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THE EFFECTS OF ROW ORIENTATION, TRELLIS TYPE, SHOOT
AND BUNCH POSITION ON THE VARIABILITY OF SAUVIGNON
BLANC (*Vitis vinifera* L.) JUICE COMPOSITION.

A thesis

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ABSTRACT

Grape composition is important in determining the flavour and aroma characteristics of the resultant wine. Samples of the juice composition are described by their average value, yet the variability in fruit composition around the mean may also have a large impact on wine quality. The objective of this study was to identify the variance contribution of row orientation and trellis type within the vineyard, and bunch and shoot position within the vine.

For two years primary and secondary bunches were sampled from basal, mid-cane and apical shoots of five year old Sauvignon blanc vines on the Wairau Plains of Marlborough, New Zealand (41° 29' south, 173° 54' East). Vines were trained on either the Scott-Henry (S-H) or vertically shoot positioned (VSP) trellis and located in either east/west (E/W) or north/south (N/S) oriented rows.

The bunch position contributed 30% to 50 % to juice composition variance in 1999 and 50 % to 90 % in 2000. Whilst trellis type and row orientation contributed 42%, 50% and 40% to the brix, TA and pH variance respectively in 1999, they contributed only 26%, 16% and 4% in 2000. This was attributed to a change in canopy management which increased the fruit and leaf exposure, therefore reducing the effects of trellis and row orientation on juice composition variance. Despite bunch position accounting for most of the data variance in 2000, differences between apical and basal shoots were the largest single differences in brix (0.9°), TA (0.9 g/L) and pH (0.07). The least mature bunches on the vine were secondary bunches on basal shoots regardless of trellis type or year. They were from 1.3° - 2.2° brix lower, and 1.0 - 2.7 g/L TA higher than primary bunches on mid cane or apical shoots.

In the first year of the trial differences in fruit exposure caused maturity differences between trellis types. Fruit exposure levels were improved in the second year, and maturity differences were similar to differences in phenology at flowering. The phenology of apical shoots was advanced by 2 to 3 days compared to basal shoots in both years, whilst primary bunches were advanced 1 to 2 days relative to secondary

bunches. Variation in the leaf area or leaf area:fruit weight ratio of shoots was not correlated to variation in berry weight or soluble solids. This was probably because of low vine crop loads and remobilisation of carbohydrate reserves.

The results indicated that to reduce variability in the grape crop the viticulturist must promote uniform fruit exposure and try to reduce phenological differences between shoot positions. Further study should consider the relationship between vine crop load and the leaf area or leaf area:fruit weight ratio of individual shoots on the vine. A better understanding of how light exposure on the fruit and leaves contributes to the weighted average juice composition of a vine would also be useful. Whilst the effects of variable fruit exposure on the variance of the data were not clear, biologically significant differences in maturity were not reflected in the data variance, so this line of research is of less concern to the viticulturist / wine maker.

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1.0 INTRODUCTION

Grape composition is important in determining the flavour and aroma characteristics of the resultant wine. Simple chemical analyses of juice composition samples are commonly used to identify optimum harvest date, or describe the relationship between fruit composition and wine style. Although these samples are described by their average value, it seems that the variability in fruit composition around the mean may have as large an impact on wine quality and style as the mean itself (Long, 1987; Trought, 1996).

Where fruit has been sorted in some way (usually by density gradient), wine quality often reaches an optimum at a soluble solids generally considered lower than those desirable for commercial harvest (Singleton, 1966). The implication is that commercial harvest is delayed until most, or all, of the fruit has reached an acceptable composition standard, even if this means that some fruit might be considered overripe.

Sources of this variability in juice composition may be a reflection of:

- berry to berry
- bunch to bunch
- or vine to vine variability

Despite the extensive literature on the impact of vineyard management on fruit composition, little has been reported on the variability of fruit composition around the mean value. The objective of this study was to investigate the bunch to bunch differences in fruit composition of Sauvignon blanc within individual vines, and the extent to which some commonly used vineyard practices influenced the variability.

2.0 LITERATURE REVIEW

2.1 Grape Berry development.

The grape berry develops in three stages from anthesis to maturity (Coombe 1992) (Figure 2.1). During stage I the increase in berry size is due to growth of the seed and berry tissue through cell division. The embryo develops and the seed hardens in stage II, but there is little increase in overall berry size. The beginning of stage III is referred to as véraison, the beginning of ripening. The increase in berry size during stage III is due to an increase in cell volume (Mullins *et al.*, 1992).

The date of anthesis of individual flowers varies between and within inflorescences (May, 1988). These differences at the start of berry development may account for much of the variation in the véraison date between berries within a bunch, and within a vineyard (Coombe, 1992). A reduction in the light exposure and temperature of the fruit and leaves increases the duration of stage I and II (Alleweldt *et al.*, 1984; Dokoozlian and Kliewer, 1996), delaying the date of véraison. Within the grape canopy, variable light and temperature levels could be expected to promote differences in the duration of stages I and II between berries within a bunch and bunches within a vine.

2.2 Grape Juice composition

The flavour and aroma of wine originates in part from the grape skins where high concentrations of pigments and flavour compounds are found. The grape juice containing sugars and acids also affects the flavour. There are many factors which determine the juice composition though, and these act either directly or indirectly through other factors (Figure 2.2). They include the soil type, cultivar, macro- and meso-climate, and the micro-climate created by canopy management practices (Jackson and Lombard, 1993).

Determining the ideal maturity by taste and smell can be subjective as each person has a different perception of the blend of flavour and aroma compounds within the fruit. Objective indicators of maturity can be used though, the most common three are the sugar and acid concentration of the juice, and its pH. Some compounds have been

isolated and related to particular aromas and flavours in the juice and wines (Jackson and Lombard, 1993). The concentrations of these indicators and compounds change throughout the three stages of grape berry development, the largest changes occur during stage III, the period when the berry matures (Coombe, 1992).

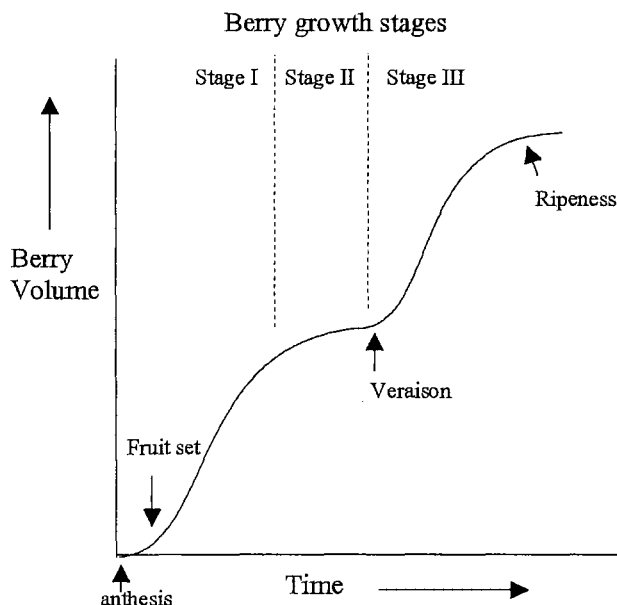


Figure 2.1 The volume curve of a grape berry after anthesis illustrating the three developmental stages referred to above. (From: Coombe, 1992).

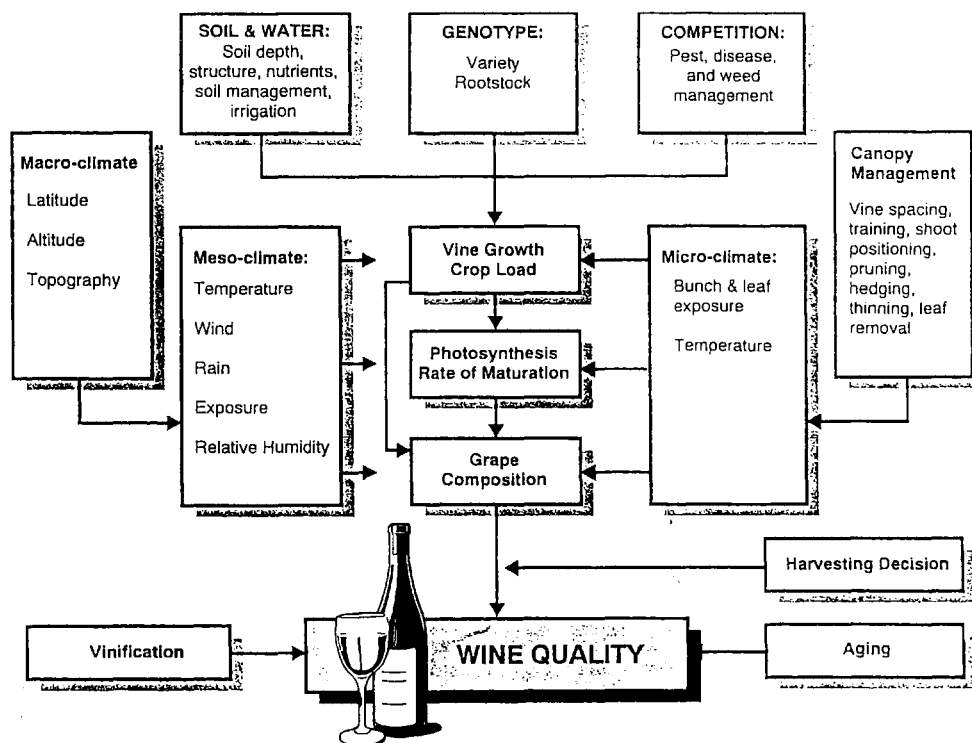


Figure 2.2 : Environmental and viticultural inputs into grape composition and wine quality. (From Jackson and Lombard, 1993).

Many of the reported juice composition results are expressed as concentrations but the berry size is an important factor in interpretation of juice composition (Coombe, 1992). As an example, exposed berries of Cabernet Sauvignon were found to have higher concentrations of malate and tartrate than shaded berries (Crippen and Morrison, 1986). This was contrary to the expected result, and further analysis revealed that berries had the same tartrate and malate content on a per berry basis but as exposed berries were smaller, the concentrations of tartrate and malate were higher.

2.2.1 Juice composition components

The many environmental and viticultural inputs (Figure 2.2), determine the rate of change and the concentration of each component. Although the juice composition components each follow a general trend as maturity advances (Figure 2.3), knowing the level of one component can rarely be used to reliably predict the level of another. To understand how a treatment is effecting maturity it is necessary to measure a number of juice components (Amerine and Ough, 1980).

Each of the components has a different aroma or flavour, and their balance is important to the aroma and flavour of the wine. The concentration of a single compound in a group may be more important than the total group concentration if it has a strong aroma or flavour (Marais, 1996). The monoterpene aroma compounds may also interact with one another to increase the aroma above the level that they could achieve individually (Marais, 1983).

The main components relevant to this study and how they are affected by light and temperature are discussed below.

2.2.1.1 Sugar

Prior to véraison, the soluble solids of fruit is low, but after véraison the fruit softens, it may change colour, and sugars - mainly glucose and fructose - accumulate (Coombe, 1992). The soluble solids is often expressed as a concentration, °brix. Sugars may be derived from leaves (Conradie, 1980), or they can be translocated from the reserves of the vine (Candolfi-Vasconsales *et al.*, 1994; Kliewer and Antcliff, 1970). In general,

Sauvignon blanc is harvested in Marlborough at a mean concentration of between 20 - 24° brix (Hubscher, 1988).

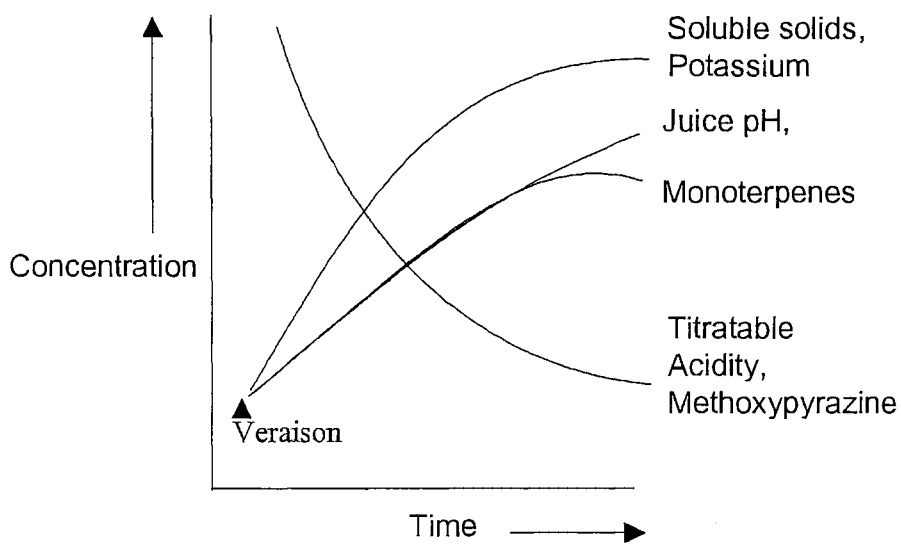


Figure 2.3: The pattern of increase / decrease of various juice composition components between véraison and harvest.

2.2.1.2 Acidity

Malic and tartaric acids account for up to 90 % of the organic acids in grapes (Ruffner, 1982a) and are usually expressed as titratable acidity (TA), in g/l tartaric acid equivalents. Malic and tartaric acids accumulate in the berry up to véraison (Crippen and Morrison, 1986). After véraison, the berry volume increases and oxidation and respiration results in the conversion of malic acid to oxalacetic acid and then to hexose sugars. As a consequence the concentration and amount of malic acid falls (Crippen and Morrison, 1986; Hrazdina *et al.*, 1984; Ruffner 1982b). The rate of decline is largely temperature dependant, the higher the temperature the greater the decline. The concentration of tartaric acid declines slowly after véraison (Hrazdina *et al.*, 1984), largely due to increases in berry volume, as the amount of tartrate per berry remains stable (Crippen and Morrison, 1986). Typical TA values for Marlborough Sauvignon blanc ranged from 9.3 to 12.5 g/l during the 1980's (Hubscher, 1988). The accumulation and decline in malic acid is influenced by light exposure and temperature of the leaves and fruit during all stages of berry development - see section 2.2.2.

2.2.1.3 Juice pH and potassium

The juice pH increases after véraison (Mullins *et al.*, 1992), but does not in itself contribute to flavour. It is a useful indicator of maturity and potential fermentation problems though, as high pH levels (>3.60), can create colour instability in red wines and reduce their ageing potential (Jackson and Lombard, 1993).

The amount of potassium in the juice increases after véraison, and is higher at harvest if leaves are shaded during berry development (Morrison and Noble, 1990). The juice pH is poorly correlated to the potassium content though, because the titratable acidity and malic to tartaric acid ratio also influences pH (Boulton 1980). To avoid false conclusions, a difference in juice pH between treatments needs to be interpreted in relation to the juice TA and cation content, as well as the soluble solids level. An increase in pH does not indicate an increase in maturity if unaccompanied by an increase in soluble solids and a decrease in TA. The juice pH for Marlborough Sauvignon blanc is typically between 3.2 and 3.3 at harvest (Hubscher, 1988).

2.2.1.4 Methoxypyrazine

The distinctive green capsicum / herbaceous aroma of Sauvignon blanc has been related to isobutyl methoxypyrazine (ibMP), (Allen *et al.*, 1991; Lacey *et al.*, 1988). Isobutyl methoxypyrazine has a very low sensory detection threshold (2 ng / l in water), and is present in grape juice and wine at extremely low levels (Lacey *et al.*, 1991). Therefore, detection requires Gas Chromatography / Mass Spectrometry equipment (Allen *et al.*, 1996).

Isobutyl methoxypyrazine is one of three types of alkyl methoxypyrazines which occurs in Sauvignon blanc, along with isopropyl methoxypyrazine, and sec-butyl methoxypyrazine (Allen *et al.*, 1996). The concentrations of isopropyl and sec-butyl methoxypyrazine are typically one tenth of ibMP, and they are of lesser importance to the aroma of the wine (Allen *et al.*, 1996). Although methoxypyrazine levels are relatively high at véraison they decrease quickly after véraison (Allen *et al.*, 1996). The accumulation of ibMP in unripe grapes, and the decrease of ibMP in ripening grapes are both positively correlated to light exposure levels (Hashizume and Samuta, 1999). Leaf removal is effective in reducing the vegetal aroma of Sauvignon blanc juices (Smith *et al.*, 1988), and the increase in light exposure may be causing a greater reduction in ibMP concentration.

The concentration of ibMP is higher in fruit from cool climates, or cool seasons compared to warmer ones, (Lacey *et al.*, 1991). A comparison of New Zealand and Australian Sauvignon blanc wines found that the levels of ibMP in New Zealand wines were higher than in Australian wines (average 24.8 ng/l compared to 6.9 ng/l respectively) (Lacey *et al.*, 1988). From each country, wine with high levels were judged higher for varietal character than those with low levels, and it was suggested that the levels in New Zealand Sauvignon blanc are responsible for the success of the wine style in the market place.

2.2.1.5 Norisoprenoids

The C₁₃ -norisoprenoids have typical and strong fragrant notes (Calo *et al.*, 1996), and can have a strong influence on aroma. They are often present as bound conjugates and

are derived from carotenoids which are present mainly in the skin of developing berries (Razungles *et al.*, 1996). The carotenoids are sensitive to light and increasing light levels on the fruit favours their development up to véraison. After véraison, high light levels on the fruit increase the degradation of carotenoids into norisoprenoids (Calo *et al.*, 1996; Razungles *et al.*, 1996). A similar positive relationship between temperature and carotenoid levels has been described by Marais (1996), suggesting that warmer regions will have higher levels of norisoprenoids.

2.2.1.6 Monoterpenes and flavanols.

Monoterpenes are responsible for the floral and fruity flavour and aroma of Muscat and aromatic grape cultivars, such as Gewurztraminer and Riesling, but Sauvignon blanc has been classified as a cultivar that does not rely on monoterpenes for its flavour and aroma (Williams *et al.*, 1987). It has been suggested that all grapes have the ability to biosynthesise these compounds from precursors though (Strauss *et al.*, 1985), and researchers have extracted monoterpenes from Sauvignon blanc to study the effects of canopy micro-climate on juice composition (Marais *et al.*, 1996; Smith *et al.*, 1988).

In contrast to methoxypyrazine, the concentration of monoterpene compounds generally increases as the berry ripens, decreasing once the berry is over ripe (high brix) (Marias, 1983).

Flavanols are a subgroup of the phenolics extracted from skins and seeds during fermentation, so they are more important in red wines than white wines. Flavanols begin to accumulate in the skins shortly after bloom, reaching high concentrations by véraison (Price *et al.*, 1996). Flavanol synthesis is a response to increasing light on the fruit skin and accumulation is in localised areas. Quercetin is the most common flavanol and is present in the skins as a glycoside preventing UV light from damaging the berry (Price *et al.*, 1996).

2.2.2 Canopy management, the effects of light and temperature.

“Wine is a product of sunlight. Grapevine leaves use sunlight energy to change carbon dioxide into sugars. From the leaves the sugars move to the fruit which, once harvested

and crushed at the winery produce juice as a first step of wine making. Yeast cells convert sugars in the juice into alcohol and the juice is transformed into wine. And so, the close association between sunlight and wine can be seen.” (Smart and Robinson, 1991).

Canopy management is about optimising the exposure of leaves and fruit to sunlight so that they can produce fully ripened and sound fruit. Increasing the sunlight exposure of berries increases their temperature though (Kliewer and Lider, 1968), and changes in juice composition can occur due to both light and temperature increases. Therefore, the effects of light and temperature on fruit composition are difficult to separate.

The changes in juice composition due to increased light or temperature may occur through different components and for different reasons, for example: an increase in light and temperature increases photosynthesis which increases sugar accumulation; an increase in temperature increases enzymatic activity in the berry reducing malic acid concentrations (Ruffner 1982b); or increased light and temperature causes an advance in berry development resulting in more mature fruit. The interpretation of results from canopy manipulation experiments must consider the exposure of both the leaves and the fruit and the pathways by which changes in juice composition can occur.

Increasing the light exposure of berries and leaves through canopy and trellis manipulation can increase the soluble solids concentration (Bledsoe *et al.*, 1988; Reynolds *et al.*, 1986; Smith *et al.*, 1988). This may be due to an increase in enzyme activity as the ratio of red to far red light increases (Smart *et al.*, 1988), which promotes sugar synthesis (Kliewer *et al.*, 1988). Such a hypothesis would explain why bunches from exposed positions have higher soluble solids concentration compared to shaded bunches (Wolpert *et al.*, 1980). Light exposure of the fruit is not the only cause of the soluble solids increase. Leaf shading decreased the soluble solids concentration of Cabernet Sauvignon berries (Morrison and Noble, 1990), and Reynolds *et al.*, (1986) suggested that the leaves of exposed bunches may also have been more exposed. Whichever pathway is responsible, increasing the exposure of fruit and leaves to sunlight increases the soluble solids concentration of the fruit.

Canopy and trellis manipulation that reduces shading also reduces the malic acid content and concentration and hence titratable acidity of grape berries (Bledsoe *et al.*, 1988; Reynolds *et al.*, 1986; Zoecklien *et al.*, 1992). Shading the foliage decreases the rate of malate accumulation in berries pre véraison, but also slows the rate of malate decline post véraison (Morrison and Noble, 1990). This resulted in higher concentrations of malic acid at harvest in berries from shaded canopies compared to exposed ones (Morrison and Noble, 1990; Rojas-Lara and Morrison, 1989). Shading of the berries during development stages I, II and III without shading the canopy, also causes higher malic and tartaric acid concentrations at harvest (Dokoozlian and Kliewer, 1996), and part of this response is due to a delay in véraison date. The reduction of malic acid by increasing fruit exposure may be an indirect effect, as the berry temperature increases with increasing exposure (Kliewer, 1971), and the respiration of malic acid proceeds faster at higher temperatures (Kliewer, 1971; Ruffner, 1982b).

The effects of the canopy micro climate on the juice pH can be variable because of the relationship between the juice pH, TA, and potassium levels (Boulton, 1980). Shaded leaves in the canopy begin to senesce, exporting excess potassium and sugar to the berry (Smart and Robinson, 1991). The increase in berry potassium results in an increase in pH at harvest if the TA remains the same (Boulton, 1980). Leaf removal to increase the light exposure of the fruit zone of Californian Sauvignon blanc resulted in lower TA, pH and juice potassium concentration (Bledsoe *et al.*, 1988; Kliewer *et al.*, 1988). This may indicate that the shaded and senescing interior leaves were causing high pH through excessive juice potassium (Smart, 1985). Leaf removal in the fruit zone of Sauvignon blanc in New Zealand increased the pH in one of three trials and this was consistent with an advance in maturity (Smith *et al.*, 1988). The response of the juice pH to alterations in canopy micro-climate will depend on whether the amount of potassium changes, the titratable acidity changes, or whether both occur.

The concentration of methoxypyrazine and monoterpenes are also affected by the light exposure and temperature of the fruit and canopy. Isobutyl methoxypyrazine is sensitive to light, and concentrations are higher in shaded fruit than exposed fruit (Allen *et al.*,

1996; Marias *et al.*, 1996). Methoxypyrazine may also be sensitive to the increased fruit temperatures though, as the concentration of isobutyl methoxypyrazine is lower in fruit grown in warm climates or warm seasons compared to cold ones (Allen *et al.*, 1996; Marias *et al.*, 1996). It is conceivable that increased light exposure increases berry temperatures which reduces the isobutyl methoxypyrazine concentration. The monoterpenes behave in the opposite way to methoxypyrazine, they are higher in exposed fruit or in warm seasons (Marias *et al.*, 1996). Increasing fruit exposure of Marlborough Sauvignon blanc resulted in less grassy / herbaceous aroma and more ripe tropical fruit aroma and a concomitant increase in PVT and FVT concentrations (Smith *et al.*, 1988).

As well as the effects on the components of juice composition, temperature and light exposure of the fruit and canopy can influence berry size. How an increase in light and temperature will effect the berry size will depend on whether :

- berry growth is limited by source strength (leaf shading);
- berry growth is limited by sink strength (berry shading);
- low fruit turgor pressure limits cell expansion (increased berry temperature).

Leaf shading was found to reduce berry size whereas cluster shading did not (Crippen and Morrison, 1986; Morrison and Noble, 1990; Rojas-Lara and Morrison, 1989), suggesting that source strength was limiting. Dokoozlian and Kliewer (1996) found that cluster shading (complete light exclusion) throughout berry development of Cabernet Sauvignon reduced berry size, which suggested that sink strength was limited. Partially shaded clusters had larger berries compared to exposed fruit, and this was thought to be due to the near optimal temperature of these bunches resulting in low transpiration rates and higher turgor pressure increasing cell expansion (Reynolds *et al.*, 1986). Increased berry temperature may increase the sink strength of the berry though, resulting in higher soluble solids although smaller berry size (Reynolds *et al.*, 1986). If berries are not limited by sink strength, increasing the fruit exposure would not cause an increase in berry size. This may have been the case when the berry size of Sauvignon blanc did not respond to an increase in fruit exposure through leaf removal (Kliewer *et al.*, 1988; Smith *et al.*, 1988).

As the soluble solids and TA are expressed as a concentration, the effects of berry size must be considered when interpreting results. Berries of totally shaded vines had a higher brix compared to vines with their fruit exposed which was unexpected, but it was a reflection of the smaller berries on these vines as the sugar per berry was lower than the exposed fruit (Rojas-Lara and Morrison, 1989).

The canopy micro climate is not a uniform environment and some bunches may be exposed to full sunlight whereas others may be in permanent shade. To increase the amount of fruit exposed to light, growers can alter the trellis system to reduce the amount of canopy shading. The Scott-Henry trellis which vertically divides the canopy is one of these systems (Smart, 1994) (Figure 2.4).

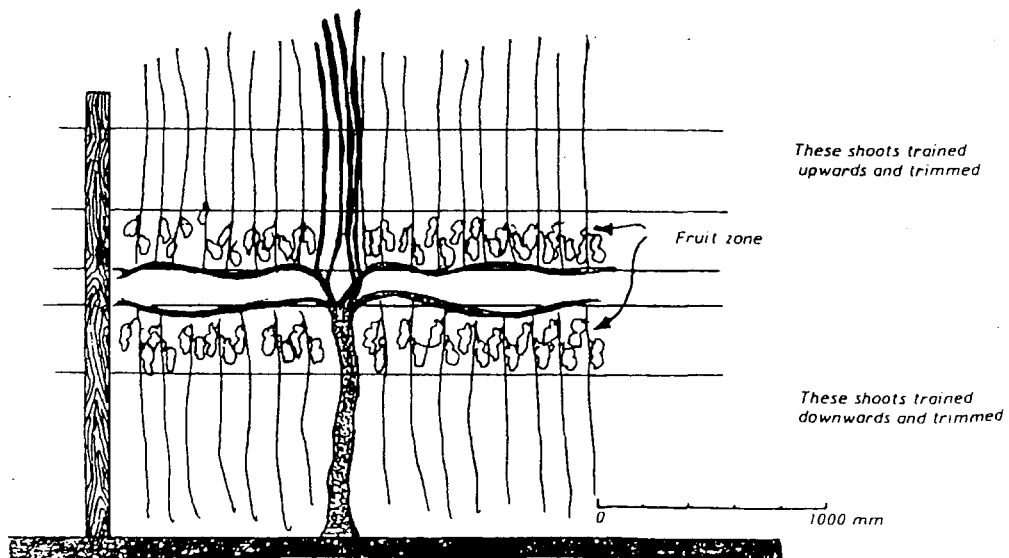


Figure 2.4. : The shoot orientation of a grape vine trained to the Scott-Henry trellis system. (From: Smart and Sharp, 1989). On a Vertically Shoot Positioned trellis the shoots growing downwards in the diagram would be trained upwards instead.

2.3 Row orientation and trellis type

The grape grower is able to influence fruit exposure through the choice of row orientation and trellis type. Each of these is difficult to alter once the vineyard is established, but they can affect the juice composition. East / west row orientation resulted in differences in Sauvignon blanc juice composition within the canopy (Smith *et al.*, 1988), and Naylor *et al.*, (2000) found these differences to be larger than in north / south oriented rows. Although the fruit and leaf exposure to light have a significant role in these differences, other reasons may also exist.

2.3.1 Row orientation

Row orientation will affect the light interception by the fruit and leaves. DeJong and Doyle (1985), found that light distribution on the sides of peach rows orientated N/S was more even than rows orientated E/W, even though total light levels received were similar. Naylor *et al.*, (2000) reported that significantly less light reached fruit on the shaded side of E/W rows compared to the exposed side. Zuffery and Murisier (1997), reported even light distribution between the east and west side of N/S rows whereas the most important light interception of E/W rows was on the exposed side of the canopy.

Despite these light interception differences, the maturity and quality of pears, or the juice composition of grapes is reported to be similar between E/W and N/S row orientations (Intrieri *et al.*, 1996; Lombard and Westwood, 1977; Naylor *et al.*, 2000). Reductions in brix and increases in titratable acidity have been reported in Sauvignon blanc grapes from the shaded side of a canopy compared to the exposed side though, suggesting a delay in maturity (Naylor *et al.*, 2000; Smith *et al.*, 1988). The differences in juice composition between the opposite sides of N/S oriented rows were not as great as those in E/W rows (Naylor *et al.*, 2000).

2.3.2 Trellis type

Canopy shading is generally believed to have a detrimental impact on fruit composition and wine quality. Many viticultural practises, including selecting the correct trellis or shoot training system are intended to improve the canopy micro-climate and light interception by the fruit.

In an early pioneering piece of research, the benefits of using canopy division to increase light exposure were shown with increases in yield matched by improvement in fruit maturity as well (Shaulis *et al.*, 1966). Divided trellis systems that increased fruit exposure such as Geneva double curtain and Scott-Henry trellis, increased flavanol levels in grapes compared to vertical shoot positioning (Price *et al.*, 1996). These two canopy types require the downward orientation of shoots.

Shoots that are oriented downwards have exhibited lower growth rates and reduced leaf area compared to upward oriented shoots (Kliewer *et al.*, 1989; Lovisolo and Schubert, 2000). The downward and upward shoots used by Lovisolo and Schubert (2000), were up to 2.88 m and 4.05 m long respectively. Even when shoot length was limited by trimming (Kliewer *et al.*, 1989), the leaf area of the downward trained shoots was lower than that of upward trained shoots. Lovisolo and Schubert (2000), also found that the stomatal conductance of leaves on downward shoots was less than upward shoots. They suggested that the carbon fixing capacity per unit leaf area would be reduced by this.

Kliewer *et al.*, (1989), reported a reduction in the period from bud break to bloom of 2.3 days when shoots were oriented downwards from bud break. Despite this, the authors suggested that training shoots downwards at flowering, as in the Geneva Double Curtain or Scott-Henry trellis, would not affect fruit development but could reduce shoot vigour.

2.4 Variability

The variability in the crop is a reflection of the differences between vines, between bunches and between berries (Trought, 1996). Row orientation and trellis type differences will alter the light exposure of the bunches causing between vine variation. They may also change the amount of light exposure within the individual vine, causing between bunch variability. As well as fruit exposure to light (Wolpert *et al.* 1980), the variability between bunches may be caused by different bunch positions on a shoot (Wolpert *et al.*, 1980, Trought, 1996), and differences in shoot length and leaf area (Kliewer *et al.* 1989). The variability in composition between berries within a bunch may be caused by the order in which each flower within an inflorescence reaches

anthesis (May, 1988), or by the varying degrees of fruit exposure to light and temperature within a bunch (Kliewer and Lider, 1968).

Over the past decade considerable effort has gone into improving the canopy micro-climate in New Zealand vineyards in an effort to increase fruit quality. These efforts involved leaf removal and / or changes in trellis system and shoot orientation to reduce canopy shade and increase fruit exposure. Whilst these changes have resulted in increases in soluble solids and reductions in TA, they may also increase variability within and between bunches.

2.4.1 Effects of variable juice composition

The maturity of a grape crop can be estimated from a sample of berries or clusters (Kasimatis and Vilas, 1985), and the decision to harvest the fruit is often based on the juice composition of such a sample. The sampling procedure must be robust enough to offer a true estimate of the average maturity as the composition of the crop is variable (Kasimatis and Vilas, 1985; Wolpert *et al.*, 1980). But obtaining a reliable estimate of the average crop maturity is only one part of assessing the suitability of the crop for harvest. The composite sample from the whole crop gives no indication of the degree of variability around the average, yet an increase in the variability around the average value was reported to reduce the quality of wine made from Cabernet Sauvignon grapes (Long, 1987). By grading the fruit to reduce the variability of a grape sample, the optimum wine quality was achieved at an earlier harvest date than the commercial one (Singleton *et al.*, 1966).

These findings have commercial application. If a more uniform crop may be harvested earlier, then in a cool climate that may reduce the risk of damage from early autumn frosts. More importantly, an increase in crop uniformity can lead to wines closer to a specified composition. This allows the wine maker to blend wines to a specification using wines that each have their own specific composition.

2.4.2 Sources of variability between bunches

The development of the berry, and the shoot on which it is borne is the main determinant of grape composition and hence wine quality according to Coombe and Iland (1987). The interactions of berry and shoot development with the effects of variety, site, canopy, micro climate, crop load and soil related factors, determines the juice composition (Figure 2.2).

2.4.2.1 Shoot development

Shoot and berry development begins at bud burst, when a uniform early bud burst maximises yield and advances maturity (Nir *et al.*, 1988). However bud burst is variable between bud positions. It was reported that Thompson Seedless grapes took over 30 days for all buds to burst (Antcliff and Webster, 1955). The date of bud burst was also influenced by bud position on the cane, which occurred earliest at the apical end (Antcliff and Webster, 1955). Kliewer *et al.* (1989), found that early developing shoots grew faster than later shoots, and this increases the competition between shoots (May, 1988; Nir *et al.*, 1988). Attempts to increase the percentage bud burst of grapes results in increases in uniformity of bud burst (Nir *et al.*, 1988; Zelleke and Kliewer, 1989), but the effects it has on uniformity of berry development or juice composition at harvest is not reported.

The inflorescences of earlier apical shoots begin anthesis before those of the later basal shoots (May, 1988). Such an advance in berry development at the beginning of the season has been found to continue until véraison (Alleweldt *et al.*, 1984), and harvest (Martin and Dunn, 2000). If, as Coombe suggests (1992), véraison date determines the harvest date, then a link between earlier anthesis and earlier maturity of a bunch could be expected.

Kliewer *et al.* (1989), found that leaves on shoots that burst early were larger than late bursting shoots, which resulted in a greater leaf area on these shoots. Although a positive relationship between leaf area of the grape vine and soluble solids concentration has been demonstrated (Kaps and Cahoon, 1992; Kliewer and Weaver, 1971), the

effects of individual shoot vigour on bunch soluble solids content is minimal (Kliewer and Antcliff, 1970; Trought, 1996).

2.4.2.2 Crop load

The ratio of leaf area to fruit weight is a measure of crop load (Bravdo *et al.*, 1984). A low leaf area to fruit ratio (high crop load) reduces the ability of grapevines to accumulate storage reserves of carbohydrate (Bennet *et al.*, 2000; Edson *et al.*, 1993). Such a reduction in carbohydrate reserves of the shoots reduces the percent bud burst in the following season (Hopping, 1977). Bennet *et al.*, (2000) found that a reduction in root carbohydrate concentration was positively correlated to a reduction in the inflorescence number per shoot and the flower number per inflorescence in the following season. However the effects of crop load on the variability of bud burst and shoot development in the following season are not reported. It has been suggested though, that variability in composition is increased if vines are not balance pruned (Wolpert *et al.*, 1980), and high crop loads were reported to delay the fruit maturation and reduce the wine quality of Cabernet Sauvignon grapes (Bravdo *et al.*, 1984),

When potted Pinot noir grapevines had their leaves removed to alter leaf area to fruit weight ratios, an excess of maturing fruit (high photosynthate demand), or an inadequate leaf area (low photosynthate supply), prevented a decline in the net photosynthetic rate of shoots as the leaves aged (Petrie *et al.*, 2000b). However véraison was delayed on the vines with their leaves removed and soluble solids accumulation was reduced. Similar reductions in soluble solids concentration (brix), have been reported for field and container grown vines (Edson *et al.*, 1993; Kliewer and Weaver, 1971). When leaves were removed from every second shoot of a field grown vine the fruit maturity was no different to that of vines with a full canopy (Kliewer and Antcliff, 1970). This was attributed in part to mobilisation of carbohydrate reserves from within the vine.

Training shoots downwards, as in the Scott-Henry trellising system, can reduce the area of leaves that emerge subsequently (Kliewer *et al.*, 1989; Schubert *et al.*, 1996). The reduction in leaf area increased the time required for the fruit to develop from bloom to

harvest and the harvest brix was reduced (Kliewer *et al.*, 1989). In the shoot orientation trial described by Kliewer *et al.* (1989), the shoots were trained downwards from bud burst, whereas shoots on the Scott-Henry trellis remain vertical until about anthesis. The effect of the downward shoots' reduced leaf area on brix level may have been lessened by the contribution from the leaf area on the remaining shoots. This may explain the poor correlation between shoot vigour and bunch soluble solids described by Trought (1996). The effects on juice composition of altering shoot orientation at anthesis, or variable shoot vigour within the vine are not well described. The former is being addressed in overseas research at present (Smart, 1998), whereas the latter does not appear to be receiving attention.

2.4.2.3 Bunch and Berry Phenology.

Anthesis within each inflorescence is not uniform, there is an order of priority among berry positions (May, 1988). This may not account for berry variability at maturity though, Trought and Tannock (1996) found no consistent effect of berry position on soluble solids or berry size of Pinot noir or Cabernet Sauvignon.

The primary inflorescences begin to flower and finish flowering before secondary inflorescences, although the flowering period overlaps (Schoffling and Kausch 1974), and the difference can be maintained through the season (Alleweldt *et al.*, 1984). This difference at flowering may cause variability in composition between bunches. The primary bunch can have a higher soluble solids level than either the secondary bunch or the tertiary bunch (Trought, 1996), although this may depend on the number of bunches per shoot (Wolpert *et al.*, 1980).

2.4.2.4 Fruit Exposure

Increasing the light exposure of berries also increases their temperature (Reynolds *et al.*, 1992), with increases of up to 10.6° C reported for the berries of exposed bunches compared to shaded bunches (Kliewer and Lider, 1968). There was more variability in the temperature of berries from sun exposed clusters than shaded clusters in Kliewer and Lidars' trial (1968), which resulted in greater variability in the juice composition. This

suggests that by increasing fruit exposure - to increase maturity, bunch to bunch variability is reduced, but berry to berry variability may be increased.

3.0 PROJECT INTRODUCTION AND AIMS

Differences in juice composition of the grape berry may reflect differences between vines in the vineyard, between bunches on a vine and / or, between berries on a bunch. These differences in the juice composition can influence the style of the finished wine. As the grape and wine industry strives for increased fruit quality, the limitations imposed by composition variability will become more important. Identifying and understanding the factors with the greatest effects on variability allows the viticulturist to employ management techniques that will reduce those effects. There is a need to understand what the contribution of variability sources such as shoot position on the vine, or bunch position on the shoot make to the overall variability.

The variability in juice composition has long been studied from the perspective of the grape sampler, who tries to obtain an accurate estimate of the crop maturity. The degree of variability between bunches within a vine, and between berries within a bunch has been reported (Kliewer and Lider, 1968; Trought, 1996; Wolpert *et al.*, 1980). Fruit exposure (Kliewer and Lider, 1968; Wolpert *et al.*, 1980), shoot position and shoot diameter (Trought, 1996), and phenology (May, 1988) have been considered as sources of that variability. Few studies have reported comprehensively on the amount that those sources contribute to variability, or on the effect of varying leaf area per shoot in a field situation. Nor have they considered their relative importance to juice composition variability.

Experiments described in this thesis aimed to quantify differences in maturity within the grapevine and the extent to which variability was influenced by row orientation (E/W or N/S) and / or trellis types, (Scott-Henry or VSP). The sampling strategy allowed the contribution of shoot and bunch position to variability to be investigated and how that contribution may have arisen.

4.0 STUDY DESIGN AND METHODS

4.1 Site and Plant Material.

Sources of juice composition variation were identified on Sauvignon blanc vines grafted to Riparia Gloire rootstock in a commercial vineyard during the 1999 and 2000 vintages. The vines were planted in 1994 and spaced 2.4 and 1.8 metres apart between and within the rows respectively. The vineyard was in the Rapaura area of the Wairau Plains in Marlborough, New Zealand (41° 29' south, 173° 54' east) on a stony silt loam soil (Rae and Tozer, 1990).

Pest and disease control was achieved using vineyard practices consistent with the New Zealand Integrated Winegrape Production system (Winegrowers of NZ, 1999) and the spray programme of the vineyard owners (Montana Wines Ltd, unpublished).

The year of vintage reported relates to the September - April season, e.g. vintage 1999 is the growing season from September 1998 - April 1999. In each season vines were mechanically trimmed to maintain a canopy height of approximately 2 m above the ground. Leaf removal in the fruiting zone was carried out mechanically in 1999 and by hand in 2000 when berries were approximately 5 mm diameter. Shoot positioning in the canopy was carried out during flowering in early December each season.

In 2000 lateral growth was removed from measured shoots during the course of the flowering measurements and twice more during the season as the shoots grew to full height. Terminal lateral growth was also removed once the shoots had achieved full size. Terminal laterals were allowed to grow on three shoots that were broken by shoot rolling or side trimming of the vines.

4.2 Experimental Design and selection of material.

Twelve vines were selected in six rows on each of two vineyard blocks, one with rows oriented east-west (E/W), the other north-south (N/S). The vines were selected as pairs (replicates), within each row based on uniformity of the trunk circumference 50 cm above the ground, and the weight of wood removed during winter pruning. One vine of

each pair was trained to a vertically shoot positioned canopy (VSP), the other to a vertically divided canopy (Scott-Henry, S-H). There was no comparative pairing between E/W and N/S rows. Prior to bud burst and within each pair of vines, excess buds were removed from the vine with the higher bud number, ensuring equal bud numbers.

Each vine had a pair of bilateral canes (4 canes), and four weeks after bud burst, three shoots were selected and tagged on each cane. Shoots were selected from the bud positions 1-4 (basal), 6-10 (mid cane), and 10- end of the cane (apical), (Figure 4.1). Wherever possible shoots with two inflorescences were selected, and any tertiary inflorescences were removed prior to flowering. In the 1999 season most of the shoots selected had two bunches, but in the 2000 season shoots were less fruitful. To satisfy the shoot position criteria, shoots with one bunch were selected for measurement.

On each shoot the primary and secondary bunches were tagged at the beginning of flowering. Bunches were not selected according to exposure or aspect, their final position depended on where the shoot grew. In 1999 some bunches had few berries and pre-harvest berry samples were taken from a shoot adjacent to the tagged shoot.

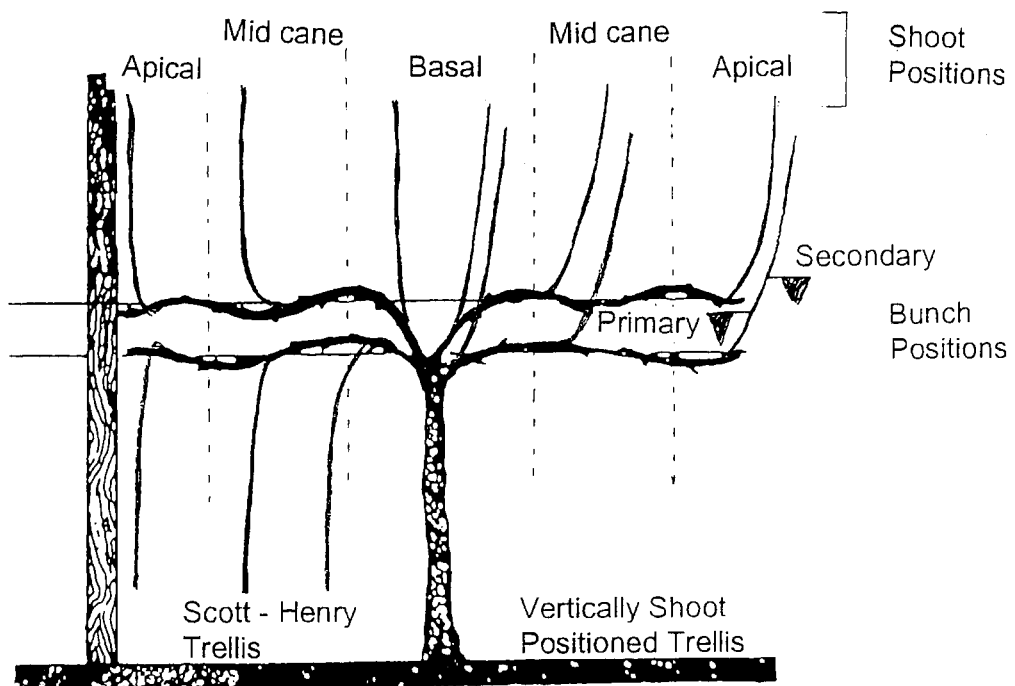


Figure 4.1 : The position of tagged shoots on a Scott -Henry and Vertically Shoot Positioned vine.

4.3 Measurements

4.3.1 Phenology

At bud burst (early October), in 1998 the development of each bud on each cane was scored according to the Eichhorn-Lorenz scale (Eichhorn and Lorenz, 1977). The scores of basal buds 2 and 3, the middle two buds and the apical two buds were averaged as the score for the basal, mid cane and apical shoot positions.

The progress of the flowering in both years, and véraison in 1999 was monitored with an eight point rating scale based on an arc sine transformation (Little and Hills, 1978). This scale avoided the difficulty of assessing the exact percentage of florets or berries that had reached a certain stage whilst providing data that was suitable for parametric analysis.

Four flowering assessments were carried out in 1998 beginning on December 5th and repeated every 3 to 4 days. In 1999 there were five flowering assessments beginning on November 27th and also 3 to 4 days apart.

Two assessments of véraison were made on February 7 th and 13 th 1999. However it was difficult to assess véraison as berries began to soften 2 to 3 days before they changed from solid green to a translucent green. No assessment of véraison was made in 2000. The fruit exposure was measured one week prior to harvest in 2000 using a 3 point scale. Bunches in 70% shade were scored 1, bunches in 30 to 70% shade scored 2 and bunches in less than 30% shade scored 3.

4.3.2 Single berry samples

The relative maturity differences due to sources of variability may alter during the ripening period. Whole bunch samples to monitor these changes would have caused an unacceptable loss of yield prior to the final harvest, so single berry samples were collected from the apical point of each tagged bunch on four occasions in 1999 and five in 2000. Berries which showed any signs of splitting or disease were not sampled. Berries sampled on the 21st of February 1999 were refrigerated until brix and weight measurements the following day. All other berries were frozen at -18° C in individually

labelled ziplock bags for 2 months prior to berry weight and brix measurements. All brix readings were obtained on a calibrated Shilac digital refractometer model Brx 242. Weights were recorded to 0.01 g on a Mettler AE 166 balance.

4.3.3 Bunch and juice composition

Bunches were harvested into individually labelled polythene bags on 23rd March 1999 and 26th March 2000. They were frozen at -18° C for 5 and 2 months respectively until they were analysed for bunch weight, berry number and weight and juice composition. The frozen bunches were weighed to the nearest gram before the berries were shattered from them. In each bunch the number of sound berries (not split, punctured or infected with botrytis), was recorded along with their total weight to the nearest gram. As a result, the reported berry numbers per bunch are not representative of typical bunches on the vine. Sound berries were retained for juice analysis, the damaged berries and the rachi were discarded.

The berries from each bunch were thawed at room temperature and manually pulped in the polythene bag before an unfiltered 10 ml sub sample of the juice (or as much as possible if less than 10 ml was available), was collected for juice composition analysis.

Brix readings on the settled juice were obtained using a digital refractometer as for the single berry readings. The titratable acidity of the juice was calculated using the titration methods outlined by Amerine and Ough (1970) for fresh juice analysis. The pH of the juice sample was measured on an Orion pH meter.

Malic and tartaric acid of juice samples in 2000 was measured using a Biofocus 3000 capillary electrophoresis system, (Bio-Rad Laboratories, Hercules, California). Prior to analysis, juice samples were centrifuged at 9 000 rpm for 10 minutes. A 10 μ l aliquot of juice was then pipetted into microcentrifuge vials with 390 μ l of distilled water before analysis.

The operating conditions of the CE were similar to those of Kandl and Kupina (1999), with the following alterations.

- The run buffer was prepared with distilled water and neither filtered nor sonicated;
- Prior to each sample run the capillary was conditioned with distilled water for 2 minutes, 0.1 N NaOH for 10 minutes and PDC -CTAB buffer (Kandl and Kupina, 1999), for 2 minutes.
- Buffer was injected for 60 seconds at high pressure between samples followed by sample injection at 3 psi.seconds.
- Separation at - 12 kV was used and the capillary temperature was set at 20 ° C.

The area under the resulting graphs was integrated using the BioFocus Integrator supplied by the manufacturer which calculated results in g/L.

4.3.4 Leaf area

At harvest all the leaves from each shoot (including lateral leaves in 1999), were removed and placed in folded plastic bags in a refrigerator until processed 2 weeks later. The petioles were removed from the leaves and the total fresh weight of leaves was recorded. A sub sampled area of 70.9 cm² and 50.3 cm² per shoot was weighed to 0.01 g in 1999 and 2000 respectively (100 discs of 9.5 mm or 8 mm diameter taken over ten leaves). The weights were used to calculate the surface area of the whole shoot using the formula:

$$A_t = W_t / W_s \times A_s$$

Where: A_t = Total area (cm²)

W_t = Total leaf weight per shoot (g)

W_s = Sub sample weight (g)

A_s = the area of the sub sample (cm²)

In 1999, 197 of the 288 shoots were randomly sub sampled to create a regression equation ($A_t = -138 + 39.5 \times W_t$; $R^2 = 0.965$; $n = 197$), the area of the remaining 91 shoots was calculated from the leaf weight. The random selection meant that leaf areas calculated from weights at the extremes of the sampled range (2.6 - 323 g) were less precise.

In 2000 the shoots used to calculate a regression equation were selected as the three lightest and heaviest shoots from each vine and one shoot in the middle of the range. This selection process meant that leaf areas were not being estimated by extrapolation. The regression equation for 2000 was $A_t = 174 + 34.1 \times W_t$; $R^2 = 0.954$; $n = 168$.

The total leaf area (cm^2) for each shoot was divided by the total fruit weight (g) for that shoot to give a leaf area : fruit weight ratio. This figure is the inverse of the crop load and referred to in the text as the LAFW.

4.4 Analysis of data.

The variance of the data was analysed using the Generalised Linear Model procedure of the Minitab Statistical package. The contribution of each main effect to the variance of the data was tested with statistical models. The first model used (model 1) was:

Row; Trellis (Row); Shoot (Trellis Row).

Terms outside the parenthesis are nested within those inside. The Row term allocated each pair of vines to a row from 1 to 12.

The variance due to each term of the model was calculated from the mean squares in the ANOVA table using the following formula where MS = Mean Square.

Variance due to Row: $((\text{MS Row} - \text{MS Trellis}) / 48)$

Variance due to Trellis type: $((\text{MS Trellis} - \text{MS Shoot}) / 24)$

Variance due to Shoot position: $((\text{MS Shoot} - \text{MS Error}) / 2)$

Variance due to Bunch position: MS Error

The percentage of the total variance that each term explained was obtained from the calculation: $\text{Variance} / \Sigma \text{Variances} \times 100$

To investigate whether the variance contributions were similar for each trellis type the data was split according to trellis type. Each subset was analysed using the model: Vine; Shoot(Vine).

The proportion of variance due to each term of this model was calculated from the mean squares in the ANOVA table using the following formula where MS = Mean Square.

Variance due to Vines: $((MS \text{ Vine} - MS \text{ Shoot}) / 24)$

Variance due to Shoot position: $((MS \text{ Shoot} - MS \text{ Error}) / 12)$

Variance due to Bunch position: MS Error

The percentage contribution to the total variance of each component was calculated as in the first model, and comparisons of the proportion of variance due to each component were made between the two trellis types.

The significance of the different levels (row orientation, trellis type, shoot and bunch position), within this design were calculated using the appropriate error term from the mixed model ANOVA of the data.

The data distribution was compared using the following parameters from SYSTAT 6 for Windows, (SPSS Inc).

- Skewness. A measure of the symmetry of a distribution about its mean. If skewness is significantly nonzero, the distribution is asymmetric. A significant positive value indicates a long right tail; a negative value indicates a long left tail. A skewness coefficient is considered significant if the absolute value of $SKEWNESS / SES$ is greater than 2.
- SES. The standard error of skewness ($SQR(6/n)$).
- Kurtosis. A value of kurtosis significantly greater than 0 indicates that the variable has longer tails than those for a normal distribution; a value less than 0 indicates that the distribution is flatter than a normal distribution. A kurtosis coefficient is considered significant if the absolute value of $KURTOSIS / SEK$ is greater than 2.
- SEK. The standard error of kurtosis ($SQR(24/n)$).

5.0 RESULTS - PHENOLOGY AND JUICE COMPOSITION

The effects of the variability sources on phenology, juice composition, yield and leaf area values are presented below. The leaf area and leaf area : fruit weight ratios were calculated for each shoot. Within each data set the row orientation results are presented last. Whilst they were not fully replicated, they did have an effect.

5.1 Effect on phenology

There was a delay in the development of basal and mid cane buds relative to the apical buds at bud burst in 1999 (Table 5.1). Bud development was not affected by trellis type or row orientation though, and there was no interaction between trellis type and shoot position.

Table 5.1 : Effect of shoot position on the development of Sauvignon blanc buds in October 1998.

Shoot position	Growth stage (Eichhorn-Lorenz)
Basal	2.8
Mid Cane	3.1
Apical	5.2
Significance ¹	*
LSD .05 ²	0.8

¹ ns= not significantly different; *significant at $p = 0.05$.

² LSD 0.05 = Least Significant Difference between means at $p = 0.05$.

The difference in the time of flowering and véraison was greater between shoot positions (2 to 3 days, Figure 5.1) than between bunch positions (1 to 2 days, Figure 5.2). Trellis type did not affect flowering, but the difference between row orientations was similar to the difference between shoot positions.

The point at which 50% of the bunch had flowered was delayed on the basal shoot inflorescences relative to apical shoot and mid cane shoot inflorescences in both years. In December 1998 the delay between basal and apical shoots at 50% flowering was about 2 days, and 3 days in December 1999 (Figure 5.1). In February 1999, 50% véraison was delayed in basal shoot bunches by about 3 days compared to apical shoots, an increase of 1 day from the delay in flowering.

The secondary inflorescences reached 50% flowering 1 day after primary inflorescences in December 1998 and 2 days later in December 1999 (Figure 5.2). The secondary bunches reached 50 % véraison 1 day later than primary bunches in February 1999.

The progress of flowering was unaffected by trellis type in either year but S-H bunches reached 50% véraison 1.5 days ahead of VSP bunches in 1999.

The flowering of N/S vines was advanced compared to E/W vines (Figure 5.3). The advance was greater in 1999, approximately 2.5 days at 50% flowering compared to 1 day in 2000. 60% véraison was advanced in N/S vines by about 4.5 days compared to E/W vines in 1999.

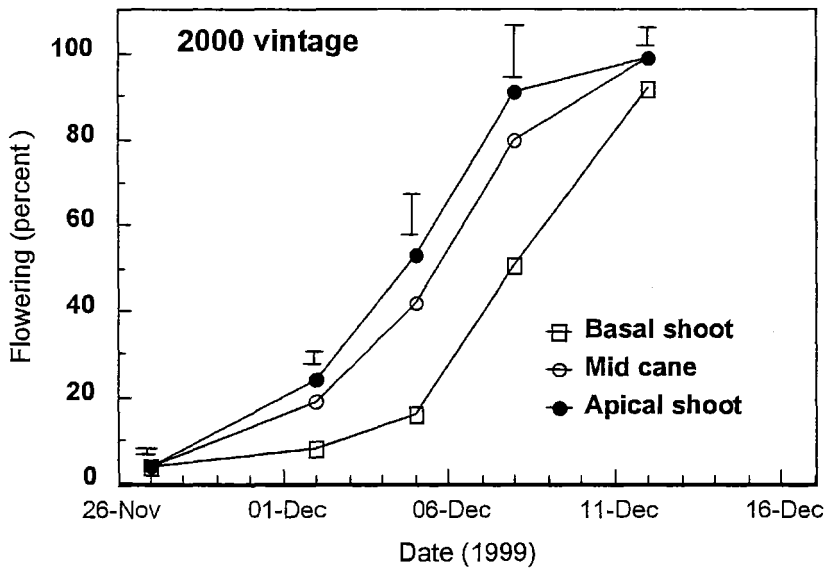
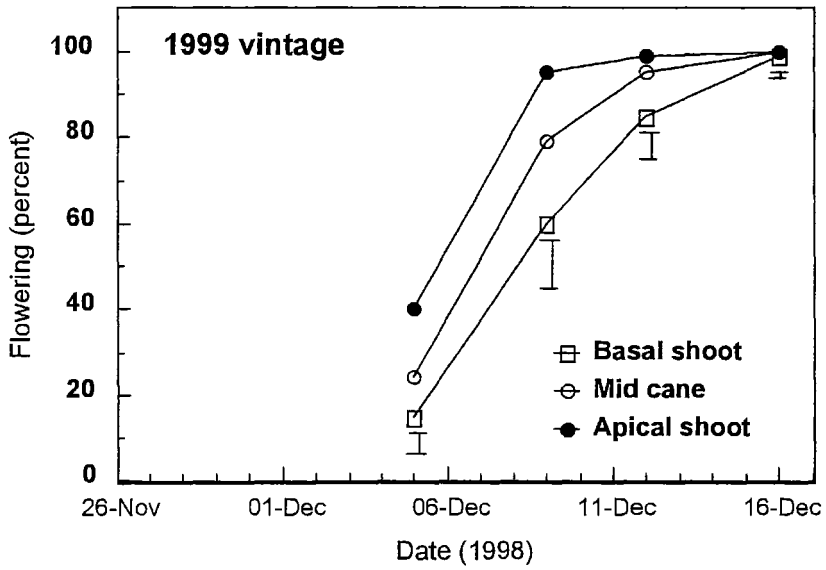


Figure 5.1 : Shoot position effects on flowering of Sauvignon blanc bunches in 1998 and 1999 (1999 and 2000 vintages). Vertical bars represent the Least Significant Difference between means at $p = 0.05$.

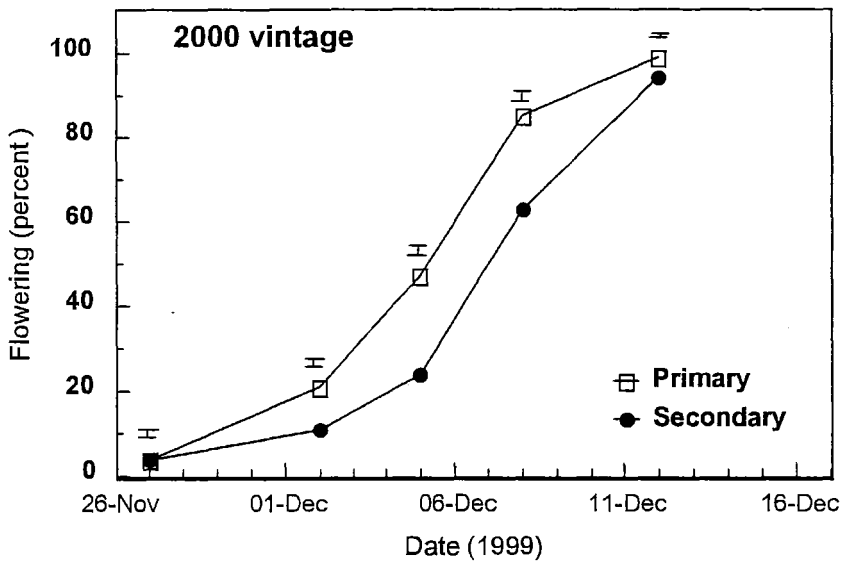
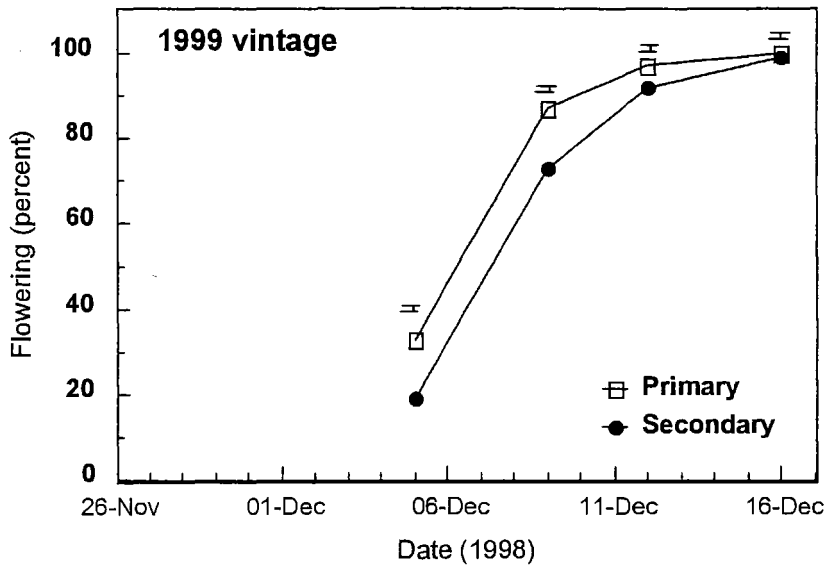


Figure 5.2 : Bunch position effects on flowering of Sauvignon blanc in 1998 and 1999 (1999 and 2000 vintages). Vertical bars represent the Least Significant Difference between means at $p = 0.05$.

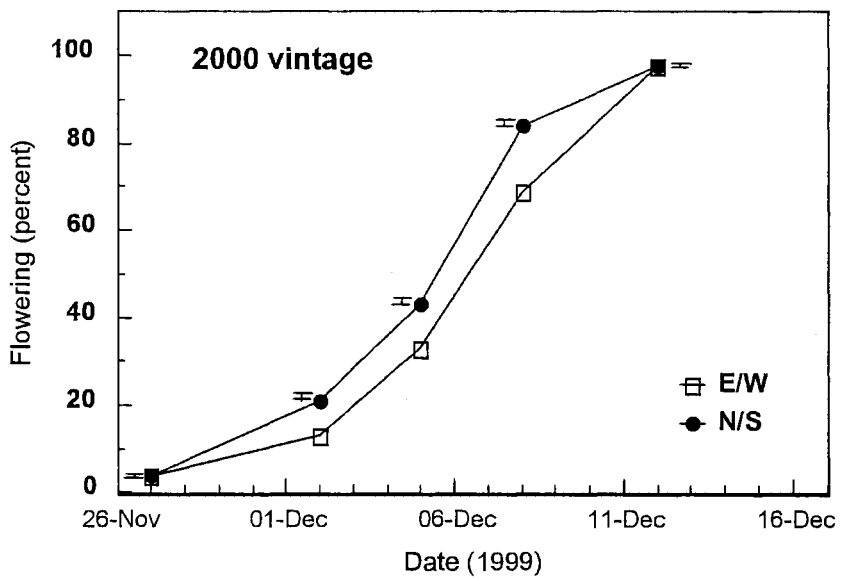
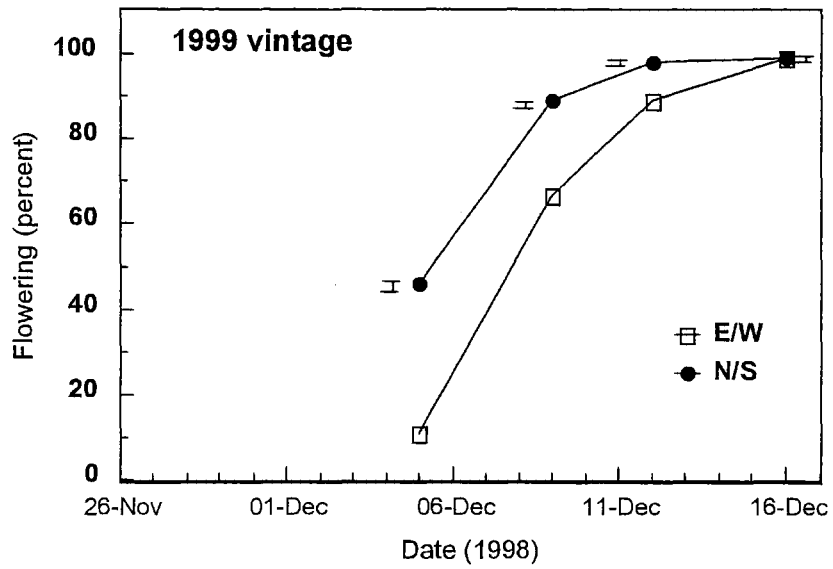


Figure 5.3 : Row orientation effects on the flowering of Sauvignon blanc bunches in 1998 and 1999 (1999 and 2000 vintages). E/W = East / west rows, N/S = North / South rows. Vertical bars represent Least Significant Difference between means at $p = 0.05$.

5.2 Changes in soluble solids (Brix), and berry weight during ripening.

The brix differences due to sources of variability were often not significant, however the delays observed in phenology were evident in early in the soluble solids accumulation phase (Figure 5.4 to 5.7). Trellis type affected the accumulation of soluble solids more than phenology in 1999, and it had the largest effect of all the sources of variability. Like the phenology results, the effect of shoot position on the brix development was larger than the effect of bunch position. The effect of row orientation on brix increase was similar to shoot position in both years.

The brix of basal shoot berries was less than on apical shoots immediately after veraison in 1999, but was unaffected by shoot position after that (Figure 5.4). There was a delay of about 2.5 days between basal shoot berries reaching 16° brix compared to apical shoot berries. In 2000 the brix of berries on basal shoots was less than apical shoots on the first four sample dates and there was a delay of about 3.5 days for basal shoot berries to reach 16° brix (Figure 5.4). The brix difference between shoot positions decreased from the time of the first sample to the sample immediately pre harvest in each year (Figure 5.4).

In pre harvest sampling, berries from secondary bunches reached 16° brix 1 day after primary bunches in 1999, and about 3 days later in 2000 (Figure 5.5). The difference in brix between the bunch positions decreased as ripening progressed.

Ripening of S-H berries was approximately 4.5 days ahead of VSP berries in 1999 with a difference of up to 2.1° brix. In 2000, ripening of the S-H berries was only 1 day ahead of VSP berries and there were no significant differences in brix level (Figure 5.6).

There was no significant difference between row orientations in the pre harvest brix samples in 1999, although N/S bunches reached 16° brix 2.5 days ahead of E/W bunches. In 2000, the brix of pre harvest samples was higher on N/S bunches and 16° brix was reached approximately 3.5 days earlier than E/W bunches (Figure 5.7).

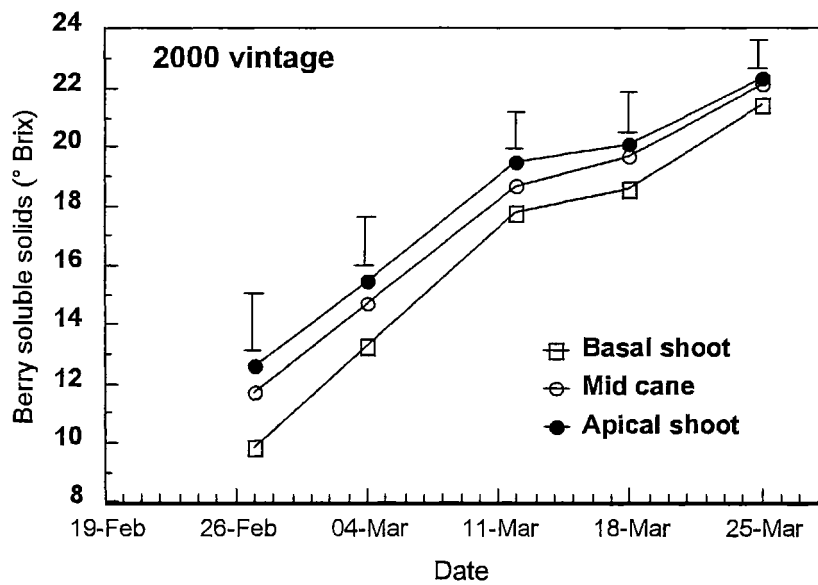
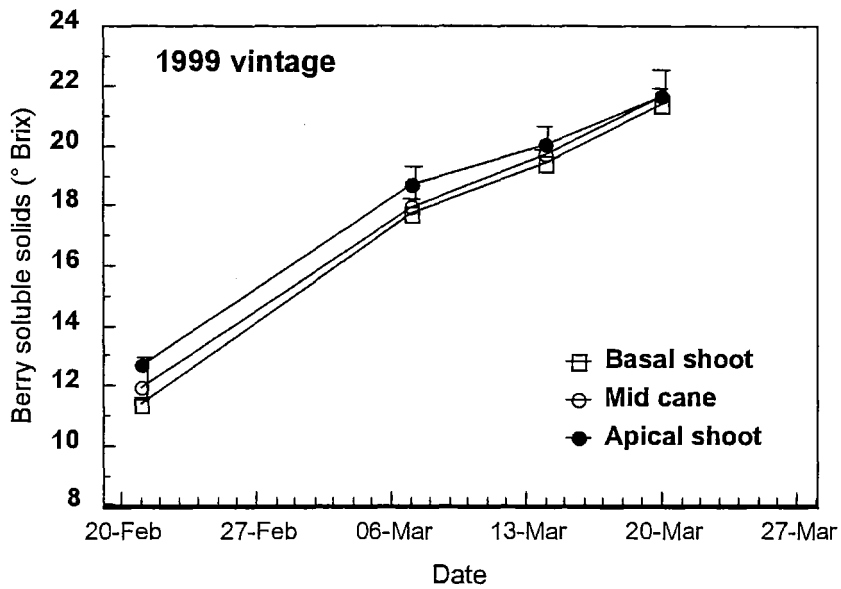


Figure 5.4 : Shoot position effects on the soluble solids development of Sauvignon blanc berries. Vertical bars represent Least Significant Difference between means at $p = 0.05$.

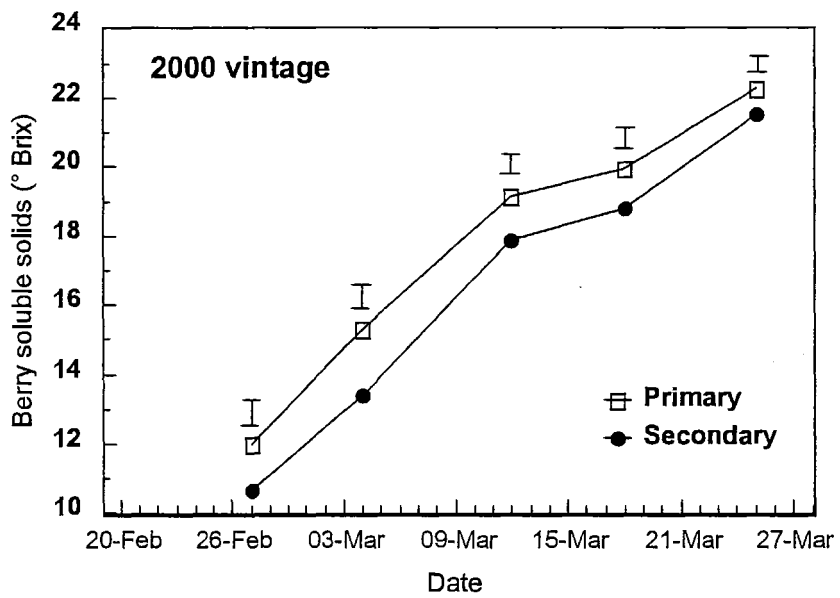
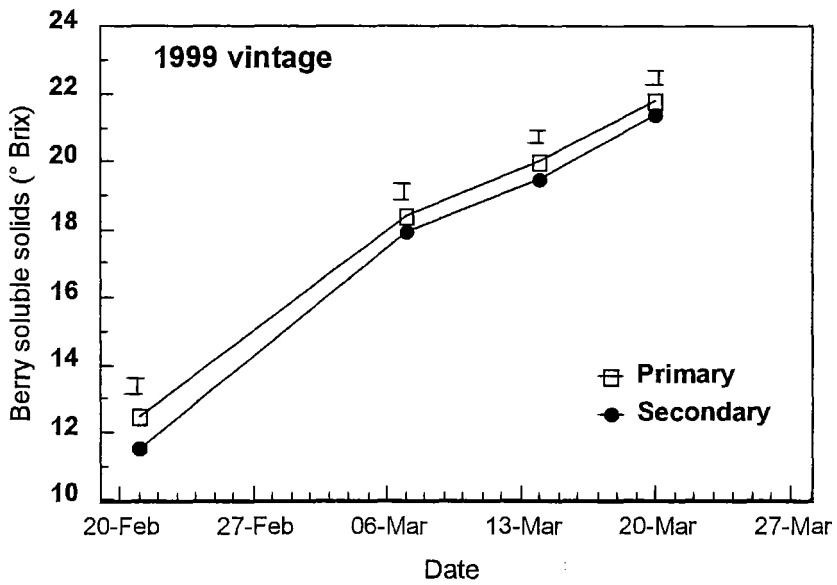


Figure 5.5 : Bunch position effects on the soluble solids development of Sauvignon blanc berries. Vertical bars represent Least Significant Difference between means at $p = 0.05$.

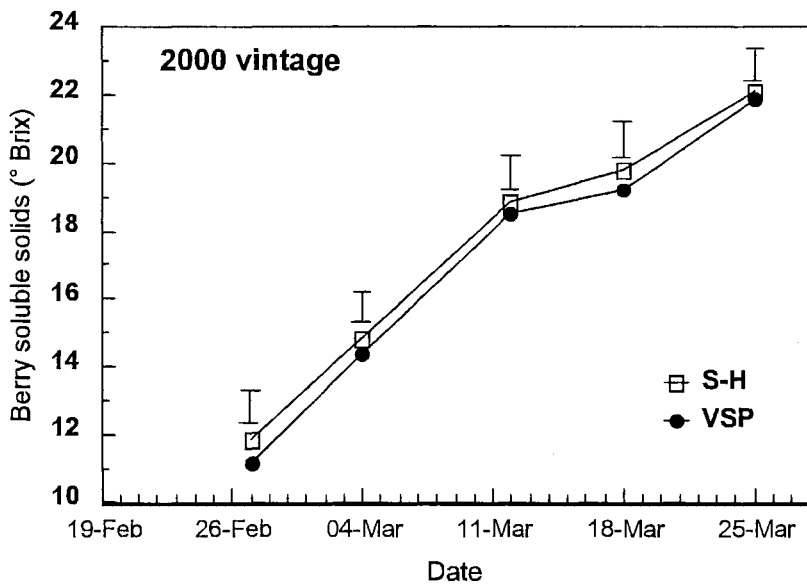
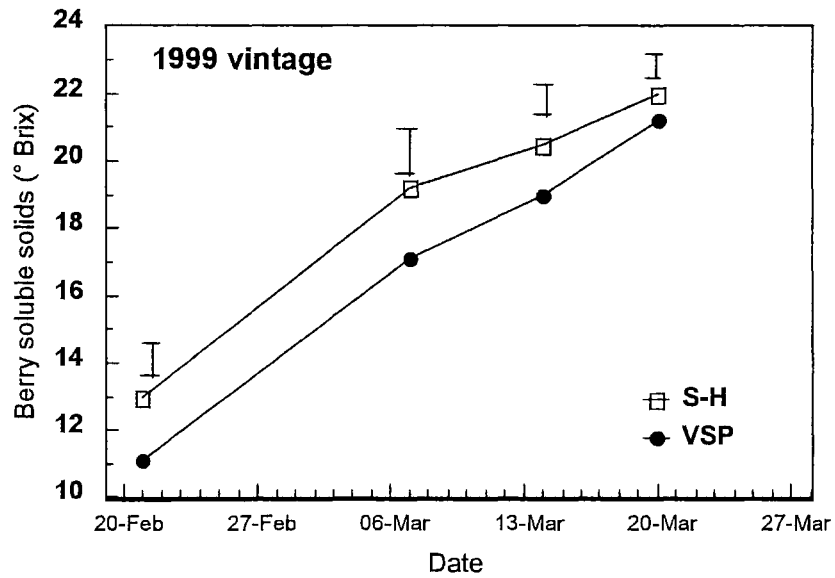


Figure 5.6 : Trellis type effects on the soluble solids development of Sauvignon blanc berries. S-H = Scott-Henry trellis, VSP = Vertically Shoot Positioned trellis. Vertical bars represent Least Significant Difference between means at $p = 0.05$.

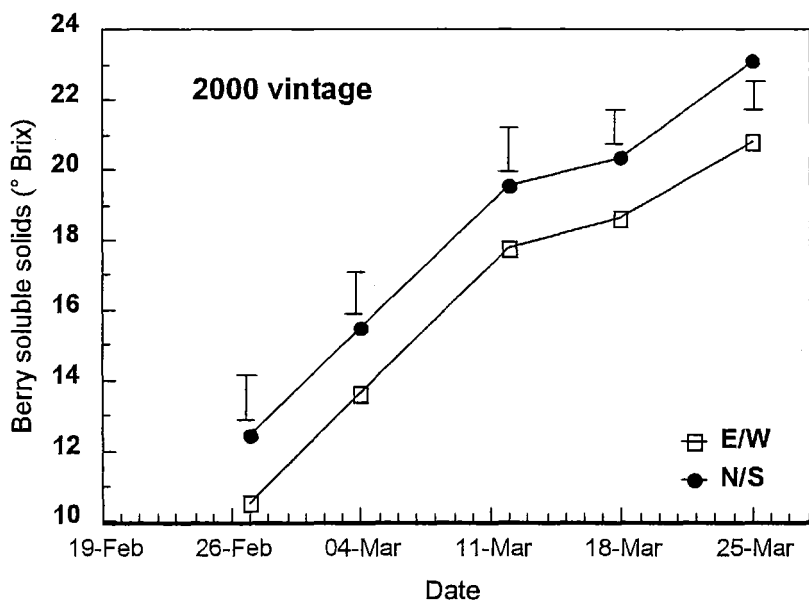
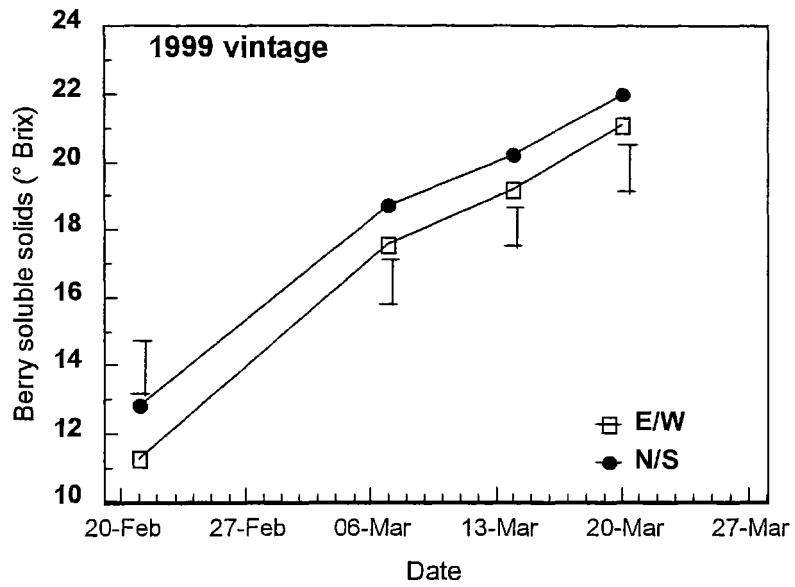


Figure 5.7 : Row orientation effects on the soluble solids development of Sauvignon blanc berries. E/W = East / west rows, N/S = North / South rows. Vertical bars represent Least Significant Difference between means at $p = 0.05$.

Berry weights were not consistently affected by any of the sources of variability in either season, but there was variation in berry weight between sample dates (Figure 5.8). Despite this variation, the soluble solids per berry increased throughout the ripening period in each season (Figure 5.9).

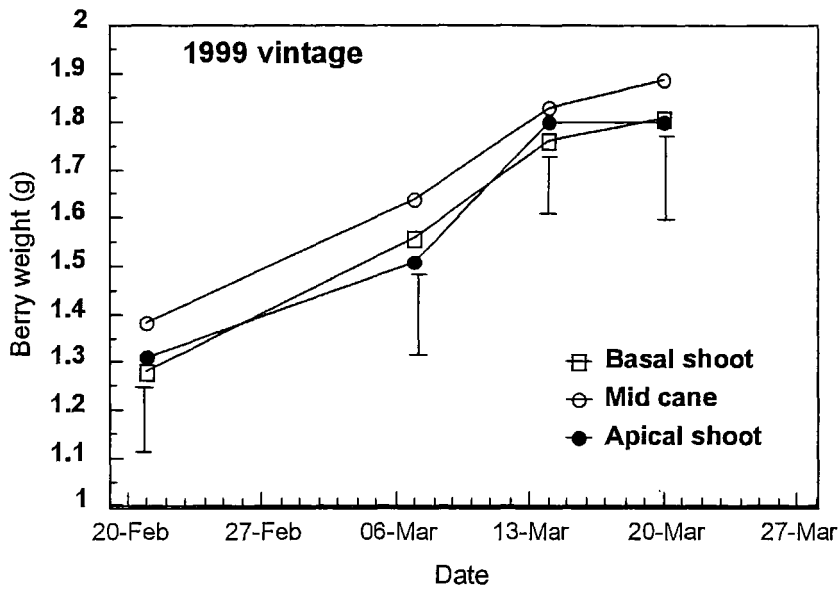


Figure 5.8 : Shoot position effects on the weight of Sauvignon blanc berries. Vertical bars represent Least Significant Difference between means at $p = 0.05$.

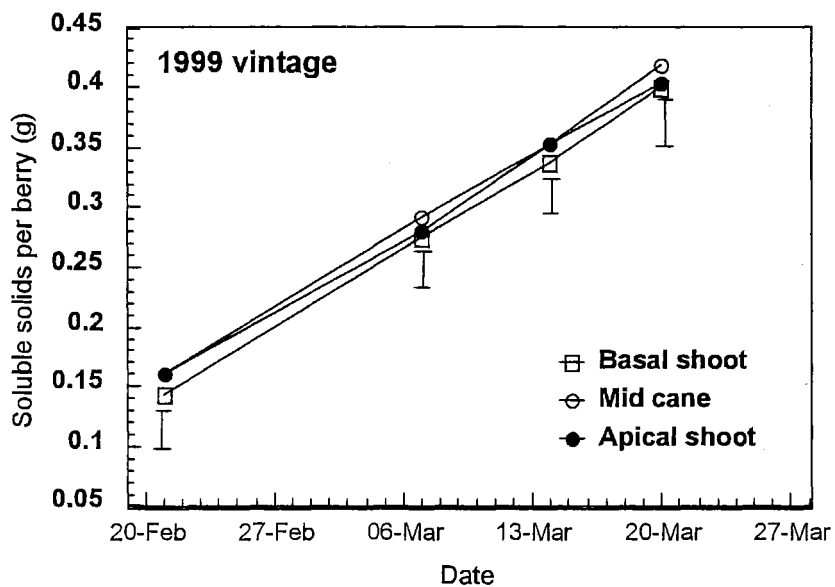


Figure 5.9 : Shoot position effects on the accumulation of soluble solids in a Sauvignon blanc berry. Vertical bars represent Least Significant Difference between means at $p = 0.05$.

5.3 Juice composition at harvest.

The differences in juice composition due to shoot position were usually larger than the differences due to bunch position or trellis type. Differences due to row orientation were larger than those due to shoot position (Table 5.2). The general trend in the results indicated an advance in fruit maturity on apical shoots, primary bunches, S-H trellis (in 1999), and N/S rows (Table 5.2).

Table 5.2 : Effect of shoot and bunch position, trellis type and row orientation on juice composition of Sauvignon blanc bunches in 1999 and 2000.

Source of variability	1999			2000				
	°Brix	TA (g/L)	pH	°Brix	TA (g/L)	pH	Fruit exposure ¹	Malic acid (g/L)
Shoot position								
Basal	21.6	8.1	3.24	20.5	10.6	3.03	2.0	5.5
Mid cane	21.9	7.9	3.26	21.4	10.0	3.07	2.0	5.0
Apical	21.8	7.7	3.29	21.4	9.7	3.10	2.2	4.9
Significance ²	ns	ns	*	*	*	*	ns	ns
LSD 0.05 ³	0.5	0.4	0.04	0.8	0.8	0.05	0.4	0.7
Bunch position								
Primary	21.9	7.8	3.26	21.4	9.8	3.08	2.2	5.0
Secondary	21.5	7.9	3.26	20.7	10.5	3.05	1.9	5.4
Significance ²	*	ns	ns	*	*	*	*	*
Trellis type⁴								
S-H	22.1	7.6	3.29	21.3	10	3.08	2.2	5.1
VSP	21.4	8.6	3.24	21.1	10.1	3.06	2.0	5.1
Significance ²	ns	*	ns	ns	ns	ns	ns	ns
Row Orientation⁵								
E/W	21.4	8.7	3.23	20.5	10.5	3.08	1.9	6.1
N/S	22.1	7.1	3.30	21.8	9.7	3.06	2.3	4.3
Significance ²	ns	*	ns	*	*	ns	*	*

¹ 1 = > 70 % shaded, 2 = 30 - 70 % shaded, 3 = <30 % shaded.

² ns= not significantly different; *significant at $p = 0.05$.

³ LSD 0.05 = Least Significant Difference between means at $p = 0.05$.

⁴ S-H = Scott Henry; VSP = Vertical Shoot Positioned

⁵ E/W = East/West; N/S = North/South

In 2000, the maturity of fruit on the apical shoots and primary bunches was significantly advanced compared to basal shoots and secondary bunches respectively (Table 5.2).

Fruit on mid cane shoots was intermediate to the other two positions. Fruit on N/S rows had significantly higher brix and TA values than on E/W rows. Trellis type had no

effect on juice composition in 2000, but S-H fruit had a lower TA than VSP fruit in 1999 (Table 5.2).

The fruit exposure was unaffected by shoot position and trellis type. Primary bunches were better exposed than secondary bunches though, and had a lower malic acid concentration. Bunches on N/S rows were more exposed than E/W rows and also had a lower malic acid concentration (Table 5.2).

5.4 Effect on leaf area, berry weight, soluble solids content and leaf area : fruit weight ratio.

Differences in leaf area, berry weight and leaf area:fruit weight (LAFW) ratio were consistent but not always significant (Table 5.3). Leaf area and the LAFW ratio was lower on mid cane shoots compared to apical shoots and basal shoots. The yield of basal shoots was less than mid cane or apical shoots, but berry weight was unaffected by shoot position (Table 5.3).

The yield per shoot on the S-H vines was lower than the VSP vines and the leaf area was greater (significant only in 1999). This caused a non significant increase in the LAFW ratio on S-H shoots compared to VSP shoots. The primary bunches were larger than secondary bunches but they tended to have smaller berries (Table 5.3).

The low yield per shoot on basal shoots in 2000 was due to both smaller bunches (64 g vs. 80g and 90g for mid cane and apical shoots respectively), and a 55% reduction in the number of basal shoots with secondary bunches compared to the other two shoot positions.

There was no relationship between the shoot position, the LAFW ratio, and the average brix of bunches on a shoot in 1999 (Figure 5.10), or 2000.

The weighted soluble solids concentration per shoot (calculated from bunch weight and soluble solids per bunch), was unaffected by the LAFW ratio whether the shoot had one or two bunches on it (Figure 5.11). The accumulation of soluble solids per berry was

also unaffected by LAFW ratio and bunch number per shoot (Figure 5.12). Similarly, the rate of soluble solids accumulation of primary or secondary bunches was unaffected by LAFW ratios (Figure 5.13).

The LAFW ratio on the X-axis of Figures 5.10 to 5.13 was restricted in order to clearly show that the bunch number, bunch position and shoot position did not affect the relationship between LAFW and increase in soluble solids content or concentration. The LAFW where differences were most likely to occur ratio was between 0 and 14 cm²/g (Kaps and Cahoon, 1992), see page 66.

Table 5.3 : Yield and leaf area of Sauvignon blanc shoots and vines as affected by shoot and bunch position, trellis type and row orientation, 1999 and 2000.

Source of variability	1999 vintage				2000 vintage				
	Berry weight (g)	Leaf area (cm ²)	Yield ^a (g)	LAFW ^b (cm ² /g)	Berry weight (g)	Leaf area (cm ²)	Yield ^a (g)	LAFW ^b (cm ² /g)	Yield (kg/vine)
Shoot position									
Basal	1.82	2,566	167	19.1	1.47	1,805	83	35.4	
Mid cane	1.86	2,211	189	13.9	1.48	1,581	136	17.5	
Apical	1.83	4,229	170	29.0	1.48	2,094	150	21.5	
Significance ^c	ns	*	ns	*	ns	ns	*	ns	
LSD 0.05 ^d	0.05	1,295	42	10.7	0.04	529	39	22.4	
Bunch position									
Primary	1.82	N/A	96.2	N/A	1.46	N/A	82.9	N/A	
Secondary	1.85	N/A	87.7	N/A	1.51	N/A	72.1	N/A	
Significance ^c	ns		*		*		*		
Trellis type^e									
S-H	1.88	3,330	157	24.6	1.49	1,878	114	29.3	4.7
VSP	1.80	2,668	193	16.7	1.47	1,776	133	20.3	5.5
Significance ^c	*	*	*	ns	ns	ns	ns	ns	ns
Row orientation^f									
E/W	1.91	3,371	159	25.5	1.45	1,814	101	30.4	4.7
N/S	1.76	2,617	192	15.8	1.51	1,839	145	19.2	5.5
Significance ^c	*	*	*	*	ns	ns	*	ns	ns

^a Yield is per shoot except for Bunch position where yield refers to the bunch weights.

^b LAFW is the Leaf Area : Fruit Weight ratio.

^c ns= not significantly different; *significant at $p = 0.05$.

^d LSD 0.05 = Least Significant Difference between means at $p = 0.05$.

^e S-H = Scott Henry; VSP = Vertical Shoot Positioned

^f E/W = East/West; N/S = North/South

In 2000 the vines studied had a low crop load (yield:pruning weight ratio) averaging 2.1:1. Only one vine had a crop load that was considered moderate, 5.1:1.

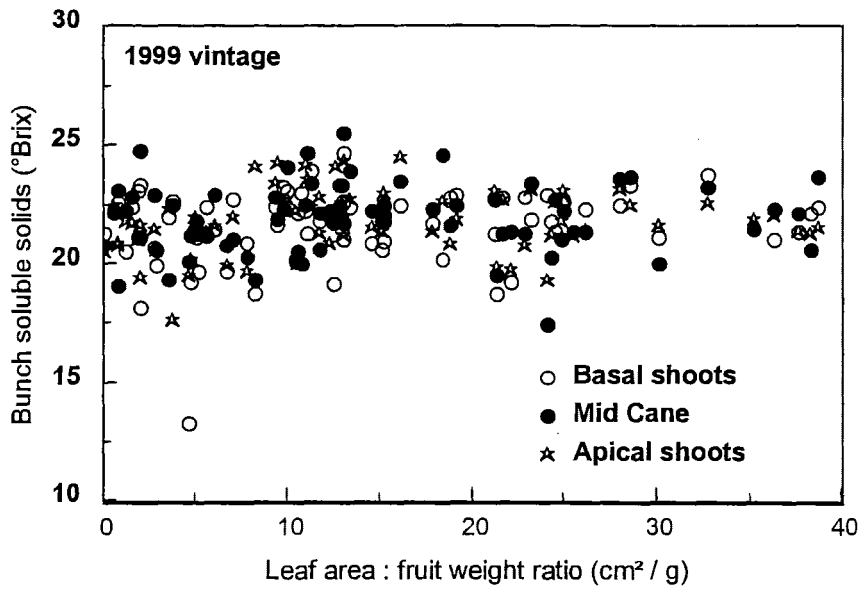


Figure 5.10 : The effect of shoot position and leaf area:fruit weight ratio (cm²/g) on the soluble solids of Sauvignon blanc bunches. The data set has been restricted to leaf area:fruit weight ratios below 40 cm²/g to clearly show the area where differences are most likely.

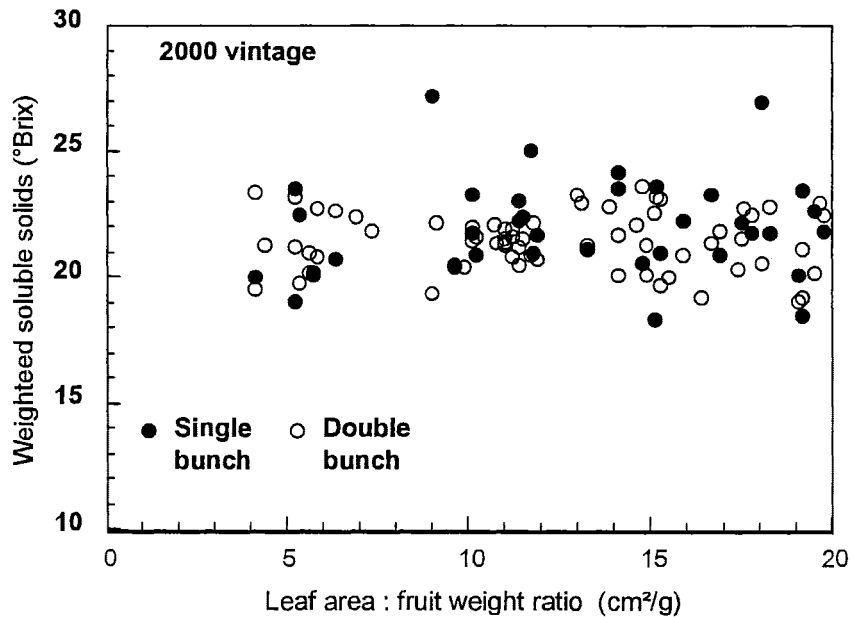


Figure 5.11 : The effect of bunch number per shoot on weighted soluble solids concentration per shoot of Sauvignon blanc. The data set has been restricted to leaf area:fruit weight ratios below 20 cm²/g to clearly show the area where differences are most likely.

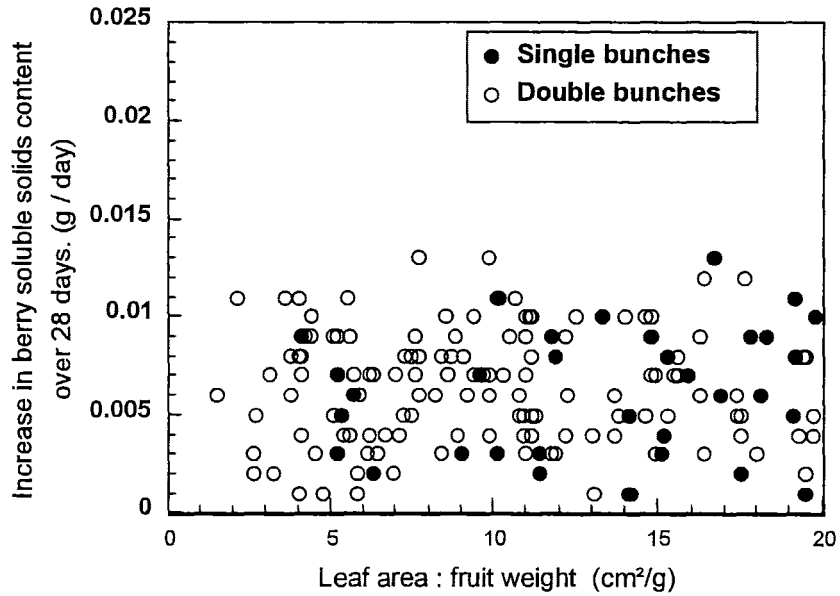


Figure 5.12 : Soluble solids accumulation rate of Sauvignon blanc shoots with either one or two bunches as affected by leaf area : fruit weight ratio per shoot. The data set has been restricted to leaf area:fruit weight ratios below 20 cm²/g to clearly show the area where differences are most likely.

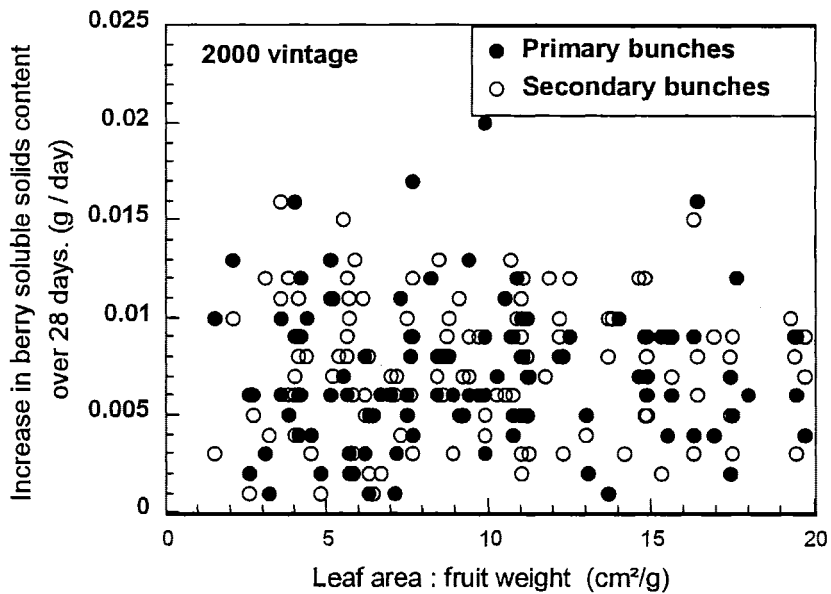


Figure 5.13 : Soluble solids accumulation rate of primary and secondary bunches of Sauvignon blanc as affected by leaf area : fruit weight ratio per shoot. The data set has been restricted to leaf area:fruit weight ratios below 20 cm²/g to clearly show the area where differences are most likely.

An increase in leaf area per shoot slightly increased the soluble solids per berry in 1999 and 2000 (Figure 5.14). In 2000 berries from shoots with a leaf area between 0 and 500 cm² appeared to have a lower soluble solids level than those above 500 cm². Data points at the ends of Figure 5.14 are the means of only 12 - 14 berries each compared to more than 60 berries in the middle of the figure.

The points in Figure 5.14 were averaged from all data regardless of crop load (kg yield: kg prunings) per vine or the shoot LAFW ratio. In 2000 there was a reduction in berry soluble solids content when the leaf area per shoot was below 800 cm² at a moderate crop load (5.1:1) (Figure 5.15). At a low crop load (1:1) the berry soluble solids content decreased with increasing leaf area per shoot. The leaf area per shoot did not effect the berry weight at either crop load per vine (Figure 5.16). In both Figure 5.15 and 5.16 one point was left out of the low crop load regression because of the large influence that it had on the relationship.

To test the interaction between LAFW ratio and leaf area per shoot, data from low and moderate LAFW ratios was averaged according to leaf area groups of 100 cm². At a low LAFW ratio (0 - 2 cm²/g), there was a positive relationship between the leaf area per shoot and both berry soluble solids content and weight in 1999 (Figure 5.18). At a moderate LAFW ratio (8 - 10 cm²/g), an increase in leaf area per shoot had less impact on the soluble solids content or berry weight. The R² values indicated there was a stronger relationship at a LAFW ratio of 0 - 2 cm²/g than at 8 - 10 cm²/g in 1999 (Figure 5.18). There was a negative relationship between leaf area per shoot and brix in 1999 at a low LAFW ratio (Figure 5.18). This was because of the large increase in berry weight relative to the soluble solids content of the berry.

The slope of the relationship at 2 - 4 cm²/g was very similar to that at 8 - 10 cm²/g in 2000 (Figure 5.18). One data point at 200 cm² per shoot was excluded from the regression calculation (Figure 5.18). That data point arose from only one bunch which had recorded consistently low berry weights and brix levels during pre harvest sampling.

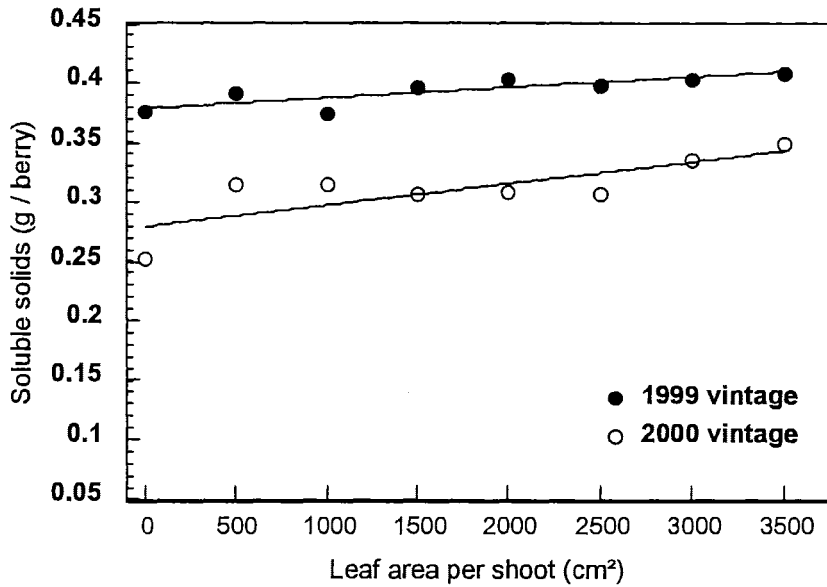


Figure 5.14 : Shoot leaf area effects on soluble solids of Sauvignon blanc berries. Regression equation for 1999 is: Soluble solids (g/berry) = 0.379 + (0.0000089 x leaf area (cm²)); R² = 70.5; compiled from 402 data points. The regression equation for 2000 is: Soluble solids (g/berry) = 0.608 + (0.0000181 x leaf area (cm²)); R² = 60.8; compiled from 336 data points.

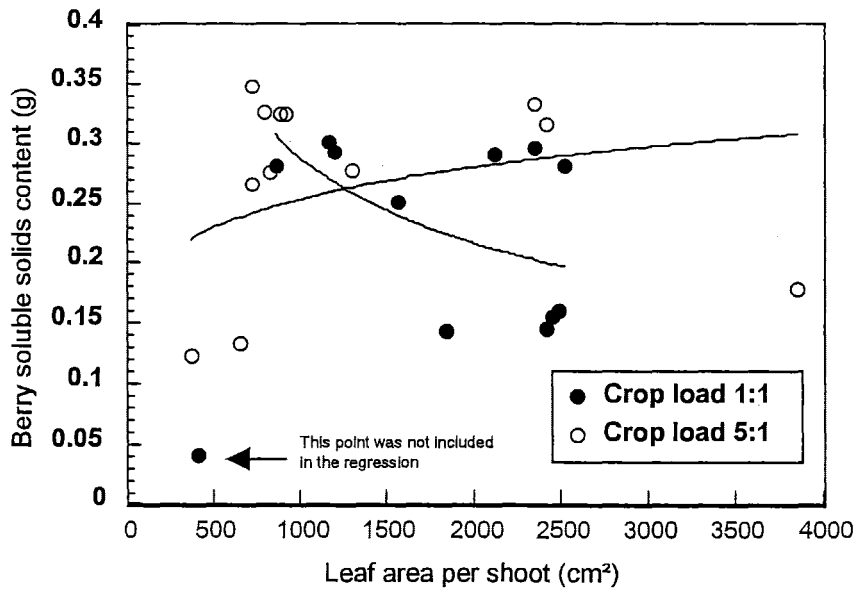


Figure 5.15 : Soluble solids content of Sauvignon blanc berries as affected by shoot leaf area at two crop loads. Equation for crop load 1:1 is $Y = 4.97 \times X^{-0.412}$; R² = 23.2%; n=12. Equation for crop load 5.1:1 is $Y = 0.093 \times X^{0.145}$; R² = 6.9%; n=12

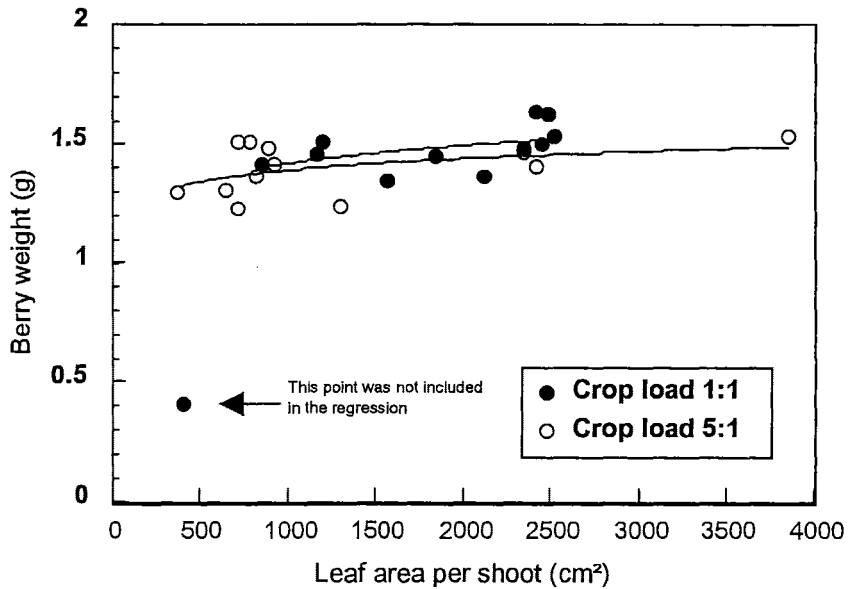


Figure 5.16 : Sauvignon blanc berry weight as affected by shoot leaf area at two crop loads. Equation for crop load 1:1 is $Y = 0.838 \times X^{0.076}$; $R^2 = 21.6\%$; $n=12$. Equation for crop load 5.1:1 is $Y = 0.984 \times X^{0.050}$; $R^2 = 17.8\%$; $n=12$

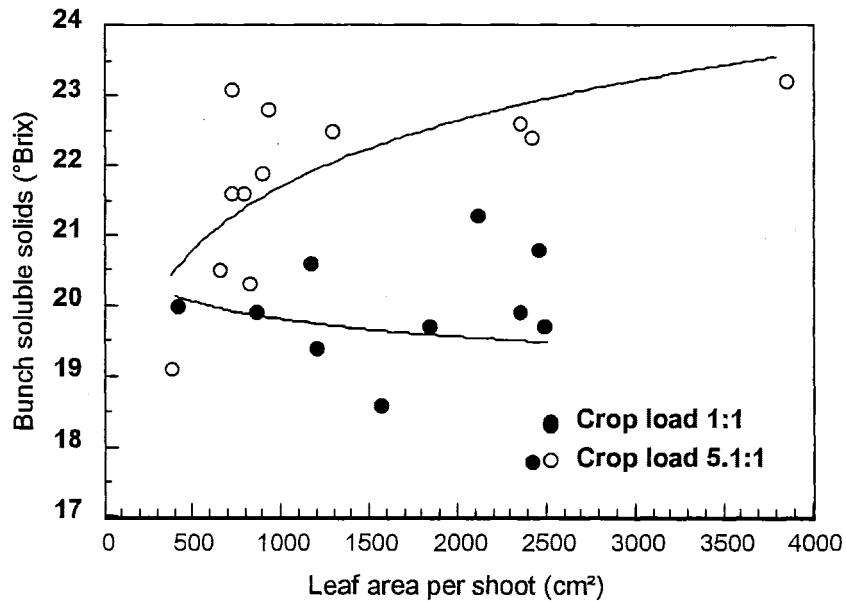
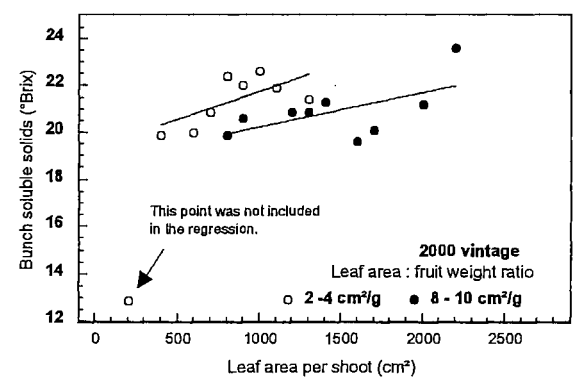
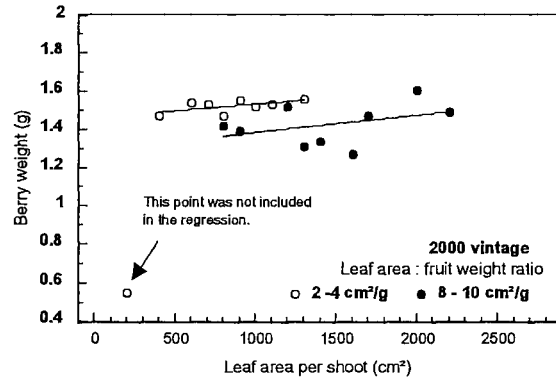
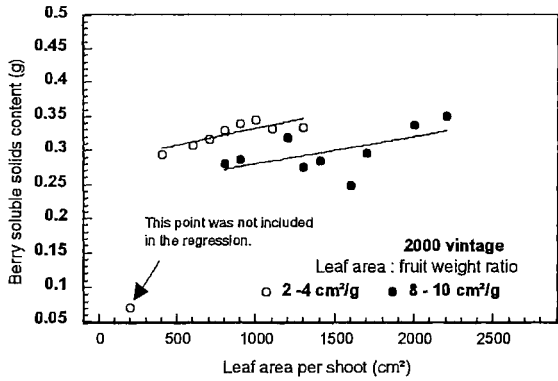
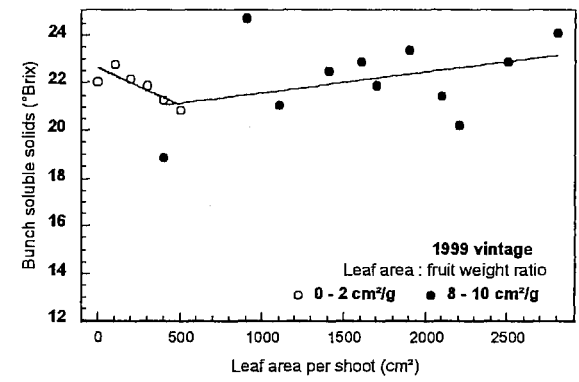
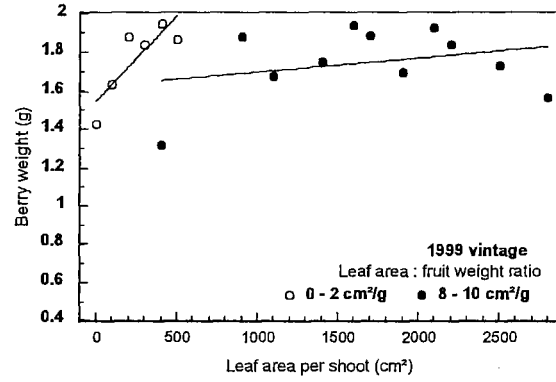
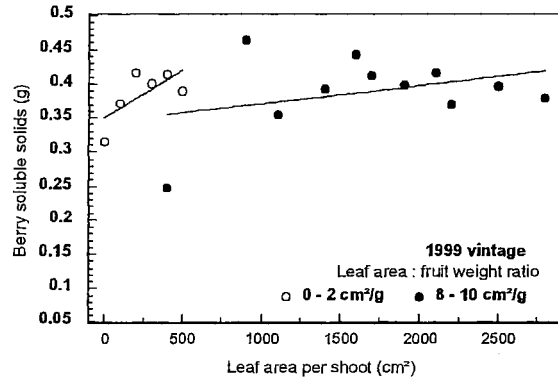


Figure 5.17 : Bunch soluble solids concentration (°brix) of Sauvignon blanc as affected by shoot leaf area at two crop loads. Equation for crop load 1:1 is $Y = 22.5 \times X^{-0.018}$; $R^2 = 3.7\%$; $n=12$. Equation for crop load 5.1:1 is $Y = 14.1 \times X^{0.062}$; $R^2 = 47.8\%$; $n=12$



A

B

C

Figure 5.18 : The relationship between leaf area per shoot of Sauvignon blanc and berry soluble solids content (A), berry weight (B), and bunch soluble solids concentration (C), for two leaf area : fruit weight ratios. R² values are : 0-2cm²/g 1999 A, 46.5; B, 71.1; C, 72.7; 2-4 cm²/g 2000 A, 68.3; B, 35; C, 44; 8-10 cm²/g 1999 A, 11.4; B, 8; C, 13.1; 8-10 cm²/g 2000 A, 33.5; B, 15; C, 34.7

5.5 Effect of shoot orientation

The brix and TA of downward facing shoots of the S-H trellis was compared to the corresponding shoot positions on the upper cane which were grown upwards. There was an increase in brix and decrease in TA of bunches on the downward facing shoots which indicated an advance in maturity compared to bunches on upward facing shoots (Figure 5.19). When the same shoot positions on VSP vines were compared, there were similar brix and TA differences between the upper and lower canes even though the shoots were all facing upwards (Figure 5.19). The leaf area per shoot was similar for upward and downward oriented shoots in both seasons (Table 5.4)

Table 5.4: Effect of shoot orientation on the leaf area per shoot (cm²) of Scott-Henry trained Sauvignon blanc vines.

Shoot orientation	Vintage	
	1999	2000
Down	3,893	1,951
Up	3,273	1,935
S.E.M. ^a	265	99

^a SEM is the Standard Error of the Mean

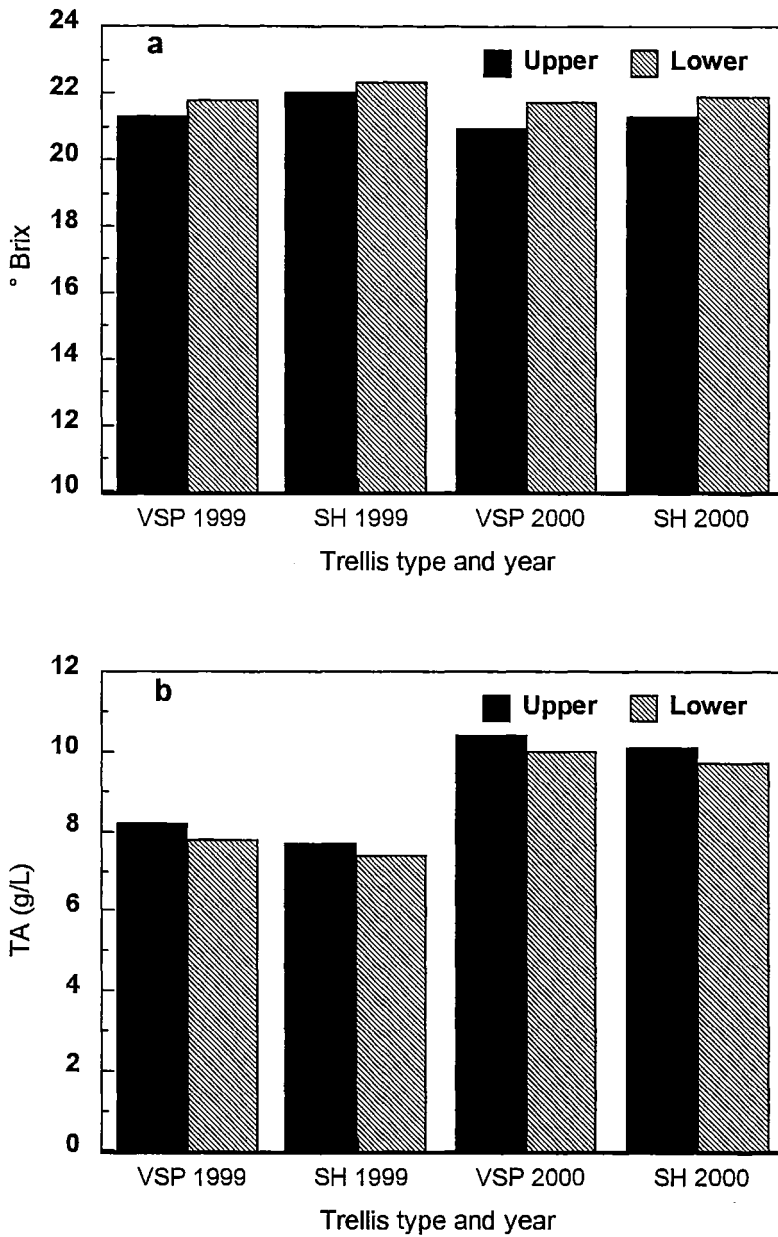


Figure 5.19 : The contribution of shoot orientation to differences in brix (a) and TA (b) between Vertically Shoot Positioned (VSP) and Scott-Henry (SH) trained vines in 1999 and 2000. Shoots on the upper cordon of both trellis types and the lower cordon of VSP vines were trained upwards. Shoots on the lower cordon of SH vines were trained downwards.

6.0 RESULTS - VARIANCE AND DATA DISTRIBUTION.

The variance that was due to the effects of Row, Trellis type, Shoot position and Bunch position was determined within each year. The variance due to row, included the effects of the two row orientations as well as the natural variability between vines. Each of the other variance results included only the variance due to that source of variability.

6.1 Allocation of Variance

The majority of the variance in both the 1998 and 1999 flowering scores was due to the shoot and bunch position. The amount that each was responsible for changed as flowering progressed. On the last assessment date, the two bunch positions were the main source of variance as the shoulder of primary bunches had often not flowered (Table 6.1).

Table 6.1 : Percentage of the total variance in flowering scores of Sauvignon blanc bunches in 1999 and 2000 vintages due to four variance components.

Source of variance	Date (1998)				
	05-Dec	09-Dec	12-Dec	16-Dec	
Row	33.7	4.5	1.5	0.0	
Trellis	7.5	9.7	8.3	4.2	
Shoots	31.7	53.4	56.6	27.6	
Bunches	27.1	32.3	33.6	68.1	
	Date (1999)				
	27-Nov	02-Dec	05-Dec	08-Dec	12-Dec
Row	3.3	2.7	1.9	3.7	1.6
Trellis	0.0	1.4	0.0	0.0	0.0
Shoots	22.4	28.1	38.3	25.4	0.0
Bunches	74.2	67.9	59.8	70.9	98.4

In both years, bunch position was the main source of variance in the berry brix samples on any date (Figure 6.1). Trellis was an intermediate source of brix variance in pre harvest samples in 1999 but in 2000, row, trellis and shoot position contributed little to the variance in pre harvest brix samples.

The bunch position was the main source of brix, TA and pH variance in 2000, and of brix and TA variance in 1999 (Figure 6.2). Trellis was the second largest source of brix and TA variance in 1999, but in 2000 shoot position was the second largest source of brix and TA variance. Trellis was the biggest contributor to the pH variance in 1999,

followed by shoot position. The row term contributed to the brix variance in both seasons but contributed to TA variance in 1999 only. Row contributed little to the pH variance in either season (Figure 6.2).

The véraison score variance was spread more evenly between variability sources than the flowering score variance, but bunch position was still a major source of variability (Table 6.2).

Table 6.2 : Percentage of the total variance in véraison scores of Sauvignon blanc bunches in 1999 vintage due to four variance components.

Source of variance	Date	
	07-Feb	13-Feb
Row	19.7	11.9
Trellis	30.7	24.9
Shoots	19.2	26.5
Bunches	30.4	36.7

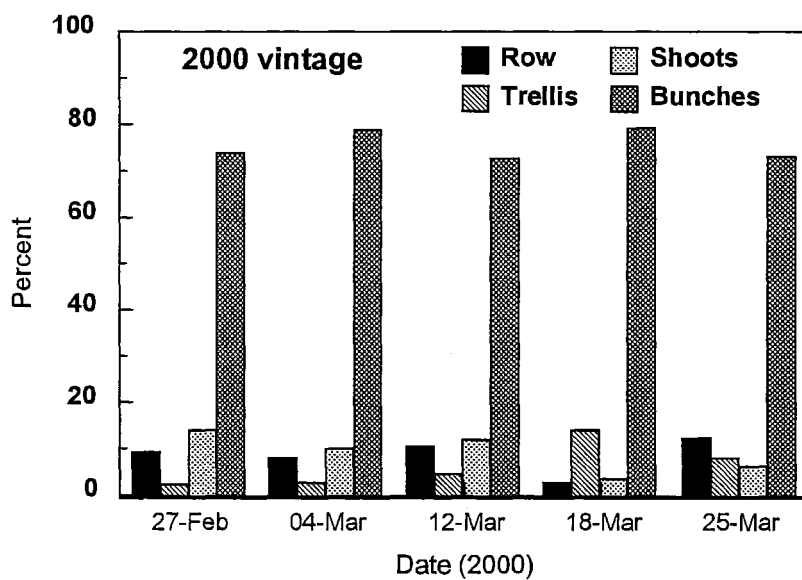
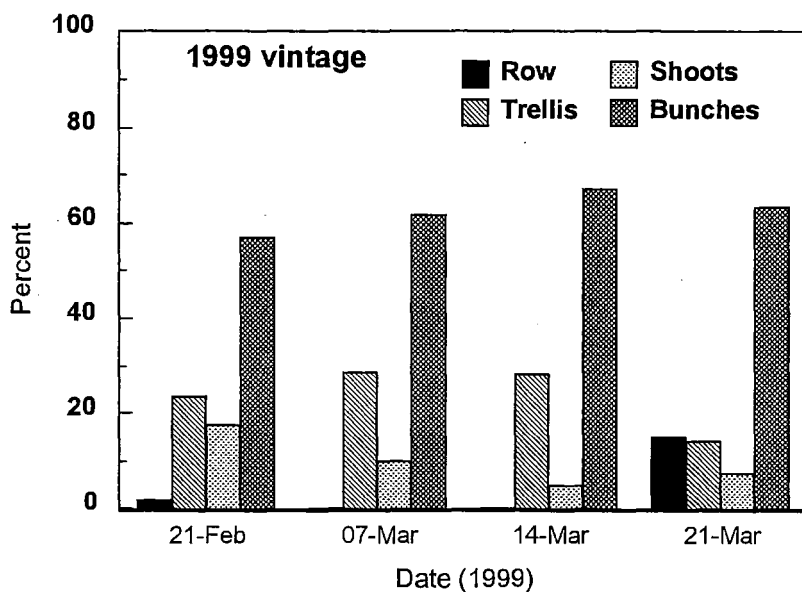


Figure 6.1 : Percent of the variance in brix of single berry samples of Sauvignon blanc that was due to Row, Trellis type, Shoot or Bunch position.

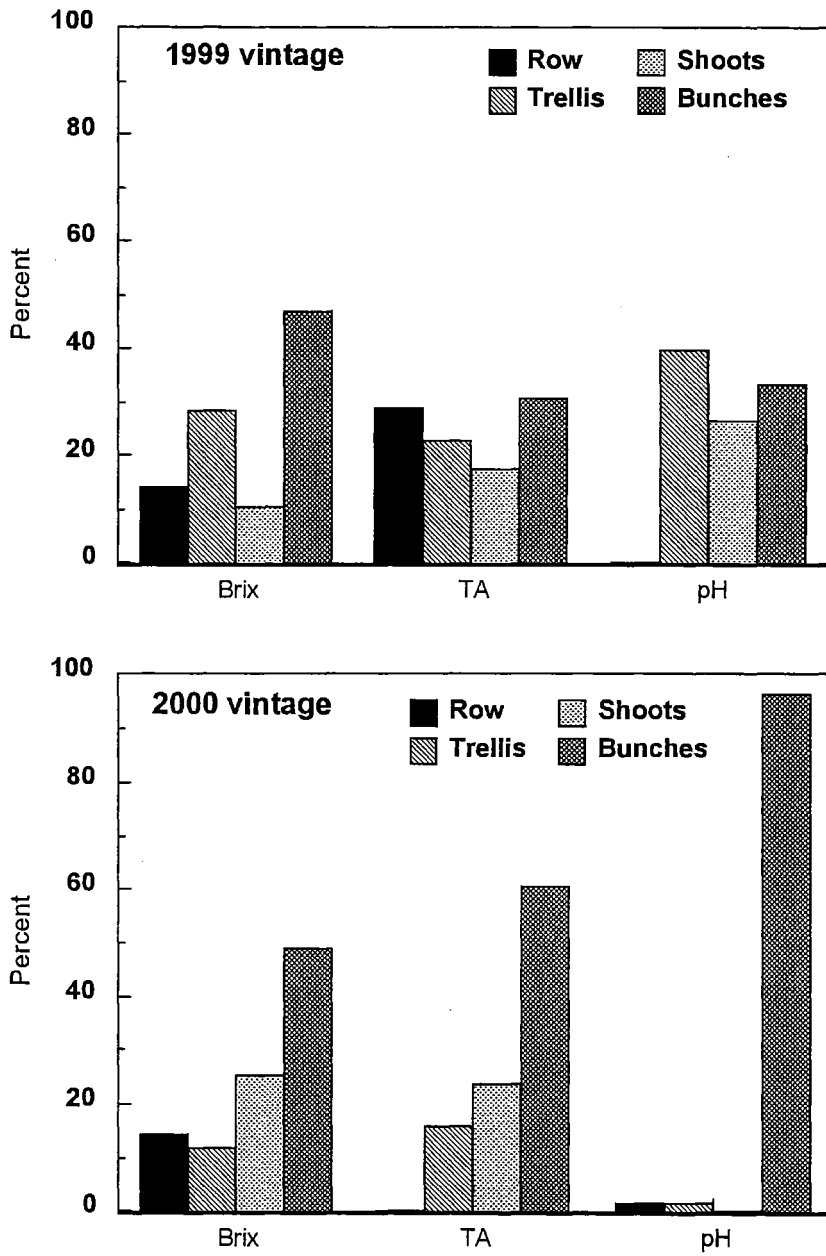


Figure 6.2 : Percent of the variance in juice composition of Sauvignon blanc that was due to Row, Trellis type, Shoot or Bunch position.

6.2 Row, Shoot and Bunch position variance within trellis type.

Where trellis type had contributed more than 15% to the variance - e.g. Brix and TA in 1999 (Figure 6.2) - the data was split according to trellis type. Within each data subset, the variance was partitioned into row, shoot and bunch position components.

Row was responsible for less variance in the pre-harvest brix, brix and TA data of S-H vines than VSP vines in 1999 (Figures 6.3 & 6.4). The same reduction in row variance in S-H vines occurred with the véraison scores. The opposite was true of the juice pH variance in 1999, where more variance was due to row in S-H vines than VSP vines. Where the variance due to row decreased, there was a proportionate increase in the variance due to bunch position. The amount of variance that was due to shoot position within each trellis type remained at a similar level.

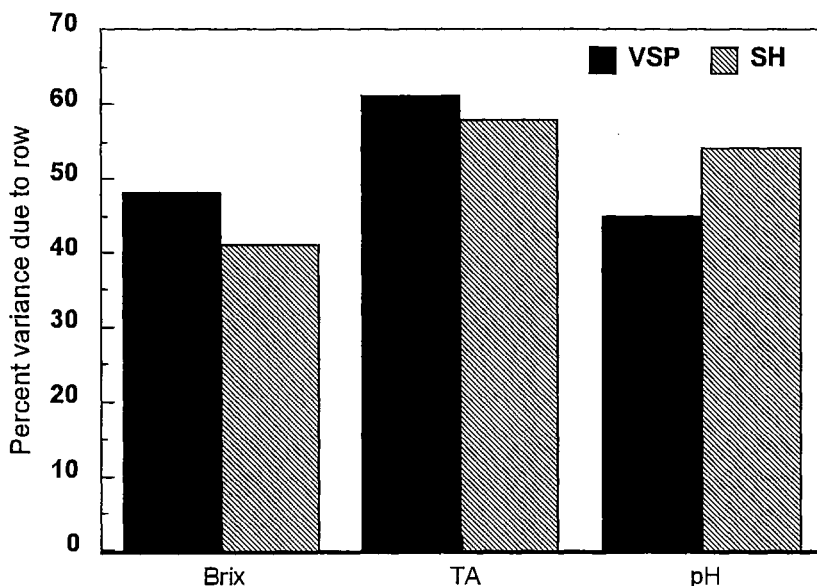


Figure 6.3 : The percent variance of Sauvignon blanc juice composition due to row in 1999. A comparison between two trellis types, Vertically Shoot Positioned (VSP) and Scott-Henry (SH). The row effect contributed more to the variance of brix and TA of VSP vines than it did to SH vines, but less to pH variance (see page 53).

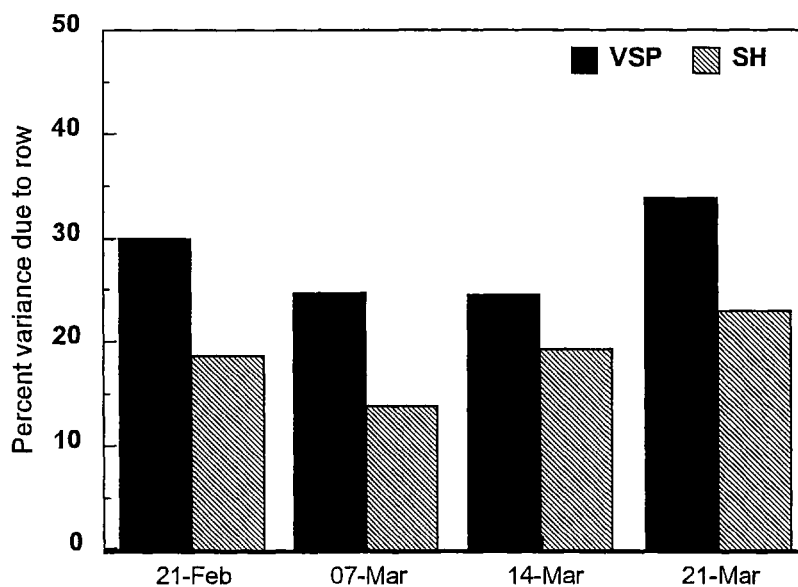


Figure 6.4 : The percent variance of Sauvignon blanc berry brix due to row in 1999. A comparison between two trellis types, Vertically Shoot Positioned (VSP) and Scott-Henry (SH). The row effect contributed more to the variance of VSP vines than it did to SH vines (see page 53).

6.3 Data Distribution

There was a reduction in the coefficient of variation (C.V.) of the brix data from the berry samples and the harvest sample during the berry maturation period in both seasons (Figure 6.5, Table 6.3). At the beginning of sampling in 1999 the distribution curves were not skewed, but as ripening progressed the curves were skewed to the left. Each of the distribution curves had longer tails than a normal distribution curve (Table 6.3).

Table 6.3 : Descriptive statistics for distribution curves a - k in figure 6.5.

	a	b	c	d	e	
	21/2/1999	7/3/1999	14/3/1999	20/3/1999	23/3/1999	
Mean	12.02	18.13	19.73	21.59	21.75	
Standard Dev	3.13	3.07	2.37	2.13	1.59	
CV %	26	17	12	10	7	
Skewness	-0.09	-0.12	-0.33	-0.77	-1	
SE Skewness	0.1	0.1	0.1	0.1	0.1	
Skewed ^a	n	n	L	L	L	
Kurtosis	1.04	1.27	2.42	2.47	6.34	
SE Kurtosis	0.21	0.21	0.21	0.21	0.21	
Shape of curve ^b	LT	LT	LT	LT	LT	
	f	g	h	i	j	k
	27/2/2000	4/3/2000	12/3/2000	18/3/2000	25/3/2000	26/3/2000
Mean	11.51	14.59	18.69	19.52	22	21.17
Standard Dev	3.69	3.6	3.29	3.01	2.87	1.87
CV %	32	25	18	15	13	9
Skewness	0.37	-0.27	0.09	-0.09	-0.38	-0.24
SE Skewness	0.11	0.11	0.11	0.12	0.12	0.12
Skewed ^a	R	L	n	n	L	n
Kurtosis	-0.66	0.04	1.93	0.56	1.42	1.96
SE Kurtosis	0.23	0.23	0.23	0.23	0.23	0.23
Shape of curve ^b	F	n	LT	LT	LT	LT

^a Whether or not the curve is skewed: n = normal, L=skewed left, R = skewed right

^b How the distribution curve compares to the normal curve: n = normal, F = flatter, LT = longer tailed.

The harvest brix data had a smaller standard deviation and C.V. than the pre harvest samples in both years. Harvest brix readings were from bunches instead of berries, so removal of berry to berry variability may have been the reason.

The distribution of berry soluble solids content data was skewed to the right on the first sample in 1999, and like the brix data, skewed to the left on the last two samples and at

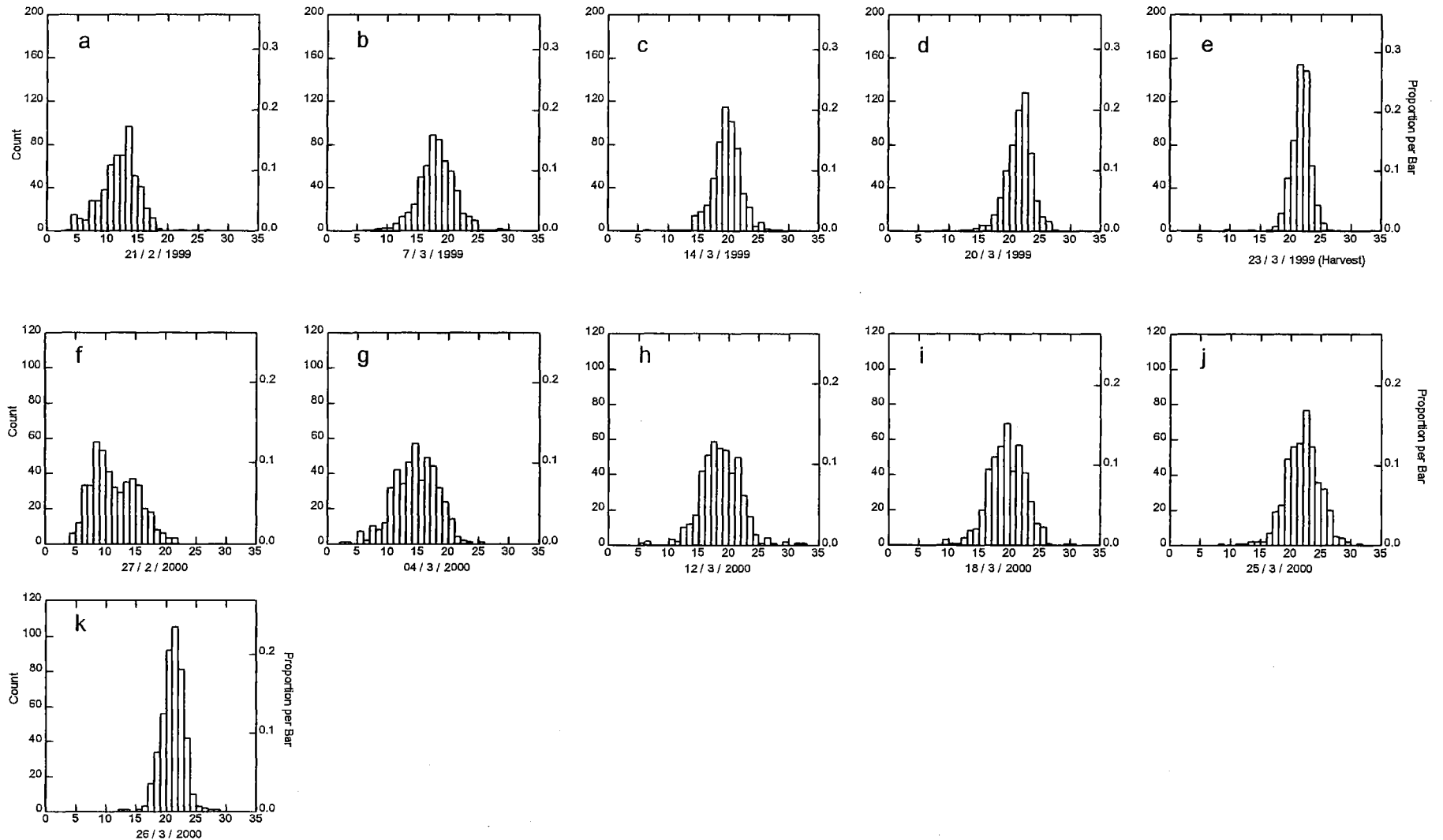


Figure 6.5 : The distribution of brix readings from individual berries on each sample date (a-d and f - j), and bunch samples at harvest (e & k) in 1999 and 2000 vintages.

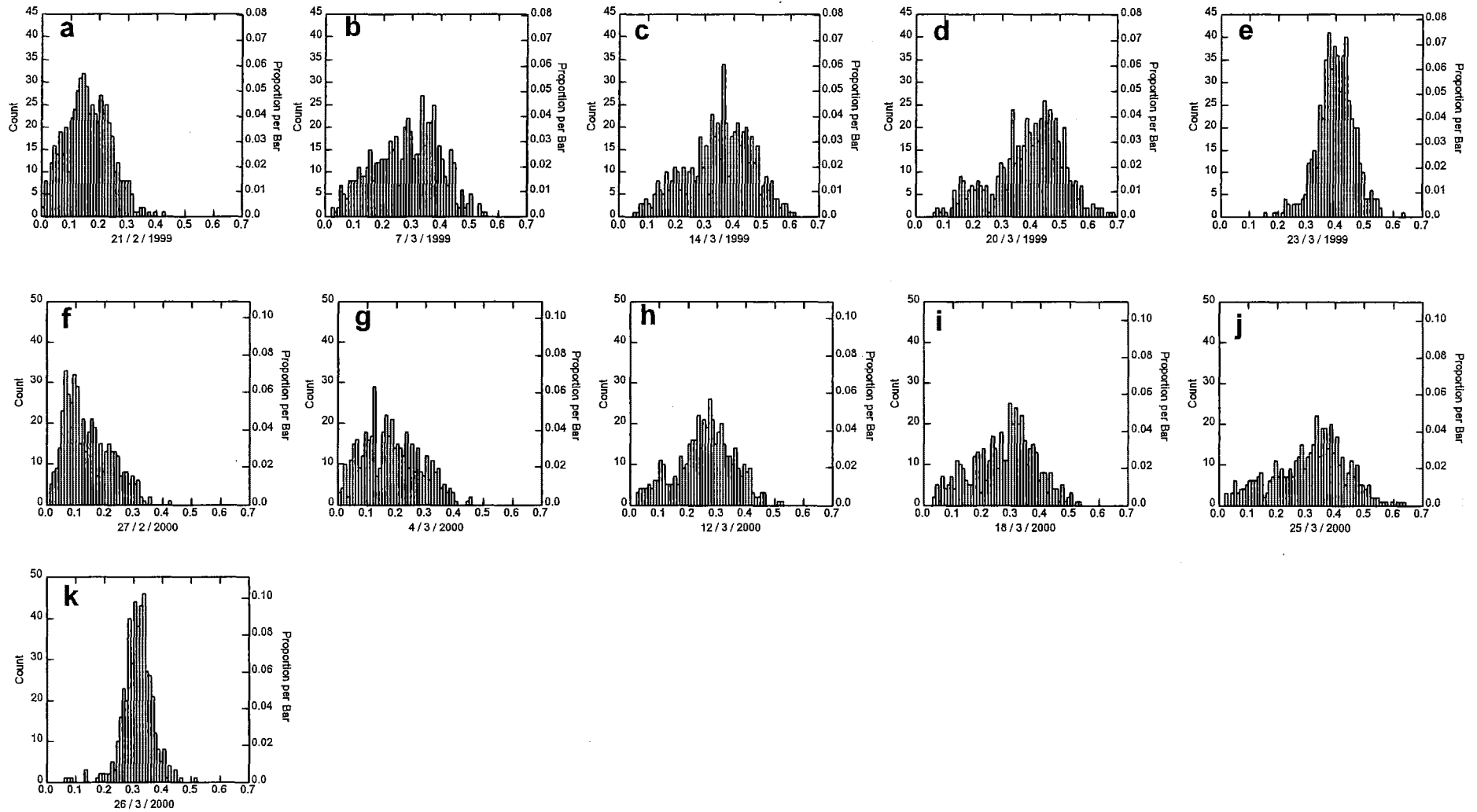


Figure 6.6 : The distribution of berry soluble solids content readings from individual berries on each sample date (a-d and f - j), and bunch samples at harvest (e & k) in 1999 and 2000 vintages.

There were some differences between the data distribution of subsets of the main source of variation. As an example, the distribution of flowering data from apical bunches had a lower C.V. than the basal and mid cane data in 1999 (Figures 6.7) when shoot position accounted for 42% of the variance (Table 6.1). There was no difference in the C.V. of the TA data in 1999 (Figure 6.8), but shoot position accounted for about 18% of the variance (Figure 6.1).

The distribution differences were unrelated to the variance due to that source variability though. This poor relationship between the C.V. range of the data and the variance that was due to a source of variability is shown in Figure 6.9.

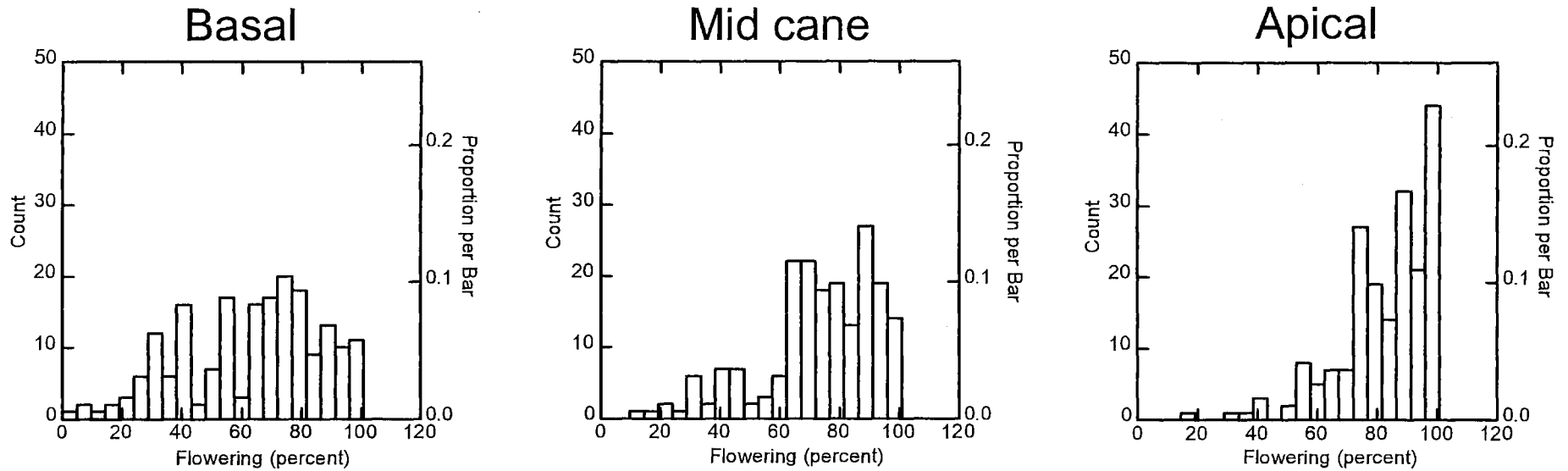


Figure 6.7 : Effect of shoot position on the distribution of Sauvignon blanc flowering percentage in December 1998. Descriptive statistics for each distribution are given in the table below.

	Shoot position		
	Basal	Mid cane	Apical
Mean	63.0	72.7	81.8
Standard Dev	22.8	19.0	15.1
CV %	36	26	20
Skewness	-0.46	-0.93	-1.29
SE Skewness	0.17	0.17	0.17
Skewed ^a	L	L	L
Kurtosis	-0.61	0.47	2.2
SE Kurtosis	0.35	0.35	0.35
Shape of curve ^b	n	n	LT

^a Whether the distribution is skewed: L = skewed left, n = normal, R = skewed right

^b Whether the shape of the curve fits a normal distribution: LT = longer tails than normal, n = normal, F = flatter than normal.

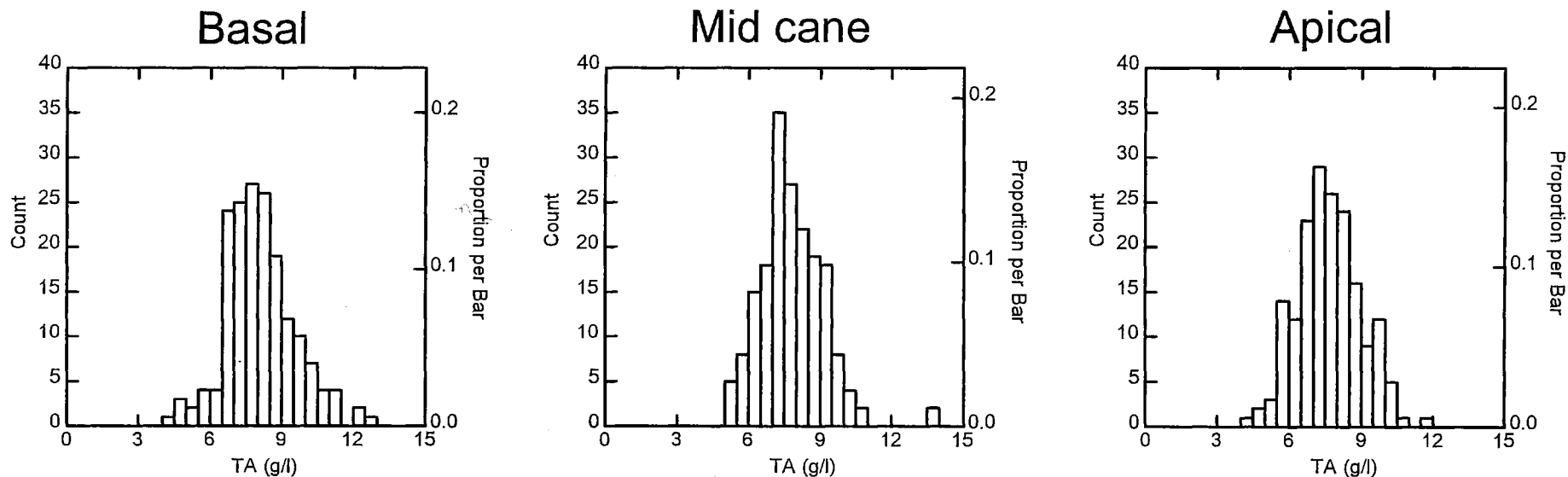


Figure 6.8 : Effect of shoot position on the distribution of Sauvignon blanc titratable acidity, 23 March 1999. Descriptive statistics for each distribution are given in the table below.

	Shoot position		
	Basal	Mid cane	Apical
Mean	8.11	7.86	7.7
Standard Dev	1.45	1.35	1.28
CV %	18	17	17
Skewness	0.4	0.8	0.16
SE Skewness	0.18	0.18	0.18
Skewed ^a	R	R	n
Kurtosis	0.65	2.24	-0.18
SE Kurtosis	0.36	0.36	0.36
Shape of curve ^b	n	LT	n

^a Whether the distribution is skewed: L = skewed left, n = normal, R = skewed right

^b Whether the shape of the curve fits a normal distribution: LT = longer tails than normal, n = normal, F = flatter than normal.

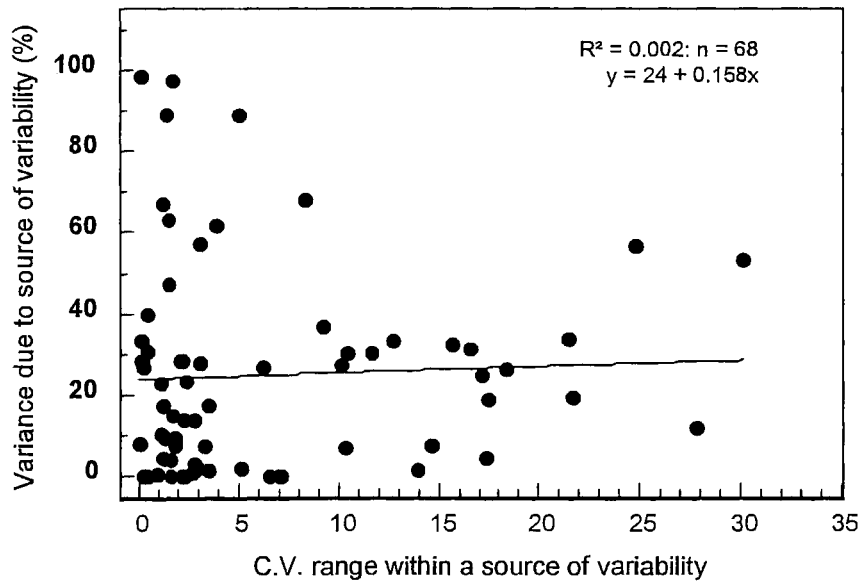


Figure 6.9 : The relationship between the C.V. range in data subsets within a source of variability and the variance due to that source of variability. Produced from phenology and juice composition data of Sauvignon blanc in 1999.

7.0 DISCUSSION

7.1 Variance and row orientation

There are few studies with which to compare the variance results. The proportion of brix and TA variance that was due to the shoots in 1999 was similar to that found over two seasons by Wolpert *et al.* (1980). However they selected shoots based on exposure, not on position. Both experiments had allocated vines into groups based on size. They found brix variance due to exposure varied from 1 to 32% between seasons whilst TA variance varied from 6 to 17%. The variance component estimates were described as “well within the range expected due to random variability” (Wolpert *et al.*, 1980). Given those results, the variance distribution differences between seasons in Figures 6.1 and 6.2 do not seem out of the ordinary.

Whereas this study found bunch position to be the major cause of variability, the study of Wolpert *et al.* (1980), found variance between vines was the major contributor to variability in juice composition. The row term of the analysis model used in this experiment included the vine to vine variability and accounted for 28.7 % at most of the variance in brix, TA or pH in either year.

Although the bunch position accounted for the majority of the variance in the juice composition data in 2000, the differences between bunch positions were not as large as differences between shoot positions or row orientation (Table 5.2). This seems to concur with the results of Wolpert *et al.* (1980). They found that vines contributed to 56% of the brix variance and the mean brix values differed by 1.2°, yet the shoot exposure contributed to 32% of the brix variance, and the mean brix values differed by 1.6°. The variance in the data due to a variability source does not appear to reflect the difference in mean values within that source. This is important for the viticulturist and wine maker, as it suggests that while a lot of variance in the composition may be due to one source of variability, there may be larger differences between mean values caused by other sources of variability.

The microclimatic effects of trellis and row orientation were expected to have a bigger effect on phenology post flowering than pre flowering. This was confirmed by the variance that was due to trellis and row at flowering increasing during véraison, and at harvest in 1999 (Tables 6.5, 6.6; Figures 6.1, 6.2). The air temperature, which effects the date of flowering (Ebadi *et al.*, 1995), was not likely to be influenced by the trellis type or row orientation. But environmental factors, light exposure and fruit temperature which effect the developing berry (Dokoozlian and Kliewer, 1996; Kliewer and Lider, 1968), would have varied with changes in trellis or row orientation (Naylor *et al.*, 2000; Smart and Robinson, 1991). In 2000 a change in canopy management caused a reduction in leaf area per shoot and most likely an increase in fruit exposure. The change in variance distribution was not as great between flowering and harvest in 2000 as it was in 1999, suggesting that the increased fruit exposure reduced the effect that trellis and row orientation had on the variance of the juice composition.

One of the ways in which the row orientation may have affected the variance in juice composition is the light environment of the fruit. The light distribution among E/W rows is more variable than N/S rows (DeJong and Doyle, 1985; Naylor *et al.*, 2000), causing greater maturity variability within E/W than N/S rows (Naylor *et al.*, 2000).

Variability in the maturity may arise from any combination of the following causes:

- Differences in photosynthetic ability - Leaves on the exposed side in full sunlight would be able to photosynthesise at a greater rate than the shaded leaves (Kreidermann, 1968), but their photosynthetic ability may decrease in the afternoon (Correia *et al.*, 1990). If this occurred, leaves on E/W rows would have a lower rate of photosynthesis than leaves on N/S rows in the afternoon.
- Altering berry phenology - A reduction in fruit exposure can delay the onset of véraison (Dokoozlian and Kliewer, 1996), and is known to delay fruit maturity (Smart, 1985).
- Light and temperature effects on juice composition - less light reaches fruit on the shady side of E/W rows compared to the exposed side (Naylor *et al.*, 2000). Whilst

the juice composition of grapes is reported to be similar between E/W and N/S row orientations (Intrieri *et al.*, 1996; Naylor *et al.*, 2000), there are larger differences in composition between each side of the canopy in E/W than N/S rows (Naylor *et al.*, 2000). The TA, brix, exposure and malic acid differences caused by row orientation in this experiment may be due to the sampling technique. The differences found by Naylor *et al.* (2000) and Smith *et al.* (1988), were from berries sampled equally from each side of the canopy. The sampling strategy in this trial was not based on fruit exposure and so these differences may have been caused by differences in fruit exposure (Table 5.2).

One of the problems facing viticultural researchers is when to harvest or sample a trial to ensure that any differences will be observed in the results. If a trial is harvested after one treatment has reached its maximum brix level through normal ripening (physiological ripeness), fruit from the other treatment(s) is then able to “catch up” to the first treatment. This can lead to treatment differences being detected in initial samples but not closer to, or at, harvest (Kasimatis and Vilas, 1985). The soluble solids content of the berries in the experiments reported here continued to increase throughout the sampling period (Figure 5.9), and the data distribution graphs (Figure 6.6) did not indicate that the berries had ceased to accumulate soluble solids. The implication of this is that treatment differences were not masked by one or more treatments having achieved physiological ripeness.

7.2 Leaf area and Leaf area:fruit weight (LAFW) ratio

Increases in LAFW have increased brix levels in field and container vines (Edson *et al.*, 1993; Kliewer and Weaver, 1971), and an optimum value given was 10 - 14 cm² /g (Kaps and Cahoon, 1992; Kliewer and Weaver, 1971). These studies and others (Petrie *et al.*, 2000a), have only used LAFW ratios for single shoot container vines or on a whole vine basis. Apart from Kliewer and Antcliff (1970), other studies have not described the effect of varying shoot LAFW ratios within a vine.

The LAFW ratio per shoot is not directly related to the whole vine crop load, which is usually expressed as a yield:pruning weight ratio. A high LAFW ratio per shoot can occur on a high crop load vine and a low LAFW per shoot on a low crop load vine. The average crop load of vines in this trial was 2.1:1 (kg of fruit:kg of prunings) in 2000, which is considered a low crop load (Smart and Robinson, 1991).

Many researchers have reported that a decrease in leaf area reduces the berry soluble solids content and berry fresh weight or volume (Buttrose, 1966; Edson *et al.*, 1993; Kaps and Cahoon, 1992; Kliewer and Antcliff 1970; Kliewer and Weaver, 1971). Petrie *et al.* (2000a) also found a reduction in soluble solids concentration and content with a reduction in leaf area. They found that berry dry weight was more sensitive than fresh weight to a 60 % reduction in leaf area though. The results of the present trial did not concur with these previous reports. Apart from shoots with a leaf area between 0 and 500 cm² per shoot there was no increase in soluble solids content per berry as the leaf area increased (Figure 5.14), and an increase in LAFW ratio did not increase bunch soluble solids (Figure 5.10), or soluble solids accumulation rates (Figure 5.13).

However the vines in this trial were field grown, whereas most of those cited were single shoot vines grown in pots. Kliewer and Antcliff (1970) using field grown vines, found that total leaf removal on every second shoot per vine did not greatly reduce brix levels on those shoots compared to shoots with their leaves retained. They cited four possible reasons for the lack of effect of defoliation and some of these were also likely to have played a role in the present trial.

- Better light utilisation of the remaining leaves, their defoliation treatments reduced shading. The mid cane shoots in this trial had the smallest leaf area in both seasons and so it is feasible that in this area of the canopy the leaves were better exposed to sun light.
- An increase in photosynthetic efficiency. Petrie *et al.*, (2000b) found that the rate of photosynthesis in older leaves does not decrease when carbohydrate supply is source limited. So total photosynthesis per shoot is related to leaf area, leaf age and sink strength, hence a low LAFW ratio does not automatically translate to a reduction in carbohydrate supply.
- Mobilisation of carbohydrate reserves. Vines totally defoliated at véraison in Kliewer and Antcliff's trial (1970), were still able to increase fruit brix levels from 8° to 14°, and Candolfi-Vasconsales *et al.*, (1994) found that carbon reserves were mobilised to the fruit of defoliated shoots. It is feasible that shoots with very low LAFW ratios in the present study would have been able to draw on the reserves of the vine to ripen their fruit.
- Low crop load. The vines in this trial had an average yield:pruning weight ratio of 2.1:1 in 2000, which is regarded as a low crop load (Smart and Robinson, 1991). This would not have put a carbohydrate stress on the vines.

At a crop load of 5:1 there was a positive relationship between berry soluble solids content and leaf area per shoot, but at a crop load of 1:1 it was a negative relationship (Figure 5.15). The relationship between leaf area and berry weight was also similar for each crop load if the effect of one berry was ignored (Figure 5.16). However, there was a positive relationship between brix and leaf area at a crop load of 5:1 but not at 1:1 (Figure 5.17). What did appear to be influencing these relationships, was the effect of shoots with a leaf area of less than about 600 cm².

When the effects of leaf area and LAFW ratio per shoot were plotted separately, it appeared that berry soluble solids content and berry weight would respond positively to an increase in shoot leaf area up to about 500 cm² regardless of LAFW ratio (Figure 5.18). Beyond a leaf area of 500 cm² per shoot the response was much less marked. These two relationships corresponded generally with those found using potted single

shoot vines (Buttrose, 1966; Kaps and Cahoon, 1992; Petrie *et al.*, 2000a), but the response to increasing leaf area in those studies continued beyond 1000 cm². Buttrose (1966) recorded an improvement between 850 cm² and 2470 cm² of leaf area but had no intermediate area. Kaps and Cahoon (1992) suggested an optimal LAFW ratio of 8 - 10 cm²/g which corresponded to a leaf area of 2000 - 3000 cm², but the response continued beyond that. The vines in both of those trials would have been unable to mobilise significant carbohydrate reserves as field vines are able to, and perhaps the soluble solids content and berry weight was more dependant on the leaf area for carbohydrate.

The relationships discussed above suggested that juice composition variance due to bunch and shoot position was not likely to have been caused by leaf area and LAFW ratio of the shoots. At a higher crop load per vine it may well have had a greater impact, but in the following sections other causes of variability are discussed.

7.3 Bunch position

The advance in phenology and maturity of the primary bunches was similar to other published results and reviews (May, 1988; Trought, 1996; Wolpert *et al.*, 1980). The differences in phenology and composition due to bunch position were much greater in 2000 than 1999 though, and the reasons for this seem to lie with the phenology at flowering.

The 1 day delay in flowering of the secondary bunch in 1999 was the same as the delay in it reaching 16° brix compared to the primary bunch. This suggested that the phenology of the bunches was not being influenced separately by fruit exposure between flowering and harvest in 1999. Shading Cabernet Sauvignon berries during stages I and II of berry development delayed the onset of véraison (Dokoozlian and Kliewer, 1996), so the increased fruit exposure of primary bunches in 2000 (Table 5.2), may have been sufficient to increase the difference in phenology from 2 days at flowering to 3 days at harvest (Figures 5.2 & 5.5).

An increase in LAFW ratio may also increase fruit soluble solids, Kliewer and Weaver (1971) increased the brix of the fruit from approximately 12° to 18° by increasing the

LAFW ratio from 3cm²/g to 8cm²/g. However, the LAFW ratio per shoot for primary and secondary bunches is essentially the same. At LAFW ratios between 3 and 20 cm²/g, neither the average weighted brix per shoot, nor the increase in berry soluble solids content per day was affected by the number of bunches per shoot (Figures 5.11, 5.12). Similarly, primary and secondary bunches had the same rate of increase in berry soluble solids content per day at a range of LAFW ratios (Figure 5.13). The figures presented are from the 2000 vintage, but the response was the same in each season. The reasons for this lack of response to an increase in LAFW ratio have been outlined above (Section 7.2).

The reason for the bunch position accounting for so much of the variance in 2000 relative to 1999 was probably a reduction in variability due to trellis and row in 2000. A reduction in the proportion that one source accounted for could only lead to an increase in one or all of the other sources. This is covered in more detail under section 7.5 below.

7.4 Shoot position

As with the differences between the bunch positions, the advance in phenology and maturity of apical shoots compared to basal shoots described here is consistent with other studies and reviews (Antcliff and Webster, 1955; May, 1988). Harder to explain, was why the difference in phenology between apical and basal shoots at flowering and véraison decreased by harvest in 1999, yet stayed the same in 2000.

The lower leaf area of basal shoots could have been expected to increase the gap in phenology in 1999 if, as Petrie *et al.* (2000a) reported, a reduction in leaf area delayed véraison. The leaf area was not responsible for changes in soluble solids and berry weight unless it was below about 500 cm² though (see section 7.2). Nor did the shoot position affect the rate of soluble solids accumulation (Figure 5.9), or the relationship between brix and LAFW ratio (Figure 5.10). So it seems unlikely a reduction in leaf area per shoot on basal shoots would have advanced the phenology relative to apical shoots. These results indicated that, if anything, the delayed phenology of basal shoots at flowering and véraison should have been maintained at harvest in 1999. The fact that

there were only small differences in maturity, and the relative leaf area differences were similar between the years of the experiment suggests that the difference lies elsewhere.

One of the main differences between the years was the change in canopy management with more extensive leaf removal as well as lateral removal in 2000. Apical shoots had a greater leaf area in 1999 and, being on the end of a cane, were in close proximity to other shoots that also had large leaf areas. Following this line of reasoning, it is possible that the apical shoots were more shaded than the basal or mid cane shoots in 1999. Therefore the effects that shaded leaves and fruit have on fruit development should be considered.

Shading of the leaves or fruit increased the length of stages I and II of berry development (Dokoozlian and Kliewer, 1996), delaying véraison. Shading of leaves decreased the soluble solids concentration of Cabernet Sauvignon berries (Morrison and Noble, 1990), and increasing fruit exposure has resulted in increases in brix level and reductions in TA (Kliewer *et al.*, 1988; Smith *et al.*, 1988). The maximum increase in soluble solids and decrease in TA was obtained by increasing fruit exposure before véraison (Smith *et al.*, 1988).

However the juice composition results did not suggest that the fruit on apical shoots was less mature than basal or mid cane shoots in 1999 (Table 5.2). However, the facts that the phenology was advanced at flowering in both years; there was no difference in juice composition at harvest in 1999; and a change in canopy management the following year resulted in a difference at both flowering and harvest, all pointed to leaf or fruit shading delaying the development of fruit on apical shoots post flowering in 1999.

With the change in canopy management in 2000, the difference at flowering was maintained at harvest and the delay in maturity of basal shoot bunches in 2000 seemed to be a direct result of the delay in flowering.

The amount of variance that was due to shoot position decreased after flowering in each year. By véraison in 1999 it accounted for only 27 % of variance having been as high as

almost 58 % at flowering. As with the variance due to bunch position, this decrease was probably due to an increase in the effects of row orientation and trellis type on fruit development post flowering.

The large decrease in the amount of juice pH variance due to shoot position from 1999 to 2000 may have been due to the increase in leaf removal. Juice pH is known to increase if there is significant shading of the leaves. An increase in pH is not considered an indicator of increased maturity if unaccompanied by increased brix and decreased TA (Boulton, 1980). This was possibly the case in 1999, as the TA and brix differences between shoot positions were not significant yet the juice pH difference was (Table 5.2). If the apical shoots were more shaded in 1999 as speculated above, then this may have led to more variable juice pH levels. In 2000 with even fruit exposure between shoot positions (Table 5.2), there was a reduction in pH variance due to shoot position.

The shoot orientation of S-H canopies often causes concern about the variation between upward and downward facing shoots (Smart, 1998). While leaf area, phenological, brix and radiation absorption differences have been found between upward and downward oriented shoots (Kliewer *et al.*, 1989; Lovisollo and Schubert 2000; Morsi *et al.*, 1992), they do not relate well to the S-H trellis system. Morsi *et al.*, (1992) were comparing shoot orientations on separate vines; Kliewer *et al.* (1989), altered the shoot orientation from bud burst onwards, not flowering; and Lovisollo and Schubert (2000), removed the fruit and laterals from the vines.

In this study there was a similar brix and TA difference between the shoots on the upper and lower bilateral cordon irrespective of whether they were upward or downward oriented. Research in Oregon, USA has not found any consistent quality differences between the upper and lower curtains of a S-H trellis either (Smart, 1998). The brix increase on upwards shoots observed by Kliewer *et al.* (1989), did not occur in this experiment when the shoot orientation was altered at flowering instead of bud burst (Figure 5.19). Kliewer *et al.* (1989), suggested that reduced leaf area on downward shoots may have slowed their phenology and fruit development. In this experiment the leaf area of the two shoot orientations was similar though (Table 5.4). It was expected at

the beginning of the trial that shoot orientation differences would contribute to the trellis effect on juice composition variance. However, as both trellis types had similar differences between shoot positions (Figure 5.19), the shoot orientation was unlikely to increase the juice composition variance of S-H vines compared to VSP vines.

7.5 Trellis

The increase in brix and reduction in TA of S-H fruit in 1999 is consistent with reported advances in maturity compared to VSP trellising (Smart and Robinson, 1991). The largest differences in juice composition occur when the VSP canopy is vigorous and creates a shaded fruit zone (Smart, 1998). This is because increases in both fruit exposure and active leaf area are responsible for the advanced fruit maturity of S-H vines (Smart and Robinson, 1991).

As there was no difference in the flowering time between the trellis types, the advanced maturity of S-H fruit in 1999 must have arisen after flowering. It may have been due to:

- an increase in leaf area on S-H shoots compared to VSP shoots.

The leaf area of the S-H trellis can be up to 60% greater than the VSP trellis, giving it a greater photosynthetic capability (Smart and Robinson, 1991). The leaf area of S-H shoots was 25% and 6% greater than VSP shoots in 1999 and 2000 (Table 5.3). The S-H fruit maturity was only advanced compared to VSP fruit in 1999 when the difference in leaf area was greatest. This suggested that the greater leaf area of S-H shoots and vines was at least partly responsible for the advance in maturity. However, earlier in the discussion it was shown that there was a poor relationship between the leaf area per shoot and the soluble solids of the subtending fruit. For the leaf area of S-H shoots to have caused the increase in fruit maturity in 1999, a better relationship between leaf area and soluble solids would have been expected.

- An increase in the amount of fruit shading in the VSP trellis.

Whether the advance in maturity of S-H fruit was partly due to an increase in fruit exposure was difficult to determine. Whilst increased fruit exposure has

been found to advance fruit maturity (Bledsoe *et al.*, 1988; Naylor *et al.*, 2000; Smith *et al.*, 1988), the increase in S-H fruit exposure in 2000 was not great enough to decrease the malic acid concentration, or advance fruit maturity (Table 5.2). A dense shaded canopy in VSP vines was more likely to have occurred in 1999 than 2000. Leaf removal by hand (as in 2000) can result in 95% fruit exposure compared to 56 % for machine leaf removal (Smith *et al.*, 1988). Lateral leaves were also removed in 2000, further reducing the likelihood of shading. With the leaf area in 1999 being 64 % greater than 2000, the fruit exposure differences between S-H and VSP bunches were probably greater in 1999.

An increase in fruit and leaf exposure is the most likely reason for the maturity advance in 1999. The benefits to the fruit maturity of an increase in leaf and fruit exposure and their likely effect on other sources of variability have already been alluded to.

The suspected poor fruit exposure in VSP vines in 1999 is probably the reason for the amount of variability in the juice composition that was due to trellis in 1999. When the canopy management resulted in a similar fruit exposure level in 2000 (Table 5.2), very little of the variability in juice composition was due to trellis (Figure 6.1, 6.2).

The reduction in brix and TA variance due to row within S-H data compared to VSP data (Figures 6.3 & 6.4), was likely to be due to a reduction in shading of fruit and leaves. Naylor *et al.*, (2000) found that both fruit exposure and juice composition was more variable in E/W than N/S rows. They suggested reducing fruit shading may reduce the juice composition variability. Because the fruit shading in S-H vines is typically less than VSP (Smart and Robinson, 1991), the juice composition variability of S-H vines in E/W rows should have been less than VSP vines. This would cause the reduction in variance within the S-H data due to row orientation compared to the VSP data.

The increase in pH variance due to row within the S-H data was difficult to explain (Figure 6.3). There was no pH variance due to row when all the data was analysed together (Figure 6.2), and so it was suspected that splitting the data, and analysing for

row variance would have led to false results. However, there was no brix variance due to row in three of the pre harvest samples in 1999 (Figure 6.1), yet the variance due to row reduced in the S-H data set just as it had in the harvest brix data (Figure 6.4). So if the pre harvest brix variance had responded consistently, why hadn't the pH variance?

The juice pH variability was expected to respond in a similar manner to the brix and TA, an increase in fruit exposure would reduce the variability. However leaf shading can increase the juice pH (Smart and Robinson, 1991), but the relationship is complicated by the role of potassium, which will also increase in the berry due to leaf shading and increase the pH (Boulton, 1980). Increased fruit exposure caused an increase in juice pH consistent with an increase in fruit maturity (Smith *et al.*, 1988), but potentially, an increase in fruit exposure may not override the effects of leaf shading. Leaf shading had a larger influence than fruit shading on pH of Cabernet Sauvignon juice (Morrison and Noble, 1990), and shading of bunches had no effect on juice pH of potted Pinot noir and Cabernet Sauvignon vines (Dokoozlian and Kliewer, 1996).

Juice pH seems unlikely to respond to leaf and fruit shading in the same manner as acids and soluble solids. Leaf shading can increase the malic acid content at harvest and also reduce soluble solids accumulation (Morrison and Noble, 1990). However, this could be mitigated by an increase in the fruit exposure which increased the fruit temperature (Kliewer and Lider, 1968), in turn increasing the respiration of malic acid (Kliewer, 1971; Ruffner, 1982b). An increase in fruit exposure has also been suggested as increasing the enzymatic synthesis of sugars (Kliewer *et al.*, 1988).

The pH response indicated that variability of leaf shading within the S-H vines was greater between row orientations than the VSP vines. This could cause the increase in juice pH variance due to row in the S-H data as shown in Figure 6.3.

7.6 Shoot and bunch position interaction and flavour implications.

The shoot and bunch position effects caused the largest differences in maturity to occur between secondary bunches on basal shoots (least mature), and primary bunches on apical or mid cane shoots (most mature). This is illustrated in Figure 7.1 where the average °Brix and TA values for bunches at those positions are presented. The size of the brix and TA differences between the shoot/bunch positions is generally similar between the two trellis types.

The differences in fruit maturity have implications on the flavour spectrum of the fruit as well. Whether the delay in maturity was caused by a delay in flowering or differences in fruit and leaf exposure, it is likely that the concentrations of methoxypyrazines, norisoprenoids and monoterpenes were different also.

The concentration of methoxypyrazine decreases rapidly after véraison (Allen *et al.*, 1996), so a delay in maturity should translate into a delay in the decrease of methoxypyrazine also. Increased concentrations of isobutyl-methoxypyrazine are likely to increase the grassy / herbaceous / vegetal aroma of the juice and wine (Lacey *et al.*, 1988). If the maturity delay was due to an increase in fruit shading, then the effect on the methoxypyrazine level is more complex. Fruit shading is likely to reduce the accumulation of methoxypyrazine prior to véraison, but also the degradation of methoxypyrazine after véraison (Hashizume and Samuta, 1999). As well as this, the degradation of methoxypyrazine will be delayed by the delay in véraison.

Fruit shading is likely to have reduced the accumulation of norisoprenoids (Calo *et al.*, 1996; Razungles *et al.*, 1996). In contrast to the methoxypyrazines, their formation is positively correlated to light exposure and temperature post véraison (Calo *et al.*, 1996; Marais, 1996; Razungles *et al.*, 1996). A delay in véraison due to delayed flowering, would also reduce the time for norisoprenoid formation prior to harvest.

A delay in maturity of 2.2° brix (Figure 7.1), between bunch and shoot positions was likely to have caused an increase in the methoxypyrazine concentration (green flavours), and a reduction in the norisoprenoids (ripe flavours) of the less mature fruit.

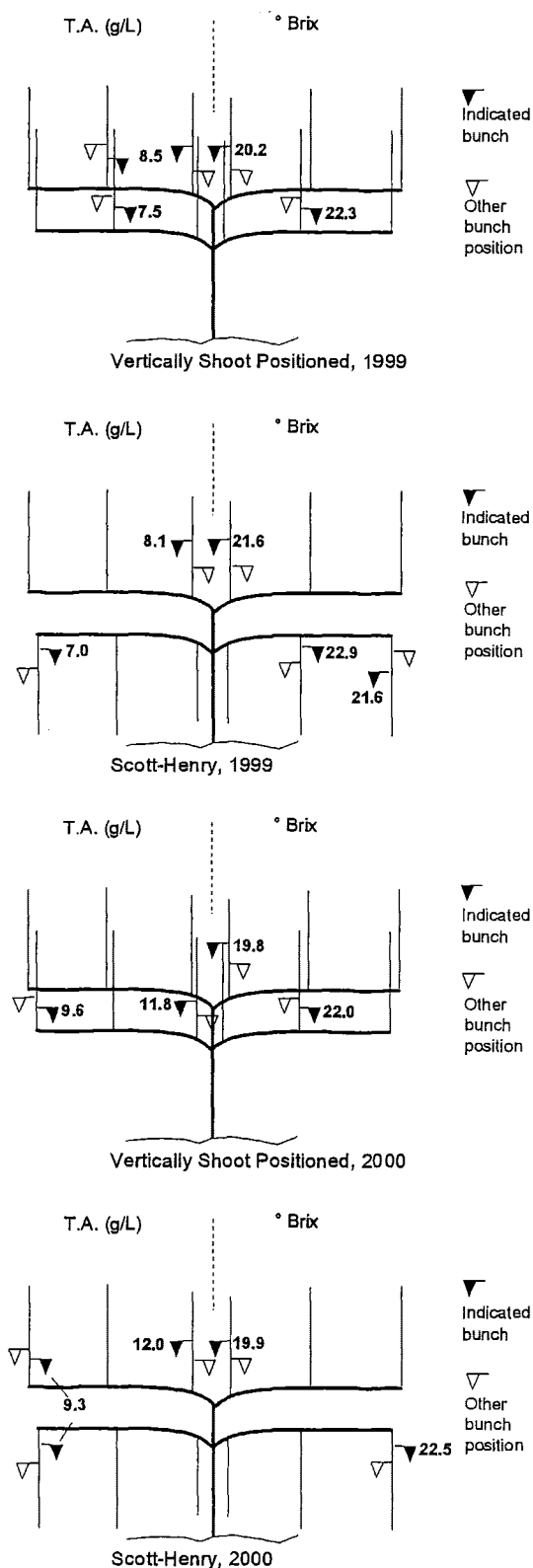


Figure 7.1 : The highest and lowest average bunch soluble solids (°Brix) and TA of Sauvignon blanc according to bunch and shoot position within two trellis types. The diagrams indicate the general shoot x bunch position where the maximum/minimum occurred, e.g.: basal shoot/secondary bunch. Secondary bunches on basal shoots are generally the least mature on the vine.

8.0 CONCLUSIONS AND FUTURE RESEARCH

The least mature bunches on the vine at harvest are likely to be secondary bunches on basal shoots, the most mature will be primary bunches on apical (S-H) or mid cane (VSP) shoots. Within the vine however, the shoot position causes a larger juice composition difference than the bunch position on a shoot. The differences are due to both delays in phenology inherent in the vine, and differences in fruit exposure at the different shoot positions. The size of the differences were unaffected by trellis type, and this was probably due to similar differences in fruit exposure between shoot positions within each trellis type.

A small delay in the maturity of VSP fruit was attributed to a reduction in the fruit exposure relative to S-H fruit. Whilst brix differences between row orientations were larger than differences between shoot positions, they were more likely to be a result of the bunch position within the canopy than a true reflection of row orientation effects.

Differences in fruit exposure will cause larger juice composition differences than phenological differences in a cool climate. When trellis types and shoot positions had similar fruit exposure levels, juice composition differences caused by trellis type were reduced, but differences caused by shoot position remained. For the viticulturist, these results demonstrated that to reduce juice composition variability within the vine, the fruit must be well exposed, and the phenological variability reduced.

Neither variation in leaf area, nor LAFW ratio per shoot caused variation in the soluble solids and berry weight as expected. The relationships obtained by other researchers using potted grape vines were irrelevant to individual shoots in this study. This was probably due to the crop load of the vines being low enough that carbohydrate reserves were remobilised. The effects of varying leaf area or LAFW on individual shoots is worth researching on vines at a higher crop load than those used in this study. At a higher crop load, variable leaf area and LAFW ratios between shoot positions may increase the differences in juice composition. Utilising shoot thinning, or limiting the bud number at pruning are ways in which the viticulturist may be able to manipulate the shoot vigour and reduce this source of variability.

Juice composition differences are not reflected in the variance of the data. Despite the juice composition differences caused by shoot position, the bunch position caused most of the variance when the fruit exposure of shoot positions and trellis types was similar. In the first year of the trial, juice composition variance was spread between all of the sources of variation, and this was attributed to a lower level of fruit and leaf exposure to sunlight. This supposition really needs to be confirmed with experiments which measure fruit and leaf exposure as well as data variability.

Whilst this experiment quantified the differences in juice composition, it did not quantify the amount of fruit within a maturity category on the vine to produce a weighted juice composition. This is also worthy of further study, and would link with the variability of juice composition in East/West and North/South rows found in previous research.

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APPENDIX I - The effects of row orientation and fruit exposure on the juice composition of Sauvignon blanc (*Vitis vinifera* L.).

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The effects of row orientation and fruit exposure on the juice composition of Sauvignon blanc (*Vitis vinifera* L.)

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Abstract

The effects of N-S and E-W row orientation and fruit position on the juice composition of Sauvignon blanc grapes were measured using five vineyard sites around the Wairau Plains in Marlborough, NZ. Light measurements and fruit samples were taken from the exposed sides of exterior bunches and the shaded sides of interior bunches in late March 1999. Northward (N), facing fruit received more light (80 % ambient), than southward (S), facing fruit (23 % ambient). The light received by eastward (E) and westward (W), facing fruit varied with the time of day. The brix of N fruit was 22.7 compared to 19.9 for S fruit and 20.6 for interior (I), fruit. The titratable acidity and malic acid levels of N fruit were lower (6.8 and 2.7 g/l respectively) than S (8.9 and 4.4 g/l), or I fruit (8.9 and 3.7 g/l respectively). The malic acid concentration was negatively correlated with light exposure of the bunches ($R^2=0.648$). Juice composition differences between fruit positions were larger in E-W rows than in N-S rows. The flavours of the juices were not measured, but it is likely that there was a broader flavour spectrum in E-W rows than N-S rows. Fruit from N-S rows would be more suitable for blending options, but fruit from the shaded side of E-W rows may be useful to maintain typical herbaceous Sauvignon blanc flavours in warm seasons.

Introduction

Within the grapevine canopy the micro climate has a major impact on the development of grape maturity and flavour. Light exposure of the fruit is perhaps the most important part of the canopy micro climate, as an increase in exposure influences some flavour compounds directly (Marais 1996), and increases the fruit temperature (Kliewer and Lider 1968), altering the phenology of the plant.

Increasing the shoot leaf area and the shoot density reduces the light interception of the bunches and leaves within the canopy. Viticultural practices such as leaf removal and divided trellis systems aim to improve the canopy micro climate by increasing fruit exposure. Leaf removal can increase fruit maturity and reduce herbaceous aromas of Sauvignon blanc, due to a reduction in methoxypyrazines (Allen et al., 1996). Designing the trellis to increase fruit exposure increases fruit maturity.

The row orientation also affects the light interception of the fruit. The light distribution on the sides of rows orientated N-S is more even than rows orientated E-W, even though the total light received is similar. The reduction in light interception patterns of rows orientated E-W has resulted in yield reductions for both pears (Lombard and Westwood, 1977), and peaches (DeJong and Doyle, 1985). Yield reductions of 20 % have also been noted for grapes grown on E-W rows compared to N-S rows, the difference being due to a reduction in clusters per shoot (Intrieri et al., 1996).

There was no apparent effect of row orientation on the maturity and quality of the pears (Lombard and Westwood, 1977), or the juice composition of Chardonnay grapes (Intrieri et al., 1996). A reduction in soluble solids and an increase in titratable acidity were reported for grapes from the southern side of a canopy compared to the northern exposed side, suggesting a delay in maturity (Smith et al., 1988).

Whilst Smith et al., (1988) reported these differences, the experiment was not comparing row orientation effects and there is little in the literature regarding the effects of row orientation on juice composition or flavour of grapes. The experiment reported here studies the differences in juice composition between fruit from N-S and E-W row orientations.

Methods and Materials

Sauvignon blanc vines grown at five vineyards within the Lower Wairau Valley, Marlborough, NZ (Latitude approx. 41.5° South) were used in the study. The treatments consisted of two row orientations, north south and east west and three positions in the canopy - the exterior of each side and the interior zone. Within each row orientation at each site three to five vines that had similar canopy vigour were identified and on those, five basal bunches were tagged in each position. These bunches were used for light measurements and fruit sample collection.

Light energy was recorded as W/m² between March 18th 1999 and March 26th 1999 using point measurements at the top, middle and bottom of the exposed side of each exterior bunch, and the shaded side of each interior bunch. The measurements were taken at 0800, 1200 and 1600 hours NZST at each site on a day with no cloud cover, and the ambient light level was also recorded. Each group of 15 readings for each plot / time combination was expressed as a percentage of the ambient light energy and then averaged.

Juice composition was determined on a sample of 125 berries which consisted of 25 berries from each tagged bunch collected prior to commercial harvest. The berry sample was weighed and frozen at -18° C prior to analysis. After thawing, the whole berries were crushed in the plastic bags by hand and the juice strained through muslin cloth.

The soluble solids of the juice was read on a

digital refractometer and the titratable acidity and pH of 10 ml of juice in 50 ml of distilled water were analysed using a Metrohm autotitrator with 0.1N NaOH and a titration endpoint of pH 8.2. 10 ul samples of juice in 390 ul of distilled water were used to determine malic and tartaric acids, glucose and fructose levels of the juice in a Biofocus 3000 Capillary Electrophoresis System (Biorad Scientific, Hercules, CA.).

The trial was analysed as a split plot design where each row orientation was a main plot, and the three areas of the canopy were the subplots. Each of the vineyard sites was treated as a block so that the viticultural differences between the sites were removed from the treatment effects.

Results

Light levels

Fruit on east west rows received more light than north south rows at 0800 h but the opposite occurred at 1200 h. At 1600 h there was no difference in light exposure between row orientations (Table 1).

Table 1. Effect of row orientation on fruit exposure (percent of ambient light).

Row orientation	Time (NZST)		
	0800 h	1200 h	1600 h
E-W	31.7	54.8	42.2
N-S	49.9	33.0	48.0
Significance ¹	**	*	NS
LSD ²	11.9	12.7	17.8

¹ NS, *, **: Not significant, significant at $P \leq 0.05$ and $P \leq 0.01$ respectively

² LSD is calculated at $P = 0.05$ where significance is NS or * and at $P = 0.01$ in all other cases.

The amount of light that reached the exterior fruit varied according to the aspect of the exterior fruit (north, south, east or west) and the time of day (Figure 1). Northward facing fruit was exposed to high levels of light (60 - 98 % of ambient), at each measurement time whereas southward facing fruit received 18 - 31% throughout the day. Eastward facing fruit received 76 % of ambient light in the morning but less than 45 % from midday

onwards whereas the opposite is true of westward facing fruit.

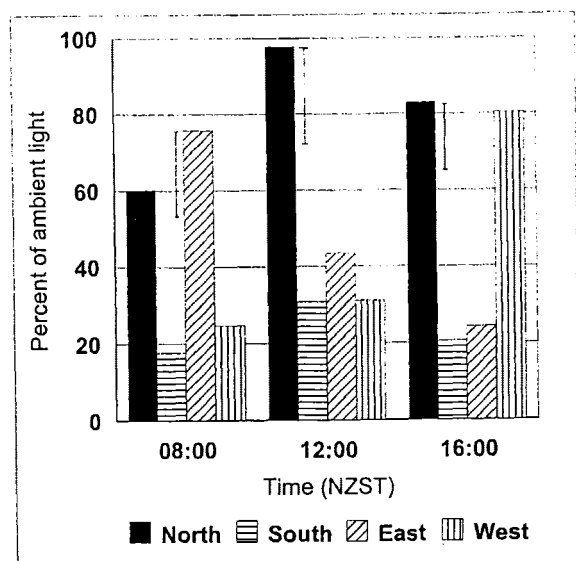


Figure 1. Effects of the interaction between row orientation and fruit position on the percent ambient light interception of exterior fruit. Bars are the LSD for comparing means at each measurement time.

The percentage of ambient light intercepted by the fruit was not uniform. At 0800 h readings from northern, eastern, and bunches from the interior of N-S rows were the most variable. At 1200 h readings from the eastern bunches were the most variable, and at 1600 h readings from the northern bunches were more variable than eastern and southern bunches and the interior of E-W rows.

Juice composition

The average berry weight, and the juice composition parameters for each row orientation were similar (Table 2). However there were differences due to fruit position and the fruit position within each row orientation.

Fruit from the row interiors had a higher titratable acidity and malic acid concentration than fruit from the exterior positions. The differences in juice composition between

Exterior 1 and Exterior 2 were due to the differences between the northern and southern exterior fruit. The juice composition of eastward and westward facing fruit was similar.

The northward facing berries were 0.3 g lighter than the interior fruit of N-S rows (Table 2). The brix of northwards facing fruit was higher than all other positions except the eastward facing fruit. The amount of sugar per berry was not significantly different between the fruit positions (*Mean 0.40 g/berry, range 0.38 - 0.42 g/berry*). The titratable acidity and malic acid concentration of northward facing fruit was lower than southward facing fruit, or the interior fruit of either row orientation. Eastward, westward or northward facing fruit all had similar titratable acidity and malic acid concentrations (Table 2, Figure 2).

Table 2. Effect of row orientation, fruit position and their interaction on berry weight and juice composition of Sauvignon blanc.

	Berry wt (g)	Brix	T.A (g/l)	pH
Row orientation				
East / west	1.84	21.0	8.32	3.23
North / south	1.94	21.1	7.72	3.27
Significance ¹	NS	NS	NS	NS
LSD ²	0.08	1.3	0.71	0.12
Position				
Ext1 (N or E)	1.79	22.0	7.08	3.33
Interior	1.96	20.6	8.92	3.25
Ext2 (S or W)	1.93	20.6	8.05	3.18
Significance ¹	*	**	**	NS
LSD ²	0.13	0.8	0.71	0.14
Orientation x position				
E-W North	1.73	22.7	6.82	3.38
Interior	1.89	20.6	9.24	3.23
South	1.91	19.9	8.89	3.08
N-S East	1.86	21.4	7.34	3.27
Interior	2.03	20.6	8.60	3.27
West	1.94	21.2	7.21	3.28
Significance ¹	NS	**	**	NS
LSD ²	0.21	1.4	1.27	0.23

¹ NS, *, **: Not significant, significant at $P \leq .05$ and $P \leq .01$ respectively.

² LSD is calculated at $P=0.05$ where significance is NS or * and at $P=0.01$ in all other cases.

Treatment differences in titratable acidity were due to differences in malic acid concentration (Figure 2). The only juice pH difference was an increase of the northward facing fruit pH compared to southward fruit.

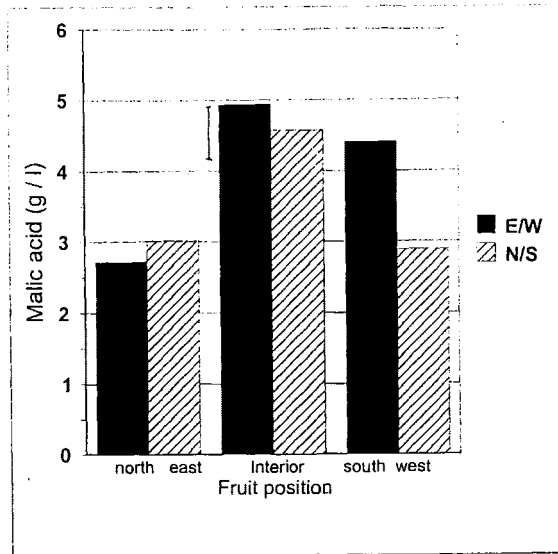


Figure 2. Effect of fruit position on malic acid concentration of Sauvignon blanc juice. Vertical bar represents $LSD_{0.01}$

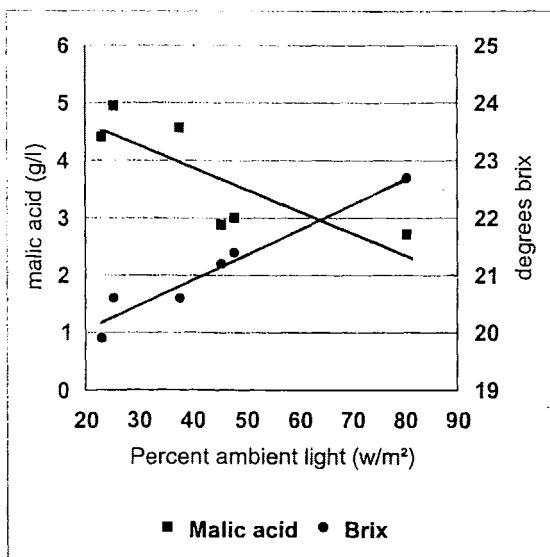


Figure 3. Effect of average daily light exposure (percent of ambient) on the malic acid and soluble solids concentration (brix)

of Sauvignon blanc juice.

There was a negative correlation between the percent of ambient light received and the malic acid concentration ($R^2 = 0.648$; $n = 6$; $y = 5.41 - 0.0383x$), (Figure 3). There was a positive correlation between the percent of ambient light received and the brix of the juice ($R^2 = 0.947$; $n = 6$; $y = 19.1 + 0.0448x$), (Figure 3).

Discussion

The amount of light intercepted by the fruit in the morning and around midday varied according to row orientation. DeJong and Doyle (1985), found that total light interception was similar for these two row orientations in a peach orchard. They measured photosynthetic photon flux density (PPFD) at 10 second intervals over 24 hours and calculated an average over the whole day. This is a much more accurate way of assessing the total light energy received throughout the day than measuring light levels at three times in the day (Cain, 1972).

The results of the current study are in agreement with DeJong and Doyle (1985), in that light distribution was more uniform in N-S rows than E-W rows. Fruit on both the eastern and western sides of the N-S canopy received in excess of 75 % of ambient light during the day. Fruit on the southern side of the E-W canopy received about 35 % of ambient light at the most compared to the northern fruit receiving nearly 100 % at the same time (Figure 1).

The interior fruit of N-S rows also received higher light levels at 0800 h than E-W interior fruit and a similar trend occurred at 1600 h. The angle of the sun is close to perpendicular to the canopy wall at these times, allowing greater light penetration through canopy gaps. The increase in variability of light readings from N-S interior bunches at 0800 and 1600 hours is a reflection of more sunflecks being intercepted at these times. At 1200 h the sun is directly overhead a N-S row and sunlight

must penetrate all the leaf layers if it is to be intercepted by the bunch.

The effect of row orientation on the amount of light intercepted by each side of the canopy will vary during the season. In the middle of summer the sun will rise in the south-east and set in the south-west. This means light is intercepted by the southern side of the canopy during the early morning and late afternoon (DeJong and Doyle, 1985).

The effects of row orientation on the overall juice composition were not significant (Table 2), which is similar to the results reported by Intrieri et al. (1996). However, there were greater differences in juice composition between the positions of E-W rows than N-S rows. This may be detrimental to wine quality. When two wines were made from grapes with similar maturity indices the higher quality wine was made from the fruit with the least variation around the mean maturity (Long, 1986). Comments of Montana Wines wine makers indicate that there are benefits to E-W row orientation in some years though. In a hot year such as the 1998 vintage, the E-W rows retained more of the typical herbaceous flavours than N-S rows (Materman, pers. comm.). Isobutyl methoxypyrazine is responsible for the herbaceous aroma of Sauvignon blanc and is known to decrease rapidly after véraison in high light or temperature conditions (Lacey et al., 1988; Marais et al., 1996). In hot seasons the shaded fruit on the southern side of the E-W canopy may be able to retain more methoxypyrazines than the exposed fruit of N-S orientated rows.

The selection of extremely well exposed and shaded interior fruit in this experiment may have exaggerated the size of the differences present within the crop. The variability in composition within the exterior bunches can be greater than that within the shaded bunches (Kliewer and Lider, 1968), and this effect was not considered. To understand the true effects of the variability within the E-W rows, some measure of the variability along a

transect through a vine may be necessary.

The juice composition of fruit from the interior of both row orientations and the southern fruit, indicates that maturity was delayed compared to exterior fruit from the northern, eastern or western positions. Smith et al., (1988), found similar differences between northern, southern and interior fruit of rows orientated E-W. Because of the complex relationship between light and temperature, and the way in which they affect fruit maturity, it is possible that the differences were due to direct effects of light exposure and not a delay in maturity.

There is an increase in fruit temperature associated with increased light exposure (Kliewer and Lider, 1968), and this may explain the smaller berry size and high brix level of northern fruit. The amount of sugar per berry was not affected, suggesting that the increase in brix was a result of concentration of sugar in the smaller berries. A decrease in berry size and an increase in the brix of exposed fruit compared to partially shaded fruit was attributed to an increase in the fruit temperature by Reynolds et al., (1986).

An increase in berry temperature can also increase the rate of malic acid reduction during maturity (Ruffner, 1982; Kliewer 1971). In this experiment, the concentration of malic acid was lowest in berries from well exposed positions (Figure 3). The malic acid concentration is also reduced when leaves are well exposed to light (Morrison and Noble, 1990). In the current experiment, the light exposure of leaves supplying the sample bunches was not measured. However visual observation of the canopy at each site indicated that exposure of leaves supplying bunches on the shaded side was likely to be quite variable as the canopies were narrow allowing good light penetration. The fact that the juice pH and berry size were largely unaffected by fruit position suggests that the differences were due to direct effects, not a delay in maturity caused by leaf shading.

The differences in light exposure and (potentially) berry temperature may also affect the development of flavour compounds in the fruit. The northward facing fruit in this trial was likely to have lower levels of isobutyl methoxypyrazine than the interior or southward facing fruit.

Other compounds such as norisoprenoids, and their precursors carotenoids are also sensitive to light levels during both fruit development and fruit maturation (Razungles et al., 1996; Caló et al., 1996). An increase in exposure or fruit temperature is likely to favour the development of norisoprenoids which have strong fragrant aromas (Caló et al., 1996; Marais, 1996).

The canopy management of the vineyard may mitigate the effects of row orientation to some degree. Shading of the leaves and fruit can be reduced by changes to the trellis system or leaf removal. By improving light interception of the interior fruit, or even allowing sunlight to penetrate to the 'back' of the southern bunches, the variability in juice composition would be reduced.

Conclusion

Currently there are few reports in the literature about the effects of row orientation on juice composition. This experiment provided useful information on the differences in juice composition that are possible in E-W and N-S row orientations. The fruit maturity indices brix, TA and malic acid concentration were correlated to light exposure of the fruit, which was affected by row orientation and fruit position. This resulted in the maturity spectrum of fruit from E-W rows being wider than that of fruit from N-S rows.

Although fruit flavours were not measured in this experiment indications in the literature suggest that, like maturity, the flavour spectrum of E-W rows will be wider than N-S rows. This has implications in the wine making process where fruit with a tight

maturity / flavour spectrum can be made into uniform batches of wine for later blending to a desired flavour specification. The effects of row orientation and fruit position on fruit flavour need to be studied.

Canopy manipulation practices that reduce fruit shading in the interior of the canopy may help to reduce the variation in fruit maturity. The experiment focused on the extremes of exposed and shaded fruit and it is unlikely that the majority of the grape crop will fall into these categories. The quantity of fruit that is present in each exposure category is worthy of further study if the flavour profile of E-W row orientation is to be better understood.

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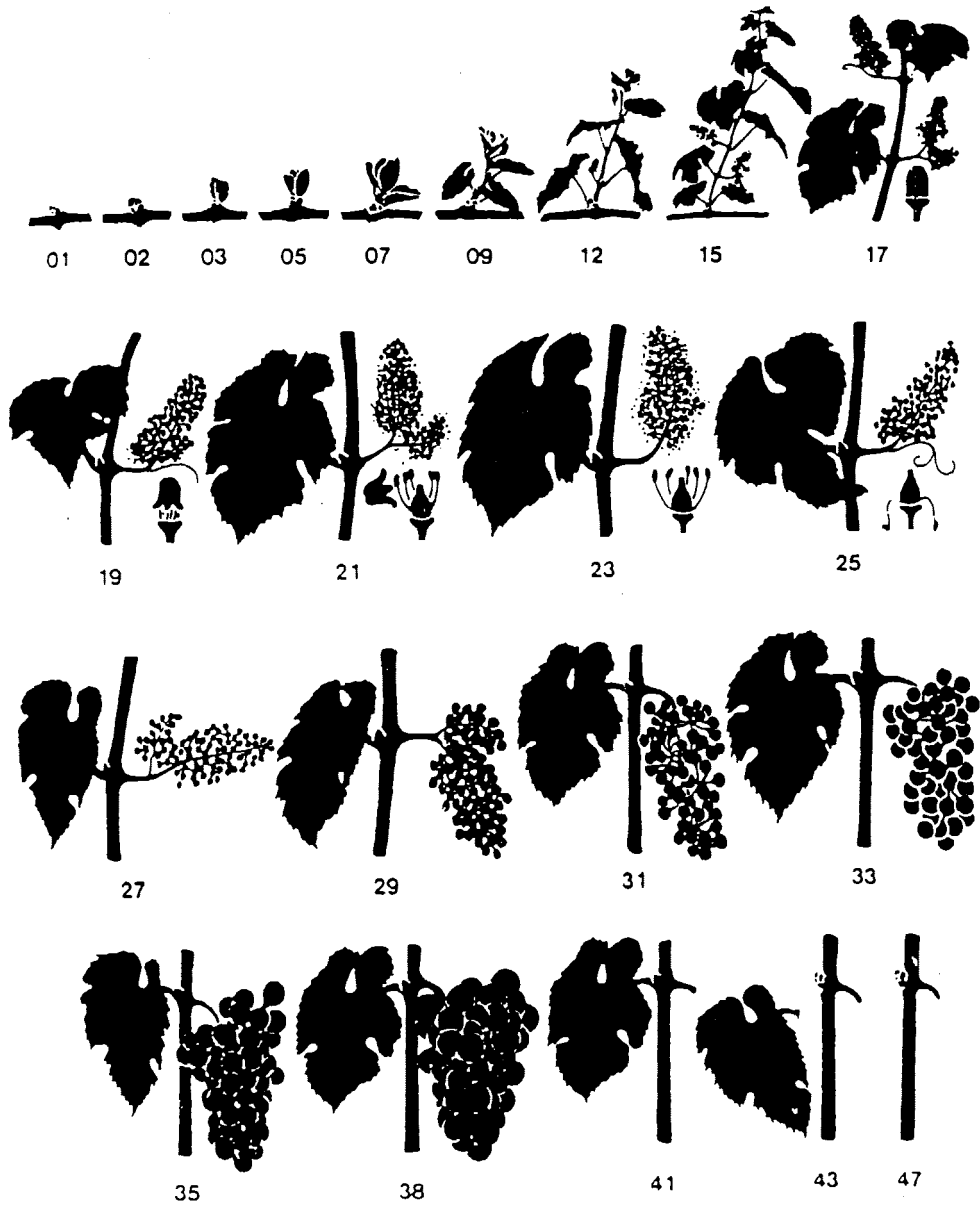
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APPENDIX II - The Eichhorn-Lorenz scale for describing grapevine phenology.

Reproduced from : MULLINS, M.G.; BOUQUET, A. and WILLIAMS, L.E. 1992. *Biology of the Grapevine*. p 94. Cambridge University Press, Cambridge.



Phenological stages in the growth and fruiting of grapevines. The more important phenological stages represented here are: bud swell (03), green shoot visible (05), clusters visible (12), bloom (19 to 25), set (27) and fruit maturity (38)

ACKNOWLEDGEMENT

No-one's thesis ever just happens! A thesis requires a huge amount of input from the author in terms of the planning, the data collection, the data analysis, presenting the results and interpreting them - oh yes, and the occasional spot of reading the scientific literature.

None of the authors can claim all of the "glory" for themselves though, and rarely do they wish to. I am no different. The work that you have in front of you required significant input from many others as well. My supervisors, Mike Trought and Chris Frampton kept me on the straight and narrow as I wandered from this to that. They managed to encourage me when I needed it, and whilst that it is what supervisors are supposed to do, it is a skill that not everyone has. I was fortunate enough to have the assistance of my employer, Montana Wines Ltd, who asked few questions when I could not be found, and even less about where their staff were when leaves had to be removed from shoots prior to harvest. Throughout the course work that went with this degree I was fortunate to have the support of staff and fellow students at Lincoln University. They helped to find the equipment and time that I needed to complete my assignments. Then there was all the encouragement and interest from friends who asked "how it's going?", even if they thought I was crazy for even starting.

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Andrew Naylor
February 2001