Prologue
‘Mareschalchi has carefully compiled the observations recorded on the weather and the size of the grape crops during the period 1855-1907 for the region around Mougerrato in North-Western Italy, and concludes that the big crop is always obtained when the preceding year has been fairly warm and dry. A dry and mild (not cool) spring allows the young shoots and their eyes (sic. Buds) to develop well and ripens the wood well, with the result that the following crop will be heavy if it is not destroyed by hail and diseases, or if the previous crop had not already been a very big one………

According to Mareschalchi, we can, with fair accuracy, predict the size of the crop, even before the vines begin budding, by taking into account the weather conditions (heat and rainfall) during the preceding twelve months, and the size of the preceding crop’ (Perold 1927)

Introduction
When the cork is pulled, or the cap unscrewed from a bottle of wine and the contents evaluated, the culmination of considerable effort is experienced. The humble *Saccharomyces* yeast, the ebullient winemaker, the grapevine, the sun, the rain and of course the dedicated viticulturist have all had a part to play. However, it is generally accepted that the wine style will reflect the flavour and aroma compounds in the harvested fruit, brought to fruition during the winemaking process.

While the changes in fruit composition can be described in a general form (e.g. sugars, pH, monoterpenes and thiol precursors increase, while acidity and methoxypyrazine fall), the relative concentrations vary, often reflecting changes in the fruit development during a particular season. These in turn occur as a result of differences in seasonal development, particularly at specific phenological stages of vine development. However, given that the winemaker wishes to make a consistent style of wine between seasons, it is important that the ‘target’ fruit composition also remains consistent between seasons. Understanding and managing these differences between seasons are particularly important in marginal cool climates, where small changes in temperature can have a large influence on vine development and fruit composition.

Impact of yield on fruit ripeness and quality
Anecdotal evidence suggests that high yield results in inferior wine, while low yield leads to quality. Unfortunately this relationship has seldom been rigorously tested. Most investigations on the influence of yield on wine sensory characters have relied on fruit thinning (e.g. Bravdo et al. 1985; Reynolds et al. 1996) and may have been harvested on the same date at different Brix levels (Cordiner and Ough 1978). Sinton et al. (1978) and Gray et al. (1994) published relationships that indicate that while excessive yields generally result in inferior wine, the reverse is not necessarily true and low yields may or may not result in quality. Recently Chapman et al. (2004) reported that when harvested at a similar Brix, Cabernet Sauvignon cropped at low levels produced higher herbaceous character than vines with high crop, and that early vine manipulation was necessary to alter fruit development. In practice, achieving an optimum yield to match the environment, and producing a vine in which the yield and vegetative growth are in balance is central to good viticulture.

One of the challenges in quantifying and understanding the yield quality relationship is the impact time has on fruit composition. On a particular site in any season, the date on which a particular ripeness (for example a target Brix) is achieved will largely depend on crop load. Thus comparing wines from vines harvested on a particular date (and hence ripeness) is of limited value, and modifying harvest date so fruit is of a similar ripeness would appear more appropriate and closer to commercial practice. Unfortunately, higher yields result in a later harvest date which in cool climates puts fruit at greater risk due to leaf senescence and adverse weather events, in particular autumn frost. Thus anticipating the potential yield in any season is critical to managing wine quality.

Seasonal changes in fruit yield
Grapes are perennial plants. The yield at the end of a particular season is the culmination of events that have occurred in at least the preceding 18 months and possibly longer and is the product of a number of components:

- Shoots per hectare
- Inflorescences per shoot
- Flowers per inflorescence
- Fruitset
- Berry weight

Shoots per hectare reflect the vineyard design (e.g. vine spacing, training, uniformity of bud break, etc.). Of these only bud break and subsequent shoot development are likely to vary between seasons, probably reflecting the over-wintering carbohydrate and nutrient reserves in the vine, which in turn potentially reflect the cropping level in the previous season.

National average yields of New Zealand Sauvignon Blanc have varied approximately two fold and Chardonnay three fold between 1990 and 2004 (Figure 1). The year-to-year differences suggest...
that much of this variation can be attributed to weather events occurring at critical times during the season. In some cases these may be catastrophic events, such as frosts in 2003, however, in other seasons, more subtle events are likely to be the cause.

Of particular importance in a cool climate are the temperatures during the initiation of inflorescence primordia and flowering. As these events occur at approximately the same time of year (late spring) (Figure 2), temperatures at this time can influence both the current and subsequent season.

**Temperatures at bunch initiation**

Inflorescence induction starts early in the spring, with the formation of an uncommitted primordium opposite a leaf primordium on the developing shoot of a latent bud. Once formed, the primordium will, depending on environmental conditions (in particular light and temperature), develop into either an inflorescence or tendril (Srinivasan and Mullins 1981). Cool conditions, which favour gibberellin synthesis, promote vegetative growth and favour tendril differentiation. In contrast, warm conditions promote cytokinin accumulation, favouring inflorescence differentiation (Jackson 2000). The induction and subsequent differentiation of the basal inflorescence of Chenin Blanc was reported to start in basal buds when shoots have approximately 12 leaves, about 12 days before the onset of flowering (Swanepoel and Archer 1998). Once complete (approximately 10 days after the onset of flowering) the second inflorescence on the same bud undergoes the same process. It can be anticipated that the onset of inflorescence development in adjacent buds on a shoot will commence sequentially along the developing shoot, probably reflecting the emergence of new leaves at the apex.

The impact of temperatures on the differentiation of the uncommitted bud during initiation has been described by McGregor (2000) who monitored inflorescence number per shoot on spur-pruned, own rooted Chardonnay in California (Figure 3a). He described a strong linear correlation with average bunch number per shoot increasing by 0.22 per degree centigrade.

**Temperatures at flowering**

Flowering generally commences (depending on the variety and temperatures) 8 to 10 weeks after bud break. It commences on the primary (lower) inflorescences of the shoot arising from apical buds of cane pruned vines, with the secondary inflorescence starting two to four days later. Inflorescences on shoots arising from basal buds on the cordon (closer to the head of the vine) begin some four to six days after the equivalent inflorescence on the apical shoot (Naylor 2001). Flowering in Marlborough Sauvignon Blanc appears to take between 10 and 25 days, largely depending on temperatures at this time.

In addition to influencing the duration of flowering, temperatures also influence the success of fertilization. Under average weather conditions, flowers start to open shortly after dawn, reaching a maximum between 07:00 and 09:00 and finish at midday (Staudt 1999). Once pollen is deposited on the stigma, the pollen grain swells, with pollen tube growth rate being a reflection of temperature (Staudt 1982). Pollen tube growth is limited to about 18 to 24 hours (Figure 4a), suggesting that it is the average temperature immediately post pollination that will determine whether or not an individual flower will be fertilized.

Using the data presented by Staudt, it is possible to estimate the maximum pollen tube length at any temperature (Figure 4b). Over a temperature range of 10 to 28 °C, maximum tube length increased by 13 μm per degree centigrade (Kheun and Trought unpublished data). This possibly suggests that the size of the flower (distance from stigma to ovary) may influence the likelihood of fertilization and where the mean daily temperature is cooler only small flowers will be fertilized.

The impact of mean daily temperature over the flowering period was studied by McGregor (2000). Average cluster weight of Chardonnay from 1983 to 1999 exhibited a sigmoid response to flowering temperature (Figure 3b).
The sigmoid relationship between bunch weight and temperature during flowering suggests that an increase in average temperature from 15.5 to 17.5 °C resulted in an increase in average bunch weight of 60% from 50 to 80 g.

**Using meteorological data to predict grapevine yield**

Growing degree days (GDD) and related approaches have been widely used to assess the suitability of a particular site for grape production (Winkler 1974; Jackson 1998; Gladstones 1992). While these approaches can be used to compare long-term averages, temperatures at specific phenological stages of vine development can have a major impact on subsequent vine development. By comparing the current GDD accumulation with historical data (the long-term average) and relating these to the particular stage of vine development, the impact of short-term changes in weather can be predicted.

For example Figure 5a shows the accumulated GDD for 1999-2000 and 2003-2004 in Marlborough, New Zealand. The total seasonal accumulated GDD for both seasons was similar, yet the average yield of mature Sauvignon Blanc vines in 2000 were amongst the lowest on record, while those of 2004 were the highest. Normalizing the data to the long-term mean (Figure 5b) emphasizes the short-term temperature differences in the two seasons. In 2000, the spring was warmer than average, and by late November accumulated GDD were nearly 80 GDD ahead of the long-term average. This suggests that flowering was earlier than average. However, a particularly cold December and January meant that by late January the accumulated GDD were now 50 GDD behind average. This cold period coincided with flowering, and largely caused the low yield. In contrast, in 2003-04, data suggests that the onset of flowering was later than average, but a warm flowering (reflected in the rapid increase in accumulated GDD during December and January) resulted in an excellent fruitset and high yields.

Using temperatures during initiation and flowering, a grapevine yield prediction model has been developed for Sauvignon Blanc in Marlborough. Extensive plantings of Sauvignon Blanc in Marlborough are a reasonably recent phenomena. Average grape yields from 1996 to 2004 of 10 mature vineyards on the Wairau Plains, Marlborough were used to provide yield data. The vineyards were all 4-cane, VSP-pruned vines planted at 1.8 m within row and 3.0 m between row spacing and commercially managed to a high standard. A stepwise, multiple regression technique was used to develop a relationship between actual and predicted vine yields, adjusting the start and finish of the initiation and flowering dates until the line of best fit (highest correlation coefficient) was achieved.

The best fit between actual and estimated yield (R² 0.92) (Figure 6) was achieved using an average GDD over the initiation period from 11 December to 17 January and a flowering period of 9 December to 9 January, and the estimated yield was described by:

\[
\text{Estimated Yield (t/ha)} = (2.728 \times \text{initiation temperature}) + (2.918 \times \text{flowering temperature}) - 29.48
\]

The 2003 season was excluded from the analysis as the particularly low yield in that year was associated with a severe frost in the Marlborough region in November. It should be emphasized...
that the model relates to the vineyards under consideration and the absolute yield values may vary where vine spacing and management practices alter.

Extending the yield analysis back to 1988 (Figure 7) provides an estimate of the long-term average Sauvignon Blanc yield in Marlborough (10.64 t/ha) from these vineyards, and demonstrates the seasonal differences that may be anticipated. The impact of cool seasons in 1993 and 1994 associated with the Mt Pinatubo eruption in the Philippines is clearly apparent, together with the expected yield loss from the spring frost in 2003.

The range and relative importance of initiation and flowering temperatures in determining yield is demonstrated in Table 1. The above average yields of 1999 and 2002 reflected the above average initiation and flowering temperatures, while low yields in 1993, 2000 and 2005 were a reflection of below average flowering temperatures. Data suggests that the 2001 harvest was saved by the exceptionally warm flowering, as initiation temperature was the coldest over the 18-year period. Using the model the forthcoming season’s data would suggest that yields in 2006 are likely to be less than average, but as in previous years, events over flowering will determine the final outcome.

Using meteorological data to predict wine quality

In addition to influencing fruitset, weather conditions at flowering may also influence flowering duration. Flowering can occur over a period from two days to 2-3 weeks, largely reflecting the temperature with warmer temperatures resulting in a compressed flowering (Howell personal comm.). The consequence of flowering duration on final fruit composition still has to be determined, but it can be anticipated that a longer flowering may result in greater variation in fruit composition (at a berry level) at harvest and a higher range of flavours in the fruit (Figure 8). This is particularly important where herbaceous character, associated with less ripe fruit, may dominate the flavour and aroma profile of the wine.

### Table 1. Seasonal GDD during the estimated initiation and flowering periods of Sauvignon Blanc in Marlborough

<table>
<thead>
<tr>
<th>Year of harvest</th>
<th>Average daily GDD over initiation (11 Dec-17 Jan) (18 months prior to harvest)</th>
<th>Average daily GDD over flowering (9 Dec-9 Jan) (4 months prior to harvest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>6.8</td>
<td>7.5</td>
</tr>
<tr>
<td>1997</td>
<td>7.8</td>
<td>6.2</td>
</tr>
<tr>
<td>1998</td>
<td>6.2</td>
<td>8.0</td>
</tr>
<tr>
<td>1999</td>
<td>7.8</td>
<td>7.5</td>
</tr>
<tr>
<td>2000</td>
<td>8.1</td>
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<tr>
<td>2001</td>
<td>5.2</td>
<td>8.7</td>
</tr>
<tr>
<td>2002</td>
<td>8.6</td>
<td>7.3</td>
</tr>
<tr>
<td>2003</td>
<td>7.7</td>
<td>7.0</td>
</tr>
<tr>
<td>2004</td>
<td>7.0</td>
<td>8.4</td>
</tr>
<tr>
<td>Average 1988-2005</td>
<td>7.2</td>
<td>6.9</td>
</tr>
</tbody>
</table>

### Table 2. Effect of grapevine training system on yield components on 26 April 2005

<table>
<thead>
<tr>
<th>Pruning Treatment</th>
<th>Yield* (kg/vine)</th>
<th>Trunk carbohydrate concentration (August 2004)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2004</td>
<td>2005</td>
</tr>
<tr>
<td></td>
<td>Starch (g)</td>
<td>Soluble sugar (g)</td>
</tr>
<tr>
<td>Trt</td>
<td>Yield</td>
<td>Yield</td>
</tr>
<tr>
<td>1</td>
<td>4 cane</td>
<td>4 cane</td>
</tr>
<tr>
<td>2</td>
<td>4 cane</td>
<td>2 cane</td>
</tr>
<tr>
<td>3</td>
<td>2 cane</td>
<td>2 cane</td>
</tr>
<tr>
<td>4</td>
<td>2 cane</td>
<td>4 cane</td>
</tr>
</tbody>
</table>

*Means within the same column with the same letter are not significantly different at LSD P ≤ 0.05
Influence of previous season cropping on grapevine yield

While temperatures during inflorescence initiation and flowering appear to explain most of the seasonal differences in Sauvignon Blanc yield, over-wintering carbohydrate reserves may also affect production. Initial shoot growth largely depends on carbohydrates stored in the vine from the previous season (Perez and Kliwer 1990) and these reserves may be influenced by crop level. Following high crops, reserves may be depleted resulting in poor bud break and uneven shoot development. Potentially this results in low yields, which in turn results in high carbohydrate reserves, good bud break and high crops in the subsequent season. The consequence is that vines may exhibit biennial cropping.

To investigate this further, trials have been initiated to investigate the influence of crop level and over-wintering reserves on following season's production in Marlborough. Sauvignon Blanc vines are traditionally pruned using a 4-cane VSP system with 50 to 60 buds being retained after pruning. The impact of changing the pruning from 4-cane to 2-cane on yield, pruning weight and trunk carbohydrate reserves was investigated and some preliminary results are presented.

In the first season (2003-2004) 2-cane pruned vines produced 56% of the yield of 4-cane vines in 2004 (compare treatments 1 and 3, Table 2), and resulted in a significant increase in winter starch and total carbohydrate concentrations. In the second season (2004-2005) the 2-cane vines produced 64% of the 4-cane pruned vines. Converting the vines back from 2-cane to 4-cane at the end of 2003-2004 (treatment 4, Table 2) doubled the yield when compared to vines that had been 2-caned throughout and resulted in a 32% increase in yield over vines that had been 4-cane pruned throughout.

No significant differences in berry or bunch weight were recorded (data not given), and the increase in yield was a reflection of higher bud break on the 4-cane pruned vines. In contrast, yield of the 2-cane pruned vines was unaffected by crop level in the previous season, suggesting that the reserves in the vine was not limiting subsequent shoot development. The data suggests that the crop level in the previous season was having a carry over effect, particularly were an excessive number of buds are retained post pruning, and this was independent of any temperature effects at initiation or flowering.

Summary: Impact of fruitset on wine quality

Recent research (Chapman et al. 2004) questions the adage that to produce high quality wines, low yields are essential and there is still much to know about the impact of fruitset and vine yield on wine quality. Fruitset influences potential yield, which in turn will influence the time and probability of achieving a particular fruit ripeness. This will influence the balance of the various flavour and aroma components in the fruit that will be expressed in the wine. Secondly temperatures at flowering will influence the duration of flowering, and may influence the variability in fruit composition around the mean at harvest. The extent to which this affects wine quality probably depends on the variety being considered, but a small proportion of unripe, herbaceous fruit in the sample may have a disproportionate effect on the quality of wines such as Pinot Noir and Cabernet Sauvignon, where herbaceous character is considered unpleasant. Conversely it may be seen to be a positive attribute in Sauvignon Blanc.

Acknowledgements

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References


