BETTER YIELD FORECASTING IN VINEYARDS

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TABLE OF CONTENTS

CHAPTER 1 STATUS OF FORECASTING IN THE AUSTRALIAN WINE INDUSTRY

INTRODUCTION

There is a strong demand for improved crop forecasting in the wine industry. Lately this demand has intensified as major producers and purchasers of grapes are increasingly stipulating that particular yield targets should be met, in the belief that this will improve and maintain wine quality and substantial cost savings and revenue gains could be realised if the volume of grape intake did not fluctuate so much. Apart from the substantial economic benefits of improved crop forecasting alone, it is an essential first step to successful yield regulation. Consequently there is a strong demand for improved systems to forecast yield.

The performance of the Australian wine industry is sensitive to mismatches between expected and actual grape intake. These mismatches generate inefficiencies that result in foregone revenue and extra costs in vineyards, wineries and distribution chains. Winery intake planners seek accurate estimates of likely grape production from vineyard managers at various stages throughout the season in advance of harvest. However, inaccurate forecasts have been a source of irritation, discontent and conflict throughout the Australian wine industry.

Wineries in some ways are ‘factories’ that would benefit from a smooth, predictable supply of grapes. They seek forecasts from growers at various stages in advance of harvest in order to schedule grape intake, allocate fermenter space and downstream tank space, decide how many (expensive) oak barrels to but, manage wine stocks and forecast wine production (Figure 1.1). All of these things affect the planning of labour, inventory and marketing strategies. Hence, accurate forecasts of grape deliveries are very important.

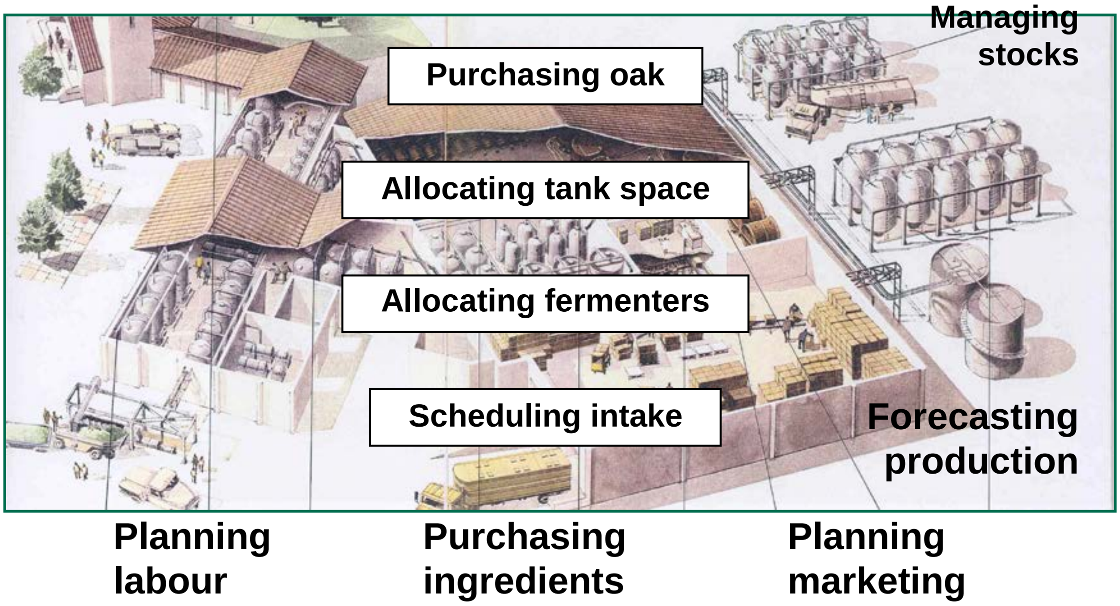


Figure 1.1. Wineries need accurate forecasts of grape deliveries.

In any grape-growing district in Australia there are some growers who have a subjective 'knack' of supplying accurate forecasts. However, on average, growers supply forecasts that are 33% out (Clingeleffer 2001). Even experienced vineyard managers who have worked for decades with established patches can find it difficult to forecast production reliably, particularly in patches which where the yield fluctuates greatly from season to season. Furthermore, a knack developed on one vineyard may not work on another.

This book will first discuss how the performance of forecasts can be assessed before describing reproduction in grapevines, the drivers of season-to-season yield variability and implications for yield forecasting. Then it will describe cost effective and practical tools for estimating yield in vineyards and across regions at critical times during crop development. It will simplify sampling statistics required to ensure that forecasts are based on representative and adequate sampling necessary to improve estimates of both vineyard and regional yields.

ASSESSING FORECASTING PERFORMANCE

To judge the performance of a forecasting system fairly, one needs to assess it over many vineyard blocks and preferably over a number of seasons. Clingeleffer (2001) compared forecasts made in January (i.e. after fruit set) with records of actual deliveries provided by growers. Table 1.1 is presented as an example of this. It compares actual crop forecasts made in January with deliveries at harvest for four patches of wine grapes. For instance, the forecast for patch 1 was a delivery of 20 tonnes, but at harvest 22 tonnes were delivered to the winery. This represented a difference of –2 tonnes or a 9% underestimate. If the % differences for the four forecasts in Table 1.1 are added together, underestimates tend to cancel out overestimates and the total delivery forecast is only 5% higher than actual. If assessed over many forecasts this average % difference is a measure of the bias in the system, that is, whether the system tends to overestimate or underestimate actual yield. However, fruit from each of the four patches of grape vines may not have been able to be bulked because each patch may have been destined for different products in the winery. Therefore, the impact that a collection of forecasts has on a winery is better described by the average of the absolute differences between forecasts and deliveries irrespective of whether they are underestimates or overestimates (column 6). Average absolute difference is a measure of the precision of a forecasting system. In the example below average absolute difference equated to 31%.

Table 1.1. A comparison of four crop forecasts made by a vineyard manager in January (post fruit set) with actual deliveries at harvest.

Patch	Forecast (tonnes)	Actual (tonnes)	Difference (tonnes)	% Difference	Absolute % Diff.
1	20	22	-2	-9	9
2	15	9	6	67	67
3	18	17	1	6	6
4	18	32	-14	-44	44
Mean				**5**	**31**

*****negative figures show underestimates, positive figures show overestimates

INDUSTRY PERFORMANCE IN AUSTRALIA

Data were obtained from a Victorian winery, which crushed 11,600 tonnes in the 2000 vintage. The winery nominated an experienced grower representative of 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 by 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.

For the representative grower the annual mean absolute difference (precision) ranged from 25% to 40% of actual production and the grand mean for the four years was 33%. The sum of all the forecasts provided to the winery in 2000 was only 6% more than the sum of the actual deliveries (bias). However, the sum of the absolute differences was 2,433 tonnes, and the mean proportional absolute difference was 33% of the total actual delivery (Figure 1.2). In 2001 and 2002 other large wine companies have confirmed that the annual average absolute difference between grower forecasts made in January and actual deliveries is consistently about 33%.

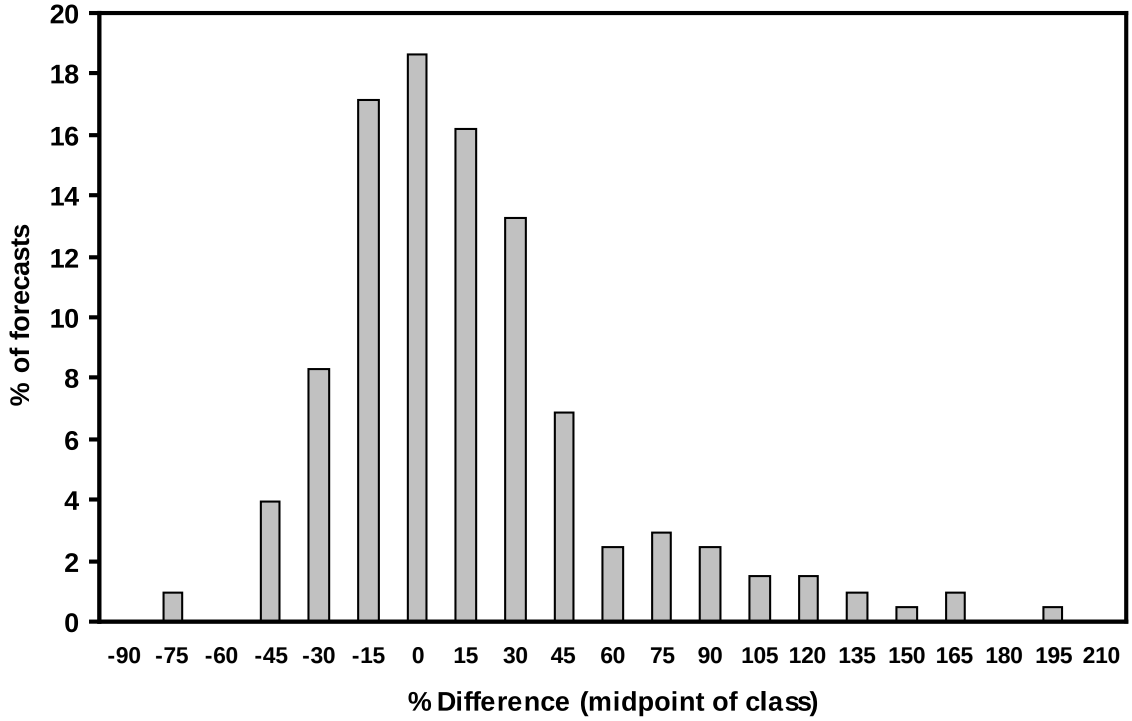


Figure 1.2. Two hundred mid January (post fruit set) yield forecasts from 63 growers for 41 varieties for the 2000 vintage

Figure 1.3 compares the sum of all the forecasts made by the representative grower in each year to actual vineyard production. It demonstrates that his forecasting was inhibited by an inability to vary his estimates sufficiently from the mean. Consistent overestimation of production in low-cropping years and large underestimation in high-cropping years is widespread. Growers may have a good feel for average production over time, but fail to adjust as much as production actually deviates.

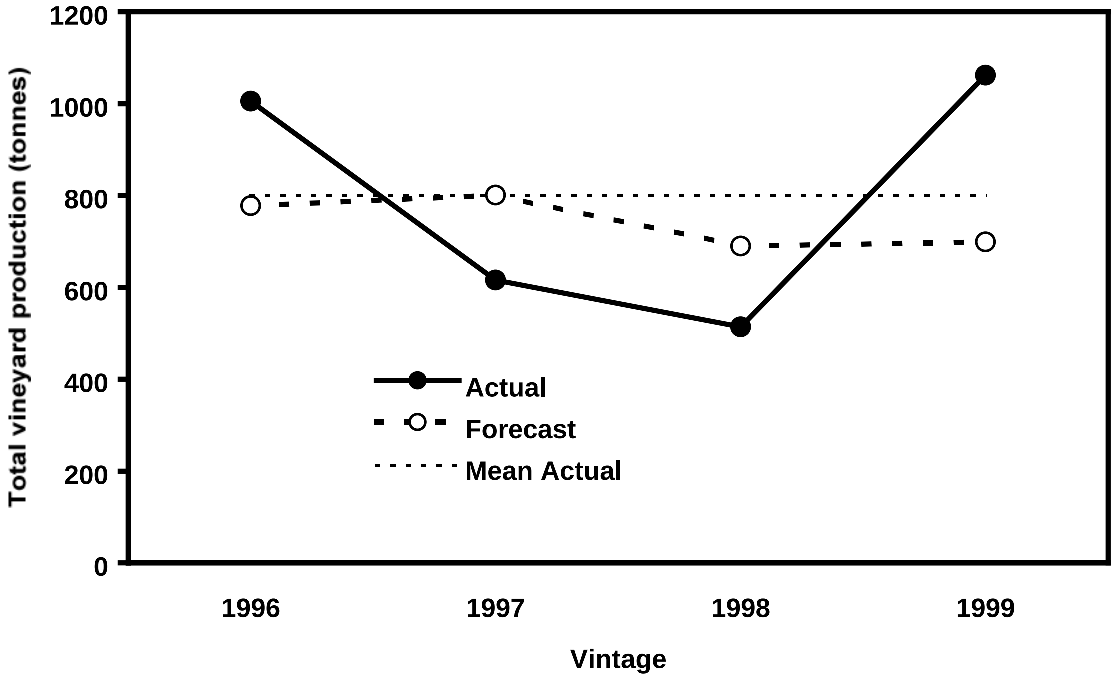


Figure 1.3. Actual and forecast production (post fruit set) from a vineyard over a four year period

The performance of the representative grower also demonstrated that it is more difficult to forecast yield in patches of grapes where production is more variable over time (Figure 1.4). The implications of this when providing incentives is that one should consider applying a difficulty rating to more variable patches to avoid unfairly rewarding lucky forecasters who have stable patches. It may be better to consider rewarding forecasters who use a reliable system, particularly if changes in the management of the patch are a source of yield variation over the years.

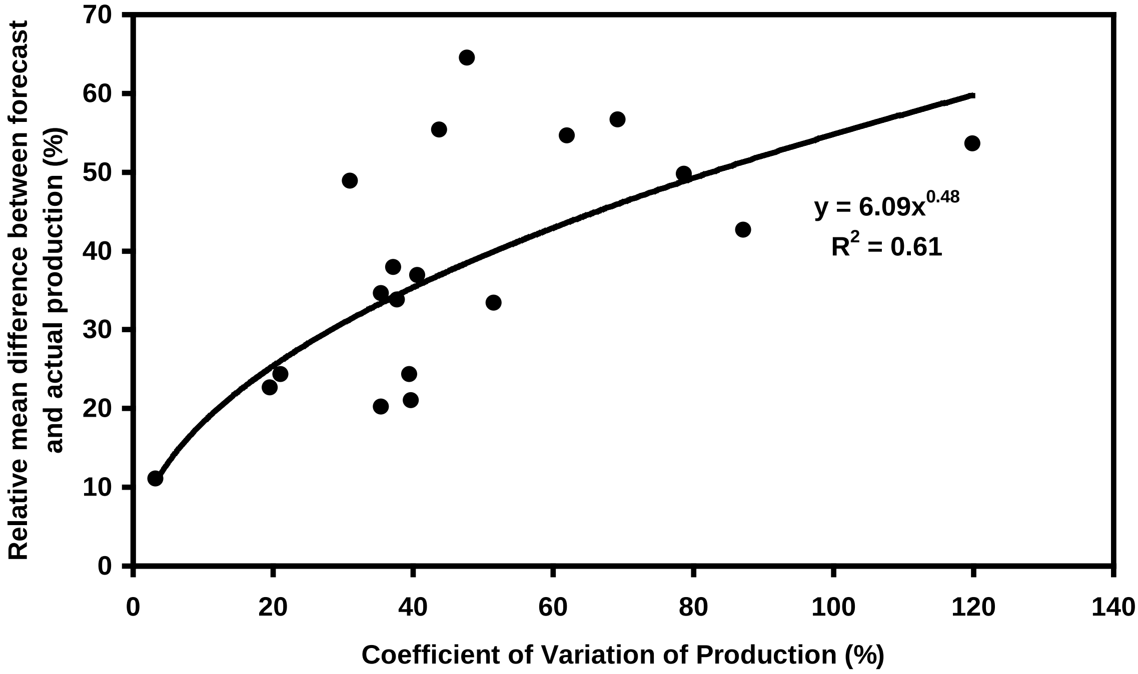


Figure 1.4. Relationship of forecasting performance to patch variability over time.

In summary, measures of forecaster performance commonly used by 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 at a batch-by-batch level can be quantified. During the late 1990s and early 2000s in Australian vineyards, the mean absolute difference achieved by grape growers when making forecasts was about 33% of actual.

WINEMAKER EXPECTATIONS

In many ways the ‘customer’ of a yield forecast is the winemaker and as part of an earlier GWRDC funded project many Australian winemakers were surveyed to find out what sort of accuracy they would like to see from a yield forecast. The large majority stated that they would be happy with an accuracy of +/- 5% (Clingeleffer 2001). Given that industry performance at the time was closer to +/-30%, there was, and still is, a substantial mismatch between the wishes of the winemakers and the actual quality of the forecast.

The application of best practice measurement based forecasting will lead to accuracies significantly better than +/- 33%. However, accuracies are not likely to be in the order of +/- %5, with the exception of immediately prior to harvest when +/- 5% is obtainable. The inability to 'hit' +/- 5% earlier in the season is due to the high level of variability in the vineyards and also the fact that many important determinants of yield are not set until later in the season. For instance berry numbers not really know until a few weeks after fruit set and berry size can still be altered by cultural practices or weather conditions right up until harvest in ways that are difficult to quantify. Furthermore, a lot can happen during the season to alter yield potential, e.g. hail, crop thinning, heat stress.

Pragmatism would dictate a solution in two parts. First forecasters need to adopt best practice measurement-based systems that will substantially improve accuracy and, secondly, wine makers need to accept that the expectation of +/- 5% earlier in the season is not realistic given current knowledge, resources and technology.

This book describes best-practice forecasts made at various stages throughout the season. Obviously, as the season progresses and more yield components are ‘set’ and environmental conditions play their part the more accurate the forecast becomes.

CHAPTER 2 REPRODUCTION IN GRAPEVINES

Viticulture seeks to manipulate the balance between vegetative growth and fruiting in grapevines. This is done for a variety of reasons including: ensuring crops ripen adequately; meeting grape delivery contracts; and, guaranteeing vineyard profitability (i.e. the costs of fruit production are exceeded by economic returns). Fundamental to understanding this balance and managing it is an understanding of yield formation. This begins with the formation of potential yield, which can be described as the product of inflorescence number and inflorescence size (flower number per inflorescence). The realisation of this potential is then determined by flowering and fruit set and finally by the growth of berries. This chapter first describes anatomical developmental which underpins the setting of yield potential. Then, what is known about the effects of environmental and plant drivers and vineyard management on yield development is summarised. Finally, the implications this has for when and how to make forecasts is discussed.

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 variables (mainly light and temperature) on inflorescence initiation. Srinivasan and Mullins (1981) reviewed the physiology of flowering in grapevines, placing particular emphasis on the controlling role of phytohormones. More recently, Vasconcelos et al. (2009) reviewed the flowering process in the grapevine while Carmona et al. (2008) reviewed the process from a genetic perspective.

Here we revisit grapevine reproduction to synthesise this information. For each stage, in turn, our state of knowledge on of the effects of the environment and vineyard management will be reviewed.

FLOWER FORMATION

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 (Figure 2.1) 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 determines the potential number of berries that may be set on that bunch. To summarise:

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 primordial (Barnard 1932, Barnard and Thomas 1933).

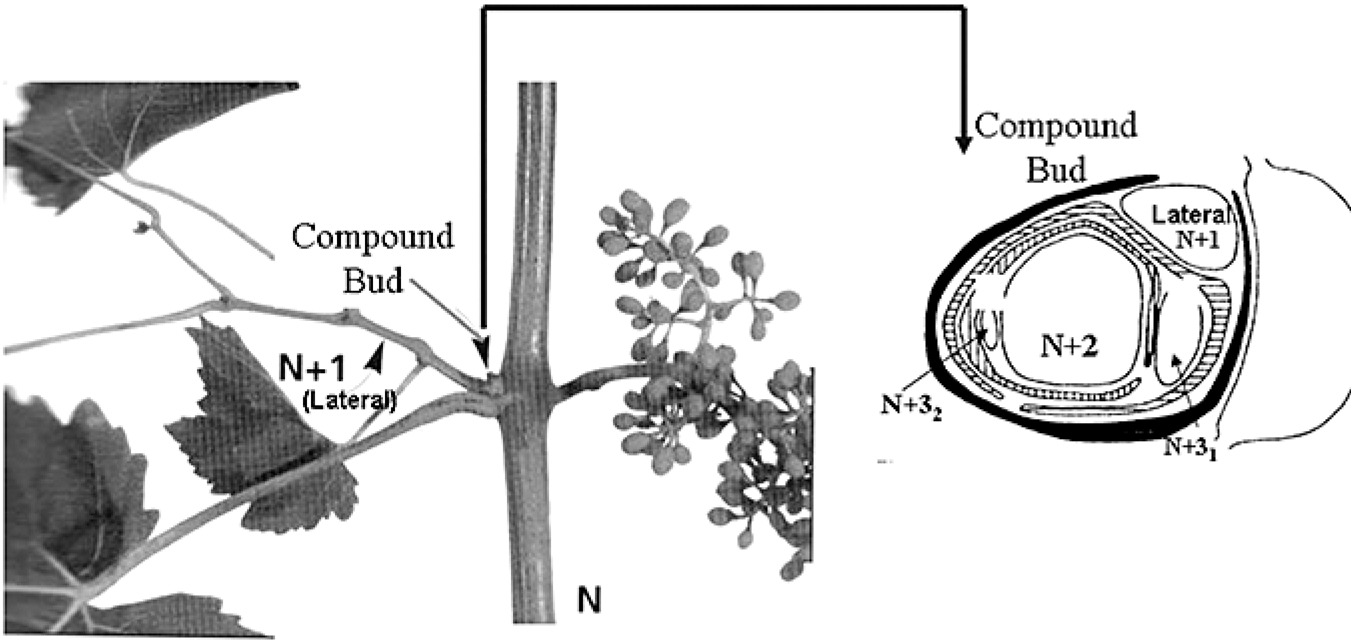


Figure 2.1 The position of the latent compound bud in relation to the current season's primary shoot (N) and the 'summer lateral' shoot (N+1) after Lavee and May (1997) (reproduced with permission from the *Australian Journal of Grape and Wine Research*), accompanied by a cross section of a compound bud adapted from Pratt (1971) (reproduced with permission from the *American Journal of Enology and Viticulture*) showing the bud giving rise to the 'summer lateral' shoot (N+1), the primary latent bud (N+2) and the accessory buds (N +3_1 and N+3_2). All scanning electron micrographs in this paper are of primary latent buds (N+2) (reproduced with permission from the *Australian Journal of Grape and Wine Research* Watt *et al. 2008)*.

For grapevines grown in temperate climates, steps 1 and 2 are completed during the previous season. Individual flowers, on the other hand, are not formed until during budburst in the current season (Barnard 1932, Snyder 1933, Winkler and Shemsettin, 1937, Srinivasan and Mullins 1981, Scholefield and Ward 1975, Figure 2.2).

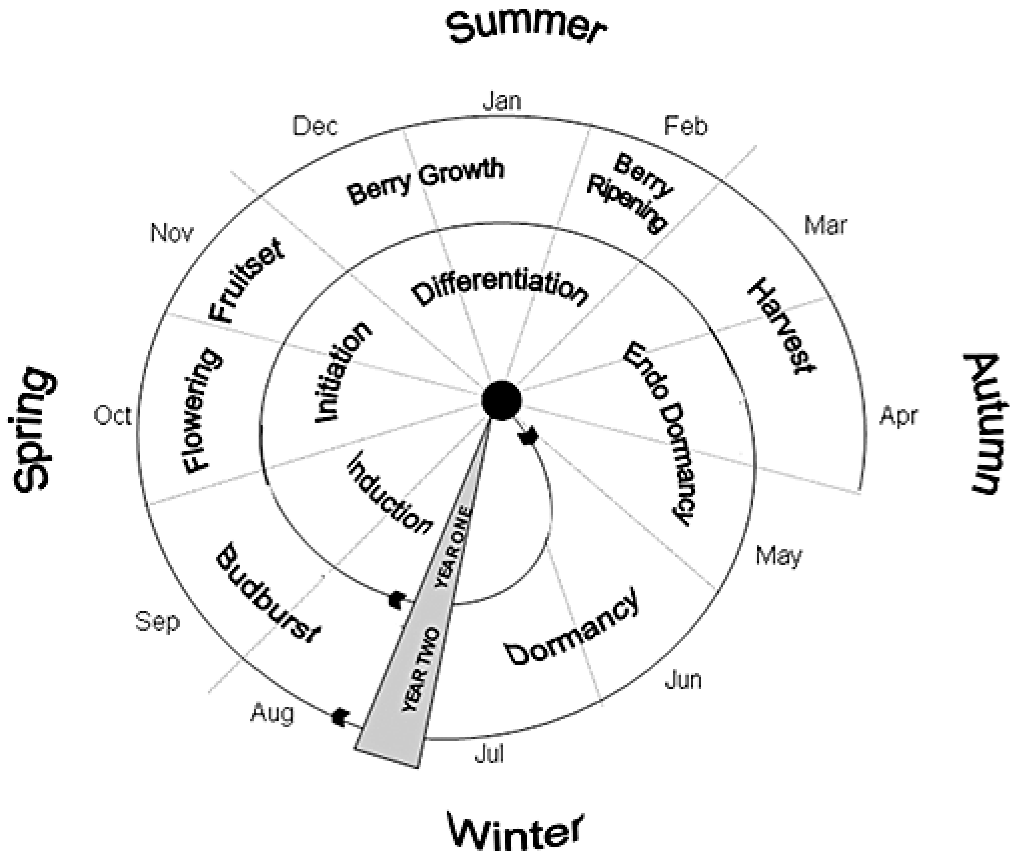


Figure 2.2 Typical timing of key phases of grapevine reproduction in temperate south-eastern Australia. The black centre indicates the start of the life cycle. The black arrows indicate the clockwise direction of spiral (reproduced with permission from the *Australian Journal of Grape and Wine Research* Watt *et al. 2008).*

Developmental morphology

Flower formation in grapevines involves a long multi-step process. The first visible sign is ‘initiation’, during spring. This is the formation of a specialised structure called the ‘anlage’ in dormant latent buds. The anlage, a term introduced by Barnard (1932) first forms a bract primordia, then divides into an ‘inner’ and ‘outer’ arm. This next step is referred to as ‘differentiation’ and this takes place around flowering. The inner arm, and often the outer arm, may differentiate branch initials (the precursors to actual branches) 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, 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 (potential bunch size).

Initiation takes place in basal buds in spring and progresses up the shoot. Anlagen may become tendrils, inflorescences, shoots (rare) or even transitional forms between all three. However, 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 suggesting that the extent of branching prior to dormancy determines potential bunch numbers.

Tendrils and inflorescences are considered to be homologous structures (Morrison 1991) since they are derived from the same meristematic tissue. 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, 1978, 1980, Yahyaoui et al., 1998) and led Srinivasan and Mullins (1981) to propose a simple model for the transition of the vegetative apex to an inflorescence based on variations in cytokinins, gibberellins and inhibitors whose effect is mimicked by synthetic growth retardants such as chlormequat. Boss and Thomas (2000) suggest that the close relationship between tendrils and inflorescences indicates a control step at the gene level, which controls the differentiation of anlagen down one or the other pathway.

As potential yield, to a large extent, is set prior to dormancy this an assessment of bud fertility during dormancy should be able to provide an estimate of fruiting potential. This will of course be modified by how many buds burst and which buds burst. So from this perspective there it will always involve uncertainty.

Fertility and yield components

That the extent of branching prior to dormancy determines potential bunch numbers is consistent with the observation that the yield component bunch number tends to drive fluctuating yield in vineyards shown graphically in Figure 2.3. Thus, it is theoretically possible to stabilise yield fluctuations by altering the severity of pruning in response to an assessment of bud fertility, and thus yield potential, during dormancy.

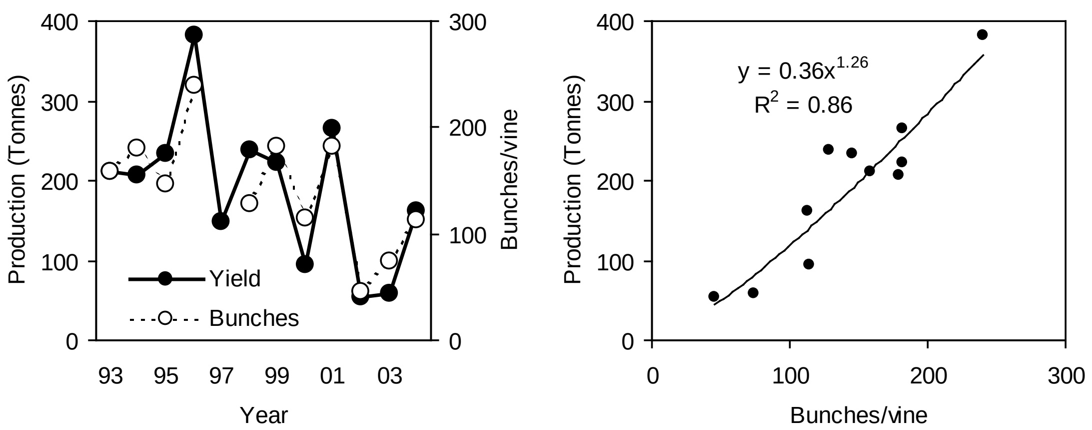


Figure 2.3 Patterns of yield variation over time in a commercial block of Cabernet Sauvignon at Coonawarra

Environmental effects on inflorescence formation

<u>Temperature</u>

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.

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.

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. 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. Also, any increase in flower number may be offset by a decrease in bunch number (Pouget 1981) and/or poorer budburst (Kliewer 1975).

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 fi eld (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). 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 perhaps indicating a role for phytochrome in the control of flowering. 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 1974a).

The timing of maximum sensitivity has been studied for Sultana. Shading (70% shade) had its greatest effect over a four-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 two weeks or the last two 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 two 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 Thurgau was reduced at 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.

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. 1981) on PBN, which also increase vegetative vigour in grapevines (Weaver and McCune 1961), suggest a causal role for endogenous gibberellin levels (Lavee 1987).

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.

Water stress

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. 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). However, leaf removal and shoot thinning can improve fertility. The severity and timing of these operations in relation to initiation and differentiation of anlagen is likely to be important as they may also affect carbohydrate accumulation and storage.

FLOWERING AND FRUIT SET

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 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, 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 cultivars, 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, however, be due to:

- incomplete fertilisation and subsequent early abscission;
- insufficient nutrition (especially boron and/or zinc) leading to abscission of ovaries soon after fertilisation;
- insufficient or excess hormones preventing the activation of the abscission layer;
- insufficient carbohydrates stored over winter inhibiting the normal development of flowers;
- seedless berries with less than adequate hormones for partitioning carbohydrate to berry growth and development;
- competition between growing shoots and flowers or berries for photosynthate; or
- 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 (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 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 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.

BERRY GROWTH

In seeded grape cultivars, berry growth is initiated by pollination and subsequent fertilisation. Flowers that fail to fertilise, shrivel and die (Mullins et al. 1992). Berry growth typically follows a double sigmoidal growth pattern (Mullins et al. 1992). This can be divided into three arbitrary stages;

- *Stage 1* – The initial phase of rapid berry growth, characterised by the growth of the seed and pericarp. There is little development of the embryo (Mullins et al. 1992). During this stage, the majority of the cell division occurs within the berry. Berries also accumulate organic acids and are still green and hard.
- *Stage 2* – The 'lag' phase, characterised by slow growth of the pericarp and by the maturation of the seeds within the berry (Mullins et al. 1992). The berry remains green and hard during this phase, which may last between 7-40 days depending on cultivar and growing region (Mullins et al. 1992).
- *Stage 3* – This stage is marked by the onset of berry softening, berry ripening and by colour change in pigmented varieties. The stage at which anthocyanin pigments appear in the skins of red or black grape cultivars is known as 'veraison'. In this stage rapid berry growth resumes, due solely to cell expansion (Mullins et al. 1992).

Berry size is greatly influenced by the number and dry weight of seeds per berry (Clingeleffer 2001). It is also greatly influenced by irrigation management. While berry growth is important it typically only explains approximately 10% of the year-to-year variation in vineyard yield (Clingeleffer 2001).

YIELD VARIATION

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 marketers to match supply to demand. This was most recently evident in the low yields of the 2003 vintage being followed by the large crops seen in 2004. These yield fluctuations are mainly driven by the weather but can also be exacerbated by changes to vine management in response to the season. They can lead to an inconsistent supply of fruit to wineries and variations in fruit composition and wine quality (Table 2.1).

Variations in grape yield and composition also occur across sites, between regions, within individual vines and between berries within an individual bunch. Spatial yield variation is very much related to the environment that individual plants experience (edaphic factors , aspect, meso-climate, proximity to neighbours etc.). Like annual variation it also has implications for fruit composition and wine quality. It can pose problems for managing both inputs and outputs of the production system. The high level of spatial variability in vineyards often dictates high sampling intensities to meet accuracy targets for estimating means of measurements of grapevine samples (eg. bunches per vine, grape maturity). A geo-referenced understanding of spatial variability may instruct the location of sampling points and facilitate more precise management of inputs and outputs (eg. differential harvesting).

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

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

Annual (temporal) variation

Season-to-season fluctuations in grapevine yields may be considerable. Generally, individual vineyard blocks form management units to which many management actions (eg. pruning, weed control, harvesting) are homogenously applied. Figure 2.4 presents examples of annual variation for three such vineyard blocks *viz.* a Cabernet Sauvignon block in Coonawarra, a Shiraz block in the Barossa Valley and a Shiraz block near Mildura (Sunraysia). Coonawarra experiences a cool to warm climate compared with the hot climate of Sunraysia. The Barossa Valley is intermediate between the two.

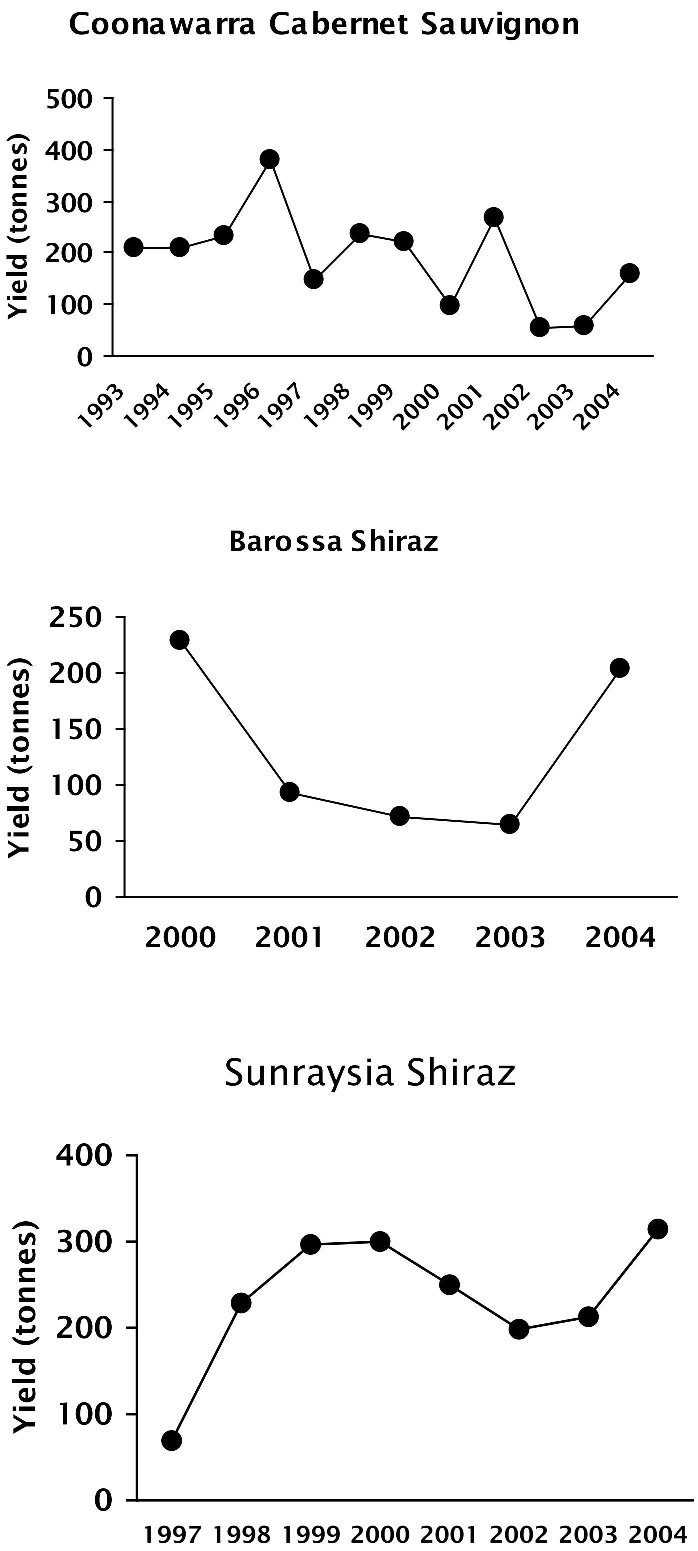


Figure 2.4 Annual yield over time for three irrigated vineyard blocks: Cabernet Sauvignon in Coonawarra, Shiraz in the Barossa Valley and Shiraz near Mildura (Sunraysia).

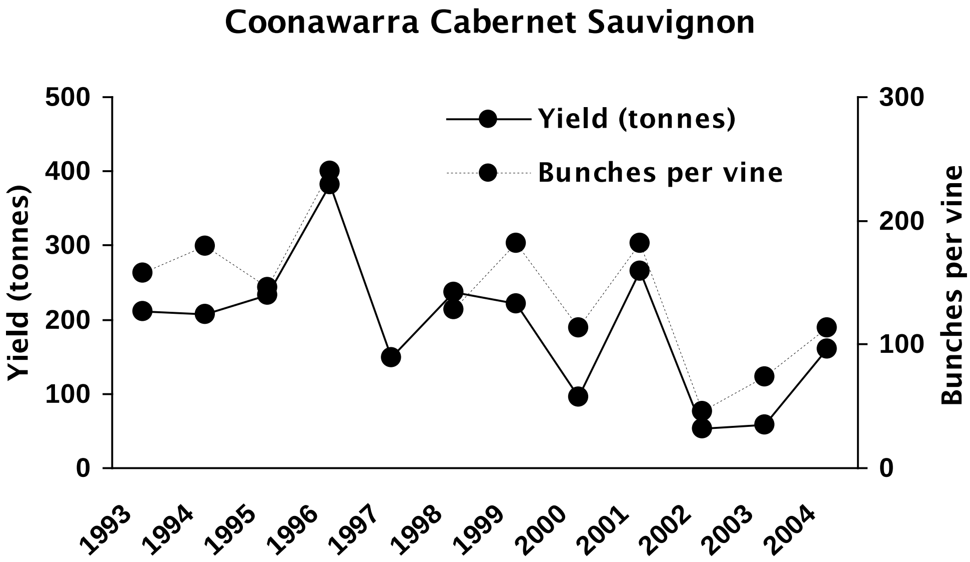
A simple measure of yield variability is the coefficient of variation (CV). For distributions of yield the CV equals the standard deviation divided by the mean and expressed as a percentage. High CVs indicate a wide distribution of yields relative to the mean while low CVs describe a more stable system where the distribution of yields around the mean is narrow. The CVs for the blocks in Figure 2.7 are 49%, 38% and 34% for ‘Coonawarra Cabernet’, ‘Barossa Shiraz’ and ‘Sunraysia Shiraz’, respectively. This level of variation is fairly typical across the industry but large in comparison with many other agricultural systems (eg. dry land wheat farming in humid and irrigated regions (Hazell 1989)). It is important to note that variation can be substantial even in climates like Sunraysia where conditions during cardinal events of grapevine reproduction (ie. initiation, differentiation, budburst and flowering) are perceived to be less variable in comparison with cooler climates.

Data presented in Figure 24 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 practical management unit. For individual vines, the components of 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. In general terms, recent statistical studies have analysed the comparative importance of yield components such as bunches per vine, berries per bunch and weight per berry as factors contributing to variation in vineyard productivity (Clingeleffer 2001). These studies consistently show that annual variation in bunches per shoot (or vine) is the major contributor to fluctuating (both high and low) yields, explaining 60% – 80% of season-to-season yield variation for the cultivars Cabernet Sauvignon, Chardonnay and Shiraz. Further analyses we have done confirm that this also is true for other cultivars. A graphic illustration of this can be seen in Figure 2.5 where the average number of bunches per vine overlays the Figure 2.4 yield traces for ‘Coonawarra Cabernet’ and ‘Barossa Shiraz’.



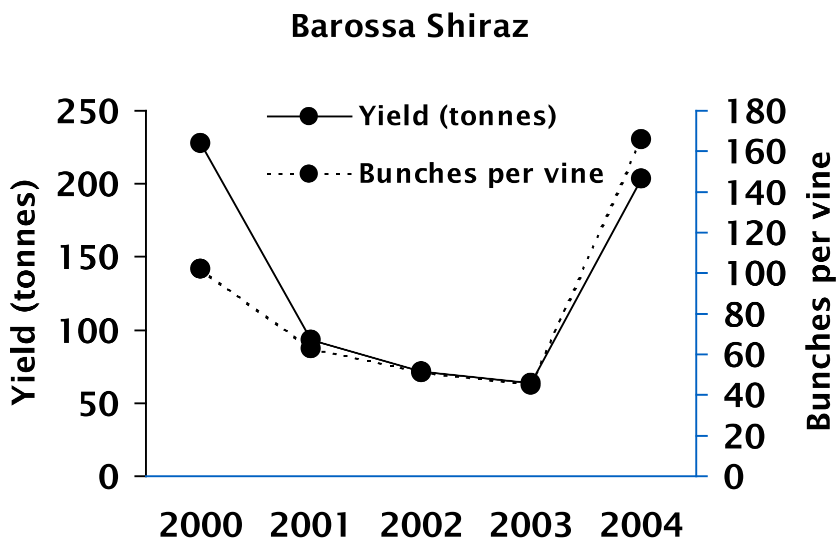


Figure 2.5 Association between the average number of bunches per vine and annual yield for two irrigated vineyard blocks: Cabernet Sauvignon in Coonawarra and Shiraz in the Barossa Valley.

While problems of fruit set are important, at least in some regions and some seasons, these results suggest that, in the main, stabilising yield hinges upon understanding and being able to manipulate the determinants of bunch number in grapevines. It is important to note here that our research has shown that there is often a positive relationship between bunch number and bunch size from one season to the next. Some caution needs to be exercised when attributing causes for small bunch seasons. The cause is often assumed to be fruit set, but without assessing the ratio of set berries per bunch to flowers per inflorescence it is not possible to determine to what extent small bunch size was a function of poor fruit set or the low number of flowers to begin with. Our research has shown that there is a commonly a relationship between lower bunch numbers and smaller inflorescences in spring.

IMPLICATIONS FOR FORECASTING

The cycle of yield development in grapevines extends over two growing seasons and typically is in excess of 14 months from initiation through to harvest (Figure 2.2). There are a number of critical control points during reproduction notably:

- *inflorescence initiation and differentiation* – this is the most important step in the determination of yield potential in grapevines. Bunch number per vine explains 60-70% of the annual variation in yield and the weather conditions influencing the processes are broadly understood.
- *budburst and floral development* – knowing which buds will burst and the weather conditions experienced during the early floral branching and differentiation can also have a major influence on the yield potential of grapevines.
- *flowering and fruitset* – the number of berries per bunch typically explains around 20-30% of the total annual variation in yield. The weather conditions around this stage of development can have a major

influence on the success of these flowering and fertilisation processes. Grapevines are also sensitive to nutrient disorders, water status and pest and disease pressures at this stage of development.

A grapevine has the ability to self regulate its yield to a limited degree, most likely through effects on carbohydrate balance within the vine. This plasticity allows the vine to regulate percentage bud burst, fruitset and berry growth effectively.

Although many, including most winemakers (Clingeleffer 2001), would like to see yield forecasts that are out by no less than 5%, the system that we are dealing with is extremely variable with yield components set at various times during the season. For instance, in spring while it is possible to estimate the number of inflorescences per vine, it is not possible to know how large bunches will be at harvest. This is a function of how many flowers are on inflorescences, how many of these flowers set fruit and how large berries then grow.

However, there are cardinal times during grapevine phenology when yield potential is set and a prediction of yield from measurements of crop components at these important phenological stages can be made. The first of these is **bud dissections** made during dormancy that allow for a prediction of yield potential. The next stage is ‘in season’ with **bunch counts** made about 6 weeks after budburst followed by **berry counts** made after fruit set. Another forecast can be made close to **harvest** by destructively sampling vines or segments of vines. This forecast is important for intake scheduling. Following correct sampling protocols it is possible to $\pm$ 15-20% after fruit set and $\pm$ 5% close to harvest. It is likely that the post budburst forecast could be improved if a rapid method for assessing the number of flowers per inflorescence could be developed.

CHAPTER 3 ASSESSING YIELD POTENTIAL DURING DORMANCY

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 predicting yield potential and 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’. 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).

FORCING SINGLE NODE CUTTINGS

Budburst from lower nodes of single node cuttings is consistently poor and cannot be recommended for use in spur pruned vineyards (Clingeleffer 2000). Although poor budburst from lower nodes is likely to be due, in part, to incidence of PBN this did not explain the phenomenon entirely as 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.

Aside from difficulties associated with budburst, the low predictive capacity of the technique due to low numbers of buds bursting presented further problems. 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^{o}C to 25^{o}C. It is possible that by forcing cuttings to burst at 20^{o}C one might be overestimating bunches per shoot as air temperature during budburst is likely to be much lower.

DISSECTING DORMANT 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 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. If proper care is taken, and some simple rules are applied, bud dissection is a reliable method for estimating yield potential during dormancy.

Dissection technique

Assessments of the condition and fertility of the buds can be made using a dissecting microscope. There are two methods that are currently used:

1. Thin slices are shaved off progressively, starting from the top of the bud, to reveal the shoot and bunch primordia. Each ‘bud’ usually contains a primary bud (in the middle) and two secondary buds (on either side).
2. Dissecting needles are used to carefully remove bud scales and leaf primordia to reveal entire inflorescence primordia.

The first method has the advantage of being substantially quicker and, depending on the skill of the dissector, just as accurate. If the primary bud is healthy, all the bunch primordia in it should be counted assuming that only the primary bud it would shoot. If the primary bud iss necrotic (dead), then bunch primordia in the secondary buds need to be counted, and a decision made as to whether just one or both secondary buds are likely to burst. Measures of bud fertility can then calculated for each node position: percentage total bud death, percentage primary bud necrosis (PBN), and expected average number of bunches per node.

Collection

It is important when collecting buds to ensure that only the type of buds that are likely to be retained are sampled and dissected. For instance, if the vineyard is to be spur pruned one would collect only from lower nodes. However, if the vineyard is to be cane pruned longer canes would need to be collected and higher nodes as well as lower nodes would need to be dissected. If the vineyard is to be hedged or minimally pruned then the whole population of nodes would need to be sampled from.

Buds sampled before leaf fall could be dissected and assessed just as successfully as buds sampled after leaf fall as extra bunch primordia do not appear after veraison. However, complete bud death and primary bud necrosis can still increase over leaf fall. Thus it would be unwise to assume that the results of an assessment of bud fertility made before leaf fall would be reliable. It is unlikely that bud fertility would be underestimated, but there is a real possibility that it could be significantly overestimated

It is important to cut the cane off as near to its base as possible. Canes should be wrapped in wet newspaper, sealed in a plastic bag, kept out of direct sunlight and stored at approximately 4°C until dissection.

Sampling considerations

Estimates of node fertility are made from samples of canes either provided to bud dissection services by growers or dissected by the growers themselves. Typically a bud dissection service will dissect buds on these samples and provide a grower with an estimate of the mean fertility at each node position along the canes. Growers compare results obtained in successive seasons Due to variation for each patch f vines there may be a different “Best Sample Size”. If the size of the sample is smaller than the Best Sample Size, it is less likely that forecasts of yield that are made from the estimates of node fertility will be as accurate as required. On the other hand, if the sample size is bigger than the Best Sample Size, time and money will be wasted on unnecessary sampling and payments to a bud dissection service.

The Best Sample Size is the minimum number of canes that will achieve a “tolerance of doubt”. If many different samples of canes are taken from the same patch, the estimates of mean node fertility derived from them will vary. So, unless every cane in the patch is measured (obviously impractical), there will always be some uncertainty or “doubt” surrounding an estimate of the true mean that is derived from a sample. Just as a mean number of bunches can be calculated for each node position, so can a standard measure of the doubt that surrounds this estimate. Here and in other literature produced by the project “doubt” is defined as the range either side of the sample mean in which one can be 95% sure that the true mean will be, expressed as a percentage of the sample mean (ie, in statistical terms, the 95% confidence interval expressed as a percentage of the mean). For example, if a bud dissection service is provided with a cane sample and it estimates that, on average, there is 1 bunch per node at a particular node position with a doubt of 15%, then a grower can be 95% sure that the true node fertility will be in the range 1.0 ± 0.15, or from 0.85 to 1.15 bunches per node.

Clearly there are good reasons why the amount of doubt surrounding an estimate of node fertility should be minimised to an acceptable level. The Best Sample Size can be calculated using the following formula:

Best Sample Size = t2 x Variation2 / Tolerance of Doubt2

where *t* is an appropriate value of Student’s t-distribution (for the purpose of sampling canes to estimate node fertility it is sufficient to assume that *t* = 2, so *t2* = 4) and *Variation* is the Coefficient of Variation of the sample measurements.

The key problem for the project has been providing bud dissection services with a statistically sound and practical method to calculate the Best Sample Size for each sample of canes provided to them. In theory a bud dissection service can calculate the Best Sample Size for each patch that a grower samples when it knows the Variation in the measurements of node fertility for the sample and if the grower has specified a Tolerance of Doubt. If growers could measure their own samples, they could guess at the best sample size and then see if it was adequate. If it wasn't, they could re-sample and re-measure until the doubt is less than their tolerance. This works well with measurements that growers can make themselves, such as bunch counts, bunch weights, maturity samples, etc. However, in most cases, growers send their cane samples away to be dissected. A buddissection service can calculate the best sample size if a grower tells them how much doubt they are prepared totolerate and the bud dissection service can determine the variation of the sample. However, if the best sample size is bigger than the size of the sample a grower sends to them, it would be a nuisance to have to collect and send another sample, so a better solution is needed.

The most expensive part of the process of getting estimates of node fertility is the cost of the bud dissection service, which will generally price its service per bud. Compared to bud dissection, cane sampling is cheaper and there are ways to increase the sample size with relatively little additional expense in the vineyard. Thus, we recommend that growers sample a larger number of canes than is likely to be needed, specify a tolerance of doubt to their bud dissection service, and then get them to dissect the minimum number of canes to meet that tolerance.

In the past, relatively large total numbers have nodes have been dissected to produce estimates of node fertility, because all the nodes on full canes were dissected on a sample of canes collected for a region, e.g. for Sultana in the Sunraysia. However, growers now seek, and bud dissection services provide, estimates of mean node fertility for each node position along spurs or canes for each individual patch within their vineyard or perhaps for each variety. They do this because they recognise that a different outcome will be obtained if they leave, say 2 x 3- node spurs in the same length of cordon as 3 x 2-node spurs.

However, using the above formula, very large Best Sample Sizes are required to provide accurate estimates of the mean fertility at each node position, typically in the order of 200 – 400 canes if 15% doubt is specified. Clearly this has major consequences for the potential cost of getting a sufficientlyprecise estimate. A transformation of the data (e.g. y2 = (y1+0.5)0.5) will reduce the Variation and hence the BSS to manageable sample sizes (typically about 30 – 60 canes). However, is not valid and can be misleading (Martin *et al*. 2006). Techniques such as averaging groups of data to try to make the data more continuous have also not changed the Variation or the BSS. Therefore, it is in fact necessary to take large samples of canes to derive reliable estimates of mean fertility. However, there is a way around this problem. As noted above, in the past, reasonably precise estimates have probably been produced by bud dissection because large numbers of nodes have been dissected and the means have been derived for all nodes regardless of position on the cane. Therefore, it is suggested to use the mean of all nodes up to longest spur or cane length specified for pruning. This is can then be multiplied by the total number of nodes per metre to yield an estimate of potential bunches per metre. This approach saves bud dissection costs and also has the added benefit of using numbers that relate to the node counts that vineyards actually do at present, which do not partition into nodes at each node position. The net result is a simpler system and one that overcomes the problem of cane sample sizes being too small at each node position.

CHAPTER 4 YIELD FORECASTING IN SPRING

INTRODUCTION

The earliest an in-season yield forecast can be made is during spring and many wineries seek an early indication of yield between budburst and flowering. A forecast for any contiguous patch of vines at this time is based on estimating the number of flower clusters (inflorescences) in the patch, knowing the number of vines in the patch and predicting average bunch weight at harvest. These forecasts are not as accurate as forecasts made after fruit set when a better estimate of bunch size can be made (Clingeleffer 2001). Nevertheless, they can still be extremely useful for both wineries and vineyards. This chapter describes best practice yield forecasting based on inflorescence counts in spring, including a discussion on sampling and vineyard considerations.

Clusters and Bunches

There is some confusion in the use of these two terms to describe the reproductive structures of grapevines. For instance, in Australia the term bunch is often used to describe the cluster of flowers (inflorescence) before flowering as well as the bunch of berries after fruit set. While in some other countries the term cluster is preferred. Here we will refer to the 'cluster' of flowers prior to flowering and during fruit set as an **inflorescence**. After berries are set we will refer to the structure as a **bunch**.

WHEN TO MAKE A FORECAST

Experience has shown that the best time to count inflorescences is about 6 weeks after budburst (Clingeleffer 2001). Not all the inflorescences are visible if counts are made earlier than this. If counts are left until much later, both the canopy and inflorescences grow and the slowness of counting increases as it gets harder to find inflorescences and untangle them. This added difficulty contributes to ‘counting fatigue’ and associated errors.

USING THE CORRECT FORMULA

It is critical to use the correct formula when making an inflorescence count forecast. Essentially the formula for calculating the amount of fruit that makes its way from the vineyard to the winery is:

Vines/patch

x

inflorescences/vine

x

bunch weight (at harvest)

x

harvest efficiency

=

Yield/patch

When counting inflorescences in vine segments (Figure 4.5) rather than for whole vines the formula is:

Segments/patch

x

inflorescences/segment

x

bunch weight (at harvest)

x

harvest efficiency

=

Yield/patch

VINES OR VINE SEGMENTS PER PATCH

The first term, vines per block or segments per block, is crucial to get right. Experience has shown that many forecast are inaccurate because errors in estimating vines per block have lead to errors in scaling up from vine measures to patch yields.

When counting inflorescences there are essentially three options:

1. Record only the actual number of vines per patch and sample from these alone, ignoring any missing vines.
2. Record the actual number of vine spaces in the patch and sample from the whole population recording zeros for missing vines (or segments of bare wire if counting in segments rather than for whole vines).

3. Record the length of bare wire in the patch and subtract this from the total length of fruiting wire and then ignore any bare wire when counting inflorescences per vine segment.

Option 2 is practically the simplest, requiring less preparation and fewer decisions to be made in the vineyard and can be used for both sampling of whole vines or vine segments. Options 1 and 3, however, reduce the number of zeros recorded and thereby reduce the variability of the sample which will, in turn, reduce the number of samples that need to be taken.

HARVEST EFFICIENCY

Along with making sure that the block dimensions used in the forecast are correct it is also important to ensure that the forecast accounts for harvest efficiency. Harvest efficiency reflects the ratio of the actual delivery of fruit to the winery to the amount of fruit in the patch at harvest. Weight can be lost during harvest and transport. These losses can be due to the stalks or rachis of the bunch and some bunches not making it into the harvesting bin in machine harvesting or berries being lost on the ground. Weight per bunch usually considers the weight of the rachis. At harvest approximately 5% of bunch weight can be attributed to the rachis. Other losses can be attributed to transfers to bins and evaporative or spillage losses in the vineyard and during transit. Typical harvest efficiency factors for different situations are given in Table 4.1 below while Figure 4.1 shows the effect that correcting for harvest efficiency has on a set of real forecasts made after fruit set.

Table 4.1 Typical harvest efficiency factors for a range of conditions.

Conditions	Harvest Efficiency Factor
Meticulous hand harvesting very 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
Inefficient machine harvesting with transport losses	0.85

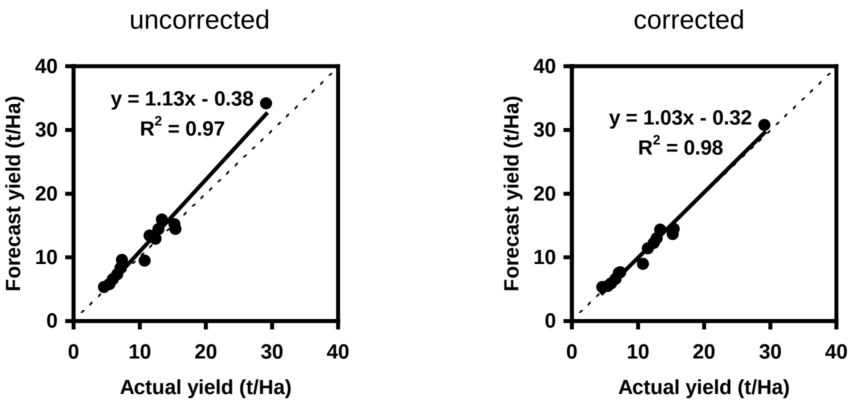


Figure 4.1 The effect of correcting for harvest efficiency on a set of actual post-fruit set yield forecasts.

ESTIMATING INFLORESCENCES PER VINE OR PER VINE SEGMENT

As it is not practical to count all of the inflorescences in a patch of vines, we need to estimate them from sampling the population. Therefore, sampling considerations are paramount and will be discussed in some detail. To ensure that individual biases, both known (e.g. ignoring weaker vines) and unknown, do not influence estimates, sampling must be random. This applies to the selection of vines, clusters or individual berries – *i.e.* each vine, inflorescence or berry must have an equal chance of being selected. Randomization means that probability theory can be applied, error estimates are valid and objective conclusions can be drawn.

What to Count

The choice of definition of an inflorescence to count has practical implications that can affect the accuracy of forecasts. From a physiological perspective, tendrils and inflorescences are homologous organs that arise from the same tissue and are distinguished by the presence or absence of flowers. 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 number of florets”. Other definitions have traditionally excluded bunches with less than 5 berries. We advocate distinguishing an inflorescence or bunch from a tendril if it has one or more flowers or berries on it. From an operational perspective, it is easier and quicker to decide whether to select a bunch when the ‘one berry’ definition is applied. It also removes some variation due to differences in the subjective judgments applied by sampling personnel. In some cases the choice of a ’5 or 10 berry’ or similar floret number definition can result in an underestimate of inflorescences or bunches per segment or vine. 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 from year to year or patch to patch it is important to ensure that a consistent definition was used.

The application of a consistent definition is also important with respect to ‘second crop’ (i.e. inflorescences that form on lateral shoots in the current season). These inflorescences usually contribute to mechanically harvested loads, but are often excluded from hand-picked loads as they flower and ripen much later than the primary crop. In some cases, a choice of definition that includes or excludes them could significantly affect a forecast.

Usually there will only be 0, 1 or 2 bunches on a shoot, but there can be 3 or more. If you find a tendril as you scan upwards you can stop looking at that shoot, because there will be no more inflorescences above it. Only count bunches that have the base of the stalk inside the segment.

Avoiding bias

When making any sort of forecast it is important to avoid any bias in sampling. There are three major sources of bias to avoid when making measurement based forecasts based on bunch counts:

- Spatial bias, i.e. areas of the block are under or over represented
- Bias in the selection of individual vines from which inflorescence counts are made
- Bias in the selection of vine segments, if a segment of a vine rather than the whole vine is used to make inflorescence counts.

Avoiding Spatial Bias

Yield in vineyards can be spatially variable (see Figure 4.2) and this needs to be considered when sampling vines. To use an extreme example sampling from just area A (Figure 4.2) would lead to an underestimate of yield while sampling from section B (Figure 4.2) would lead to an overestimate of yield.

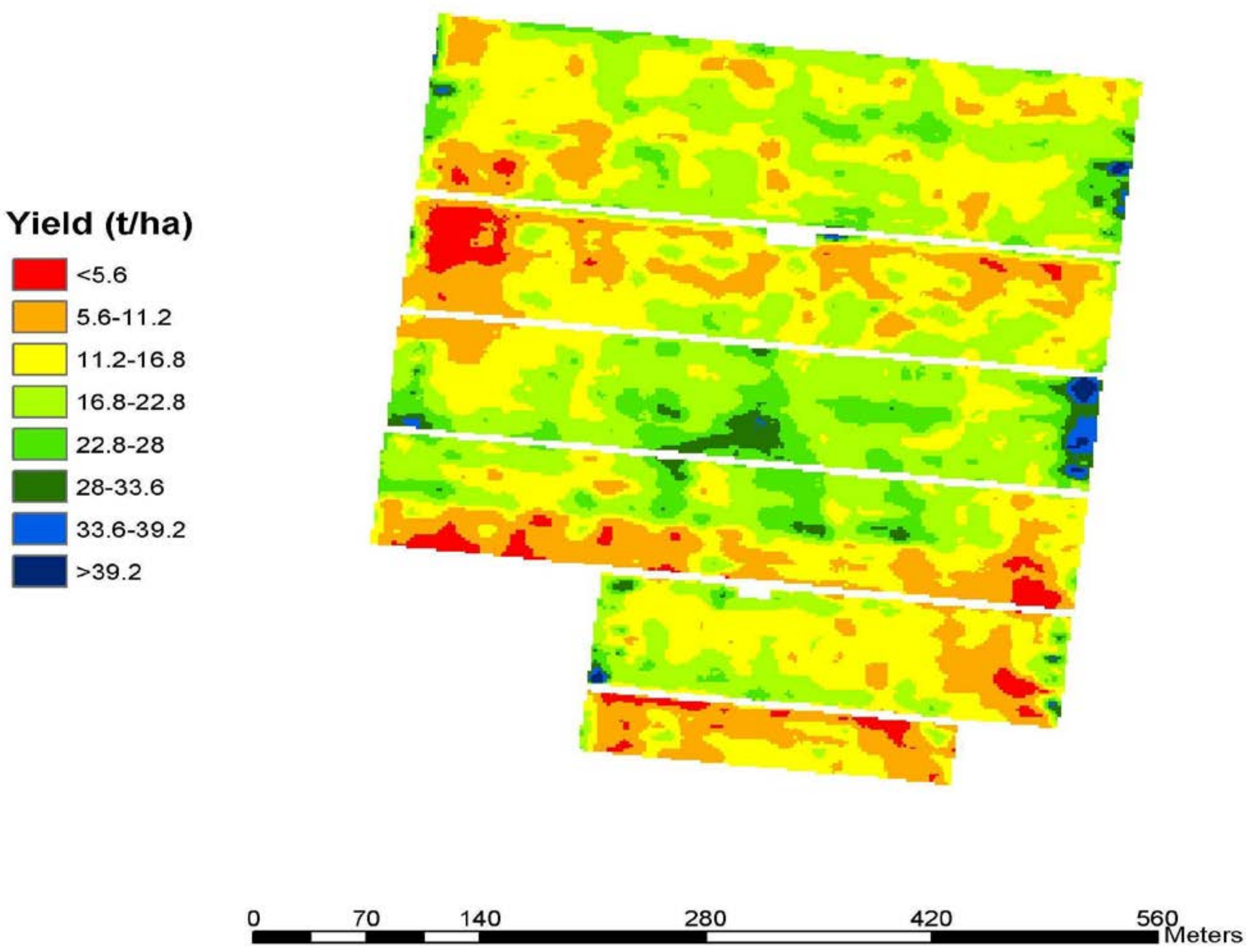


Figure 4.2 An example of spatial variation in yield from a patch of cabernet vines in Coonawarra.

When there is no random selection of vines before entering a vineyard the situation depicted in Figure 4.3a can arise, where there is not adequate spatial coverage of the vineyard. Using a gridded system (Figure 4.3b) will result in better spatial coverage but should be avoided because of the risk it entails e.g. the shaded row may be situated along a blocked irrigation dripper line or be situated on an old compacted road (Figure 4.3b). Also, avoid random row, random vine selection techniques in all but regular blocks. In irregular blocks this will lead to clumping in shorter rows (Figure 4.3c). Here we recommend 'stratified random' sampling where the block is split into into equal sized segments and vines randomly selected within these (Figure 4.3d). This method prevents human and systematic biases and constrains the locations to be distributed evenly throughout the block. The process can be facilitated easily using a purpose built excel spreadsheet (forecaster version 7, http://www.gwrdc.com.au) or purpose built crop forecasting software (http://www.fairport.com.au/index.asp). The benefits of the software over the spreadsheet are large. Because it is based on a database it has improved storage potential and can be easily interrogated (e.g. for historical yield component data). It is flexible allowing growers to make at least five different types of forecasts and to amalgamate patches of similar vines across the vineyard or vineyards (e.g. all of their Chardonnay). Furthermore, this flexibility would easily facilitate more accurate regional forecasting.

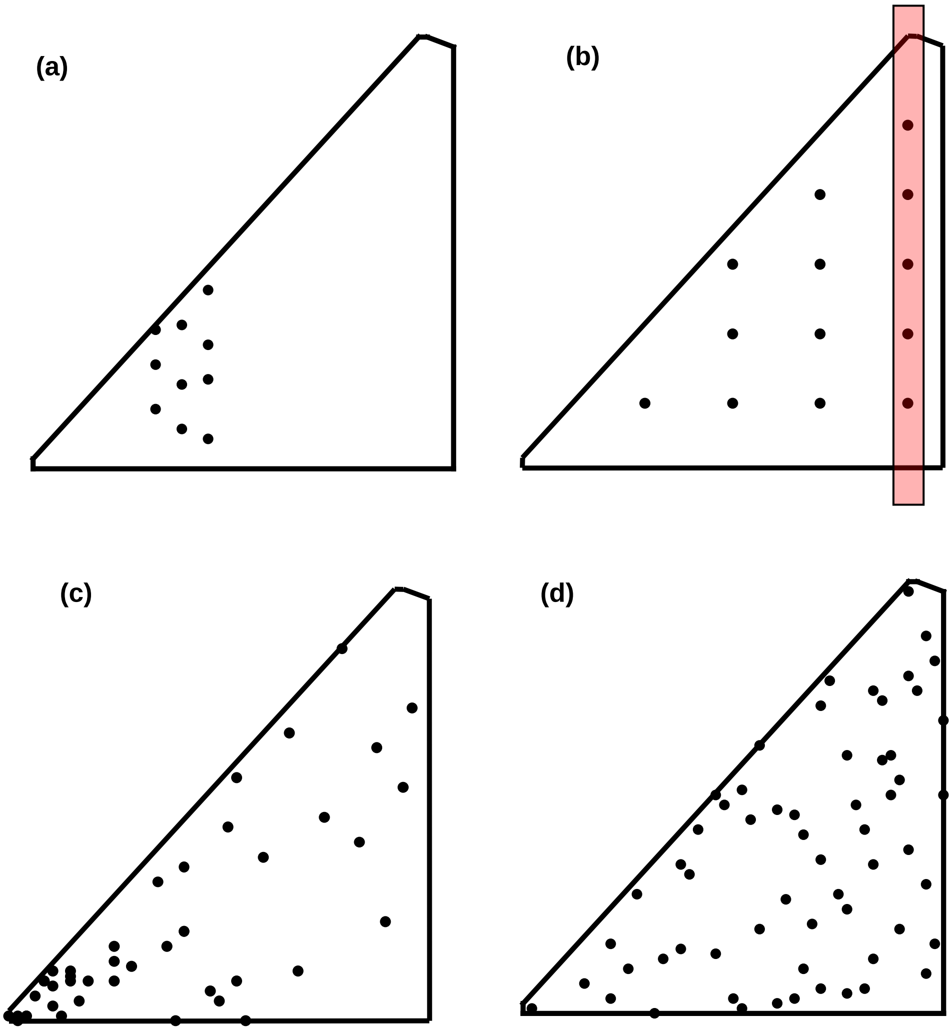


Figure 4.3 Human (a), gridded (b), random row – random vine (c) and constrained random sampling (d) in an irregular block.

Avoiding Bias in Vine or Vine Segment Selection

It is important that each vine or vine space has an equal chance of being selected. This means that weak or missing vine should be included (Figure 4.4). To ensure that each vine has an equal chance of being selected it is best to randomly select them before entering the block. This can be done using the aforementioned spreadsheet or computer program. Similarly, when counting inflorescences in vine segments (Figure 4.5) it is important not to bias selection towards the ends of the vines or the crowns. To avoid this from happening, the segments must be placed randomly along the cordon. Again, this can be easily achieved using the aforementioned spreadsheet or software.

Figure 4.7 It is important not to avoid weaker vines otherwise yield will be overestimated

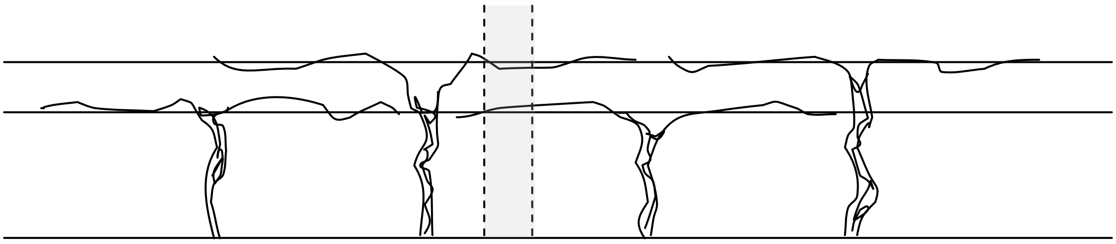


Figure 4.5 A segment is a slice across a vine of known length. When counting inflorescences in segments it is important that segments are randomly placed to avoid bias

Adequate sampling

Typically two kinds of input are used when making a forecast - estimates of known quantities and assumptions about unknown quantities. For example, we could attempt to predict yield for a block by multiplying the mean weight per bunch by the number of inflorescences in a block. We cannot know what bunch weight will be, so we need to make an assumption. We could, however, determine the number of inflorescences present in a block if we had some way of counting them all. In practice, of course, the cost of counting every inflorescences in a block would be prohibitive, so we somehow need to estimate inflorescence number. Commonly, this would involve taking a sample to estimate the mean number of inflorescences per vine or segment.

Sampling introduces an element of doubt, or some loss of confidence, because we cannot be completely sure that the vines we have sampled adequately represent all the vines in the block. For objective forecasting methods to be successful, samples must adequately represent the populations from which they are taken otherwise valid inferences about these populations cannot be made. This requirement is not trivial, and has been recognised in many research papers and articles. However, the literature is less clear on the subject of how to obtain representative samples to estimate yield.

We will now apply a statistical framework to one of the simplest forecasting situations. Suppose, shortly before harvest, we want to provide a winery with an estimate of the weight of fruit a block is carrying. We can assume that little weight will be gained or lost because the time of sampling is close to the time of delivery. If, for this exercise, we choose to ignore any yield loss associated with harvesting efficiency, we can estimate the total weight of fruit in the block by multiplying the mean weight of fruit per *sampled* vine by the number of vines in the block. This may seem simple enough, but how confident are we that our estimate of the mean weight per vine is within an acceptable range of error from the true mean for the block?

If all the vines in the block always produced exactly the same weight of fruit, we could be 100% confident that our estimate is right. In fact, in this case, we would only need to pick one vine to represent all of the vines in the block. However, the weight of fruit per vine can vary substantially, and there will always be some lack of confidence in our estimate. Consequently, we must consider how much error we are prepared to accept and how confident we want to be that our estimate will be within tolerable error limits.

If we sample more vines, the error in our estimate will decrease and our confidence in it will increase. But how many vines should we sample? The optimum number would be the minimum number required to provide us with an estimate of the mean which we can be sufficiently confident will be within an allowable error range. Fortunately, statisticians have described methods for defining optimum sampling intensity, but to use them we need to quantify the variability within the block, the range of error either side of the true mean which we will tolerate and how confident we want to be that we are right.

Variability

Consider the following sets of harvest weights per vine (kg), which were obtained by picking and weighing all the fruit from 20 randomly selected vines in two blocks of Shiraz, one mature (28 years old) and the other young (3 years old).

Individual vine yields (kg) for 20 mature and 20 young vines

Mature vines: 4.63, 6.02, 6.8, 12.38, 13.81, 5.6, 8.67, 3.94, 6.08, 10.1, 5.27, 8.55, 8.95, 10.99, 8.73, 11.04, 9.91, 7.15, 7.59, 7.7.

Young vines: 0, 4.01, 6.12, 2.18, 3.67, 4.26, 2.25, 3.35, 5.6, 0.45, 1.44, 2.88, 3.52, 6.23, 9.87, 8.68, 5.64, 2.84, 1.9, 0.

Clearly the weights per vine vary within each set. The conventional measure of this variability is *Standard Deviation (s)*. Most calculators and computer spreadsheets have standard deviation functions. The variability of the two blocks of Shiraz can be compared using the *Coefficient of Variation (CV)* for each. The *CV* is the ratio of the standard deviation to the mean, expressed as a percentage. These statistics are summarised for each block in Table 4.2.

Table 4.2 Mean harvest weights per vine (kg), standard deviations (kg) and coefficients of variation for two vineyard blocks of Shiraz varying in age.

Statistic	**Mature vines**	**Young vines**
Mean (n=20)	8.20	3.74
Standard deviation	2.63	2.67
Coefficient of Variation	32%	71%

As one might expect, the mean weight of fruit per vine is lower in the younger block. Also, the *CV*s show that yields from individual young vines are more variable than yields from the mature vines.

Error

The amount of error we will tolerate can be quantified as a *percentage error (PE)* either side of the mean.

Confidence

Confidence may be defined as the probability that we are right and will be referred to as a percentage. If we say that we are 95% confident, it means that on average, with repeated estimations, we will be right 19 times out of 20. The formula for the calculation of the optimum number of vines to sample requires us to specify a quantity which statisticians call t. Precise values of t are used to make fine distinctions in research, but for our purposes it is sufficient to assume approximate t values, which are related to confidence in Table 4.3

Table 4.3 The relationship between approximate t values (to be used to calculate optimum sample size) and confidence.

t	Confidence
1	70%
2	95%
3	99%

Typically, a 95% confidence level is considered to be adequate for most applications.

Defining sampling intensity

The optimum number of vines to sample per block *(n)* can be calculated using the formula :

$$n = \frac{t^2 CV^2}{PE^2} \qquad \text{(Equation 1)}$$

where *t, CV* and *PE* are as defined above (Wolpert and Vilas, 1992).

Equation 1 is valuable because it allows us to understand the relationship between the specifications which we define for crop forecasting and the resources that will be needed to achieve those specifications in a given block of vines. It provides us with an objective and rational basis for designing a sampling procedure. It compels us to accept that, on the one hand, if we want a reliable estimate we will need to sample a minimum number of vines, and on the other hand, if the number of vines we are prepared to sample is limited by a budget there will be limits to the reliability of the estimate.

Field studies have shown that CVs typically range from 30 to 50% for inflorescences per vine or segment (Clingelefffer 2001). If you are looking for a high degree of accuracy you cannot tolerate as much doubt (PE). With a low tolerance of doubt such as 5% at low levels of variation (e.g.20%) your best sample size would be approaching 60. However, at more usual levels of variation (e.g. 40%) you would need hundreds of measurements. If you relax your tolerance of doubt to around 15% the best sample sizes are lower. Once again the spreadsheet or program referred to will easily allow you to do this for you at any tolerance of doubt you select. Based on a PE of 15% and for typical CVs, the authors advocate starting by counting 30 vines or vine segments per patch and then using the spreadsheet or software to determine whether sampling has been adequate.

Importantly variation in inflorescences per vine or vine segment is not a function of patch size (Figure 4.6).

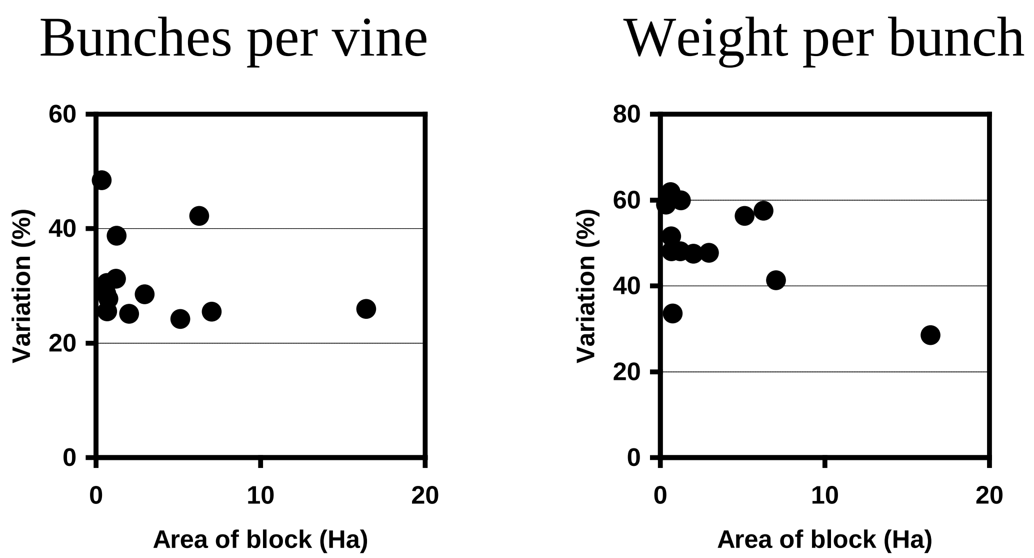


Figure 4.6 The effect of block (patch) size on coefficients of variation (CV) for bunches per vine and weight per bunch at harvest.

Sampling Units

In many cases it is not always necessary to sample whole vines or panels for bunch number counts. Research has shown that for most vine management systems used in Australia a segment (or slice) of the vine will suffice (Figure 4.5). This will reduce time spent counting and also reduce counting fatigue with smaller numbers being collected. Guidelines for optimal segment lengths are given in Table 4.4 below.

Table 4.4 Advised segment lengths for bunch counting a range of vine management 'types'

Situation	Advisable segment length (m)
Young vines	Whole vine
Cane-pruned vines with low bunch densities	0.9 – 1.2 m
Most spur and cane pruned vines	0.6 m
Minimally and mechanically pruned vines	0.3 m

However, if using segments it is important to ensure that they are also randomly placed to avoid the bias of always selecting higher or lower yielding sections of the vine. Again, the spreadsheet and software allow this to be easily done.

PREDICTING BUNCH WEIGHT AT HARVEST

The major limitation to the accuracy of forecasts based on inflorescence counts prior to fruit set is the prediction of bunch weight at harvest. This is not surprising given that the size of the bunch (number of berries) typically contributes about 30% toward season-to-season variation in vine yield

(Clingeleffer 2001). The weight of the bunch at harvest is a function of the average number of flowers per inflorescence, how many of these set and how large the berries will be at harvest.

Flower number is an important measure of potential bunch size and one method that can be used to assess potential bunch size after budburst is to count flowers on inflorescences. Even though it may not be necessary to count all the flowers on a bunch (May 1987), the process is labour intensive and impractical for most growers. There are reports of good correlations between inflorescence length, dry weight, and flower number. Although these will be valid within a population of inflorescences in any given year, they are time consuming to obtain and unlikely to be useful in another season, for another variety or at another site. During the early stages of inflorescence development the rachis (the main axis of the inflorescence) may be elongating rapidly, making it difficult to determine an appropriate sampling date. Also, across any given vine, shoots may burst over a 2 to 4 week period, and the inflorescences on them develop at different rates under a complex set of environmental influences and plant factors that can vary markedly from one year to the next. Thus, it is not possible to produce a reliable set of generic relationships between bunch weight and these dynamic measurements that would remain stable from one season to the next.

Most often bunch weight at harvest will be predicted using an historical average. It is important that this historical average is robust being gained from correct sampling practices (see Chapter 5).

USE OF REMOTE SENSING

All other things being equal larger, more vigorous vines yield more than smaller, less vigorous vines. Methods exist for stratifying patches of vines into vigour zones (CRCV report). Thus, it may be possible to improve the efficiency of and accuracy of sampling theory by using the vigour zones, to either direct a more proportional sampling regime or to reduce sampling intensity inside each zone. Studies have not yet been conducted to determine the practical implications of using these approaches, e.g. is the extra work required justified by a better or more efficient estimate of inflorescences in the patch of vines.

POLLEN COUNTS

Researchers have shown that pollen counts are a good prediction of regional wine yields (Cuhna et al. 2003). Aerial pollen counts integrate the amount of pollen (flower numbers) with conditions during flowering. Thus, when flower numbers are high and conditions during flowering are favourable and lead to widespread release of pollen, pollen counts are higher. However, at the moment it is not a useful technique for forecasting yield for individual patches of vines or even varietal yields from within a region.

CHAPTER 5 POST FRUIT SET YIELD FORECASTING

INTRODUCTION

Many wineries base their intake planning on forecasts provided by growers about a month or two before harvest. By this time, fruit set is complete, and there is an opportunity to use the measure of berries per bunch to improve the prediction of bunch weight at harvest. A lot of berries fall off in the first few weeks after flowering, so bunches are not usually collected and berries not counted until at least a month after flowering. Although they can be counted at any time until harvest, the timing will be governed by the need to meet winery deadlines. If correct procedures are used one can expect an accuracy of around +/- 15 - 20% (mean absolute difference). This chapter describes best practice yield forecasting based on berry counts after fruit set, including a discussion on how to minimise the time required to make these forecasts.

WHEN TO MAKE A FORECAST

Experience has shown that the earliest time to count berries is about 4 weeks after fruit set (Clingeleffer 2001), when berries are 'pea-sized' (Figure 5.1). This allows for the berries that fall off in the weeks following fruit set.

Figure 5.1 Pea sized grape berries.

USING THE CORRECT FORMULA

For post-set berry counts the formula for calculating the amount of fruit that makes its way from the vineyard to the winery is:

Vines (or vine segments)/patch

x

bunches/vine (or vine segment)

x

berries/bunch

x

berry weight (at harvest)

x

harvest efficiency

=

Yield/patch

Vines or vine segments per patch is known. Bunches per vine (or vine segment) can be used from an earlier inflorescence count forecast. However, if no inflorescence count forecast has been made then bunches per vine (or vine segment) will need to be estimated in the same way that an inflorescence count forecast is made and taking into account the same considerations (see Chapter 4). Berries per bunch will be estimated from a sub sample of bunches and weight per berry will need to be predicted.

SAMPLING CONSIDERATIONS

The range of typical coefficients of variation show that a sample of sixty bunches is usually adequate for estimating berries per bunch at a 95% confidence level and percentage error of 10% (Clingeleffer 2001). After counting berries per bunch and entering the data it is easy to use software to determine whether the sampling has been adequate (forecaster version 7, http://www.gwrdc.com.au) or purpose built crop forecasting software (http://www.fairport.com.au/index.asp).

Selecting bunches in the vineyard

Because we are estimating an average number of berries per bunch from a population of bunches across the vineyard, it is important that sampling is random and representative. A bunch is defined as a stalk with one or more berries on it (see section 4.6). This definition is used because it allows the true mean of the population to be estimated, is consistent and removes any subjectivity. It is very important not to overlook small bunches.

Random sampling means that sampling locations are randomly selected before entering the vineyard. The aforementioned software selects random locations (vines or vine spaces) within vineyard blocks and random sampling positions at these locations.

Because the variation in bunch size is much greater within a vine than from vine to vine, it is more efficient to sample a greater number of bunches (say 6) from fewer locations (say 10) than it is to sample each bunch from a separate location (60 individual sampling locations). To select six bunches from the one location, locate the randomly selected vine and sampling position, identify the nearest bunch (Figure 5.2) and then select it and the next 5 bunches in one direction. This procedure forces you to take the next five closest bunches and ensures that smaller and larger bunches are not overlooked.

Figure 5.2 Select the bunch that has the base of its stalk nearest to the imaginary line or plane at a randomly selected sampling position (designated by the star) within a randomly selected vine. When removing bunches snip or pinch them off at the base of the stalk.

Removing bunches

It is best to remove bunches and count berries back in the shed, laboratory or office. When removing bunches snip or pinch them off at the base of the stalk. Bunches in plastic bags may ‘cook’ in direct sunlight so it is best to keep them shaded and cool, using an esky if necessary. Bunches in sealed bags can be stored in a refrigerator for a week or two. If they need to be stored for longer periods, they can be frozen.

Counting berries

There can be up to three types of berries on any bunch (Figure 5.3). These are normal berries (‘hens’), smaller ‘chickens’, which at veraison are about 3 to 4 mm diameter and average about 0.2 g. They usually do not have a viable seed and stay green for longer and ‘shot’ berries (or hard green ovaries), which have a diameter of about 1 mm and are tiny, green and hard. ‘Shot’ berries and 'chickens' tend to fall off before harvest, so they shouldn't be counted.

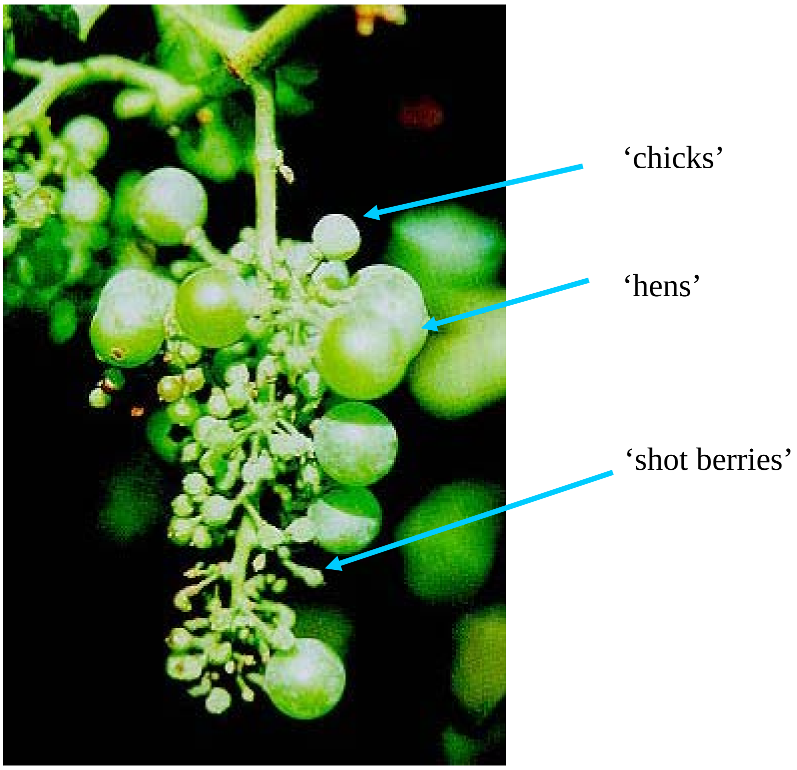


Figure 5.3 A bunch post fruit set showing normal berries (hens), smaller berries (chickens) and 'shot' berries (live green ovaries).

Estimating bunch weight

Mechanised harvesting tends to remove only berries so the bunch stems (rachises) are left behind. Thus, an estimate of bunch weight can be got by simply multiplying the average number of berries per bunch by a prediction of berry weight at harvest, usually around 1g depending on the cultivar and trellising type.

Hand harvested fruit includes the rachis which is about 5% of final bunch weight so the estimate of bunch weight will need to incorporate this extra weight

A REVISED METHOD FOR ESTIMATING HARVEST BUNCH SIZE

Counting all the berries on many bunches is both time consuming and tedious and a barrier to adoption of measurement based forecasting, so here we propose a revised, rapid method. The method is based on the knowledge that around 60 bunches are required to estimate average bunch weight but only 100 berries are needed to estimate average berry weight at a 95% confidence level and percentage error of 10% (Clingeleffer 2001). Theoretically, if a representative and random sample of around 100 berries could be collected from 60 bunches, then both average berry weight and average bunch weight could be relatively quickly estimated and then used to predict bunch weight at harvest. Thus, the following method is proposed.

Collect the 60 bunches in the field and weigh these to estimate post-set bunch weight ($BuWt_1$). From 10 of these bunches remove 20 berries starting at the base. This sub sample from the base of the bunch should be reasonably representative of the whole bunch (Petrie pers. comm., Sanchez pers. comm.). The 200 berries collected should provide an acceptable estimate of average post-set berry weight ($BeWt_1$). It may be beneficial to use a counting frame (Figure 5.4). The rachis weight a month after set is around 15% of the bunch (Trought pers. comm.) and this drops to about 5% at harvest, indicating that the rachis gains little weight between the post set period and harvest

(Huglin and Schneider 1998; Ribéreau-Gayon et al. 1998). We can then use a prediction of berry weight at harvest to predict bunch weight at harvest, if we assume berry weight at harvest ($BeWt_h$) is predictable and relatively stable from one season to the next.

Figure 5.4 A counting frame used to count 100 berries

For mechanised harvesting the rachises are generally left on the vine so the weight of the berries per bunch post set is ($BuWt_1$ x 0.85) and the weight of the berries per bunch at harvest can be predicted as follows:

$$\mathbf{BuWt_h \text{ (berries only)} = (BuWt_1 \times 0.85) \times (BeWt_h)/(BeWt_1)}$$

For hand harvested system you will need to incorporate the weight of the rachis:

$$BuWt_h \text{ (whole bunch)} = (BuWt_1 \times 0.85) \times (BeWt_h)/(BeWt_1) + (BuWt_1 \times 0.15)$$

VERAISON BUNCH WEIGHT PREDICTIONS

The berry growth curve is double sigmoidal in nature and Figure 5.5 shows actual bunch weight gain curves for two cultivars. It has been proposed that these curves can be used to predict bunch weight at harvest. Simply put, a measurement of weight/bunch at the onset of veraison can be multiplied by a factor (e.g. 1.8 for Cabernet Franc and 1.6 for Cabernet Sauvignon) to predict final bunch weight. The onset of veraison is the time when the first berries begin to soften and colour prior to the rapid importation of sugar. At this stage most of the berries won’t have reached veraison and will be growing more slowly than at earlier or later stages. This is a good time to measure because it is repeatable from year to year and any variation in timing will have less impact on the measurement.

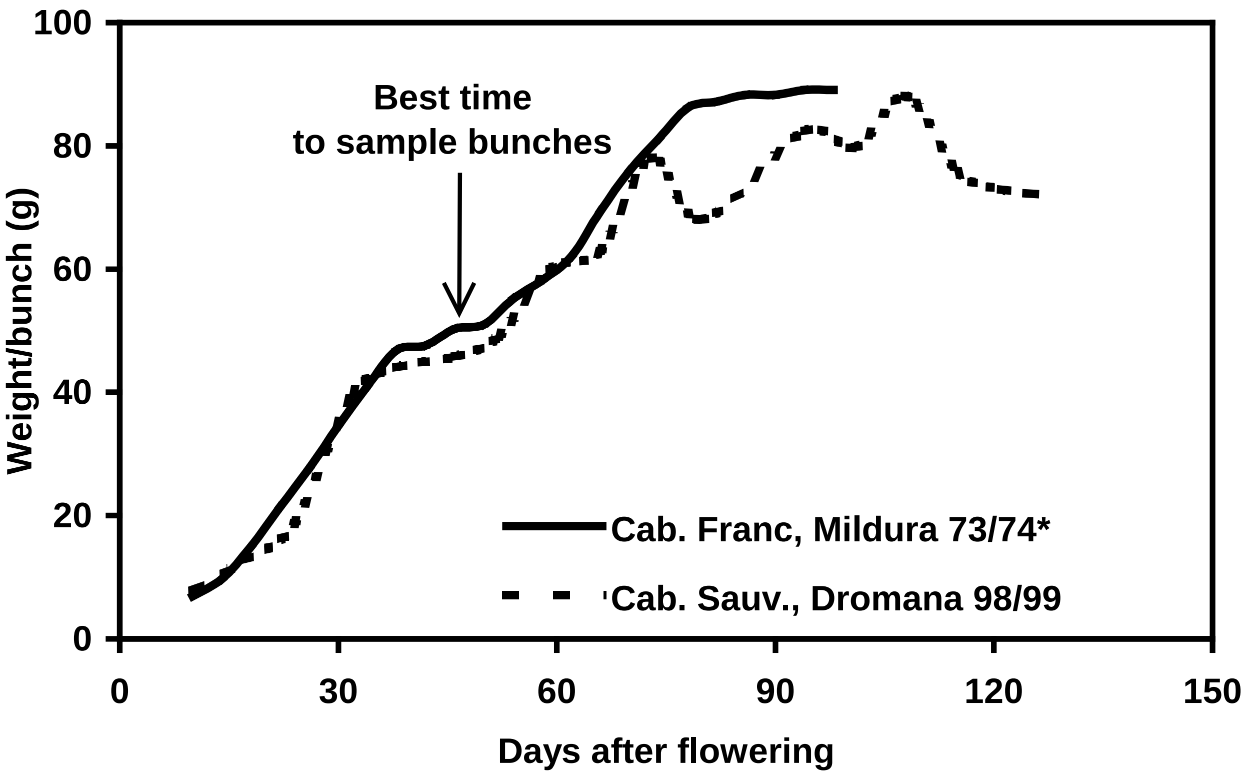


Figure 5.5 Bunch growth curves for Cabernet Franc and Cabernet Sauvignon. The arrow represents veraison.

However, studies have shown that the factor can vary considerable between cultivars and within cultivars from one season to the next (Table 5.1). The technique is not stable enough to reliably predict bunch weight at harvest.

Table 5.1 Bunch weight gain factors for nine *Vitis vinifera* cultivars across two seasons and across regions.

	Veraison to harvest weight gain ± SE	
Cultivar (across regions)	**2007**	**2008**
Cabernet Sauvignon	1.29 ± 0.07	1.47 ± 0.12
Chardonnay	1.47 ± 0.10	1.39 ± 0.08
Sauvignon Blanc	1.69 ± 0.00	1.88 ± 0.10
Merlot	1.52 ± 0.09	1.26 ± 0.08

Shiraz	1.42 ± 0.13	0.96 ± 0.14
Pinot Noir	1.78	1.57 ± 0.14
White Zinfandel	1.66 ± 0.00	1.24 ± 0.05
Sultana	1.82 ± 0.17	1.57 ± 0.26
Fiesta	2.22 ± 0.02	2.30 ± 0.11

OTHER BUNCH WEIGHT PREDICTORS

Using a similar approach to veraison bunch weight prediction, bunch weight predictions based on the relationship between bunch weight gain and the accumulation of growing degree days have been studied (Dokoozlian pers. comm.). However, the relationships are costly to obtain and not stable across cultivars or regions (Dokoozlian pers. comm.).

CHAPTER 6 YIELD FORECASTING NEAR TO HARVEST

FORECASTING IMMEDIATELY PRIOR TO HARVEST

A forecast a week to a few days before harvest can be very accurate and valuable to both the winery and the vineyard for harvest and intake planning. During the week before harvest there is usually very little change in the weight of the crop, so we can use the following formula to make a forecast:

Segments/patch

x

Weight/segment

x

harvest efficiency

=

Yield/patch

As at earlier stages, we still need to predict a harvest efficiency factor, but the accuracy of a forecast made at this time will be almost entirely dependent on how well we sample to estimate a mean weight per segment. Segment lengths for different vineyard situations can be found in Table 4.4.

There are two methods that you can use to estimate weight/segment:

1. Calculate weight/segment indirectly from data collected in the course of routine sampling of bunches near harvest, using the following formula:

Bunches/segment

x

Weight/bunch

=

Weight/segment

Bunches per segment (or vine) can be got from an earlier inflorescence or bunch count.

2. Pick all the fruit from a sample of segments and calculate weight/segment directly.

Figure 6.1 Picking segments close to harvest to estimate yield

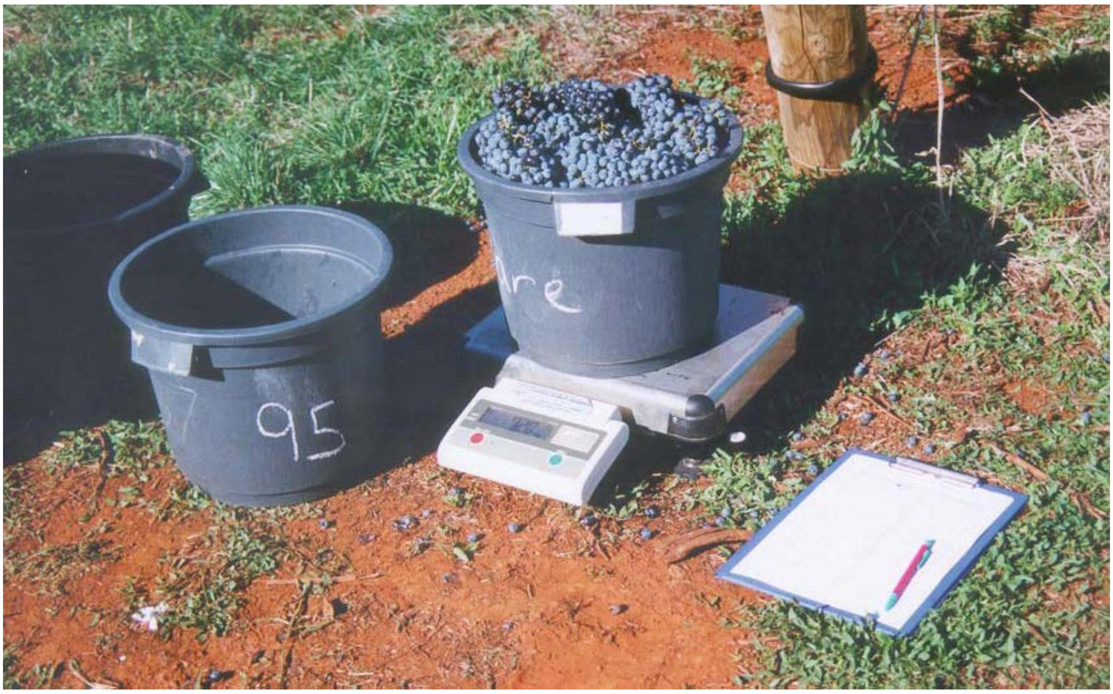


Figure 6.2 Field scales being used in the course of segment picking to estimate yield near to harvest.

The ‘harvest sampling’ method provides less reliable forecasts, but it is quicker, cheaper and makes use of information that should be collected as part of an earlier forecast. The ‘segment picking’ method produces more accurate forecasts. If bunches are counted while harvesting segments then a very accurate weight/bunch can be estimated by dividing weight/segment by bunches/segment, and this estimate of weight/bunch is more reliable than the estimate obtained from bunch samples. However, picking can be relatively slow and the fruit must be stored, added to a harvest in progress, used for some other purpose or discarded. Advantages and disadvantages of the two methods can be found in table 6.1.

Table 6.1 Advantages and disadvantages of two methods to forecast yield near to harvest.

Method	**Advantages**	**Disadvantages**
Harvest sampling	• Quicker • Cheaper • Uses data previously collected	• Forecast is less reliable • Estimates of bunches/segment and weight/bunch less accurate
Segment picking	• Forecast is more reliable • Estimates of bunches/segment and weight/bunch more accurate	• Slower • More expensive • Fruit disposal

COLLECTION OF DATA AT HARVEST TO IMPROVE FORECASTING

It is Important to collect data at harvest to understand where a forecast can be improved and to build up a history of yield components. However, harvest is an extremely busy time and it can be time consuming to collect this information. Fortunately, there is much fruit collected at harvest. The issue is to ensure that sampling for yield components at harvest is random. Fruit can be collected and frozen for later analysis.

CHAPTER 7 GENERAL CONCLUSIONS

There is a strong demand for improved crop forecasting in the wine industry. Lately this demand has intensified as major producers and purchasers of grapes are increasingly stipulating that particular yield targets should be met, in the belief that this will improve and maintain wine quality. Accurate crop forecasting is an essential first step to successful yield regulation.

This book has described best practice yield forecasting made at 4 different stages throughout the season viz. during dormancy, during spring, after fruit set and close to harvest. Obviously, as the season progresses and more yield components are ‘set’ and environmental conditions play their part the more accurate the forecast becomes.

However, irrespective of when the forecast is made there are number of factors that need to be adhered to:

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

Software that facilitates simple, rapid random sampling, the calculation of variability and the assessment and subsequent improvement of forecasting performance is now available and should be used to aid objective measurement based forecasting

However, some general issues continue to impede the adoption of better forecasting systems and these can be summarised as follows:

- The time required and costs involved to collect data are potential barriers to adoption.
- There is a lack of information for growers on the cost/benefits of improved forecasting.
- There is a lack of incentive for growers to ‘get their forecasts right’.
- There is often a lack of support from wineries for better forecasting and there may be a lack of technical support for ‘better systems’ and software.

Future RD&E should focus on facilitating relationship changes and developing simpler and quicker technology to promote more rapid uptake of objective crop forecasting systems.

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