mean date of the onset of budburst (bursting of the first bud in each plot) and the mean date of 60% budburst on clear nodes by 4.3 days and 5.3 days respectively (Table 7.5.1). This delay persisted at anthesis (5.0 days) and veraison (4.1 days). There was also evidence that a similar delay persisted until harvest. Mean TSS concentration of the fruit of Later-pruned vines was 0.91 °Brix lower than for the Earlier-pruned vines on the day of harvest. If it is assumed that juice soluble solid concentration was increasing at a rate of 0.13 °Brix/day (derived from curves presented by Coombe 1992 and McCarthy 1999), then a difference of 0.91 °Brix would represent a delay of about 7 days. Hydrogen cyanamide did not significantly affect the times of the onset of budburst, 60% budburst, anthesis or veraison or fruit maturity at harvest, but interacted significantly with 'later' pruning to delay fruit maturity (Table 7.5.1).

Table 7.5.1 Effects of two pruning times and application of hydrogen cyanamide (HCN) on the timing of budburst, anthesis and veraison, and the maturity of grapes at harvest (indicated by juice sugar concentration).

Treatment	**$Budburst_1$** (Days after reference date)	**$Budburst_{60}$**	**Anthesis**	**Veraison**	Maturity (°Brix)
Pruning time					
Earlier	1.9	9.0	8.8	9.1	24.96
Later	6.2	14.3	13.8	13.2	24.05
$LSD_{5\%}$	0.4	1.4	1.5	1.7	0.57
Hydrogen cyanamide					
+ HCN	4.0	11.9	11.2	11.8	24.27
- HCN	4.1	11.4	11.4	10.5	24.74
$LSD_{5\%}$	0.4	1.4	1.5	1.7	0.57
Pruning time x hydrogen cyanamide					
Earlier	2.0	8.2	8.6	8.4	25.27
Earlier+HCN	1.8	9.8	9.0	9.8	24.65
Later	6.2	14.6	14.2	12.6	24.21
Later+HCN	6.2	14.0	13.4	13.8	23.89
$LSD_{5\%}$	n.s.	n.s.	n.s.	n.s.	0.81

n.s. indicates no significant interaction (reproduced with permission from Martin and Dunn 2000)

Analysis of the effect of the number of bunches per shoot on the time that the shoot burst using the smaller data set 1 (225 shoots) showed that shoots without bunches burst on average about 3 days later than shoots with bunches, and analysis of the larger data set 2 (772 shoots) showed that 2-bunch shoots burst on average about 1 day before 1-bunch shoots (Table 7.5.2).

Table 7.5.2 Effect of bunches per shoot on the time of budburst determined for 2 sets of shoot data

Bunches per shoot	Mean budburst time	Shoots	% of sample
Data set 1			
2	10.1	133	59
1	10.6	68	30
0	13.4	24	11
$LSD_{5\%}$	2.3		
Data set 2			
2	11.0	474	61
1	10.0	298	39
$LSD_{5\%}$	0.5		

(reproduced with permission from Martin and Dunn 2000).

The frequency of budburst was sensitive to fluctuations in air temperature, but limited by the number of buds available to burst (Figure 7.5.1). The time-course of the rate of budburst for the 'earlier'- and 'later'-pruned shoots from which flower clusters were collected is presented in Figure 7.5.2. Daily mean air and soil temperatures have been overlayed on the budburst curves to illustrate the temperature conditions to which bursting shoots were exposed. Daily mean air and soil temperature during budburst ranged from 11.2°C to 15.7°C and from 12°C to 16°C, respectively. However, the weighted averages of mean soil temperature to which bursting buds were exposed were 13.3°C and 14.9°C for the 'earlier' and 'later' pruned populations, respectively. This represented a difference of only 1.6°C between pruning treatments. The difference in weighted averages of mean air temperature was even less, being 0.5°C (13.8°C versus 14.3°C).

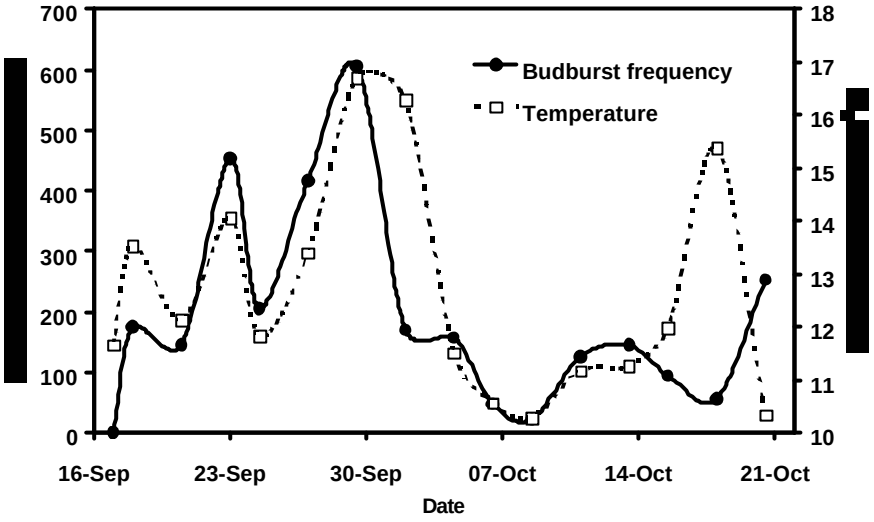


Figure 7.5.1 Mean air temperatures during the course of budburst and budburst frequencies for the entire population of buds on 60 vines
(reproduced with permission from Martin and Dunn 2000).

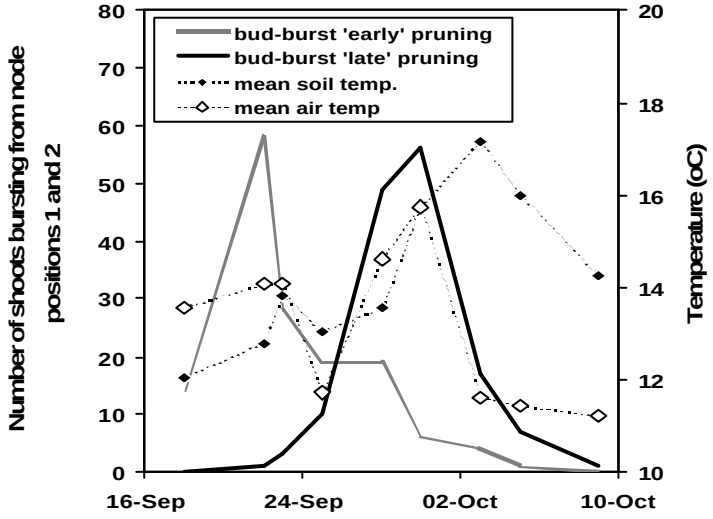


Figure 7.5.2 The time-course of budburst for shoots from which flower clusters were harvested prior to flowering. Daily mean air and soil (15 cm depth) temperature are also presented.
Vines were either pruned 'earlier' on 7th July 1998 (E) or 'later' on 17th August 1998 (L) (reproduced with permission from Dunn and Martin 2000).

Flower Number

Flowers per cluster and bunches per shoot were estimated by destructively sampling 300 clusters prior to anthesis from shoots of known bursting date. Neither pruning time nor the application of hydrogen cyanamide significantly affected flowers per cluster (Table 7.5.3). However, across the entire population of clusters sampled, flowers per cluster was weakly correlated with daily maximum air temperature on the day of budburst, daily mean soil temperature on the day of budburst and date of budburst ($P < 0.001$, Adjusted r^2 = 3.6%, 3.7%, 4.5% respectively). Clusters had fewer flowers on later bursting shoots and also as temperatures on the day of budburst increased.

Table 7.5.3 Effect of pruning time and hydrogen cyanamide on flowers per cluster (FloCl) and bunches per shoot in 13-year-old, spur-pruned Cabernet Sauvignon vines at Dookie in central Victoria.

Treatment	Mean (n=75) √FloCl	**Mean (n=75) Bunches per shoot**
E	18.51 (343)	1.60
E+D	17.42 (303)	1.55
L	17.46 (305)	1.64
L+D	16.85 (284)	1.47
L.S.D. (P < 0.05)	**1.77**	**0.48**
CV (%)	**33.9**	**31.8**

E = 'earlier' pruned (7th July 1998), L = 'later' pruned (17th August 1998), +D = sprayed with Dormex® (@ 25 mL/L, Non-ionic wetter 1 ml/L) on 26th August 1998. The numbers in parentheses in the √FloCl column are back-transformed means (reproduced with permission from Dunn and Martin 2000).

More of the variance in flowers per cluster was accounted for by the number of clusters on the shoot ($p<0.001$, Adj. r^2 = 17.4%) and the position of the cluster relative to other clusters on the same shoot, ie. lower of two, upper of two or sole ($p<0.001$, Adj. r^2 = 26.1%). Average flowers per cluster declined in the order lower of two > upper of two > sole (Figure 7.5.3) The best regression model included the position of the cluster relative to other clusters on the shoot and the date of budburst ($p<0.001$), but this still accounted for only 29.2% of the total variance in flowers per cluster. Mean flowers per cluster was significantly ($P < 0.05$) and substantially (97% for back-transformed means) higher for clusters on two-cluster shoots than for clusters on single cluster shoots (see Dunn and Martin 2000).

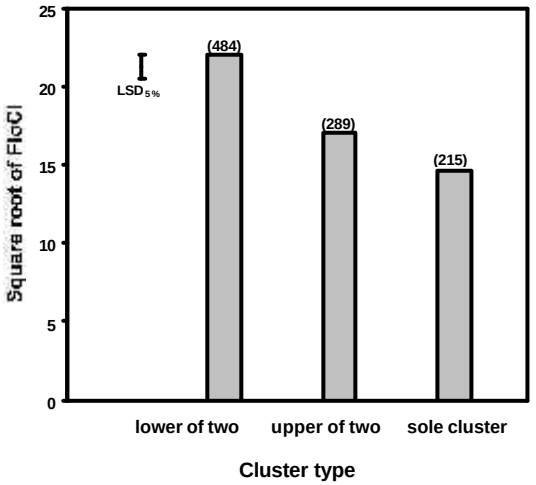


Figure 7.5.3 Effect of shoot node position on √FloCl for one-cluster and two-cluster shoots in Cabernet Sauvignon
(reproduced with permission from Dunn and Martin 2000).

Fruit Composition

Laboratory analysis of berries has been completed and data have been entered. However, a full analysis and interpretation of these results is being completed.

7.5.4 Discussion

Budburst

Applying hydrogen cyanamide to Cabernet Sauvignon vines in this region did not advance the onset of budburst or the time of 60% budburst. Its effect was to increase budburst for buds that otherwise would not have burst. As expected, a difference in the time of winter pruning led to a difference in the time of budburst. The difference of 5 days in budburst time as a result of a 6-week difference in pruning time is consistent with the results of studies for other wine grape varieties in other regions. The persistence of the difference between the budburst times of earlier- and later-pruned vines at flowering, veraison and maturity confirms long-held knowledge (Ravaz 1912). Some Victorian viticulturists prune earlier to advance the time of harvest and thus reduce the risk of losing crop due to rain-induced damage in autumn (Bailey pers. comm.). The value of varying pruning time in practice would need to be assessed in relation to specific circumstances. Managers of large varietal blocks could prune them in stages in order to reduce overall frost risk in frost-prone areas or to extend the duration of ripening to obtain more flexibility during harvesting. Alternatively, a difference of 5 days in maturity could make it difficult to optimize the time of machine harvesting of a block and in such an instance it would be sensible to avoid large differences in the time of pruning of different parts of the block.

We observed that different types of bud, as defined by their position on the vine and as indicated by the different types of shoot that they produced, burst at different times. There was a hierarchy of bursting, with more distal nodes bursting earlier on spurs, and spur bases bursting earlier than old wood. Single-inflorescence shoots burst from primary buds on clear nodes 1 day later, on average, than double-inflorescence shoots. Buds containing shoots with no inflorescence primordia burst even later again. The difference between budburst of 'fruitful' primary shoots (those with at least one inflorescence) and 'unfruitful' primary shoots (those with no inflorescence) averaged 3 days. Dunn and Martin (2000) demonstrated that for Cabernet Sauvignon, two-cluster shoots had significantly and substantially more flowers (per bunch and per shoot) than single-cluster shoots. If one introduces the concept that flower number (potential seed number) and inflorescence number (potential reproductive sites) indicate a shoot's 'reproductive potential', then one could speculate that shoots with higher reproductive potential burst in preference to those with lower reproductive potential. It is difficult to explain this in evolutionary terms because the genotypes familiar to viticulturists are highly selected, grown unnaturally and not in their native habitat. However, it is possible that vines that supported earlier bursting of the shoots most likely to result in seed dispersal could have gained a selective advantage. There would also be an advantage for a tree-climbing plant such as the grapevine in giving preference to shoots bursting at higher locations.

The effects of pruning time and reproductive potential on time of budburst are factors that are not considered in models that are currently used to predict budburst (e.g. Pouget 1988, Swanepoel *et al*. 1990). Thus, the capability of currently-available models designed to predict the time of budburst could be improved by the inclusion of a function or the adjustment of a parameter to take account of the effects of pruning time and reproductive potential.

Flower Number

To the best of our knowledge this detailed study, where over 6,500 nodes were monitored for budburst and 300 inflorescences were examined, is the first that has attempted to investigate relationships between temperature conditions at budburst and grapevine flower numbers in the field. Although delaying pruning by some six weeks delayed 60% budburst by four days and the application of hydrogen cyanamide advanced 60% budburst by one day, there was no significant ($P > 0.05$) effect of pruning or hydrogen cyanamide on flowers per cluster. However, there were highly significant ($p < 0.001$) but weak correlations between flowers per cluster, pooled across all treatments, and the temperature variables mean soil temperature on the day of budburst and maximum air temperature on the day of budburst (Adj. R^2 = 3.7% and 3.6% respectively). This field result is consistent with both the nature and the extent of the effect of temperature observed by Pouget (1981) in a growth cabinet study (cf. 24 flowers/°C with 43 flowers/°C). However, as the release of grapevines from dormancy is strongly controlled by temperature, it is unlikely that bursting shoots in the vineyard would be exposed to the large temperature range tested by Pouget (ie. 12°C versus 25°C). Although mean daily soil and air temperatures were only weakly correlated with flowers per cluster, temperature might still affect inflorescence differentiation during budburst. Temperature over shorter time periods, perhaps just a few hours, may exert a strong effect over flower formation in individual inflorescences. Until we possess a more precise knowledge of the timing of the various development stages leading to flower formation in grapevines and their relationship to the growth of other organs, the interpretation of field experiments such as this will continue to be frustrating.

One striking feature of our data is the large variability of flower numbers. We have shown that around 4% only of the total variance in flowers per cluster could be accounted for by the time of budburst or associated mean daily temperature conditions. Cluster-shoot and cluster-cluster relations appear to have a much stronger effect, accounting for up to 26% of the variance in the case of cluster position relative to other clusters on the same shoot. Moreover, where two or more clusters are present on a shoot, there are more flowers on the more proximal clusters. Thus, commonly observed differences in size between proximal and distal bunches of grapes at later stages of development are probably more closely related to flower number than fruit set. To our knowledge, there have been no previous reports that multiple-cluster shoots have substantially more flowers than single-cluster shoots or that flower number is sensitive to node position on two-cluster shoots but not on one-cluster shoots. These results also imply that there may be an association between promotion of induction of anlagen in the previous season and a pre-conditioning of inflorescence primordia which is expressed as higher flower numbers in the current season.

Taken overall, our results imply that conditions during initiation in grapevines control flower numbers per shoot and per vine in two ways. First, there is a coarse control over flower numbers through effects on cluster numbers per shoot and, secondly, a finer control may exist where an increase in the number of clusters per shoot also promotes higher flowers per cluster. This may explain the observation (Martin and Dunn, unpublished) that in seasons where grape yields are relatively high, bunch number (per shoot, per node and per vine) and berry numbers per bunch are both relatively high.

7.5.5 Implications and Recommendations

- Pruning time may be a source of variation in the timing of key phenological events in the vineyard and may be an important factor to consider in planning vineyard operations.
- The frequency of budburst was sensitive to fluctuations in air temperature, but limited by the number of buds available to burst.
- A primary shoot tended to burst earlier if it had more bunches. Thus, it may be possible to improve temperature-based models designed to predict the timing of phenological events in grapevines by including parameters that take account of pruning time and the reproductive potential of classes of buds.
- Conditions during floral initiation seem to simultaneously promote both inflorescence and flower numbers. Therefore, an excellent opportunity to manipulate yield potential exists by actions during critical periods in the development of anlagen. For this potential to be realised, however, the critical periods need to be defined, important determining factors need to be identified, and commercially viable ways of controlling them need to be developed. This is a field of research and development that has the potential to deliver very large benefits to the grape and wine industries.

7.5.6 References

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7.6 Effect of Pruning on Inhibition of Budburst

7.6.1 Introduction

The experiment reported on in [cross-ref to effect of conditions at budburst] and in Martin and Dunn (2000) and Dunn and Martin (2000) showed that buds burst approximately 5 days earlier on vines that were pruned on 7 July than on vines that were pruned on 17 August in the 1998/99 season. However, that experiment did not allow us to determine whether earlier pruning had advanced budburst or later pruning had retarded it relative to an unpruned condition. This question has relevance when considering what physiological processes may promote or inhibit budburst in earlier or later pruned vines.

In Martin and Dunn (2000) we speculated that earlier pruning may have advanced budburst because an inhibiting effect of more apical buds was removed earlier. It could be that there is a residual effect of the presence of more apical buds that diminishes with time after their removal. If this is so, earlier pruning could cause earlier budburst by enabling the level of inhibition to fall below a critical threshold sooner. More evidence for a residual predisposition for more apical buds to burst earlier comes from our observations that, even when canes that have been detached and cool-stored for many weeks are cut into single nodes and each node is forced separately, buds at more apical positions tend to burst more frequently and earlier than buds at more basal positions (see section 4.3).

In the 1999/2000 season we ran a small follow-up experiment to determine whether spur-pruning advanced or retarded budburst relative to unpruned vines.

7.6.2 Research Methodology

The experiment was conducted in previously untreated vines near the row used in the experiment reported on in [cross-ref to effect of conditions at budburst] and in Martin and Dunn (2000) and Dunn and Martin (2000). General site details are described in Martin and Dunn (2000). All vines in the experiment had previously been pruned to 2-node spurs for many years.

The experimental design was a randomised block consisting of 9 blocks and 2 single-vine plots per block to which 2 pruning treatments were allocated randomly. The treatments were 'Unpruned' or 'Spur-pruned'. The Spur-pruned vines were pruned to 2-node spurs on 10 September 1999. The number of spurs per vine ranged from 23 to 42. Budburst was monitored on 20 randomly selected canes on each Unpruned vine and all spurs on each Spur-pruned vine. Spurs were considered to be short canes. Each node on each cane was numbered in ascending acropetal order, with the cane base being numbered as Node 0.

Commencing on 17 September, each node was checked for budburst on Mondays, Wednesdays and Fridays until 22 October, with a final check on 27 October. For each node, the date when a serrated edge of a leaf was first visible was recorded. This corresponds with modified Eichorn-Lorenz stage 04 (Coombe 1995).

Budburst percentages over time and mean dates of budburst for each treatment at each node were calculated. The time unit used was days since 21 September, which was the day before the first bud in the experiment was observed to have burst. Differences between treatment means were discriminated by Residual Maximum Likelihood (REML) analyses.

7.6.3 Detailed Results

More buds burst at Nodes 1, 2 and 3 on spurs than on unpruned canes (Figure 7.6.1). At each of these nodes it appeared that budburst reached a limit of approximately 80% on spurs. Budburst exceeded 77% from Node 9 to 18 on unpruned canes, with peaks of approximately 95% at Nodes 13 and 18.

On average, buds at positions higher than Node 15 on unpruned canes burst approximately 8 days after the first bud in the experimental area burst (Figure 7.6.2). Buds tended to burst later at each successive node below this. The mean time of budburst at Node 1 was approximately 15 days after the onset of budburst. On average, buds at Node 2 on spurs burst at a similar time to buds at Node 8 on unpruned canes, and approximately 4 days earlier than buds at Node 2 on unpruned canes (Figure 7.6.2 and Table 7.6.1). The mean day of budburst at Node 1 on spurs was approximately 2 days earlier than on unpruned canes, but this difference was not statistically significant. There was no significant difference between the mean times that all buds on spur-pruned and unpruned vines burst.

Table 7.6.1. Mean budburst day at positions on canes in spur-pruned and unpruned vines.

Position	Spur-pruned	Unpruned	$LSD_{5\%}$
	(Days after 21 September)		
Node 1	13.01	15.33	3.03
Node 2	10.72	14.50	1.81
All buds	12.33	11.05	1.53

The highest buds on unpruned canes and spurs burst at nearly the same time (Day 11) (Figure 7.6.3). Budburst at the highest 9 nodes on unpruned canes was concentrated in a relatively short period between Day 9.5 and Day 11.5. By contrast, the second highest nodes on spurs burst nearly 3 days later than the highest nodes, at a similar time to the 10^{th} highest nodes on unpruned canes. On average, buds that were 10 to 20 nodes distant from the tips of unpruned canes all burst between Day 10 and 14, while buds 3 nodes distant from the tips of spurs (nearly always at the spur base) tended to burst at around Day 18.

7.6.4 Discussion

The limit of approximately 80% budburst at Nodes 1 to 3 on spurs was probably set by the percentage of viable buds at the time of budburst. The lower percentage budburst at these node positions on canes on unpruned vines suggests that many viable buds that could have burst did not. However, in unpruned canes at positions higher than Node 9, budburst reached and exceeded the percentage attained on spurs. This suggests that budburst was inhibited at Nodes 1 to 8 on unpruned canes by the presence of higher nodes.

Not only did more buds burst at Node 2 on spurs than on unpruned canes, but they burst significantly earlier. In nearly every instance, these were the highest nodes on the spurs and they burst at a similar time to the mean day of budburst at the highest node on unpruned canes (which varied in length). Thus it appears that pruning allowed the highest nodes on the spurs to behave like the highest nodes on canes. However, the second highest nodes on spurs burst later, whereas on unpruned canes they burst at a similar time. Lags between the mean time of budburst from Node 2 to Node 1 on spurs were 2.29, 1.90 and 1.40 days for vines pruned 2, 6 and 11 weeks in advance of budburst (for Spur-pruned vines in 1999/2000, and Later and Earlier pruned vines in 1998/99) respectively. This suggests that pruning may quickly remove an inhibition on buds at the tip of spurs, while a residual inhibition of lower nodes may decrease more slowly. At Node 2, pruning advanced budburst in 1999/2000, while in 1998/99 earlier pruning advanced budburst. Taken together, these observations tend to support our speculation that pruning removes an inhibitory effect of higher nodes, and that the earlier this occurs, the earlier the retained buds can burst.

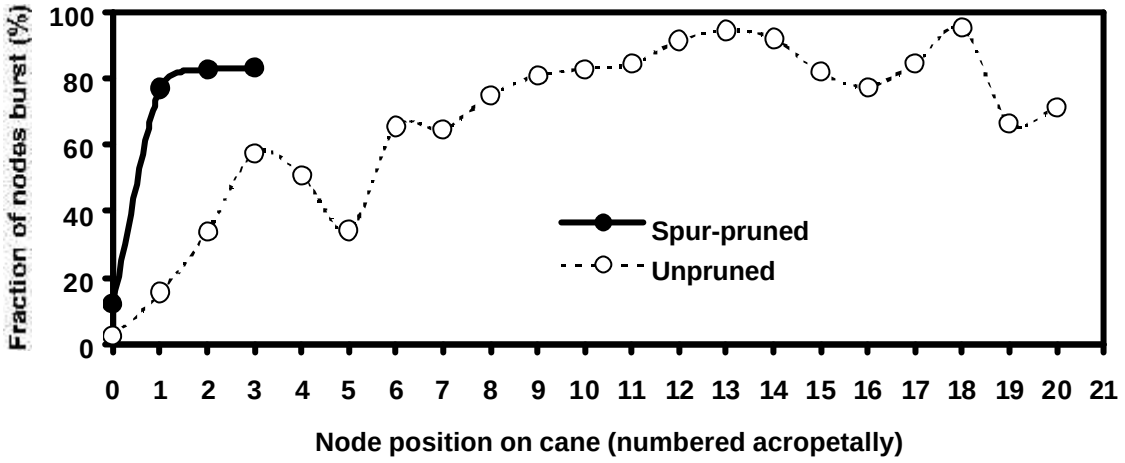


Figure 7.6.1. Degree of budburst at each node position (numbered in ascending acropetal order from Node 0 at the cane base) on canes in unpruned and spur-pruned vines.

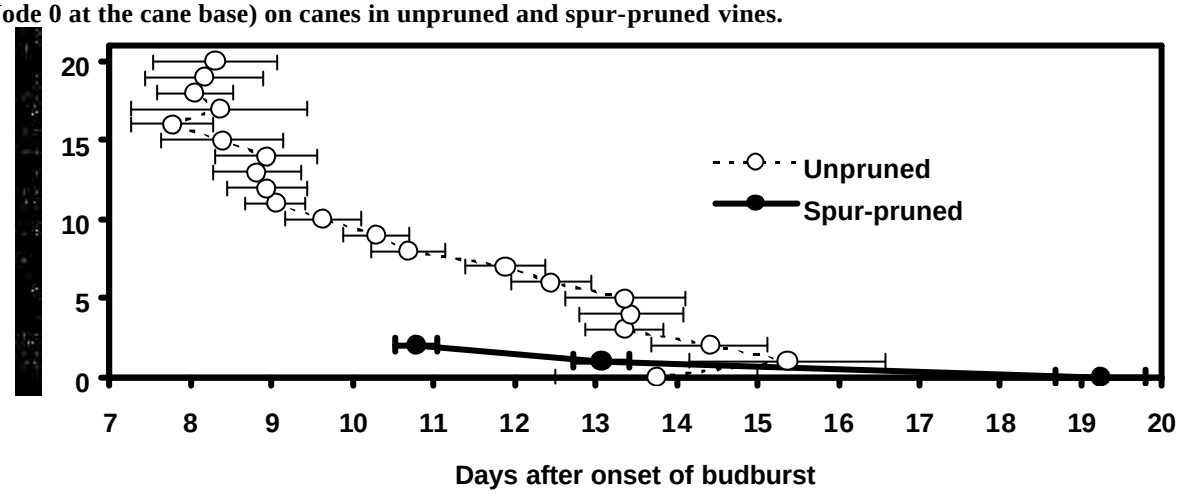


Figure 7.6.2. Mean time of budburst at each node position (numbered in ascending acropetal order from Node 0 at the cane base) on unpruned and spur-pruned vines.

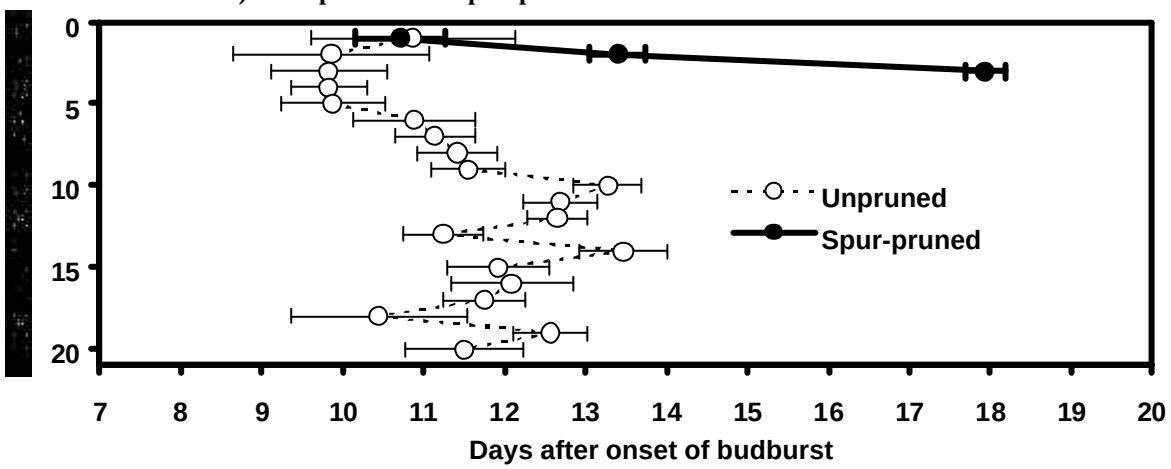


Figure 7.6.3. Mean time of budburst at each node position (numbered in ascending basipetal order from Node 1 at the cane tip) on unpruned and spur-pruned vines.
Measurements were made on Cabernet Sauvignon vines in the Dookie College vineyard, Victoria. Reference date for the onset of budburst was 21 September 1999. Bars represent standard errors of the mean. Some unpruned canes had more than 20 nodes

7.6.5 Implications and Recommendations

These results indicate that spur-pruning removes an inhibitory effect of higher nodes on lower nodes, allowing them to burst more frequently and earlier than they otherwise would have. Thus it appears that, at nodes retained on spurs, pruning advances budburst. Furthermore, when these results are considered in relation to the results presented in Martin and Dunn (2000) they indicate that earlier pruning advances budburst, rather than that later pruning retards it.

The effect of higher nodes on lower nodes is reminiscent of the effect of auxins during periods of active growth (Salisbury and Ross 1992), but the role of auxins in controlling bud dormancy is considered to be limited (Lavee and May 1997). More research would be required to determine how higher buds inhibit the bursting of more basal buds on canes, why this effect persists even after the higher buds have been removed, and how this residual effect breaks down during winter dormancy.

7.6.6 References

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7.7 Studies on Flower Number and Fruit Set

7.7.1 Introduction

One of the critical stages of grape vine growth and development is arguably fruit set, the period of growth when the pollen tube grows down through the style and into the ovule to fertilise the egg. Historically, this stage of growth is often blamed on poor yields in some years, especially when climatic conditions during the fruit set period has been unfavourable. The aim of this research was to monitor flower numbers and post-set berry numbers per bunch to examine what are the typical percentage fruit sets in the wine grape varieties Chardonnay, Shiraz and Cabernet Sauvignon, and examine if fruit set can affect subsequent yields.

7.7.2 Materials and Methods

Experimental Sites

The experimental sites consisted of 43 commercial vineyards growing *Vitis vinifera* L. varieties Chardonnay, Shiraz and Cabernet Sauvignon. 31 vineyards (10 Chardonnay, 11 Shiraz and 10 Cabernet Sauvignon) were located within a 40km radius of Mildura (Sunraysia), Victoria, Australia (142°08'E, 34°12'S) and 12 vineyards (4 Chardonnay, 4 Shiraz and 4 Cabernet Sauvignon) within a 10km radius of Coonawarra, South Australia, Australia (140°50'E, 37°22'S).

Flower number

Average flower number per cluster was calculated by randomly collecting 100 individual clusters from each experimental vineyard, just prior to cap fall. A rapid method of determining flower number per cluster was developed using a multilinear relationship between cluster dry weight and cluster length (R^2=0.80-0.97). This relationship was established at each experimental site using 20 extra clusters, which were collected at the same time as the other clusters.

Berry number assessment

Average berry number per bunch was calculated by randomly sampling 100 individual bunches from each experimental vineyard, when berries were approximately pea-sized. Each bunch was frozen and stored at –18°C prior to counting. Individual berries were separated by braking apart each individual bunch and the berries counted by using a automatic berry counter developed by CSIRO Plant Industry. The percentage fruit set was calculated by expressing the ratio of average berry number per bunch with the average flower number per cluster and expressing this as a percentage.

Harvest Assessment

Harvest samples were collected during the week prior to harvest. 10 randomly selected vines were hand picked (trunk to trunk) and the fruit weight and bunch number recorded for each vine. A randomly pre-allocated 20cm transect was removed from each harvested vine and taken back to the laboratory. From this transect sample, bunch weight and bunch number were also recorded. 10 bunches were randomly subsampled and the berries from each of these 10 bunches removed. A 100 random berry subsample was collected and average berry weight recorded.

7.7.3 Results and Discussion

Varietal Differences

The average percentage fruit set in Cabernet Sauvignon (20%) was significantly lower than either Chardonnay (33%) or Shiraz (28%) (Figure 7.7.1a). Although Cabernet Sauvignon had a significantly lower fruit set in comparison either Chardonnay or Shiraz it did however have a significantly higher mean flower number per inflorescence (397) in comparison to either Chardonnay (225) or Shiraz (235) (Figure 7.7.1b). However, there was no significant difference in average number of berries per bunch between all varieties (Figure 7.7.1b).

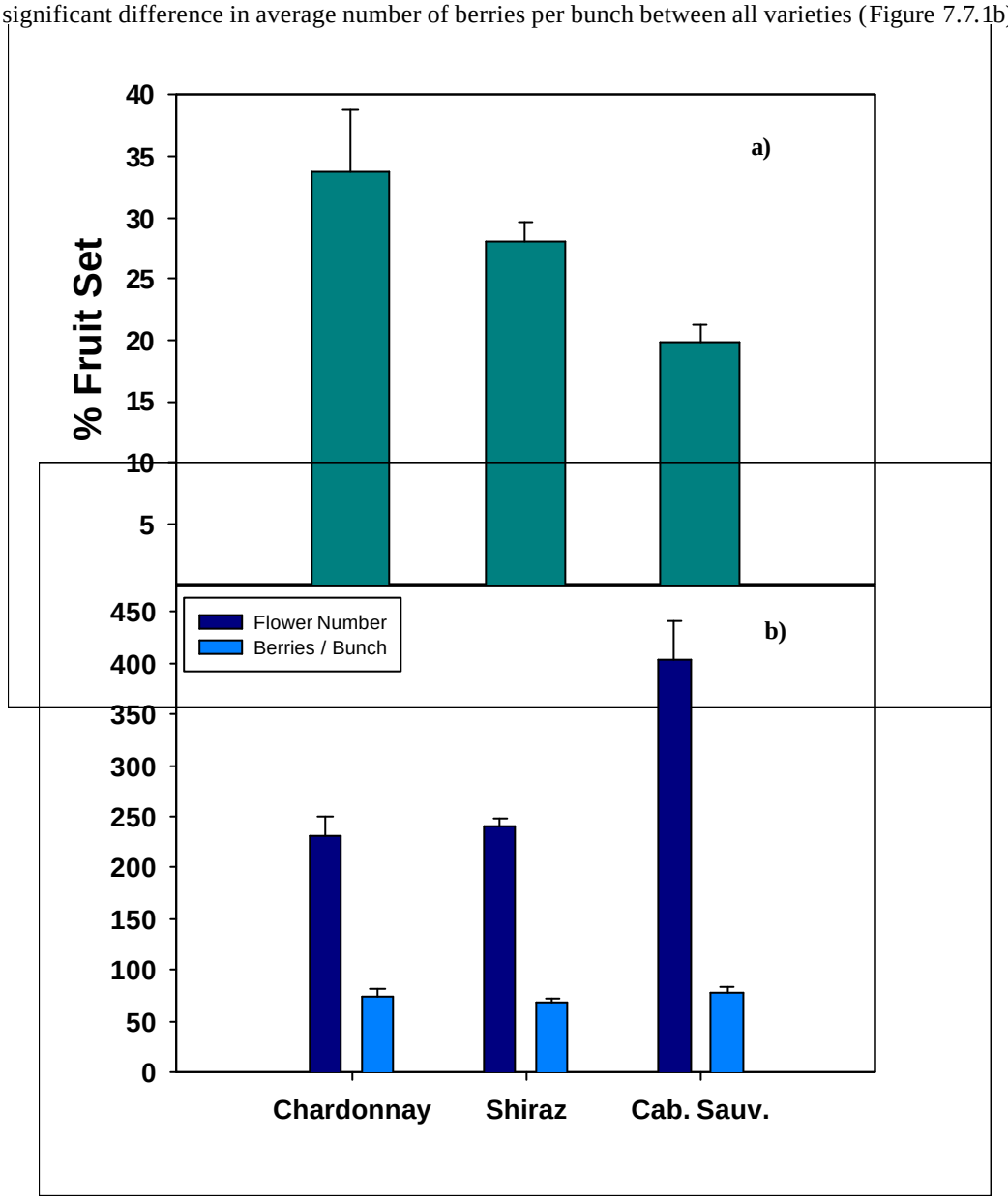


Figure 7.7.1 The average percentage fruit set (a) and the average number of flowers per inflorescence (b) for Chardonnay, Shiraz and Cabernet Sauvignon
The bars at the top of each column represent standard errors of the mean (n=5).

Regional and Seasonal Differences

Percentage fruit set in Cabernet Sauvignon did not differ significantly between seasons and between regions (Figure 7.7.2a). Sunraysia Cabernet Sauvignon did have a significantly higher average flower number per inflorescence (395) compared to both 1997 (235) and 1998 (228) Coonawarra data (Figure 7.7.2b). The number of berries per bunch did not differ significantly between seasons and across regions. No data was collected on flower numbers per inflorescence in the Sunraysia region for 1997.

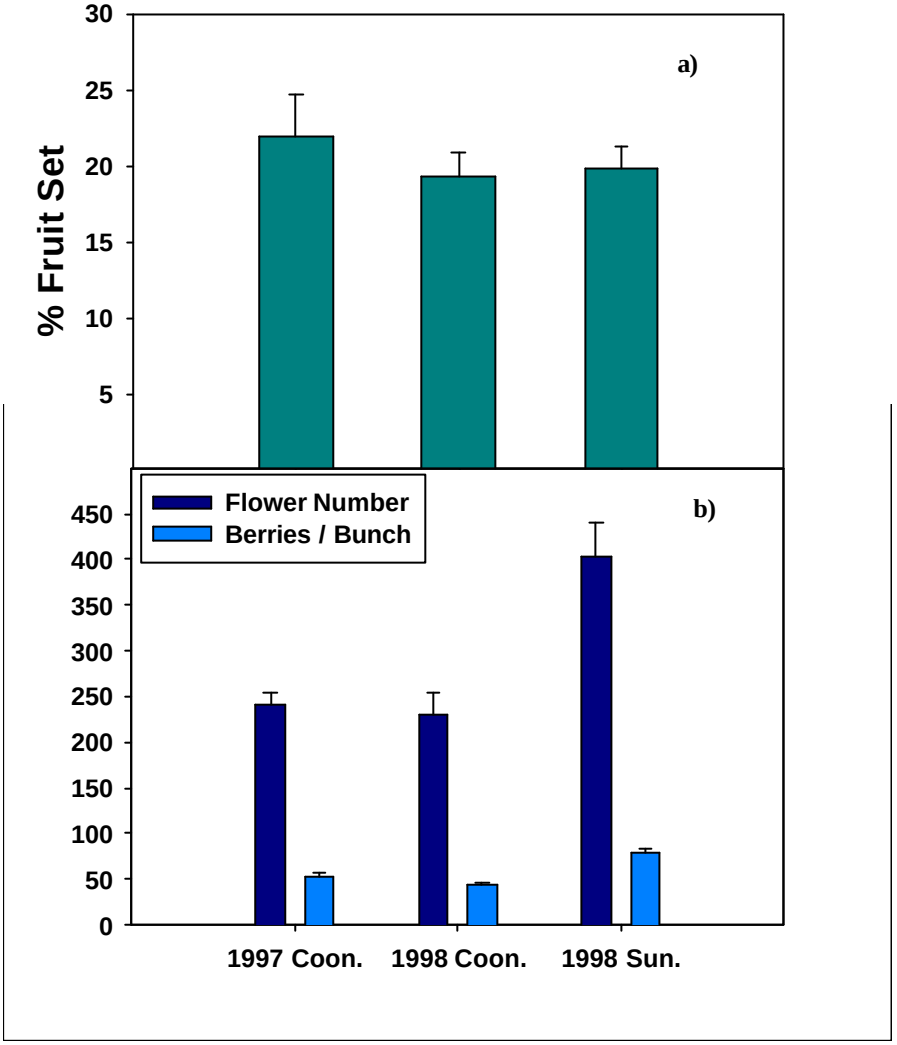


Figure 7.7.2 Average percentage fruit set (a) and average number of flowers per inflorescence and berries per bunch (b) for Cabernet Sauvignon grown in Coonawarra in 1997 and 1998 and Sunraysia in 1998
The bars at the top of each column represent standard errors of the mean (Coonawarra 1997 and 1998: n=4. Sunraysia 1998: n=5).

Effects on Yield

Examination of fruit set studies conducted in Coonawarra over two seasons (1998/1999 & 1999/2000), indicated that Shiraz and Cabernet Sauvignon behaved very differently with respect to percentage fruit set in the same growing season (Table 7.7.1). In the 1999/2000 season a reduction in percentage fruit set of 5% in Shiraz and 11% in Cabernet Sauvignon was observed in comparison to the 1998/1999 season. The reduced fruit set in both varieties resulted in larger berries being produced in the 1999/2000 growing season. In Shiraz, the increase in berry weight compensated for the slightly reduced fruit set, with respect to yield. However, in Cabernet Sauvignon, the reduction in fruit set (50%) resulted in approximately half the yield being produced by those vines in the 1999/2000 growing season.

Table 7.7.1 Yield components and percentage fruit set in Shiraz and Cabernet Sauvignon vines grown in Coonawarra during the 1998/1999 and 1999/2000 growing seasons.

	1998/99	1999/00	1998/99	1999/00
Bunches/vine	178	178	207	156
Flowers/bunch	141	151	230	212
Berries/bunch	47	41	50	23
% fruit set	34	29	22	11
Avg. bunch wt. (g)	34.8	35.5	29.1	17.2
Avg. berry wt. (g)	0.82	1.10	0.51	0.76
Yield/vine (kg)	6.14	6.03	6.10	2.82

7.7.4 Summary

Fruit set is a critical stage of grapevine growth and development. Results here indicate that there are inherent differences in the percentage fruit set of different varieties. This will also depend on the system of canopy management and most importantly climatic factors within a particular growing season. In seasons where there is a low percentage fruit set, the plastic nature of the grapevine enables it to alter its growth to produce larger berries. However, if these differences in percentage fruit set are large, the ability of the vine to make compensatory growth to avoid yield change will be insufficient.

7.8 Crop Control Through Mechanical Thinning

7.8.1 Introduction

The use of crop regulation techniques (bunch thinning, shoot thinning, etc) has been practiced for many years (Pool, 1992; Clingeleffer, 1995). The results have demonstrated that increasing the leaf area to fruit ratio can have favourable effects on ripening. However, the use of mechanical harvesters for crop thinning has not been well documented, and the effects on other quality parameters is not well understood. An experiment was established to investigate the influence of mechanical thinning, using a standard wine grape harvester, on fruit maturation, yield and some key indices of wine grape quality.

7.8.2 Materials and Methods

During the 1999/2000 growing season, a standard wine grape harvester (Gregoire) was used to mechanically thin approximately 30-35% of a high yielding Shiraz vineyard in Nangiloc, Victoria. This was done in mid-December (7th of December) when berries were at approximately pea size (7-9mm diameter). The Shiraz block used was traditionally a high yielding vineyard (~40 T/ha) which had always had problems reaching baume and colour quality specifications.

When using a harvester to mechanically thin, care was taken to set the harvester up correctly. This involved removing some picking rods and setting the picking head to the right spacing so as fruit will be removed from the desired regions of the canopy (Figure 7.8.1). It is very important to ensure that the vines are not under high levels of moisture stress when trying to mechanically thin, as this can result in excessive amounts of crop being removed than is desired. The aim was to drop approximately 20% of the bunches onto the ground, allowing for a further 15% death of bunches on the vine. This bunch death on the vine is due to the breaking of bunch rachis or stalks and the splitting of berries.



Figure 7.8.1 Harvester used for mechanical thinning

7.8.3 Results and Discussion

The mechanically thinned treatments resulted in maturity was brought forward by approximately 3 weeks (Figure 7.8.2). Fruit from the mechanically thinned treatments reached 23 Brix on the 8th of March, while the control/unthinned treatment did not reach 23 Brix until the 26th of March. The thinned treatment appeared to have a delayed veraison date, but ripened at a much higher rate (Brix/day) than the unthinned treatment.

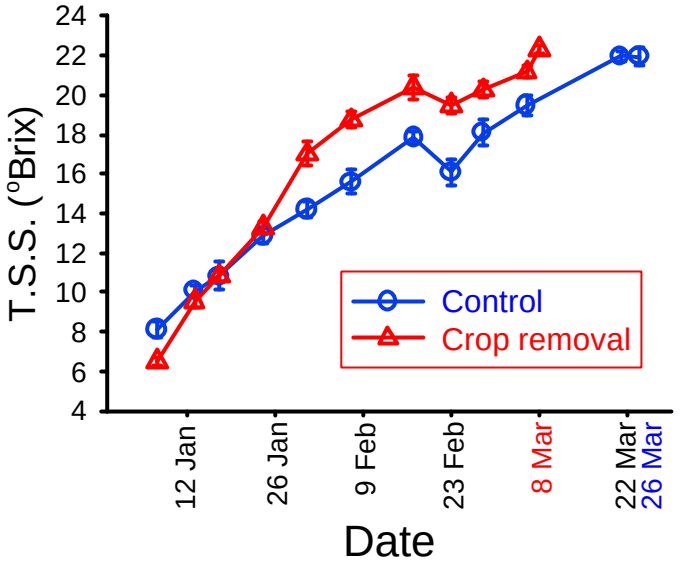


Figure 7.8.2 The effect of crop removal by mechanical thinning on total soluble solids (T.S.S.) increase in Shiraz grown at Nangiloc in Victoria in the 1999/2000 season.

Yield was reduced by approximately 35%, from approximately 19 kg/vine in the control to approximately 14kg/vine in the mechanically thinned treatment (Figure 7.8.3a). This was a result of a reduction in both bunch number/vine and also a reduction in average bunch weight (Figure 7.8.3b and Figure 7.8.4a respectively). The average berry weight did not differ significantly between the control and thinned treatments (Figure 11.7.4b).

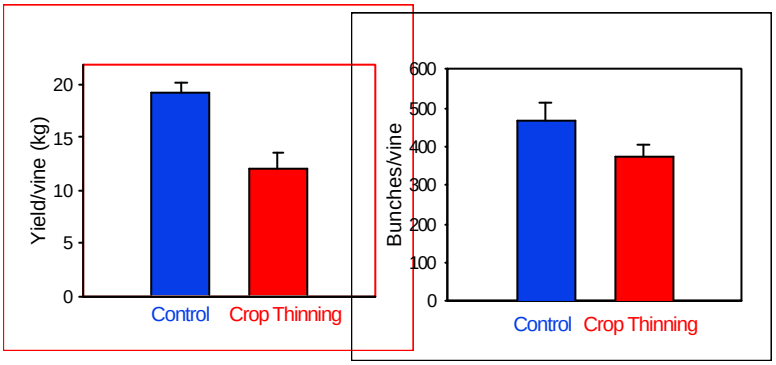


Figure 7.8.3 (a) average yield per vine (kg) for control and thinned vines; (b) average bunch number per vine for control and thinned vines.

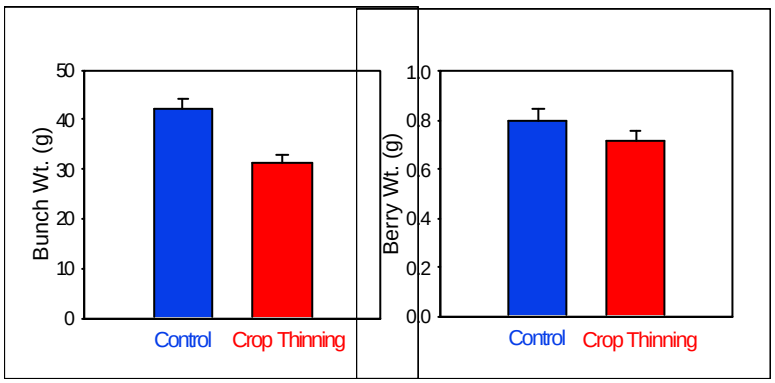


Figure 7.8.4 (a) average bunch weight (g) for control and thinned vines; (b) average berry weight (g) for control and thinned vines.

In terms of wine grape quality parameters, the mechanically thinned fruit had significantly higher levels of titratable acidity and lower juice pH than that of the control treatments (Figure 7.8.5).

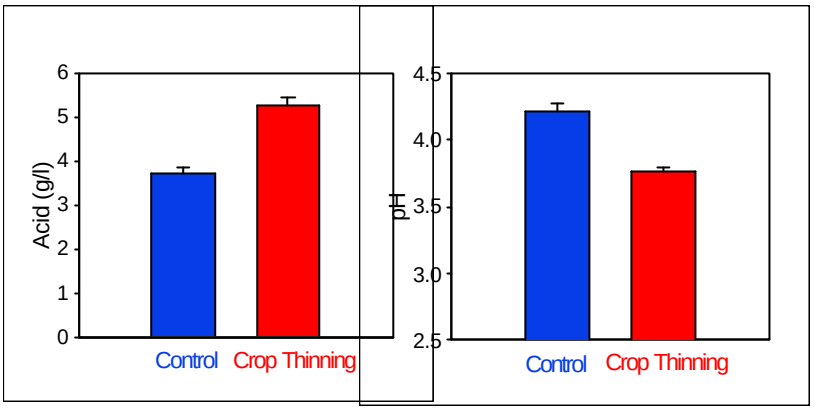


Figure 7.8.5 (a) average titratable acidity (g/L) for control and thinned vines; (b) average juice pH for control and thinned vines.

Also, the anthocyanin (colour) and phenolic levels were significantly higher (approximately 30% higher) in the mechanically thinned treatments in comparison to the control treatments (Figure 7.8.6). This is an important result considering that wineries are now starting to pay on the basis of colour.

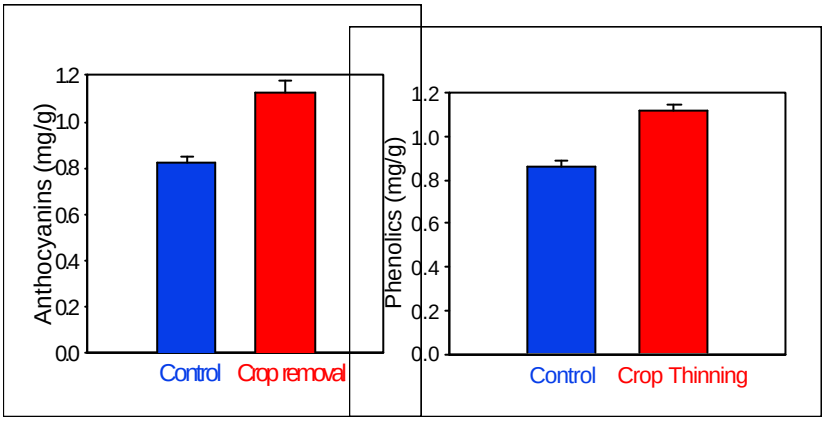


Figure 7.8.6 (a) average anthocyanins (mg/g) for control and thinned vines; (b) average phenolics (mg/g) for control and thinned vines.

7.8.4 Summary

The use of crop control techniques offers the potential to deliver more consistent production to the industry by evening out the high years of production. It also offers a tool for the industry to use in the improvement of wine grape quality, and therefore improving both grower and industry returns.

Research into crop thinning is continuing through a collaborative project between Department of Natural Resources and Environment and CSIRO Plant Industry in a project titled "Crop control for consistent supply of quality wine grapes" which is funded by GWRDC (from 2000-2003). This season crop control experiments have been established on Chardonnay, Shiraz and Cabernet Sauvignon sites throughout Victoria and South Australia.

7.9 Ripening and Quality Studies

7.9.1 Introduction

The accumulation of hexose sugars into berries after veraison is a very important stage of grapevine growth and development. The achievement of minimum sugar levels before harvest is essential for the style of wine being produced and also in some cases for the payment of bonuses to growers for quality. The rate of ripening has traditionally thought to be linked to the "crop load" of the vine, where higher crop loads are generally thought to take longer periods of time to ripen. The aim of this research was to examine the rates of ripening across a number of varieties and across a number of experimental sites within Sunraysia with different cropping levels.

The introduction of Near Infra Red Spectroscopy (NIRS) colour payment systems into the wine grape industry has been a significant leap forward in rewarding growers for producing quality based on objective measurement systems. This has translated into growers looking for practical methods of manipulating colour in the vineyard. Historically, lower yielding vineyards are thought to have higher colour contents in the berries. The aim of this research is also to examine some of the yield and colour relationships.

To reduce this section, only results on the variety Shiraz will be presented.

7.9.2 Materials and Methods

Experimental Sites

The experimental sites consisted of 31 commercial vineyards growing *Vitis vinifera* L. varieties Chardonnay, Shiraz and Cabernet Sauvignon (10 Chardonnay, 11 Shiraz and 10 Cabernet Sauvignon) were located within a 40km radius of Mildura (Sunraysia), Victoria, Australia.

Berry Development and Maturity Monitoring

After veraison, 5 randomly selected 20cm transects were collected from each vineyard in Sunraysia every 10-14 days. From the bunches collected in the transect, total weight and bunch number were recorded. 10 bunches were randomly subsampled and the berries from each of these 10 bunches removed. A 100 random berry subsample was collected, average berry weight and ^{o}Brix recorded on this sample.

Harvest Assessment

Harvest samples were collected during the week prior to harvest. 10 randomly selected vines were hand picked (trunk to trunk) and the fruit weight and bunch number recorded for each vine. A randomly pre-allocated 20cm transect was removed from each harvested vine and taken back to the laboratory. From this transect sample, bunch weight and bunch number were also recorded. 10 bunches were randomly subsampled and the berries from each of these 10 bunches removed. A 100 random berry subsample was collected and average berry weight recorded. The 100 berry sample was crushed using an electric juicer and total soluble solids (^{o}Brix) recorded using an Atago digital refractometer, pH and titratable acidity (TA) were also recorded using a Metrohm autotitrator.

7.9.3 Results and Discussion

Relationship between crop load and rate of ripening

In Shiraz, there is a inverse relationship between crop load and the rate of ripening, ie. the higher the crop load the slower the rate of ripening (Figure 7.9.1). However, in the varieties Chardonnay and Cabernet Sauvignon, this relationship between crop load and rate of ripening was not observed.

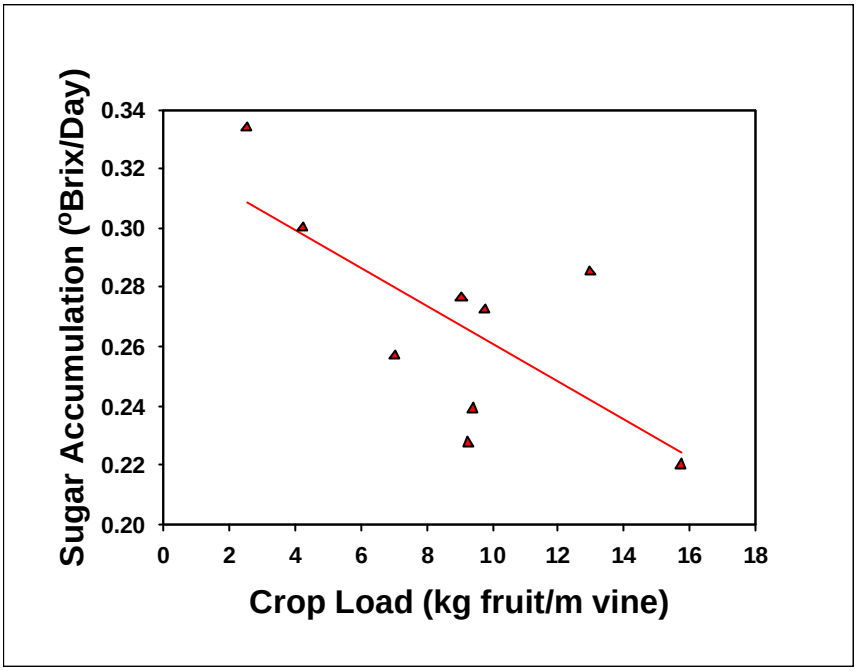


Figure 7.9.1 The relationship between crop load (kg fruit per metre of cordon) and the rate of sugar accumulation (°Brix per day) in the variety Shiraz grown in Sunraysia during the 1998/99 season.

Relationship between crop load and colour content of fruit

In the variety Shiraz, there was no relationship between yield (tonnes/hectare) and colour concentration of the fruit (measured as milligrams of anthocyanins per gram of fruit) (Figure 7.9.2). The same relationship has also been observed in Cabernet Sauvignon and over a number of different growing seasons. However, berry weight can explain some of this variability (Figure 7.9.3). The smaller berries generally have higher concentrations of colour. This relationship does hold up better for Cabernet Sauvignon. Also, this relationship holds up over different growing seasons.

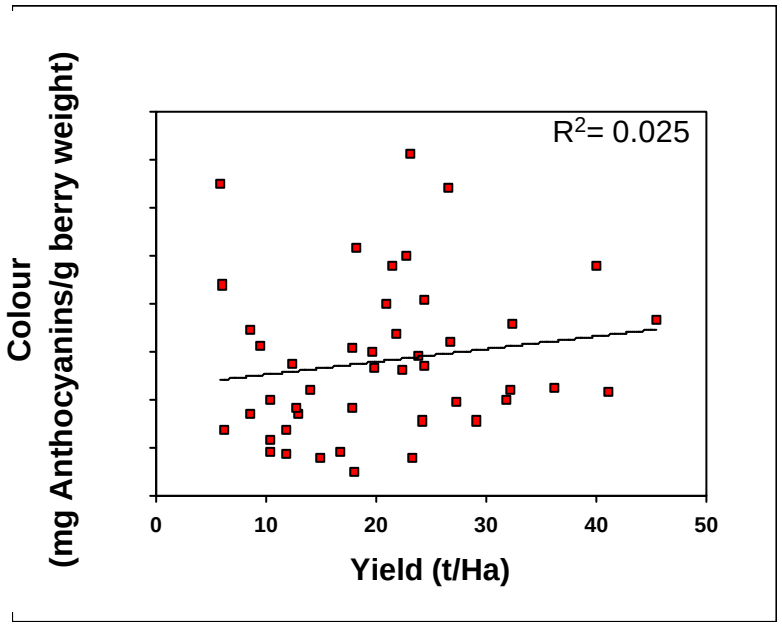


Figure 7.9.2 Relationship between crop load (T/Ha) and Colour (mg Anthocyanins/g berry weight) in Shiraz grown in Sunraysia during the 1998/1999 growing season.

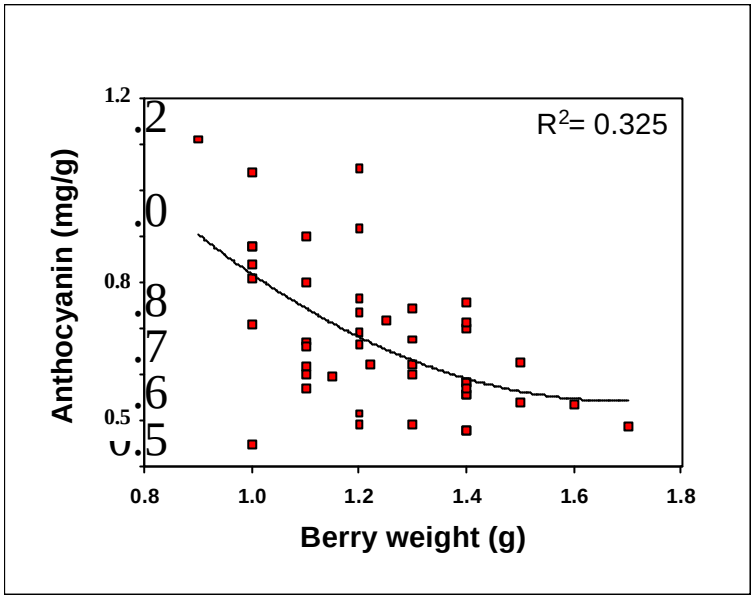


Figure 7.9.3 Relationship between berry weight (g) and Colour (mg Anthocyanins/g berry weight) in Shiraz grown in Sunraysia during the 1998/1999 growing season.

7.9.4 Summary

In Shiraz, the rate of ripening was related to the crop load of the vine (R^2=0.50). However, this relationship did not hold up for the varieties Chardonnay and Cabernet Sauvignon. In these varieties, other factors such as water stress etc may be responsible for controlling the rate of sugar accumulation into the berries.

The poor relationships between yield and colour lead us to conclude that other factors are responsible for controlling colour development in the berries. Small berries account for some of this variability, but other factors, like climate, are also responsible.

8 Technology Transfer

During the course of the project, the project team has endeavoured to deliver up-to-date information to the Australian wine industry. Information has been disseminated both broadly and in a strategically targeted way to as many growers and other key stakeholders within the industry as possible. This section summarises activities undertaken by the team to keep the industry informed and to transfer technology from researchers to practitioners.

Development of crop forecasting kits for industry

Since the project commenced in 1997, the demand for more accurate crop forecast technology has grown dramatically. Accordingly, particular attention has been given to providing the industry with robust methods of accurately forecasting grape crops.

In 1997/98, a crop forecasting 'kit' was developed by the CSIRO Merbein team in conjunction with the Murray Valley Winegrape Growers Industry Development Committee (MVWGGIDC) and the Rural Finance Corporation. This incorporated a set of crop forecasting protocols and an instructional video, which was produced by Sunraysia TAFE. The release of this kit was an initial response to huge demand from industry, particularly in the Murray Valley. The kit was based on protocols developed predominantly by CSIRO researchers, notably Dr Peter May, and constituted a statement of best practice at the time. However, the project team regarded the kit as a working prototype because the project had only just begun. The initial response to the kit was mixed. Many growers thought that it was a system being imposed on them by the wineries, and many could not see how its use would benefit them. In the first year of its release, over 200 copies were sold by the MVWIGGIDC. The 'kit' was also incorporated into a TAFE teaching module as part of the Viticulture III certificate level course.

In 1998/99, the crop forecasting kit was revised and improved. This version was welcomed more positively by growers and winery personnel, and unsolicited demand for the 'how to' information increased dramatically. Hands-on training was provided, in the form of an introduction to forecasting theory and practical demonstrations, resulting in a dramatic increase in the level of understanding and satisfaction expressed by growers. Simultaneously, commercial consultants (including, for example, Reg Johns and Associates) began to teach these protocols to the industry. In this year, the Victorian and Murray Valley Wine Grape Growers Council (VMVWGGC, which had taken over the responsibility for disseminating the kit from the MVWGGIDC) sold approximately 350 kits Australia-wide.

In 1999/2000, with demand for forecasting technology still increasing, a number of developments occurred. In the Murray Valley, the NRE team at Irymple collaborated in the development of e-commerce systems of recording crop estimation data using an on-line system in conjunction with Freshport™ and the development of a TAFE on-line crop forecasting learning program. This was due for release in the middle of 2001.

At the time of its release in 1997, the protocols included in the Murray Valley crop forecasting kit were simplified to a level that it was believed would gain acceptance by growers, on the assumption that their forecasting performance would improve if they used a measurement-based approach. It was recommended that the method contained in the kit should only be used on fairly uniform vineyards, with vines more than 4 years old, and should not be used in patches with more than 10% missing vines. In addition, the level of accuracy attainable using the kit was limited by its sampling procedures and the omission of some factors from its formulae. Taking the kit developed in the Murray Valley as a starting point, the NRE team at Tatura developed a version which can be used in any vineyard block and which incorporated improvements derived from its research program in test blocks throughout Victoria. This version of the kit requires the user to have a much better grasp of issues relating to variability in their vineyards and to do more calculations. Consequently, an associated training program was produced to enable growers to develop their sampling and forecasting skills.

Scientific Achievements

Scientific achievements include the following publications and presentations:

- Clingeleffer, P.R., Sommer, K.J, Krstic, M.P., Small, G. and Welsh, M.A. (1997). Winegrape crop prediction and management. Australian and New Zealand Wine Industry Journal, Vol 12(4): 354-359.

- Clingeleffer, P.R., Sommer, K.J and Walker (1998). Holistic system approach for sustainable vineyard management for grape and wine quality. In the proceedings of the 10th Australian wine industry technical conference, August 8-10, Sydney, pp188-196.
- Krstic, M.P. and Clingeleffer (1998). Variation in Chardonnay yield components between growers in a warm irrigated region. In the proceedings of the 10th Australian wine industry technical conference, August 8-10, Sydney, pp 269-270.
- Krstic, M.P. and Clingeleffer (1998). Winegrape yield development and its estimation. In the proceedings of the 10th Australian wine industry technical conference, August 8-10, Sydney, pp 270.
- Dunn, G.M. and Martin, S.R. (1998). Optimising vineyard sampling to assess yield. In the proceedings of the 10th Australian wine industry technical conference, August 8-10, Sydney, pp 270.
- Dunn, G.M. and Martin, S.R. (2000). Do temperature conditions at budburst affect flower number in Vitis vinifera L. var. Cabernet Sauvignon? *Australian Journal of Grape and Wine Research*, **6 (2)**: 116-124.
- Martin, S.R. and Dunn, G.M. (2000). Effect of pruning time and hydrogen cyanamide on budburst and phenology of Vitis vinifera L. var. Cabernet Sauvignon in central Victoria. *Australian Journal of Grape and Wine Research*, **6 (1)**: 31-39.
- Krstic, M.P., Clingeleffer, P.R. and Sommer, K.J. (2000). Crop components and yield prediction in Vitis vinifera, varieties Chardonnay, Shiraz and Cabernet Sauvignon. Peter May 'Reproductive biology in grapevines' symposium, Merbein, June 1999.
- Clingeleffer, P.R., Krstic, M.P. and Sommer, K.J. (2001). Production efficiency and relationships among crop load, fruit composition and wine quality. Paper presented to American Society of Enology and Viticulture 50th Anniversary Annual Meeting, Seattle, 19-23rd June, 2000 (318-322).
- Dunn, G.M. and Martin, S.R. (in preparation). Effect of pruning time and hydrogen cyanamide on berry composition of Vitis vinifera L. var. Cabernet Sauvignon in central Victoria. *Australian Journal of Grape and Wine Research*.
- Dunn, G.M. and Martin, S.R. (in preparation). Effect of temperature during the previous season on early bunch development in Vitis vinifera L. var. Cabernet Sauvignon in central Victoria. *Australian Journal of Grape and Wine Research*.
- Dunn, G.M. and Martin, S.R. (2000). Spatial and temporal variation in vineyard yields. Paper presented to the Precision Management Workshop, 5th International Symposium on Cool Climate Viticulture and Oenology, Melbourne, 16-20th January 2000 (4 pp.).
- Martin, S.R., Dunn, G.M, Tanya Hoogenraad, Mark P Krstic, Peter R Clingeleffer and William J Ashcroft (2000). Crop forecasting in cool climate vineyards. Paper presented to 5th International Symposium on Cool Climate Viticulture and Oenology, Melbourne, 16-20th January 2000 (3 pp.).
- Other key involvements in the development of VineLOGIC, especially in relation to the development of yield algorithms.

Industry interaction

During the course of the project many oral presentations and technical articles were delivered to industry to deliver up-to-date information to key industry stakeholders. Examples are:

Grapecheque

The grapecheque program services approximately 20 grower groups across Victoria. Members of the Project team have given presentations to all of these groups during the last 3 years and have guided some of them through exercises in sampling and forecasting. By July 2000, some form of crop forecasting methodology was used by 68% of North West Victoria growers, 90% of Port Phillip growers and 70% of Central Victoria growers. The greatest increase in the use of crop forecasting methodology has been in North West Victoria where there has been an increase from 30% in 1997 to 68% in 2000. There has been a 20% increase in crop forecasting in Central Victoria, and 14% in Port Phillip.

Wine Grapes Marketing Board, Griffith, NSW

In 1999, the CSIRO Merbein and NRE Irymple team commenced work with the Wine Grapes Marketing Board in Griffith to assist in developing a systematic approach to crop forecasting in the Riverina grape growing district, because of historical problems associated with yield prediction. The project team collaborated in the development of a method that industry members were happy to adopt, with the primary aim of producing a accurate crop forecasts at a regional scale. This program has operated successfully for the last 2 seasons and has produced more reliable and accurate estimates than the traditional visual methods.

Winemaking and grapegrowing companies

The project team has worked actively with larger wine companies throughout South-Eastern Australia, especially Southcorp Wines, Mildara Blass, BRL Hardy, the Orlando-Wyndham Group and Simeon Wines. In addition, it has worked with a number of smaller wineries and regional grapegrower organisations. This has necessitated extensive travel through most of the major grape growing regions in Australia to deliver presentations and facilitate training. These presentations would number approximately 40-50 during the 3 years of the project. Formal and informal evaluations have consistently revealed a high level of appreciation by the participants, with a recognition of the attention given to communicating a relatively complex subject in a clear, simple, but thorough manner.

Industry/Technical Publications

Throughout the project technical articles were published in a range of popular viticultural magazines. These included articles designed to raise grower awareness of crop forecasting and its importance to the industry, the methodology associated with generating a crop estimate and information of a more technical nature designed to improve understanding of crop development in grapevines. These articles include:

- Dunn, G.M. and Martin, S.R. (1998). Optimising Vineyard Sampling to Estimate Yield Components. Australian Grapegrower and Winemaker, Annual Technical Issue 1998, 102-107.
- Martin, S.R., Urbanski, A. and Dunn, G.M. (in preparation). Benefits and costs of forecasting wine grape crops.
- Martin, S.R. , Dunn, G.M., Krstic, M.P. and Clingeleffer, P.R. Guide to crop forecasting in vineyards (in preparation, draft available)
- Martin, S.R. Is your yield data trying to tell you something? Australian Grapegrower and Winemaker, 440, Sept. 2000, 84-85.
- Martin, S.R. and Dunn, G.M. (in preparation). Yield instability in Australian vineyards, I: Which components cause the most variation?
- Clingeleffer, P.R., Krstic, M.P., Welsh, M.A and McCarthy (1999). Winegrape crop estimation and quality management. Murray Valley Winegrapegrower, 5(5) pp 6.
- Krstic, M.P., Clingeleffer, P.R. and Welsh, M.A. (1999). Crop estimation in winegrapes. Murray Valley Winegrapegrower, 5(1) pp 11.
- Krstic, M.P., Welsh, M.A. and Clingeleffer, P.R. (2001). Crop control through mechanical thinning. Murray Valley Winegrapegrower, 7(2) pp 12.
- Dunn, G.M. and Martin, S.R. Environmental and physiological control of crop development in grapevines – An industry review.
- Dunn, G.M. and Martin, S.R. (2000). Conquering the crop estimation problem for better yield management and wine quality. Paper presented to the VWIA technical seminar program – The new horizons for wine quality, 10th August 2000, Melbourne.
- Martin, S.R. and Dunn, G.M. (2000). The voice of the grape production process. Horticulture in NRE – Awareness 2000 Conference, 6-7th September 2000, IHD, Knoxfield.
- Krstic, M.P., Welsh, M.A. and Clingeleffer, P.R. (2000). Crop control for consistent supply of quality winegrapes. Horticulture in NRE – Awareness 2000 Conference, 6-7th September 2000, IHD, Knoxfield.

One of the major objectives of the project was to prepare a position statement that would review existing literature, unpublished results and anecdotal evidence on the physiological and environmental controls of crop development, particularly as they relate to bunch number, size, architecture and berry development. The industry review included in this report addresses this objective, and negotiations are in progress with a view to its publication in the Australian Journal of Grape and Wine Research.

Student Projects

The NRE Tatura team was proactive in encouraging university students to engage with the project. This reinforced links with tertiary institutions, provided the students with first hand experience of industry-relevant research and augmented the outputs of the project. Major reports produced by University of Melbourne students include:

- Benedict, C. (1998). Analysis of variation of critical yield components between five varieties of grapevines for sampling and crop forecasting. Major study project, final year B. App. Sci. (32 pages plus appendices)

- Hoogenraad, T. (1999). Timely, non-destructive final bunch weight prediction for grapevines. Major study project, final year B. App. Sci. (38 pages)

These are attached as Appendices.

Industry Reference Group

The project team has reported to and been advised by an industry Reference Group since the commencement of the project in 1997. The Reference Group consisted of technical representatives from all the major wine companies and some key grower and government organisations. In addition to advising the team with respect to research priorities, the Reference Group has been at the hub of an important extension network for the project. Its members have delivered information produced by the project directly into their immediate businesses and to grower networks and organisations. During the life of the project the project team presented progress reports to three annual reference group meetings. The Reference Group has been very supportive of the project, because of its potential impact on the performance of the industry. A measure of their assessment of the performance of the project team is that they were a major driver in the evolution of the project into the new project 'Crop control for consistent supply of quality wine grapes', which commenced in 2000/01.

Conferences

During the life of the project, its team members have presented its findings at a number of national and international conferences:

International Conferences

- Clingeleffer, P.R., Krstic, M.P. and Sommer, K.J. (2001). Production efficiency and relationships among crop load, fruit composition and wine quality. Paper presented to American Society of Enology and Viticulture 50th Anniversary Annual Meeting, Seattle, 19-23rd June, 2000 (318-322).
- Clingeleffer, P.R., Krstic, M.P., Dunn, G.M. and Martin, S.R. (2000) Crop Prediction – Australian Experiences. Paper presented to the Unified Wine and Grape Symposium, Sacramento, January, 2001.
- Dunn, G.M. and Martin, S.R. (2000). Spatial and temporal variation in vineyard yields. Paper presented to the Precision Management Workshop, 5th International Symposium on Cool Climate Viticulture and Oenology, Melbourne, 16-20th January 2000 (4 pp.).
- Martin, S.R., Dunn, G.M, Tanya Hoogenraad, Mark P Krstic, Peter R Clingeleffer and William J Ashcroft (2000). Crop forecasting in cool climate vineyards. Paper presented to 5th International Symposium on Cool Climate Viticulture and Oenology, Melbourne, 16-20th January 2000 (3 pp.).

National Conferences

- Clingeleffer, P.R., Sommer, K.J and Walker (1998). Holistic system approach for sustainable vineyard management for grape and wine quality. In the proceedings of the 10th Australian wine industry technical conference, August 8-10, Sydney, pp188-196.
- Krstic, M.P. and Clingeleffer (1998). Variation in Chardonnay yield components between growers in a warm irrigated region. In the proceedings of the 10th Australian wine industry technical conference, August 8-10, Sydney, pp 269-270.
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- Dunn, G.M. and Martin, S.R. (1998). Optimising vineyard sampling to assess yield. In the proceedings of the 10th Australian wine industry technical conference, August 8-10, Sydney, pp 270.
- Krstic, M.P., Clingeleffer, P.R. and Sommer, K.J. (2000). Crop components and yield prediction in Vitis vinifera, varieties Chardonnay, Shiraz and Cabernet Sauvignon. Peter May 'Reproductive biology in grapevines' symposium, Merbein, June 1999.
- Dunn, G.M. and Martin, S.R. (2000). Conquering the crop estimation problem for better yield management and wine quality. Paper presented to the VWIA technical seminar program – The new horizons for wine quality, 10th August 2000, Melbourne.
- Martin, S.R. and Dunn, G.M. (2000). The voice of the grape production process. Horticulture in NRE – Awareness 2000 Conference, 6-7th September 2000, IHD, Knoxfield.
- Krstic, M.P., Welsh, M.A. and Clingeleffer, P.R. (2000). Crop control for consistent supply of quality winegrapes. Horticulture in NRE – Awareness 2000 Conference, 6-7th September 2000, IHD, Knoxfield.

9 Acknowledgments

The project team would like to thank all the participating vineyards listed in below for their support and for allowing us to conduct research in their vineyards.

Sunraysia
Bate Bros. P.O. Box 56, Sunnycliffs VIC 3494
Beringer Blass Ltd, Box 396, Merbein VIC 3505
Binbilla Nominees, P.O. Box 331, Mildura VIC 3502
B. Ferry, P.O. Box 144, Coomealla NSW 2717
S. Freckleton, Swamp Rd, Karadoc VIC 3494
E. Lindsay, P.O. Box 740, Merbein VIC 3505
Mildura Agricultural Contractors, PMB 30, Red Cliffs VIC 3496
L. Phillips, P.O. Box 2008, Mildura VIC 3501
W. Reyne, Paschendale Ave, Merbein VIC 3505
Russell Horticultural Services, P.O. Box 469, Nangiloc VIC 3494
P. Walmsley, Dickeson Rd, Nangiloc VIC 3494
R. Wells, P.O. Box 168, Merbein VIC 3505
Wingara Wine Group, Kulkyne Way, Iraak VIC 3496
Zil Zie Estate, P.O. Box 1141, Red Cliffs VIC 3496
Coonawarra
Southcorp Wines Pty Ltd, c/o Coonawarra Post Office, Coonawarra SA 5263
Beringer Blass Ltd, P.O. Box 21, Coonawarra SA 5263
Greater Victoria
Ron & Ken Bailey, Merriang South Rd, Merriang VIC 3737
Blackjack Wines, Calder Highway, Harcourt VIC 3453
Briarston, Southcorp Wines, Briarty Rd, Gruyere VIC 3770
Brown Bothers Milawa Vineyard, Milawa VIC 3678
Chateau Tahbilk, Tabilk VIC 3608
Coalville, RMB 4750, Moe South Rd, Moe VIC 3825
Lusatia Park, Owens Rd, Woori Yallock VIC 3139.
Mitchelton, Mitchellstown VIC 3608
Narkoojee, RMB 1110, Francis Rd, Glengarry VIC 3854
Nicholson River, Liddell's Rd, Nicholson VIC 3882
Plunketts Whitegate, Tarcombe Rd, Tarcombe VIC 3664
Red Hill Estate, 53 Red Hill – Shoreham Rd, Red Hill South VIC 3937
Sarsfield Heights, RMB 8759, Sarsfield VIC 3875
Seppelts Great Western, Moyston Rd, Great Western VIC 3377
Stoniers, 362 Frankston-Flinders Rd, Merricks VIC 3196.
Wa-de-Lock, Stratford Rd, Maffra VIC 3860
Water Wheel, Raywood Rd, Bridgewater-on-Loddon VIC 3516
Tarn Pirr and Windarra, Southcorp Wines, Barooga-Mulwala Rd, Barooga VIC 3644
Lakeside, Moodemere Rd, Rutherglen VIC 3685
Dromana Estate, Harrisons Rd, Dromana VIC 3936
Mt Helen, Upton Rd, Tarcombe VIC 3664
Paringa Estate, 44 Paringa Rd, Red Hill South VIC 3937
Yarra Ridge, Glenview Rd, Yarra Glen VIC 3775
Melbourne University Vineyard, Dookie College, Dookie

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10 Appendices

Tables from section 4.1 are attached other appendices will be provided as a separate document.