Environmental effects on Cabernet Sauvignon (*Vitis vinifera* L.) when grown in different sub-regions within Hawke's Bay (New Zealand)

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The list of abbreviations and indices

Abbreviation	Description
r	Coefficient of simple correlation
R	Coefficient of multiple correlation
SE	Standard Error
CDA	Canonical Discriminant Analysis
PCA	Principal Component Analysis
CV	Coefficient of variation (%)
FTIR	Fourier Transform Infrared
ppt	Parts per trillion
TSS	Total Soluble Solids (°Brix)
TA	Titratable Acidity (g/L)
IR	Index of Ripeness, or gluco-acidometric index
IRA	Index of Ripeness corrected for Anthocyanins
AC	Concentration of anthocyanins in wine (g/L)
d.w.	Dry Weight
f.w.	Fresh Weight
O.D.	Optical Density
AOC	*Appellation d'origine contrôlée*
GDD	Growing Degree-Days (°D)
ET	Estimated potential evapotranspiration (mm)
ESA	Estimated exposed leaf Surface Area
SC	Canopy density ScoreCard points
CDI	Canopy Density Index
RDI	Regulated Deficit Irrigation
IPF	Index of precocity of flowering
IPV	Index of precocity of véraison
IPCY	Index of precocity of the vegetative cycle
SF	"Soil Factor"

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Abstract

During three consecutive seasons a study was undertaken in order to characterise viticultural environments for cv Cabernet Sauvignon in Hawke's Bay. The initial 1996/97 study showed that phenology, titratable acidity and canopy characteristics were of central importance for site characterisation. Based on fruit and canopy attributes of the initial 28 sites, six were selected for a detailed study in the 1997/98 and 1998/99 seasons. Air temperatures varied slightly between the six sites and some differences were observed in temperature amplitudes and rainfall. Variability between sites in solar radiation was low. A large variability was observed in soil temperatures, with gravel and sandy soils warmer than silt and clay. A budburst model based on air and soil temperatures is presented. Canopy density was affected by seasonal variability of soil moisture and soil temperature. Yield to pruning ratio was higher at sites with light soils than at others. Flowering date was correlated with temperature and rainfall in the month preceding flowering and with shoot length before flowering. Duration of flowering was negatively correlated with temperature and with fruit set. Véraison and ripening were significantly affected by soil and air temperatures. Soluble solids in fruit at harvest were positively correlated with air and soil temperature and negatively with soil moisture content. Total phenolic and anthocyanin concentration in berry skins was correlated with soil temperature and soil moisture content.

Harvest dates at each of the studied sites were chosen solely by their respective vineyard managers and the information driving these decisions was not made available. Differences between seasons and sites were found in sensory evaluation scores of unreplicated wines produced by microvinification. High wine scores were associated with precocity in

phenological stages, favourable canopy density and optimal Mg status of the vines. The novel TSS/malic acid*pH maturity index was positively correlated with wine scores and appears to offer potential for early prediction of Cabernet Sauvignon wine quality. Air and soil temperatures for the final ripening month were positively correlated with wine scores. Wines from soils of limited water capacity or limited root growth achieved highest sensory evaluation scores, probably by reducing vegetative growth and thus inducing canopy characteristics favourable for fruit development and ripening.

The use of a 'Soil Factor' (SF) that integrates soil temperature, soil moisture volumetric content, depth of topsoil and water availability index based on soil texture is proposed. SF is significantly correlated with several attributes of vine vegetative growth, véraison date, soluble solids, tartaric acid, malic acid, total phenolics and anthocyanins in fruit, and with wine scores. It appears that environmental characterisation of vineyard sites in Hawke's Bay based mainly on SF is possible. This site characterisation could eventually lead to determination of future viticultural 'terroirs' for Cabernet Sauvignon.

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CHAPTER 1. GENERAL INTRODUCTION

New Zealand Wine Industry

Viticulture and wine production in New Zealand has its origins in the early 19th century. According to Mabbett (1997) Reverend Samuel Marsden planted about 100 vines at Waimate in 1819. He brought those vines from Port Nicholson, Australia, and cultivated them only for table grapes. The French Roman Catholic Marist Brothers planted vines at Whangaroain in 1839, and a decade later at Meeanee (Hawke's Bay), in order to produce sacramental wine.

According to Mabbett (1997), wine merchants in Paris pronounced wine made at Meeanee in 1880s as superior to any wine produced in Australia at that time. Comte d'Abbans, the French Vice-Consul at Wellington, was quoted as saying that Hawke's Bay could become a great wine-producing district, "as the dry climate is especially suitable to the cultivation of the grape".

An important initial factor in the development of wine industry was a decline in the kauri-gum industry in Northland in the beginning of the twentieth century. Kauri-gum workers, many of whom were Dalmatian immigrants, moved to other agricultural occupations, including viticulture. The first New Zealand Government Viticulturist, Romeo Bragato, was a Dalmatian born Italian (Mabbett, 1998). Today, there is a high proportion of prominent growers and winemakers in New Zealand that are of Dalmatian extraction.

The development of wine industry in New Zealand was strongly affected by government polices, frequently unfavourable from the perspective of wine producers. The restrictions on wine sales due to tariffs placed on wine in the first half of the century favoured the consumption of other alcoholic

beverages, and it discouraged growers from planting high-quality grape cultivars (Beverland and Bretherton, 1998). Enthusiasts like Alex Corban and Tom McDonald spearheaded a major leap in viticulture and winemaking in New Zealand in 1950s and 1960s (Dunleavy, 1999b). Advances in grape and wine growing since the 1960s coincide with the increase in wine consumption in Britain and the United States of America, itself attributable to an increasing middle class in these countries (Unwin, 1991).

According to the Wine Institute of New Zealand Annual Report for 1999 (Anon. 1999a) within the last decade of the twentieth century, the number of wineries increased from 131 to 334; productive vineyard areas almost doubled from 5,440 to 9,380 ha. The wine industry in New Zealand is strongly export orientated: the total export volume has increased from 4 to over 16 million litres of wine in the period 1990-1999.

Since the early 1980s, New Zealand Sauvignon Blanc wines have received high acclaim worldwide (Cooper, 1993; Rachman, 1999). Chardonnay, Pinot Noir, sparkling wines, Riesling, Merlot and Cabernet Sauvignon wines from New Zealand have also been increasingly acknowledged as award winning wines.

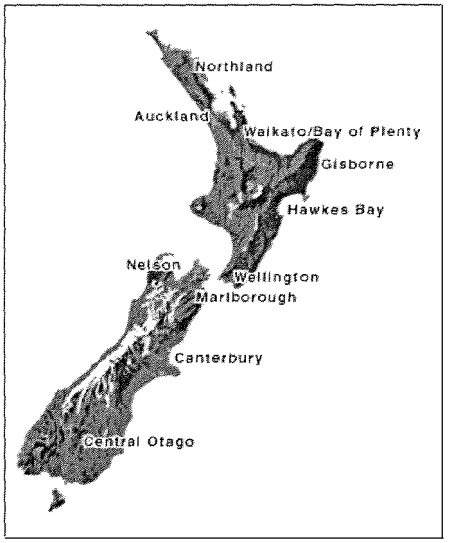

Figure 1. Wine regions of New Zealand

New Zealand has a diversity of wine growing regions (Figure 1) spread between latitudes 36 to 45 degrees. In the North Island major regions are Northland and Auckland (412 ha combined), Waikato/Bay of Plenty (140 ha), Gisborne (1756 ha), Hawke's Bay (2923 ha), Wellington (382 ha); South Island wine regions are Nelson (262 ha), Marlborough (4543 ha), Canterbury (475 ha, including Waipara) and Central Otago (294 ha). The areas given are those projected for 2002 (Anon. 1999b). The prevailing climate is temperate maritime, and it gets progressively cooler from north to south.

Marlborough is the largest wine region, although the first vines were planted only in 1973 (Dunleavy, 1999a). Very significant increases in vineyard area in Marlborough are expected in the next several years (Anon. 2000b).

Environment and Viticultural Performance, the Concept of 'Terroir'

The variability of mesoclimate (or site climate, Smart *et al.*, 1981) as affected by various landscape parameters such as altitude and slope, coupled with the regional soil and subsoil variability, creates vineyard sites with a varying viticultural and oenological potential (Scrinzi *et al.*, 1996).

The effect of soil properties on the control of water behaviour in soils, and its consequence for water availability for vines has been studied in depth by Merogue *et al.* (1998). The authors claim that the water availability was mainly linked to textural and structural soil properties influencing soil water retention, aeration, and rooting development. The most intensive vine growth was observed on deep planosols, and the least intensive on shallow planosols. Growth on very stony cambisols was rather chaotic, and was related to marked variations in water supply. Fruit from vines growing on deep planosols had a lower content of reducing sugars and anthocyanins and a higher total acidity compared to those on shallow planosols.

A varying water supply through different irrigation regimes was found to affect berry size and thus the skin/flesh ratio. In this way water supply has a

significant effect on wine quality particularly in red wines, as red grapes are fermented on their skins (Bravdo and Naor, 1996). Water regime of the vine has been shown to have fundamental effects on vine growth and grape development by Hardie (1981).

While studying the effect of soil and climate on grape and wine quality of cv Prugnolo gentile in Italy Costantini *et al.* (1996) found that the most fertile soils with no permanent limitations to crop cultivation, provided the worst viticultural and oenological results. Best results were obtained on quite fertile soils that had some pedological limitations. This work established a clear relationship between soil groups and wine organoleptic profiles.

The term 'terroir' was and is sometimes used as a mere marketing tool (Clarke, 2000). In recent years, however, 'terroir' is increasingly becoming a subject of scientific research, with the overall aim to determine the actual effect of site-related factors on the attributes of grapes and 'typicity' of wine, and also to utilise that connection for wine marketing and branding. Furthermore, investigations of the effect of 'terroir' on attributes of other agricultural products such as cheese (Mennet and Gaiff, 1998; Salette *et al.* 1998) have started in France.

'Terroir' has been the subject of some dispute, particularly between vignerons of Europe and those in the New World viticultural countries. It may be stated that different views on 'terroir' are partially rooted in a diversity of definitions of the term. According to Falcetti (1997), the concept of 'terroir' is relevant in viticultural countries with 'mature' wine industries (France, Spain and Italy) (Figure 2). Major differences between 'mature' viticultural countries and those in the stage of 'development' (New Zealand, South Africa, Australia, California and Germany) are available resources relating to the wine industry and wine market characteristics. Successful producers wish to protect their positions in conditions of low land availability and stiff competition. Such a situation gives rise to various versions of *Appellation d'origine contrôlée* (AOC) and is characteristic for countries with viticulture in the state of 'maturity' (Falcetti, 1997). While AOC is mainly a legal term and represents a topographical limitation, 'terroir' is a geologic /

edaphic / mesoclimatic term that is sometimes used to explain AOC (Falcetti, 1994). According to Falcetti, these different 'stages' of viticultural development may partly explain why 'terroir', a notion widely accepted among grape growers in most Mediterranean countries as natural, is met with a degree of scepticism in the New World.

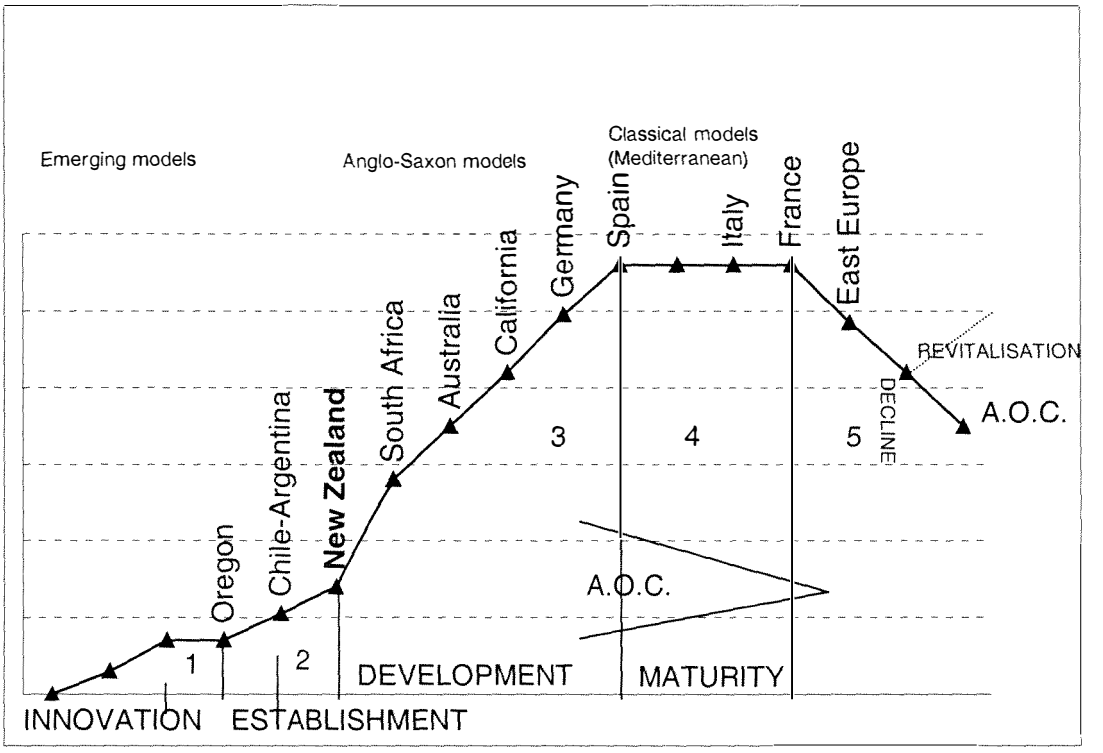

Figure 2. Life cycle of viticultural regions: current positioning. Based on Falcetti, 1997. A.O.C. refers to *Appellation d'origine contrôlée.*

Unwin (1991) states that a mistranslation of the word 'terroir' may lie at the root of debate on the importance of soils in determining the quality and character of wines. The author states that the translation of 'terroir' to 'soil' is incorrect. His definition relates to various attributes of the site: "it is the interaction between slope, aspect, soils, altitude, humidity, shelter and drainage, and the way in which these factors influence the critical elements of sunshine, temperature and wind, that distinguishes between the nature of wines made from different vineyards."

Bourguignon and Gabucci (1997) claim that the soil particle ratio (clay : silt : sand) does not always characterise a 'terroir'. For instance, the same soil particle ratio reportedly exists in soils of Latricière and Chapelle Chambertin (Burgundy), while their wines are quite different. The difference with regard of soil structure, according to the authors, lies in the specific surface to their clay particles, which they define as the total surface of the layers per 1 g of clay.

The strength of the effect of 'terroir' as viewed by some viticultural scientists is well expressed in the findings of Saint-Cricq De Gaulejac *et al.* (1998). While studying cvs Merlot and Cabernet Sauvignon grown in Bordeaux, they established that 'terroir' had influenced the phenolic composition of wines more than cultivars themselves.

Examples of traditional views on what 'terroir' represents can be found in Wilson (1998). The French growers quoted claim that "grapevines find something precious - almost sacred - in their deep rooting", and that there is "no other explanation for the sensory differences between two wines grown under the same physical conditions".

Much significance has been attributed to the effects of sub-soil, or parent rock in defining 'terroir'. This is logical, since the top-soil represents quite a thin layer (as shallow as 15-40 cm) at many highly regarded and low fertility sites. Many long vine roots, which penetrate deeply in their quest for water and nutrients, are actually located in the soil substrate, rather than in top-soil. Enjalbert *et al.*, 1974 (cited by Bohmrich, 1996) point to the difference of the subsoil at Château Lafite (very thick gravel mixed with clay and sand), and at Château Latour (calcareous-clay) as being a major factor in consistent differences between their respective wines.

According to Boissenot (1998) the geological nature of the parent material on which soils were formed and limited water supply to the plant are the conditions that favour the desirable wine attributes in Cabernet Sauvignon. The author also states that a high water supply is associated with the increased methoxypyrazine content through higher grapevine vigour.

Methoxypyrazines represent a group of aromatic components that contributes to herbaceous, green or vegetative aroma of Cabernet Sauvignon and Sauvignon Blanc wines (Allen *et al.*, 1992).

There is no one soil type that correlates with wine quality on the world scale (Bohmrich, 1996). Chalky soil (example Champagne) is highly regarded for its high soil moisture retention capacity, low matrix permeability that arrests free draining water, and a high mass permeability that facilitates drainage when saturated (Bohmrich, 1996; Hancock, 1999). Gravelly soils (example Graves in France or Marlborough in New Zealand) with their drainage and thermic characteristic may enhance fruit ripening in cooler regions. In the past, stony and chalky soils were unanimously considered to be the best for wine quality (Gladstones, 1992).

Grapevine phenology, timing and duration of developmental stages such as budburst and shoot growth, flowering and berry set, véraison and fruit ripening often vary markedly between vineyard sites within a region. By analysing the twenty-year records of phenology in the Loire Valley, Barbeau *et al.* (1998b) concluded that the timing of phenological stages enables the classification of 'terroirs' and the estimation of their viticultural potential. Phenological records are important for decision making in viticulture (Coombe, 1988), particularly for matching the cultivar to region (Mullins *et al.*, 1992), or for clonal selection (Calo *et al.*, 1987). Phenological observations are useful as a tool for correlative studies, as they can gauge the behaviour of the individual cultivars in different regions (Coombe, 1988).

In a number of recent works, some of which are quoted here, there is an increasing tendency to minimise the traditional role of 'terroir', which is often accused of bearing a certain degree of mystification and/or serving as a mere marketing tool. In this respect there are viticultural research papers dealing with what would traditionally be a 'terroir'-study (for example, comparative studies of viticultural and oenological performance of grapevines on different localities within regions) without even mentioning the word 'terroir'.

Many authors view 'terroir' as a complex influence comprising all site-related (or site-specific) factors. As Bohmrich (1996) states: "...'Terroir' encompasses all the innate, immutable features of the natural environment from sunshine, rainfall and temperature to the slope, orientation, altitude and soil composition."

Soil type is one of the most relevant among these features, and it may be no coincidence that the root of the term 'terroir' is similar to that of *terra* (earth, or land in Latin). Pedological along with geological characteristics comprise a 'pedoclimate' (Morlat, 1997), which represents an interface of vines and 'terroir' through exploration of soil by roots. Soil chemistry may also have an effect on wine flavours and aromas (Robinson, 1994).

Site location includes altitude and aspect. A very important part of this factor is the vicinity of climate modifying objects, such as hills, forests, water surfaces and buildings. Even the proximity of railroads can have a strong climate-modifying effect (Patel, 1995) as their embankment represents an obstacle to free air drainage down the slope. Dumas *et al.* (1997) have studied the differentiation of local climate in Alsace. They have found that the landscape mostly influences the wind speed. The slope, orientation, height and distance to topographic objects affect the global solar radiation. Salmon *et al.* (1997) hypothesised that through reflective properties of different soils, 'terroir' can also affect the distribution of wild yeasts flora on berry surfaces, thus affecting the spontaneous fermentation of musts.

All the above elements represent a combination of pedological and relief (or landscape) factors that form mesoclimate of 'terroir' (Morlat, 1997). According to the same author, 'Pedoclimate' in combination with mesoclimate determines the "Basic Terroir Units".

Human impact on fruit and wine attributes via viticultural and winemaking management strategies is of utmost importance. According to Morlat (1998) "natural factors, grape varieties, and human factors, make up the 'terroir'". Vineyard management can serve as a focusing (Martin, 2000) as well as blurring agent for 'terroir'.

A similar view of 'terroir' is well expressed by Mondavi (1999): "… a great wine does begin with the land – the 'terroir' – which must be actively interpreted. As winegrowers and winemakers, we need to harmonise with nature; it's up to us to understand what the wine wants to be". The same author speaks of 'terroir-driven' wines. That approach is in agreement with Martin (2000): "…['terroir'] will not appear spontaneously, but can be distilled out of a situation where many favourable factors converge". Hancock (1999) also emphasised the impact viticultural management and oenological practices have on the attributes of wines produced, while criticising the traditional approach to the subject by Wilson (1998).

Martin (2000) underlines the fundamental importance of management strategies to achieve flavour concentration and optimum ripeness of fruit in order to differentiate wines to their fullest extent by the intensification of site expression. One example of a management strategy to concentrate flavour in berries is a moderate water deficit, achieved via deficit (or no) irrigation. The possibility to apply moderate water deficit without excessive vine water stress is one of the advantages of cool and dry climates (Martin, 2000). Moisture stress during ripening has been shown to improve grape quality (Van Zyl, 1982).

The concept of 'terroir' as 'a potential for full site expression' that can be realised through judicious application of viticultural and oenological practices, means that 'terroir' does not have to be an obstacle to the advancement of wine grape production. It does not presume a rigid adherence to delimitations based on 'permanent' physical characteristics of site, although these too can be a subject to human modification. Within such a framework there is ample opportunity for further experimentations and advancements, as well as application of all the existing viticultural and oenological knowledge that may help intensify what is perceived as site expression. All this does not represent a threat to the marketing potential and even romance the word 'terroir' brings. 'Terroir' as a brand or quality standard can only benefit from future improvements in grape and wine

industry of New Zealand, as it moves towards increased sustainability and firm quality assurance.

In this work the term 'terroir' will be used in accordance with a more widely accepted view of it as a complex interaction of site related factors: soil, subsoil, water table depth and seasonal pattern, mesoclimate, altitude, slope and aspect, and the proximity of climate-modifying objects. This complex environmental influence would thus form a '**viticultural potential of a terroir**' ('*potentiel viticole d'un terroir*' – Morlat, 1996, cit. Barbeau *et al.*, 1998a). In the light of the concept of 'terroir' as a potential for site expression, this could then be further developed and amplified by selection of viticultural and oenological techniques. The analysis of the realisation of 'terroir' is, however, beyond the scope of this thesis.

In this respect it is relevant to mention microvinification as a method to assess fruit and wine quality. It is also referred to as a small-lot winemaking, because it uses relatively small amounts of fruit to assess the oenological potential of much larger vineyard areas. The idea behind microvinification as a method is that, ultimately, only wine can be used to judge the attributes of grapes for wine production. However, in the same time, maintenance of exactly the same winemaking procedure within a trial is paramount. In principle, microvinification means minimum interference with oenological techniques so that fruit is able to really express itself. Some exceptions to this rule are chaptalisation (adding sugar to must) in case of low °Brix levels in fruit, pH adjustments and in rare cases adding oak chips to new wine in order to assess how oak affects flavour expression of particular wines. The application of microvinification as a method to assess the viticultural and oenological potential of different vineyard sites hence does not fully enable the mentioned 'focusing' or 'interpretation' of 'terroir' via oenological practices as described by Mondavi (1999) or Martin (2000).

Wine-growing Region of Hawke's Bay

Hawke's Bay is a region on the eastern side of the North Island of New Zealand. The region lies within latitudes 39º20´S and 40º30´S and longitudes 176º10´E and 177º50´E. The wine region of Hawke's Bay, mostly in the Heretaunga Plains, covers a relatively small part of the whole region. The Heretaunga Plains consist of 35,000 ha of recent alluvial soils, being mainly former floodplains of the Tutaekuri and Ngaruroro Rivers (Molloy, 1998). The soils vary greatly in their drainage characteristics, depth, and fineness of alluvium over gravels (Ibid.).

The weather in Hawke's Bay is influenced mostly by the Ruahine ranges in the west. Rainfall is highly variable and sporadic, and temperature shows large and sometimes sudden variations (Thompson, 1987). Hawke's Bay is a sunny region (over 2100 hours of sunshine a year), and is less windy than many other coastal areas of New Zealand, since the high country shelters the rest of the region. Havelock North, for example, has calm conditions for about 75% of the time (Ibid.).

Compared to Bordeaux, the French region that can be taken as a benchmark for the production of high-quality Cabernet Sauvignon, Merlot, and Cabernet Franc (blends of which are indeed commonly termed as 'Bordeaux-style reds'), Hawke's Bay (Napier data, Gladstones, 1992, Table 1) is, on average, slightly cooler and with more sunshine. According to Gladstones (1992) heat summation and sunshine hours at Napier are similar to those in the Coonawarra region of South Australia. It is not a coincidence that warmer seasons in Hawke's Bay can produce outstanding red wines (Ibid.), as in those seasons this region more closely resembles the average climatic conditions of Bordeaux (but still with higher insolation).

Table 1. A comparison of main climatic data for Napier, Bordeaux and Coonawarra

Meteorological parameter	Napier, NZ	Bordeaux, F	Coonawarra, SA
MTWM*	18.6	20.5	19.6
GDD**	1315	1460	1333
Rain (mm/year)	892	833	628
Rain (mm/season)	475	427	257
Relative Humidity	63	59	48
Sunshine Hours	1583	1472	1593

Source: Gladstones, 1992. * Mean temperature of the warmest month; ** Growing degree-days (°D) with a cut-off at 19°C and adjusted for vine sites by Gladstones (1992); Relative humidity is an average, and sunshine hours is the sum for months October-April (April-October for Bordeaux).

Such comparisons between the wine regions of the world can, however, be misleading. For example, Carbonneau and Tonietto (1998) have established that a change from the traditional viticultural system employed in Bordeaux (vines with low trunks and clean cultivated vineyards) to a more modern system of growing (high-trellis vines and permanent grass cover) would see Bordeaux as a region change its position on the worldwide scale towards that of higher helio-thermic index and lower humidity. Traditional vine training and clean cultivation still dominate grape growing in Bordeaux, while high trellis and permanent or seasonal grass cover are present in most of Hawke's Bay vineyards. This could mean that the actual conditions for grape ripening in these two regions may be closer than they appear based only on their average climatic data.

The majority of vineyards are located from Eskdale in the north to Waimarama in the south, and from the coastline in the west inland up to Mangatahi. This is only about one tenth of the Hawke's Bay district, the rest of which is mostly in hills 300 m and more above sea level, with climate less suited to grape growing primarily because of high rainfall (Thompson, 1987). Some parts of this region along the coastline, both to the south and to the north-northeast, are suitable for viticulture, and may be of interest in the future.

There were 41 wineries in Hawke's Bay in 1999 (Anon. 1999a). In 1990 there were only 12 wineries, which means that the number of wineries has more than trebled within the last decade. Most wineries obtain Hawke's Bay

grapes for their wine production, although some larger wineries source additional grapes from other regions.

The median vineyard area for Hawke's Bay in 1999 was 6.9 ha, while the average was 12.6 ha, based on a poll representing 186 grape growers (Anon. 1999b). Seventy three percent of these vineyards were grafted, and this percentage is increasing, and expected to reach 83% by 2002 (Ibid.).

The wine industry in Hawke's Bay has seen a growth in the last two decades. Prior to 1980 the most common cultivar grown was Müller Thurgau with grapes mostly being grown for ordinary (or 'bulk') wines. The potential of this German cultivar for producing good quality wine has probably been underestimated in New Zealand, as many hectares were removed under a Government subsidised grubbing scheme in 1986. Some of the Müller Thurgau wines produced in New Zealand by Alex Corban, Montana and Nobilo in 1960s and 70s were regarded favourably the world over, particularly at blind tastings (Corban, 1998; Dunleavy, 1998).

The origins of winemaking in Hawke's Bay were in the late 1800s. One of the oldest wineries still operating in New Zealand is Te Mata Estate Winery. Located in Havelock North, it was established by the end of the 19th century, although it has not been continuously operational since that time. Incidentally, the same winery produces Coleraine, one of the most acclaimed Cabernet Sauvignon wines in New Zealand.

The initial difficulties encountered by growers in Hawke's Bay arose because experiences and skills moulded in other horticultural enterprises, were uncritically transferred onto the newly planted vineyards. As Dr Alan Limmer of Stonecroft Wines points out "...grape growing was initially a diversification from the traditional cropping that you see all over the Heretaunga Plains, so the driving force was to quantity, not quality" (Tudor, 1996).

In 1999 there were 2336 ha of producing vineyards in Hawke's Bay, compared to 3477 ha of Marlborough, the largest region. Hawke's Bay region represents 26.8% of the total area of producing vineyards in New

Zealand. It is projected that in the year 2002 the area will increase to 2923 ha (Anon. 1999b).

Cabernet Sauvignon in Hawke's Bay

Increased plantings of Cabernet Sauvignon have taken place in New Zealand over the past decade. The area planted with this cultivar has increased from 396 ha in 1990 to 547 ha in 1998 (Gregan, 1998). This 38% increase is notable, but when compared to the 234% increase in Chardonnay plantings, or the 350% increase for Pinot Noir, it indicates the current trend in varietal plantings and suggests that this cultivar is a "difficult proposition" (winemaker John Hancock, Tudor, 1996) both in Hawke's Bay and New Zealand as a whole (with the notable exception of Waiheke Island near Auckland). However, Cabernet Sauvignon plantings are still on the rise, and it was estimated (Anon. 1999b) that they will reach 717 ha by 2002.

Hawke's Bay represents the major region for Cabernet Sauvignon in New Zealand: the area planted with this cultivar in Hawke's Bay was 393 ha in 1999 (79% of these vineyards were grafted); this is projected to reach 473 ha by 2002 (and 86% of vineyards will be grafted), therefore an increase of 20% is expected (Anon. 1999b). In 2002 it is expected that Cabernet Sauvignon grown in Hawke's Bay would represent 2/3 of all areas under this cultivar in New Zealand. Other regions are expected to have the following areas under Cabernet Sauvignon: Auckland 62 ha, Canterbury and Wiapara 12 ha, Central Otago 2 ha, Gisborne 5 ha, Marlborough 104 ha, Nelson 14 ha, Wairarapa/Bay of Plenty 22 ha and Wellington 22 ha (Anon. 1999b).

Variability of Hawke's Bay's from season to season makes growing Cabernet Sauvignon difficult. As winemaker Tony Prichard puts it: "...in a number of years, the region is just marginal [for Cabernet Sauvignon]. In those cooler years Merlot seems more forgiving: Cabernet [Sauvignon] is unforgiving in terms of giving herbal, methoxypyrazine characters" (Tudor, 1996). According to Allen (1995), isobutyl methoxypyrazine (the principal methoxypyrazine component) at 30 ppt was already perceived as

overpowering and out of balance. It was possible to detect isobutyl methoxypyrazine in wine or water at a concentration of only 2 ppt. The range of 7-15 ppt was said to represent the preferred content of isobutyl methoxypyrazine in Cabernet Sauvignon wines. The same author established a firm relationship between the thermic conditions of season and the content of methoxypyrazines for cv Sauvignon Blanc grown in Australia. Mean January temperature and the methoxypyrazine content in wine had a coefficient of correlation of –0.832.

The view that Hawke's Bay can often be marginal for Cabernet Sauvignon is in accordance with Gladstones (1992) who says that only light red wines can be expected on average in Hawke's Bay. However, the same author states that low temperature variability, high relative humidity (although it increases the disease pressure), selection of warm and well-drained, stony soils, proper attention to trellising and yield levels, can all contribute to quality, and even give the potential for making outstanding Bordeaux-style reds in warm and sunny seasons.

Data supplied courtesy of one of the most renowned local wineries (which will remain anonymous) reported eight satisfactory or near satisfactory Cabernet Sauvignon vintages in the last 20 years (seasons 1980-1999). This winery sourced fruit only from Hawke's Bay (greater Havelock North area). Four of these vintages (1982, 1991, 1995 and 1998) were evaluated as excellent by their chief winemaker, and another four (1985, 1989, 1990 and 1999) as very good. This company relied on blending with Merlot in poorer Cabernet Sauvignon vintages. Cabernet Franc was used as a minor component, mostly for its aroma.

In relatively unsatisfactory seasons (1986, 1988, 1992, 1993, 1994, and 1997), Cabernet Sauvignon wines were evaluated with a mark from 5 to 6.5 out of 10. They were either unripe (meaning unripe tannins or elevated methoxypyrazine character), or if ripe were assessed as 'diluted', or less concentrated. The only season achieving full 10 out of 10 points in view of the chief winemaker was the acclaimed 1998 year. Wines from good vintages were described as very ripe (in terms of fruit and tannins), having

no herbal character, or just the right amount of it. The eruption of Mt Pinatubo and its effect on weather in the Pacific region was blamed for the unsatisfactory 1992 and 1993 vintages.

Cabernet Sauvignon grapes can command high prices to contract growers in Hawke's Bay (data from Anon. 1999b). In 1999 most of the grapes of this cultivar fell into the price bracket NZ$1,000-2,000 per tonne of fruit (total of 926 t of fruit). A negligible amount of grapes achieved below NZ$1,000/t (17 t), while 183 t of Cabernet Sauvignon fruit brought more than NZ$2,000 per tonne. The highest price obtained was about NZ$4,000/t, but only for a very small amount of fruit. Similar median prices were achieved in Marlborough (the second largest Cabernet Sauvignon-growing region), but very little fruit has achieved prices above NZ$2,000/t (Anon. 1999b).

In order to manage the vigour potential of Cabernet Sauvignon, Hawke's Bay vignerons are planting grapes at different sites and on various rootstocks, which coupled with an increased awareness of the importance of canopy management, should enable them to manage the typical Cabernet Sauvignon vigour problem. Tony Prichard again: "...the biggest single problem is vigour control - get that and you can have very good tannins, ripe characters, even without high °Brix levels" (Tudor, 1996).

Hawke's Bay Sub-regions

The sub-regions of Hawke's Bay presented here (Figure 3) are based on geographical and/or topographical factors. Any given geographical sub-region of Hawke's Bay can include a variety of soil types over a very short distance (a detailed account of sub-regional soil properties is given in Appendix 11, page 269), and climate modifying factors such as windbreaks, hills, rivers, or proximity to the sea can also be present. Therefore one geographical sub-region does not represent only one site type (or 'terroir') for grapegrowing. However, there are certain environmental conditions relevant to viticulture, that are typical for each of the sub-regions. The

names for sub-regions used below are as published by the Hawke's Bay Vintners (Anon, 1996).

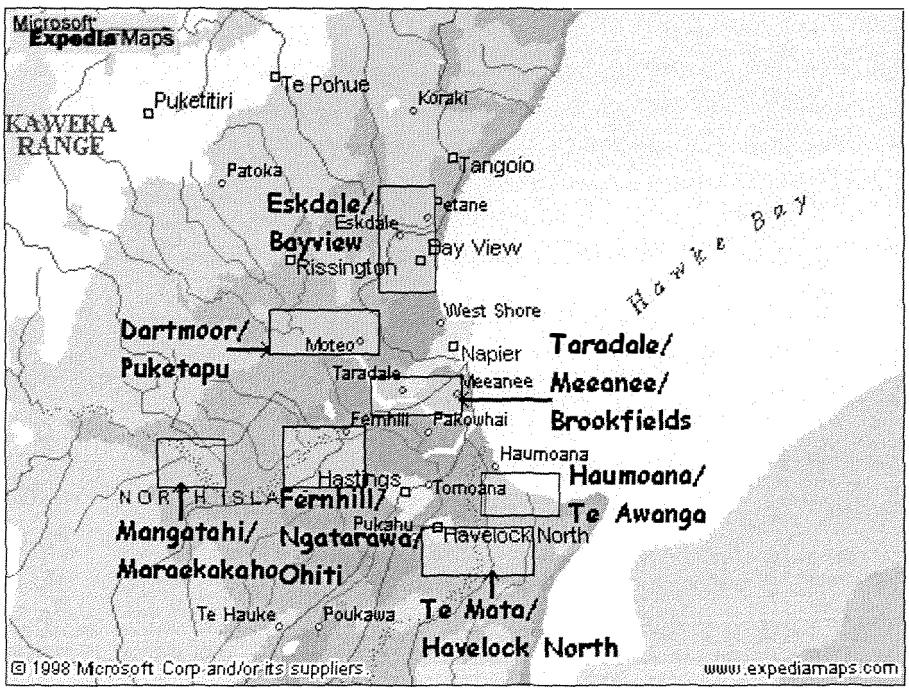

Figure 3. Viticultural sub-regions of Hawke's Bay

Fernhill/Ohiti/Ngatarawa

This is one of the fastest-growing sub-regions, also called the Western Plains. It is situated west of Hastings on both sides of the Ngaruroro River. The majority of soils in this area are either stony gravels (Omahu), or loams on gravel (Flaxmere). These soils have a low moisture retention capacity, enabling control of vine vigour through irrigation management. As a result, a number of cultivars successfully ripen regardless of inter-seasonal variability. Gravelly soils in this sub-region are currently in very high demand from the grape and wine industry. In 1991/92 local government legislation preserved these soils for viticultural purposes by prohibiting further developments of the shingle extraction industry. Urban expansion of Hastings has rendered some of the gravelly soils unavailable to viticulture. Before the success of viticulture on Hastings gravels, urban developments had been directed quite logically onto the gravelly soils of lower fertility in

order to preserve the deeper and finer alluvium soils for other traditional horticultural crops (Molloy, 1998).

Dartmoor/Puketapu

This sheltered inland sub-region is situated in the Tutaekuri River valley, between the townships of Moteo, Dartmoor and Puketapu. Vineyards are located on a variety of soil types of different fertility. Recently this sub-region has seen some new developments in the area of limestone hills.

Taradale/Meeanee/Brookfields

This sub-region lies approximately 10km southeast of the Dartmoor/Puketapu sub-region, on the east bank of the Tutaekuri. Areas within this sub-region include suburbs of Napier and the township of Taradale. Soil type is mostly silty loam with moderate fertility. In some parts waterlogging can occur in seasons of above average rainfall.

Mangatahi/Maraekakaho

This is an inland sub-region secluded from the coastal influences. It is appealing to grape growers due to the relatively lower soil fertility of its shingly and sandy loams, and good drainage properties. Many vineyards are planted on old river terraces of the Ngaruroro River. Most of the sub-region is relatively higher in altitude than the other sub-regions (up to 100 m a.s.l.).

Eskdale/Bayview

This northernmost sub-region is exposed to a pronounced oceanic influence. It has a slightly higher rainfall than other sub-regions, which increases significantly just 15-20km westwards (yearly rainfall for Esk Forest is 1752 mm, Thompson, 1987). Most of the vineyards in the Eskdale area are located on alluvial sands on the banks of the Esk River. Bayview vineyards are in many cases only a few hundred metres away from the Pacific Ocean.

Haumoana/Te Awanga

This relatively small sub-region is located on the coastline between Haumoana and Te Awanga. Because vineyards are in a very close proximity to the sea this area has a frost-free, favourable mesoclimate. Occasional salt damages can occur to growing shoot tips of vines. This sub-region is only a few kilometres away from Havelock North, and could considered a part of a greater Havelock North wine-growing sub-region.

Te Mata/Havelock North

The sheltered area of Havelock North is less windy than most of Hawke's Bay (Thompson, 1987). Soils in some areas are relatively heavy, which can delay ripening particularly in seasons with more rainfall. The Te Mata wine-growing area at the foot of Te Mata hills south of Havelock North boasts one of the oldest wineries in New Zealand (Te Mata Estate Winery).

Objectives and Experimental Rationale

The aim of this study was to investigate the effect of main meteorological and edaphic factors on viticultural and oenological performance of cv Cabernet Sauvignon in the wine growing region of Hawke's Bay. A further aim, based on the patterns expected to emerge from this main aim, was to establish a subdivision of distinctively different environmental conditions in this region into particular types, or 'terroirs'. The final objective was to propose a model of viticultural behaviour and oenological potential of this cultivar in different 'terroirs' within Hawke's Bay, in order to facilitate site selection for Cabernet Sauvignon so as to maximise the typicity and preferred attributes of wines.

A particular interest in studying Cabernet Sauvignon's behaviour in Hawke's Bay arises from the fact that Hawke's Bay is the main region for this cultivar in New Zealand. As the inter-seasonal variability makes it hard to consistently obtain high quality grapes for vintage wines, it is important that Cabernet Sauvignon be grown at the sites with highest potential for

enhancing preferred fruit attributes. Sub-regions within Hawke's Bay with markedly different environmental conditions exist quite obviously, so identifying and characterising these is clearly of both scientific and commercial interest.

The above objectives were achieved by a comprehensive observation of the experimental blocks consisting of 12-20 Cabernet Sauvignon vines with reasonably similar characteristics at 28 different sites and over one growing season. This provided an insight into the extent of variability in phenological stages, vegetative and generative growth, as well as the basic fruit quality attributes. Based on these results a selection was made of six sites markedly different in most of the above indices and at the same time providing good coverage of the whole region.

These selected sites were then used for a detailed study of their environmental characteristics over a period of two growing seasons. This study included below ground attributes such as soil profile and texture, rooting pattern of vines, soil moisture and soil temperature variability within season and depth. Above ground environmental attributes observed were hourly minimum, average and maximum air temperature above the top of the canopy, daily solar radiation values in the same zone, and weekly rainfall.

In addition to the environmental conditions, comprehensive sets of attributes relating to phenology, vegetative growth and canopy characteristics, yield and yield components were observed. Berry ripening dynamics was observed weekly with measurements of berry weight, total soluble solids, total acidity and malic and tartaric acids content, the pH of juice, potassium content in juice, and total and extractable polyphenols and anthocyanins in berry skin extracts. Grapes harvested at the end of each of these two seasons were used for microvinification. Wines obtained were subjected to panel tasting to establish their organoleptic characteristic and sensory attributes.

CHAPTER 2. GENERAL MATERIALS AND METHODS

Introduction

Grapevines (*Vitis vinifera* L.), used in this research were cultivar Cabernet Sauvignon clone UCD7, grafted onto Berlandieri x Riparia SO4 rootstock. Experimental blocks of vines were located in 28 vineyard sites throughout the wine-growing region of Hawke's Bay. Cabernet Sauvignon is generally considered to be a cultivar that produces wines of excellent quality (Kerridge and Antcliff, 1996; Pongracz, 1978). It is a vigorous vine and is generally low yielding (Galet, 1979). As a late-ripening cultivar in certain years and in some Hawke's Bay localities there are difficulties in achieving desired ripeness of grapes.

Clone UCD7 of Cabernet Sauvignon is one of the most frequently planted cultivars in this region. Five of the sites investigated in the initial study during 1996/97 were planted with Cabernet Sauvignon clones other than UCD7. These were UCD6 and UCD8, the latter identical to UCD7 (James Wolpert, pers. comm.). In a three-year trial in California (Wolpert *et al.*, 1995), clone UCD8 had consistently bigger clusters than UCD6. Clusters of UVD8 had more berries and those were larger than in UCD6. With regard to fruit composition, UCD8 had lower TSS and higher pH than UCD6.

Clone UCD7 is also known as G9V3 in Australia, where it is one of the most widely planted clones (Clarke, 1996a). The same author commends the quality of wine and yields (10-12 t/ha) that the clone UCD7 achieved in New Zealand.

All experimental vineyards were on one rootstock (with one exception), because of the significant impact the rootstock has on various scion properties (Delas and Pouget, 1989). Berlandieri x Riparia SO4 is one of the

most frequently used rootstocks with Cabernet Sauvignon in New Zealand (Clarke, 1996b). It is moderately vigorous but tends to be very vigorous on deep fertile silt soils in New Zealand. It is also prone to magnesium deficiency and shanking (Clarke, 1996b; Anon., 1997). According to Clarke it is no longer considered to be a good choice for production of high quality wines. According to some growers, the perceptions of undesirable "green" or herbaceous taste in wine appear to be induced by this rootstock (Tudor, 1996).

The range of training systems and pruning styles used at vineyard sites included in this study certainly had an effect on vegetative growth, yield and fruit composition. However, a sufficient number of vineyards in Hawke's Bay with the same training and pruning systems was not available. This study was conceived similarly to 'terroir'-defining studies done by Barbeau *et al.* (1998a), Barbeau *et al.* (1998b), Morlat and Salette (1982) and Vadour *et al.* (1998). One common characteristic of these studies is that they were conducted in 'classic' regions of France, where there is an abundance of mature vineyards and one predominant training, pruning, and overall vineyard management system.

Methods utilised represent a range of different measurements, analyses, counts, observations, and environmental data logging. Some very specific methods (eg. microvinification) will be described in detail in chapters that deal with these particular aspects of this study.

Environmental data collection was a particularly important part of the study of selected vineyard sites and data loggers were used to collect a range of environmental variables including air temperatures, solar radiation, rainfall and soil temperature. Soil temperatures affect the root physiology by influencing general metabolism, the absorption and transport of water and minerals, and synthesis of growth substances that are transported to aerial vegetative and generative plant parts (Champagnol, 1984; Gladstones, 1992).

Growing degree-days (GDD) were calculated in this study using a base of 10°C, which is by far the most common "vegetative zero" for grapevines and many other horticultural plants (Winkler *et al.*, 1974). However, use of this base temperature is not flawless, and many authors have claimed other base temperatures to be more suited to grapevines. Oliveira (1998) in Portugal has established that temperatures of 8.7 °C for budburst, and 10.7 °C for flowering represent the bases providing the best agreement between heat summations and phenological records for the cv Touriga Francesa. Previously, Boehm (1970) reported that a temperature base of 8°C was suitable for the period from budburst to flowering in South Australia. Champagnol (1984) states that the vegetative zero for cv Aramon is 10.2°C in Montpellier, France and 13.5°C in Algiers.

Gladstones (1992) argued that a base of 10°C indeed represents an appropriate temperature base. Even if the responses leading to budburst or growth do occur while the mean air temperature is below 10°C they do not, according to this author, attain expression until the means have reached or exceeded 10°C.

Region

A detailed description of the wine-growing region of Hawke's Bay and its sub-regions is provided in Chapter 1 and Appendix 11.

Environmental Conditions

Above and below ground environmental conditions were monitored during 1997/98 and 1998/99 growing seasons. Li-Cor LI1000 (LI-COR Inc. Environmental Division, 4421 Superior St, Lincoln NE 68504, U.S.A.) data loggers were placed in standard meteorological screens positioned within a row of grapevines at each of the six experimental blocks.

Loggers were equipped with temperature sensors – thermistors (Edwards Industries Ltd, Palmerston North, New Zealand) calibrated to ±0.1 °C. One

temperature sensor at each of the sites was placed in a protective shield above the top of the canopy (Figure 4). Data loggers were programmed to log minimum, maximum and hourly average air temperatures using this sensor. Details of set-up and programming of the data loggers are shown in Appendix 4 (page 246).

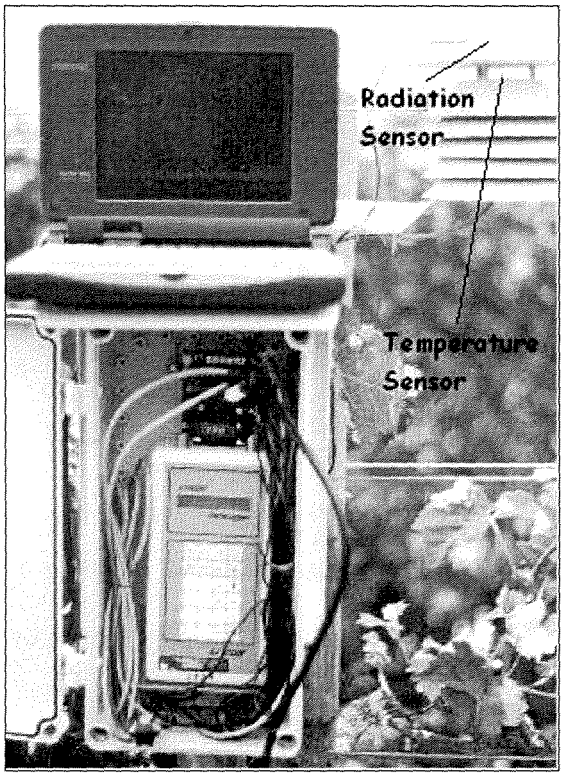

Figure 4. Li-Cor LI1000 data logger in a protective shield, placement of sensors, and data download on a laptop computer

Two additional temperature sensors buried in soil under vine at depths 15 and 30 cm measured daily soil temperature averages obtained from readings taken at 60-second intervals.

One Li-Cor Quantum 190SA radiation sensor was placed at the top of the protective shield, and data loggers were programmed to log the integrated daily photon flux. The sensors were frequently checked and cleaned to ensure accurate measurement.

GDD were calculated from mean daily temperature (t) as GDD=$\Sigma(t_{>10°C}-10°C)$. Microsoft Excel Visual Basic function that facilitates this calculation is presented in Appendix 6, page 253.

Rainfall was monitored using cylindrical rain gauges (NYLEX 1000), which were read and emptied on a weekly basis. They were placed at the top of the vineyard posts (approximately 200 cm high) close to the meteorological screens. The rain gauges were constructed to ensure minimum water loss due to evaporation and conformed to the recommendations of the Australian Bureau of Meteorology (Anon. 2000a).

Soil moisture content was measured every three to four weeks during the vegetative period. Time Domain Reflectometry (TDR) probes (welding rods) 30 and 60 cm long were placed in pairs under vine and in the middle of isle between rows at one site within the experimental blocks. TDR was recorded using a Tektronix 1502C cable tester (Tektronix, Inc, 14200 SW Karl Braun Drive, Beaverton OR 97077, U.S.A.) with a portable PC computer running the TDR software created by the Horticulture and Food Research Institute of New Zealand. Field water capacity for each site was estimated to equate the maximum soil moisture content recorded at respective sites.

Some of the data obtained in these two seasons were used to back-predict meteorological conditions at selected sites during the 1996/97 growing season. Regression of data from the network of meteorological stations of the Horticulture and Food Research Institute of New Zealand onto the second and third season's data collected at selected sites was used for this purpose. Details regarding these calculations are described in Chapter 3.

Experimental Block

Experimental block at each site was rectangular in shape comprising four rows and one bay (the space from one vineyard post to the next). This block contained different number of vines as vine spacing differed between sites. This number ranged from eight (where there were only two vines per bay, as in the case of the RVV site) to 20. Because of different vine and row

spacing, measured variables (for example yield or pruning weight) were always expressed per unit surface and not per vine (the latter being common in viticultural literature).

Two inner rows in each experimental block were used for phenological observations, berry and cluster collection, while two outer rows were used for measurement of shoot growth, using the shoots with fruit removed. The fruit was removed only from the shoots measured. Environmental data, such as air and soil temperature, rainfall and soil moisture were all collected in the central part of an experimental block.

Phenological Stages

The percentage budburst was calculated by associating scores with the phenological stages observed on 200-300 buds located over approximately 8 m of cordon length.

A bud was considered to have burst at the stage of 'green tip' and therefore corresponded to Modified Eichorn and Lorenz (E-L) scale 4 (Lorenz *et al.*, 1995; Coombe, 1995). The same criterion for establishing budburst was used by Martin and Dunn (2000), while Barbeau *et al.* (1998b) used stages A through H on Baggiolini scale (Coombe, 1995) to monitor budburst. The visual scoring system for budburst was as follows: 0 = winter bud (1); 1 = bud swell (2), 2 = green tip (4), 3 = rosette of leaf tips (5); and 4 = leaf unfolding (7). The numbers in brackets represent values for appropriate phenological stages according to modified E-L scale.

The scoring system used for monitoring phenological stages of flowering and véraison was similar to that of Barbeau *et al.* (1998b) and Martin and Dunn (2000). Percent flowering was established by counting all the inflorescences (commonly 200-300) in one bay of selected blocks on both sides of the canopy (experimental block is defined on page 25). Each inflorescence was associated with one of five possible values: 0 = no flowers open; 1 = up to 25% flowers open; 2 = 25-50% flowers open; 3 = 50-75% flowers open; and 4 = >75% flowers open. Because of the large

number of sites monitored in the first growing season, flowering percentage scoring was done using three scoring categories only: 0 = no flowers open; 1 = some flowers open, but not all; and 3 = almost all or all flowers open.

The calculation of véraison percentage was based on the colour change in berries on 200-300 clusters on the same number of vines as at flowering. Each cluster was associated with one of five possible values: 0 = no berries coloured; 1 = <25% berries coloured; 2 = 25-50% berries coloured; 3 = 50-75% berries coloured; 4 = >75% berries coloured.

The beginning of a phenological stage is defined as 5% of completion, mid stage (mid-budburst, mid-flowering, or mid-véraison) represents 50%, and the end of a stage indicates 95% of the stage completed. The terms budburst, flowering and véraison used without specification of stage of their completion in this work always denote 50% of stage completed, or mid stage.

Phenological attributes of vineyard sites were characterised by **indices of precocity** ('*indices de précocité*') developed by Barbeau *et al.* (1998b) for defining 'terroirs' for cv Cabernet Franc in the Loire Valley. Index for precocity of flowering (**IPF**) is calculated as:

$$IPFj(\text{site } j) = 100 * [1+(Fm–Fj)/Fm]$$

where Fm = mean mid-flowering for studied sites and Fj = mid-flowering for site j. Index for precocity of véraison (**IPV**) is calculated in the same way as IPF, based on Vm (mean mid-véraison date) and Vj (mid-véraison date for site j). Index for precocity of the cycle (**IPCY**) is calculated as:

$$IPCY = IPF+100*[(Vm-Fm)–(VjFj)]/(Vm–Fm).$$

Nutrient Status

The status of main grapevine nutrients (N, P, K, Ca, and Mg) was determined by leaf petiole analysis. Forty leaf petioles were sampled at mid-flowering, mid-véraison and before harvest (only at véraison in the first season) from each of the observed sites (28 in the first and six in the last two seasons). They were selected from nodes opposite the basal cluster on a shoot. Petioles were oven dried to constant weight and then ground.

Nitrogen and Phosphorus were determined by Kjeldahl digestion and colorimetric autoanalysis (Pulse Instruments Ltd., Canada), and Potassium, Magnesium, and Calcium by digestion with concentrated nitric acid and analysis by Atomic Absorption Spectrophotometry using a EBC904 (Victoria, Australia) in the laboratories of the Institute of Natural Resources, Massey University. The digestions were conducted according to following procedures:

- For nitrogen and phosphorus: 0.1 g of plant material was weighed into digestion tubes and 4 ml of Kjeldahl digestion solution (250g K_2SO_4, 2.5g Selenium powder, 2.5 L concentrated H_2SO_4) was added. Tubes were heated to 350 °C for 4-5 hours, or until solution cleared. The tubes were then made up to 50 mls using distilled water. The solutions were stored at 4 °C until autoanalysis.

- For potassium, calcium and magnesium: To 0.1g plant matter 4 ml of concentrated nitric acid was added. Digestion tubes were placed in a heating block with small funnels in the top to cause refluxing (if HNO_3 boiled off, another 4 ml was added and redigested) and heated to 150 °C for 4 hours or until solution cleared. Temperature was then turned up to 250 °C and funnels were removed. Acid was boiled off to dryness, which took up to 3 hours. While still warm 50 ml of the following was added: 0.2m HCl + 1000 ppm $Sr(NO_3)_2$/CsCl. The solutions were kept at 4 °C until compared with a standard curve using the AA spectrophotometer.

Vegetative Growth

Canopy density estimations were recorded for each site using scorecards (Smart and Robinson, 1991), with points given for canopy gaps, leaf layer number, exposed fruit area, leaf size and colour, shoot length, lateral growth and the number of growing tips. A scorecard form is given in Appendix 1.

Canopy Density Index (*CDI*) was calculated from the scorecard points as follows:

$$CDI = 1 - \frac{SC}{80}$$

SC represents the number of points obtained using the canopy density scorecards. The aim of this transformation was to inverse canopy density scores, so that the highest values represented the densest canopies and *vice versa*. The original canopy density scorecard points (Smart and Robinson, 1991) function so that the higher values represent lower canopy density.

Exposed leaf surface area (ESA) was estimated by measuring the canopy height, width and row spacing (Smart and Robinson, 1991). ESA is believed to be a good descriptor of the canopy (Carbonneau, 1996). However, it should be noted that primarily ESA has a comparative value, rather than establishing the actual exposed leaf surface area. Mabrouk and Sinoquet (1998) showed that comparing the canopy to a geometric shape leads to an overestimate of exterior leaf area, as foliage gaps are not taken into account. Although ESA can be slightly affected by summer pruning, the management systems were relatively similar at the examined sites and the measured ESA is considered representative of the site.

The methodology of shoot elongation measurements will be outlined in detail in Chapter 5.

Yield Components

Methodology for determination of yield and yield components in the last two experimental seasons will be detailed in Chapter 7. In 1996/97 these variables needed to be estimated, as harvesting of grapes at 28 sites, many of which were ripening simultaneously, was not feasible. In order to assess the yield of grapes, and with the number of clusters established by counting, it was necessary to estimate the average cluster weight.

Maximum length and maximum width was determined using callipers, and weight measured using standard digital balance to accuracy of 0.1 g on approximately 150 clusters of cv Cabernet Sauvignon grapes randomly selected from a vineyard in the Fernhill sub-region. Using values obtained the following linear regression equation was established:

$$CW = -170.118 + 1.181 \bullet ML + 2.002 \bullet MW$$

Where *CW* = cluster weight (g), *ML* = maximum length and *MW* = maximum width (both in mm). Correlation between these parameters was strong and very significant ($R^2 = 0.778$, $p>0.001$).

The limited cluster weight and yield data for the 1996/97 season that were available from growers at some of the observed vineyard sites indicated that this estimation was satisfactory.

Dry matter production was defined as the sum of approximate dry weight of grapes (grape weight in kg/m^2 * 0.25) and approximate dry weight of winter prunings (pruning weight in kg/m^2 * 0.55) (D. Martin, pers. comm).

Berry and Juice Composition

Total soluble solids (TSS) in juice were assessed in the field at harvest in 1996/97 by a hand-held digital refractometer Atago RR-1, Japan (temperature compensated) using a juice sample squeezed from a dozen berries combined, which was replicated three times. Berries were collected from random clusters with all berries in the cluster included, and randomly

from the experimental blocks. The methods used to analyse berry composition at harvest in 1996/97, and weekly during the 1997/98 and 1998/99 seasons are outlined as follows:

These analyses were conducted in the laboratory of the Horticulture and Food Research Institute of New Zealand (HortResearch), Havelock North Research Centre, New Zealand. Berry samples were collected according to the method of Reynolds *et al.* (1995). A sample of a minimum of 150 berries in 3 - 5 berry cluster fragments was taken from a block on each occasion. A minimum of one hundred berries was used for juice extraction and 50 for skin extractions. Counting of the berries was aided with counting grids, which also enabled the taking of randomised samples through systematic selection of each n^{th} berry from the grid.

Juice for analysis was obtained by mashing (blending) the berries with a hand-held mixer with a blunted blade, so the seeds were not crushed. According to Hamilton and Coombe (1992) this method (blending or mixing) gives representative samples provided the blending time is kept short and constant. Juice was then centrifuged (Kubota KR-20000T) for ten minutes at 14,000 g.

Centrifuged juice was used to determine the total soluble solids (TSS) with a digital refractometer Atago RR-1, Japan. TSS was also checked on several occasions using hydrometers in order to ascertain the accuracy of the refractometers, which was found satisfactory. Titratable acidity (TA) was determined by titration with 0.1N NaOH, and pH with a digital pH meter (Van Dam, 1979). A sub-sample of 5 ml juice was diluted in 15 ml water and frozen for later determination of malic acid, tartaric acid, and potassium.

Juice yield was determined as a percentage ratio between the volume of juice extracted and the initial berry weight of the sample. Juice turbidity was defined as a percentage ratio between the weight of sediment left after centrifuging and the initial volume of juice extracted from grape berries.

Indices that have been used to assess the maturity status of grapes are as follows:

Index of Ripeness (IR) was calculated as the ratio between sugar content in g/L (or TSS x 10) and TA, also in g/L. It is also known as the Gluco-acidometric index or sugar/acid ratio (Hamilton and Coombe, 1992), and is noted as a potentially useful index for winegrape quality assessment by Du Plessis and Van Rooyen (1982). The values of IR at harvest usually vary from 20 to 40 (Hamilton and Coombe, 1992).

Index of Ripeness adjusted for Anthocyanins (IRA). Concentration of anthocyanins in berry skins or wine in red grape cultivars was associated with wine quality by a number of authors (Somers and Vérette, 1988, Keller *et al.*, 1999, Holgate, 2000, Holzapfel *et al.*, 2000). In an attempt to include a measurement of berry skin colour as an additional indication of the red grape quality potential, the index IRA is proposed in this study as a novel indicator. IRA can be calculated as:

$$IRA = IR \bullet (K + AC)$$

K = constant that has to be established for each red winegrape cultivar individually and is here set to be 0.54 for Cabernet Sauvignon. *AC* = concentration of anthocyanins in g/L of wine (or skin extracts in the synthetic wine).

The *K* value of 0.54 was based on initial data obtained in 1996/97 when it was determined that berries of optimal ripeness (based on an arbitrary organoleptic assessment) had anthocyanin concentration of 0.46 g/L or above. Therefore, samples with a higher anthocyanin concentration were given 'bonus' points compared to those with low anthocyanins. Grape samples with anthocyanins below 0.46 g/L had their index reduced proportionally to their lack of colour.

The application of IRA in this study in effect emphasises the existing differences in fruit maturity between sites as measured by a more common maturity index such as IR. From the results of fruit analyses in the 1996/97 season it was obvious that anthocyanin concentration shows a greater variability between sites (CV=17%) than TSS (CV=4%) or TA (CV=15%).

Therefore the rationale behind deriving this novel indicator was to have a fruit maturity index that would be more sensitive to apparent differences in fruit ripening capacity of the studied sites than a more commonly used TSS or IR.

Determination of malic and tartaric acid in juice

Malic acid was determined by the UV-method (Anon. 1984), tartaric acid according to Anon. (1978) and potassium by AA spectrophotometry at the Analytical Research Laboratories Ltd, Hastings and at Massey University.

Determination of polyphenols and anthocyanins in berry skins

The remaining 50 berries were weighed and then squeezed manually in a consistent manner to obtain berry skins. Those were used for extraction and determination of polyphenols and anthocyanins. The first extraction of samples placed in wide plastic vials was done using a synthetic wine solution (12% alcohol, 5 g/L TA [4 g/L tartaric, 2 g/L malic acid], pH 3.2) for 24 hours, using the Orbital Shaker SS-70 at approximately 200 rpm.

These extracts were centrifuged and analysed using the UV Visible Recording Spectrophotometer (Shimadzu UV-2401PC) at wavelengths of 280 nm (representing total polyphenols) and 520 nm (representing anthocyanins) (Mabrouk and Sinoquet, 1998).

To determine the total content of these substances in berry skins, further repeated extractions using the same berry skins were done with a stronger solvent, 2% HCl. Total polyphenol and anthocyanin contents were calculated from these spectrophotometer readings using empirical formulas (Damian Martin, pers. comm.). These formulas are presented in the Appendix 2 (page 240).

Calculation of the content of juice compounds on a per berry basis was done using the following formula:

$$p = \frac{w \times m \times q}{100}$$

Where p = content of a substance in mg/berry, w = berry weight in g, m = juice yield percentage (the ratio between extracted juice and berry weight), and q = concentration of the same substance in g/L of juice.

The content of polyphenols and anthocyanins was initially calculated (page 240) in g/kg of fresh berry weight; when one value was multiplied by average berry weight in g the content of polyphenols and anthocyanins was obtained on a mg/berry basis.

Pruning Weights

During June in each of the experimental seasons, four opposing bays (a bay being the space between two posts) of vines was pruned at each site. This comprised a varying number of vines depending on the inter-vine spacing (8-20 vines). Vines were pruned using the standard method of pruning for each vineyard (i.e. the same as applied by vineyard management). These included spur pruning, cane pruning and mixed pruning (spurs and canes).

Pruned canes for each vine were weighed using a spring balance. In 1997/98 the number of canes was also recorded, enabling calculation of average cane weight. In the same season the mean number of nodes per cane and the cane diameter between nodes 1-10 was also observed on a random sample of ten pruned canes.

At pruning time in the last two seasons, notes were also taken on the occurrence of de-socketing (the pulling out of canes from the main stem or cordon) and its extent. The probable cause of de-socketing appeared to be the application of machine harvesting and was also potentially related to strong spring winds at some sites.

The yield and pruning weight data enabled calculation of a 'crop load' index (Bravdo *et al.*, 1985), or yield to pruning ratio (yield of grapes per vine or per

unit surface vs the weight of prunings per vine or per unit surface). This index also called 'Ravaz index' to honour Ravaz who proposed it in 1906 (Maccarrone *et al.*, 1996) numerically describes the balance between vegetative growth and vine productivity. Yield/pruning weight ratio was calculated as the ratio between yield of grapes (kg/m^2) and pruning weight (kg/m^2).

Limitations to Experiment

This study was conducted in commercial Cabernet Sauvignon vineyards throughout Hawke's Bay. This situation created the following limitations that influenced both the design and outcomes of these experiments:

- The availability of sites with the same rootstock / scion combination was limited.
- Differences in vine age, planting density and training systems added a further complication.
- It was not possible to affect or control vineyard managerial decisions at any of the studied sites (including the decision when to harvest grapes), nor was the information driving these decisions and practices made available.
- Budgetary constraints limited production of small-lot wines to only one batch of wine per site per season, and prevented use of alternative replicated vinification procedures.

Statistical Analysis

The following modules of *Statistica for Windows* 4.5 (StatSoft Inc. 1993) were used:

- Basic Statistics/Tables;
- Nonparametric Statistics and Distribution Fitting;
- ANOVA/MANOVA;
- Linear Regression;

- Nonlinear Estimation
- Cluster Analysis;
- Factor Analysis;
- Discriminant Analysis.

Data were maintained using Microsoft Excel 97, and the following custom functions written in Excel's Visual Basic for Applications (VBA) were used:

- GDD - calculated the growing degree-days and degree-hours for a given temperature base;
- ESA - calculated the estimated exposed leaf surface area based on the canopy properties and vine spacing;
- TUNKNOWN - interpolated meteorological data for a given site, based on known data for two neighbouring sites;
- INTERPOLATE - interpolated and extrapolated values for a given date, based on known data for two dates in a time series.

Detailed function listings are shown in the Appendix 6 (page 253).

CHAPTER 3. INITIAL ASSESSMENT OF DIFFERENT VITICULTURAL ENVIRONMENTS

Introduction

Consistent production of high-quality grapes is made difficult by high inter-seasonal variability in Hawke's Bay weather conditions. This makes an adequate vineyard site selection critical if the desired wine quality is to be sustained. Sub-regions of Hawke's Bay are characterised by markedly different environmental conditions. Identifying and characterising these conditions is of both scientific and commercial interest. Because of the number of variables that must be investigated, the focus of this research was on one grapevine cultivar only. Cabernet Sauvignon was selected on the basis of its importance to the grape and wine industry in New Zealand and worldwide, its late ripening trait and because it is prone to excess vigour. All of these attributes are likely to allow greater differentiation between sites than an earlier variety with a more manageable vegetative vigour (such as Chardonnay or Pinot Noir).

This correlative study had the aim of detecting and quantifying the relationships between site-related factors and vine and grape attributes. Similar studies of the environmental influence on biological and technological performance of grapevines have been conducted in many different viticultural countries and regions (Battistutta *et al.*, 1996; Bertamini *et al.*, 1996; Barbeau *et al.*, 1998a). These studies have confirmed a highly significant discriminant power of the 'site' factor, or 'terroir'

The objective of this research was to quantify the degree and the nature of selected environmental effects on main phenological, growth, cropping, and fruit ripening properties of Cabernet Sauvignon growing in the sub-regions

of Hawke's Bay, New Zealand. Based on the findings during the initial growing season, a further aim was to investigate in more detail, six sites – 'terroirs' – that would cause vines to exhibit the greatest variability in observed grapevine and wine attributes.

Material and Methods

All 28 sites included in the initial assessment during the 1996/97 growing season (Table 2, Figure 5) were planted with Cabernet Sauvignon, Clone UCD7 (exceptions noted in Table 2), grafted on SO4 rootstock (with one exception on Teleki 5C).

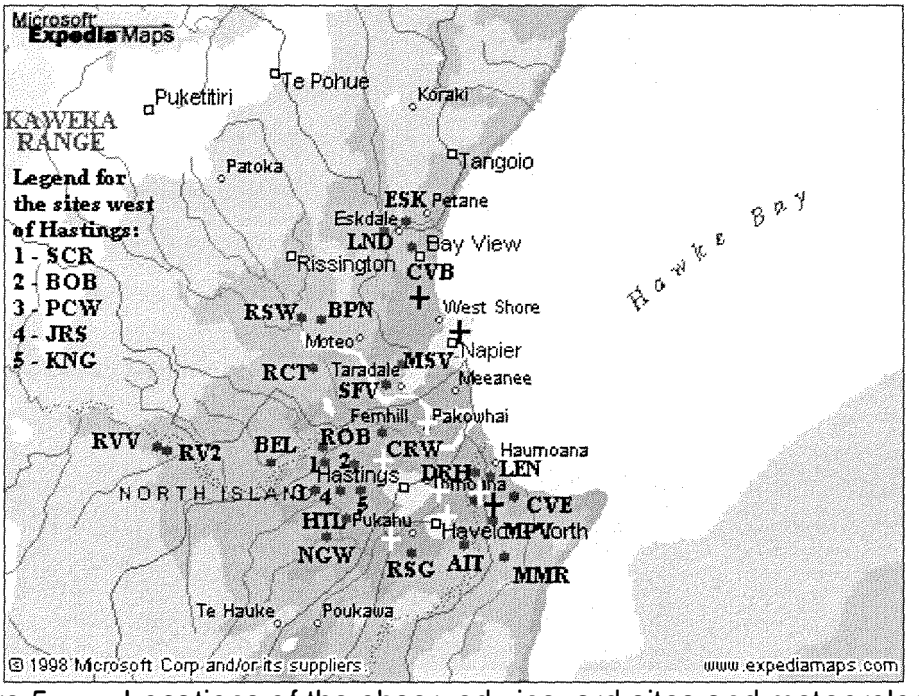

Figure 5. Locations of the observed vineyard sites and meteorological stations.
White crosses denote the Horticulture and Food Research Institute of New Zealand Ltd (HortResearch) network of weather stations, black are the National Institute of Water and Atmospheric Research, New Zealand (NIWA) stations. Site details are shown in Table 2.

Vines were planted over a period from 1981 to 1993, row spacing was about 3 m, and vine spacing within rows averaged 2 m, ranging from 1.3 to 4m. Although it would have been preferable for both vine spacing and

training systems to be identical, this was not possible because of limited availability in the vineyards in the different sub-regions investigated. Most training systems were versions of the Vertical Shoot Positioning system (VSP), generally pruned to three or four canes. Seven vineyards were trained as Scott-Henry with various modifications, five as Sylvoz. There were only two vineyards with divided canopies, one with "U" trellis, and one with Geneva Double Curtain (GDC).

All sites had herbicide strips under the vines with vegetation between rows. In most cases ground cover was a natural and permanent grass/clover mix, while at few sites a sward culture (mostly chicory) was planted between rows. Most vineyards were mown at different intervals during the season (usually during the second half of the season).

Row orientation in selected vineyards was diverse: eight vineyards had rows oriented south - north, another eight were east - west, seven were southeast - northwest, and five southwest - northeast.

The majority of sites were located 20-30 m above sea level. The highest altitude was at RVV and RV2 sites (located in the same vineyard, Mangatahi / Maraekakaho sub-region) at approximately 100 m a.s.l. The lowest were those in Haumoana / Te Awanga sub-region, at just about 5 m a.s.l. The majority of the sites around Hastings (Fernhill / Ngatarawa / Ohiti sub-region, and the acclaimed Gimblett Road area), and Havelock North were about 10-30 m a.s.l. Higher sites such as MMR, were located at 67 m, while AIT and BPN at about 40 m a.s.l.

Because of the different spacing between vines and between the rows, number of vines per hectare was markedly different between sites, varying from 862 to 3077, with an average of 1712.

Table 2. Sites in Hawke's Bay monitored in the 1996/97 growing season.

Site	Year Planted	Row Spacing (m)	Vine Spacing (m)	Training Form	Row Orientation
Fernhill / Ngatarawa / Ohiti					
BOB*	1993	3.0	1.9	Cordon	SW-NE
BEL*	1993	2.9	1.8	Cane VSP	SW-NE
CRW	1992	3.2	2.5	Sylvoz	W-E
HTL	1990	2.8	2.2	Cane VSP	SW-NE
JRS	1990	2.9	3.0	Scott-Henry	SE-NW
KNG	1991	2.9	4.0	Scott-Henry	SE-NW
NGW	1990	3.1	1.9	Cane VSP	SE-NW
PCW	1992/93	2.8	2.2	Cane VSP	SE-NW
ROB	1993	2.8	2.0	Cane VSP	E-W
SCR	1981	2.6	1.3	Cane VSP	S-N
Te Mata / Havelock North					
AIT	1989	3.0	2.0	"U" trellis	N-S
HHV	1990	3.0	2.0	Sylvoz	S-N
MPV	1989	3.0	1.9	Cane VSP	S-N
RSG	1987	3.2	1.8	Sylvoz	SW-NE
Dartmoor / Puketapu					
BPN	1990/91	3.0	2.0	Cane VSP	W-E
RSW*	1993	3.2	2.5	Cane VSP	SE-NW
RCT*	1993	2.7	1.8	Scott-Henry	S-N
Eskdale / Bayview					
CVB	1993	2.6	2.0	Cane VSP	W-E
EVV	1992	2.9	1.8	Cane VSP	E-W
LND	1991	3.0	2.7	Sylvoz	S-N
Haumoana / Te Awanga					
CVE	1991	2.8	1.6	Cane VSP	SW-NE
DRH	1988	3.1	1.9	GDC	SE-NW
LEN	1987	2.5	1.9	Cane VSP	SE-NW
MMR	1990	2.9	1.9	Scott-Henry	W-E
Taradale / Meeanee / Brookfields					
MSV*	1986	2.7	2.1	Cane VSP	S-N
SFV	1988	3.0	1.8	Cordon	E-W
Mangatahi / Maraekakaho					
RVV	1991	2.7	1.0 / 6.0***	Scott-Henry	E-W
RV2**	1988	2.8	1.8	Scott-Henry	S-N

* - clone other than UCD7 (mostly UCD6); ** - Teleki 5C rootstock; *** - Alternating vine spacing

Edaphic Conditions

Vineyard sites selected for the initial study were located on a range of different soil types. According to Griffiths (1997) there are over 30 distinctively different soil types in Hawke's Bay, many of which are being used for viticulture. Sites studied in 1996/97 were located on 14 different soil types:

- *Matapiro* sandy loam (AIT)
- *Omahu* gravels (BOB, JRS, ROB and SCR)

- *Omarunui* silt or sandy loam (BPN, CRW, KNG)
- *Tukituki* stony gravels (BEL, RSW)
- *Flaxmere* silt loam (CVB)
- *Waipukurau* sandy loam (CVE, MMR, RCT)
- *Pakowhai* sandy loam (DRH, LEN, NGW, SFV)
- *Esk* sand (EVV, LND)
- *Otane* silt loam (HHV)
- *Te Awa* clay loam (HTL)
- *Okawa* silt loam (MSV)
- *Mangateretere* silt loam (MPV)
- *Poporangi* ashy sandy loam (PCW, RSG)
- *Ngatarawa* sandy loam (RVV and RV2)

A more detailed account of soil characteristics in the Hawke's Bay sub-regions is presented in Appendix 11, page 269.

Estimation of Meteorological Data for the Observed Sites

Average air temperatures and rainfall were estimated for 28 sites using various methods depending on availability of data. Generally, data available for 1996/97 growing season were obtained from the network of meteorological stations of the Horticulture and Food Research Institute of New Zealand, Havelock North Research Centre (Figure 5).

Air temperature data from the individual meteorological stations were regressed against those collected at sites studied in 1997/98 and 1998/99 growing seasons. Regression equations obtained were used to estimate air temperatures at those and nearby sites in the 1996/97 growing season.

For those sites located away from the six sites selected for further study, the interpolation of data derived from the two nearest sites was employed. The same method was used for the estimation of rainfall.

Equations used to estimate average temperature data for 28 sites studied in 1996/97 growing season are given in Table 3.

Regressions between meteorological stations and the sites selected for further study were all statistically significant at $p<0.001$, while SE varied from 0.46 to 0.94 °C. Locations which were physically closer had stronger coefficients of determination (R^2 of ca. 0.99 or better) and lower SE than

those which were further apart. It was assumed, on the basis of these analyses, that these estimations were satisfactorily representative of their respective sites.

Interpolation of meteorological data on the basis of physical distance was also assumed to be suitable, being analogous to the interpolation of temperature data from isotherms, or of rainfall from isohyets, a procedure commonly used to estimate meteorological data (Milne *et al.*, 1995).

Table 3. Estimation of average temperatures for 28 sites in Hawke's Bay observed in 1996/97

Site	Equation
AIT	Equation A: SITEx=HN, SITEy=MMR, Dxy=6, Dxn=3
BOB	BOB = JRS
BPN	BPN = -0.559315+1.028518*PW
BEL	Equation A: SITEx=TW, SITEy=RVV, Dxy=24, Dxn=11
CVB	CVB = LND
CVE	Equation A: SITEx=MMR, SITEy=LR, Dxy=5, Dxn=3
CRW	Equation A: SITEx=TW, SITEy=SFV, Dxy=6.5, Dxn=2
DRH	DRH = LR
EVV	EVV = LND
HHV	Equation A: SITEx=HN, SITEy=LR, Dxy=8, Dxn=4
HTL	Equation A: SITEx=LL, SITEy=JRS, Dxy=9, Dxn=6
JRS	JRS = -0.487286+1.093376*TW
KNG	KNG = JRS
LEN	LEN = LR
LND	LND = -0.012041+1.015525*PW
MMR	MMR = 0.343156+1.009732*HN
MSV	Equation A: SITEx=PW, SITEy=SFV, Dxy=7.4, Dxn=6.6
MPV	Equation A: SITEx=HN, SITEy=LR, Dxy=8, Dxn=5
NGW	Equation A: SITEx=LL, SITEy=JRS, Dxy=9, Dxn=7
PCW	Equation A: SITEx=RVV, SITEy=JRS, Dxy=19, Dxn=14
RSW	RSW = BPN
RVV	RVV = -0.73998+1.048063*PW
RV2	RV2 = RVV
ROB	Equation A: SITEx=TW, SITEy=JRS, Dxy=5, Dxn=3
RSG	Equation A: SITEx=LL, SITEy=HN, Dxy=7, Dxn=4
RCT	Equation A: SITEx=BPN, SITEy=TW, Dxy=12.5, Dxn=4.6
SFV	SFV = -0.247612+1.016951*PW
SCR	Equation A: SITEx=TW, SITEy=JRS, Dxy=5, Dxn=4.9

Meteorological stations: HN - Havelock North; LR - Lawn Road; TW - Twyford; PW - Pakowhai; LL - Longlands Rd. *Equation A: SITEn = ((2*(Dxy-Dxn)/Dxy) * SITEx + (2*Dxn/Dxy) * SITEy)/2; Dxy: distance (km) between sites x and y; Dxn – distance between site x and site for which the estimation is done

Growing degree-day (GDD) values were calculated using average daily temperatures (averages of 24 hourly mean temperatures from 1am to

12am). The time from véraison to harvest index (VHI) was calculated according to Reynolds (1993).

A detailed account of other methods used is given in Chapter 2 on the following pages: phenological stages (page 26), vine nutrient status (page 28), vegetative growth (page 29), yield (page 30), and for berry analyses (page 30).

Results

A statistical overview of all the relevant variables observed in 1996/97 growing season, their averages, minima, maxima, standard deviation, and the skewness of their respective distributions is shown in Table 4. Correlation coefficients between the variables observed in the 1996/97 season are presented in Appendix 9.

Table 4. Variables observed in the 1996/97 season and their descriptive statistics

Variable	n	Mean	Minimum	Maximum	Std.Dev.	Skewness	Description
NUMVINES	28	1712.19	862.07	3076.92	425.50	0.71	*Number of vines per ha*
FD_F	28	63.29	57.00	74.00	4.44	1.13	*Days 1 Oct to flowering*
F_V	28	78.21	70.00	86.00	3.71	-0.18	*Days flowering to véraison*
FD_V	28	141.50	130.00	158.00	6.20	0.25	*Days 1 Oct to véraison*
FD_20	28	195.89	178.00	211.00	8.56	-0.04	*Days 1 Oct to TSS 20 °Brix*
F_20	28	133.61	120.00	149.00	7.41	0.28	*Days flowering to TSS 20 °Brix*
V_20	28	55.39	45.00	68.00	6.72	0.32	*Days véraison to TSS 20 °Brix*
FD_H	28	201.36	191.00	220.00	7.98	0.64	*Days 1 Oct to harvest*
FD_LF	28	232.36	221.00	244.00	5.22	0.00	*Days 1 Oct to leaf fall*
H_LF	28	31.00	9.00	47.00	8.04	-0.41	*Days harvest to leaf fall*
MDVH	28	6.20	4.28	7.95	1.00	-0.23	*Mean degree-day véraison harvest*
VHI	28	16.57	12.59	23.37	2.92	0.88	*(1/MDVH)*100*
NUMCLUST	28	6.64	3.99	9.85	1.69	0.02	*Number of clusters per m^2*
CLUSTWGT	28	134.98	87.70	189.30	23.63	0.18	*Average cluster weight (g) estimate*
YLD	28	0.89	0.49	1.38	0.24	0.34	*Estimated grape yield in kg per m^2*
BERRYWGT	28	1.48	1.16	1.85	0.17	0.65	*Average berry weight (g)*
TSS	28	20.85	19.30	22.50	0.84	0.60	*Total soluble solids at harvest (°Brix)*
TA	28	9.32	6.10	11.90	1.45	-0.48	*Titratable acidity at harvest (g/L)*
IR	28	23.03	17.12	35.40	4.58	1.13	*Ripening index (TSS*10/TA)*
PH	28	3.29	3.15	3.46	0.09	0.11	*pH at harvest*
PHENOLS	28	2106.23	1052.01	2851.70	345.99	-0.62	*Extractable polyphenols (mg/kg f.w.)*
ANTHOC	28	625.89	364.46	879.70	100.70	0.09	*Extractable anthocyanins (mg/kg f.w.)*
IRA	28	27.04	15.73	47.48	6.85	1.25	*Ripening index corrected for colour*
TPHENOLS	28	4322.12	3470.64	5716.11	492.05	0.54	*Total polyphenols (mg/kg f.w.)*
TANTHOC	28	1262.67	838.35	1856.87	183.77	0.97	*Total anthocyanins (mg/kg f.w.)*
ANTHEXTR	28	0.50	0.29	0.69	0.08	-0.17	*Extractability of anthocyanins*
MAL_AC	28	5.25	3.08	7.90	1.17	0.36	*Malic acid at harvest (g/L)*
TAR_AC	28	6.85	3.86	9.38	1.31	-0.47	*Tartaric acid at harvest (g/L)*

K_MUST	28	1.72	1.10	2.81	0.40	0.77	*Potassium in juice at harvest (g/L)*
N	28	0.67	0.41	1.10	0.16	1.54	*N in petioles at véraison (%)*
P	28	0.17	0.05	0.45	0.10	1.11	*P in petioles at véraison (%)*
K	28	1.88	0.63	3.54	0.88	0.78	*K in petioles at véraison (%)*
CA	28	1.85	1.19	3.42	0.59	1.30	*Ca in petioles at véraison (%)*
MG	28	0.32	0.02	0.76	0.16	1.31	*Mg in petioles at véraison (%)*
SCRCRD	28	45.00	22.00	60.00	9.62	-0.30	*Canopy density score*
ESA_000	28	11.61	6.67	21.94	3.84	1.26	*ESA (m^2/ha) in thousands*
PRUNING	28	0.40	0.10	0.79	0.18	0.69	*Pruning weight (kg/m^2)*
YP_RATIO	28	2.66	0.78	5.94	1.26	1.02	*Yield/pruning weight ratio*
DRYPROD	28	0.44	0.18	0.71	0.13	0.26	*Dry production (kg/m^2)*
AVETOCT	28	13.27	12.80	13.61	0.27	-0.18	*Average temperature for October*
AVETNOV	28	14.33	13.81	14.71	0.30	-0.23	*Average temperature for November*
AVETDEC	28	16.95	16.46	17.42	0.32	-0.09	*Average temperature for December*
AVETJAN	28	16.87	16.34	17.29	0.32	-0.29	*Average temperature for January*
AVETFEB	28	18.67	18.14	19.17	0.35	-0.13	*Average temperature for February*
AVETMAR	28	16.02	15.60	16.35	0.24	-0.15	*Average temperature for March*
AVETAPR	28	12.34	11.81	12.71	0.28	-0.31	*Average temperature for April*
AVETSSN	28	15.49	15.04	15.89	0.29	-0.16	*Average temperature Oct-Apr*
GDDOCT	28	103.27	90.21	113.19	7.53	-0.13	*GDD for October*
GDDNOV	28	132.54	118.26	144.07	8.40	-0.18	*GDD for November*
GDDDEC	28	215.44	200.25	229.91	10.00	-0.09	*GDD for December*
GDDJAN	28	212.93	196.54	226.02	9.91	-0.29	*GDD for January*
GDDFEB	28	242.63	227.92	256.68	9.94	-0.13	*GDD for February*
GDDMAR	28	186.67	173.58	196.73	7.58	-0.15	*GDD for March*
GDDAPR	28	81.00	69.41	89.45	6.88	-0.22	*GDD for April*
GDDSSN	28	1174.48	1084.72	1256.06	59.23	-0.13	*GDD for Oct-Apr*
GDDFD_F	28	258.56	221.10	316.73	25.34	0.64	*GDD for 1 Oct-flowering*
GDDF_V	28	570.18	515.92	661.87	37.23	0.45	*GDD for flowering-véraison*
GDDF_20	28	910.94	840.27	990.93	47.22	0.09	*GDD for flowering to TSS=20 °Brix*
GDDFD_V	28	828.74	744.23	970.35	54.40	0.54	*GDD for 1 Oct-véraison*
GDDV_20	28	340.76	201.13	421.41	51.72	-0.57	*GDD for véraison-TSS=20 °Brix*
GDDFD_20	28	1169.50	1097.06	1243.63	48.76	-0.16	*GDD for 1 Oct-TSS=20 °Brix*
RAINOCT	28	18.58	13.33	50.00	8.96	3.41	*Rainfall for October (mm)*
RAINNOV	28	31.38	20.30	41.90	7.99	-0.04	*Rainfall for November (mm)*
RAINDEC	28	125.26	111.90	160.00	12.04	1.59	*Rainfall for December (mm)*
RAINJAN	28	61.03	49.50	85.00	14.19	1.02	*Rainfall for January (mm)*
RAINFEB	28	88.93	63.00	136.60	25.54	1.00	*Rainfall for February (mm)*
RAINMAR	28	101.13	83.70	129.00	15.26	0.28	*Rainfall for March (mm)*
RAINAPR	28	40.04	33.40	54.50	7.12	1.50	*Rainfall for April (mm)*
RAINSSN	28	466.35	404.92	551.33	49.99	0.30	*Rainfall for Oct-Apr (mm)*

Phenology

Phenological observations during the 1996/97 season showed a high degree of variability between sites in dates of flowering, véraison and fruit ripening (Table 5).

Flowering

A considerable variation in mid-flowering (stage defined in Chapter 2, page 27) dates was recorded in this season. The average number of days from 1 October to flowering was 63, with a minimum of 57 days, and a maximum of 74 days. The frequency distribution of this variable is asymmetrical, with the skewness of 1.13, and a Shapiro-Wilk test shows that it is significantly different from the normal distribution. Fifteen sites had their mid-flowering beginning 60-65 days after 1 October.

Estimated average air temperatures for October and November were significantly correlated with flowering date (r=–0.38 and r=–0.39, respectively). A linear regression equation (FD_F=164.4–5.8*AVENOV, where AVENOV stands for mean air temperature for November) of flowering date against estimated average temperature in November, shows that for every 1°C increase in average temperature, time to mid-flowering from 1 October is reduced by 5.8 days. While significant, SE = 4.17 days, meaning that for a prediction with 5% tolerance, this model would give a result ±8.3 days (ie. ± two SE values), which probably has little practical use. These calculations were based on temperature data that was estimated for vineyard sites. The use of actual vineyard temperatures over a greater number of seasons could lead to models of greater precision and thus higher practical value.

Flowering was delayed more as canopy density increased (r=0.55). The relationship is linear (FD_F=54.4+20.3*CDI, SE=3.78; p=0.0024 after ANOVA; FD_F denotes the number of days from 1 October to mid-flowering). A full table of correlations between selected variables observed in 1996/97 is given in Appendix 3 (page 259).

Véraison

Mid-véraison varied from a minimum of 130 to a maximum of 158 days from 1 October. On average it occurred 141.5 days after 1 October (ie. on 19 February 1997). The frequency distribution of mid-véraison date between the sites was approximately normal (Shapiro-Wilk showed no significance).

The number of days from mid-flowering to mid-véraison varied from 70 to 86.

Berry Ripening

Only a limited number of samples were taken for measurement of TSS in this season. These were used as an indicator of berry ripening, although some TSS values were interpolated, assuming a linear growth pattern.

From 1 October 1996 it took from 178 to 211 days for juice to reach a TSS value of 20 °Brix. The average date to reach this value was 14 April 1997, or 196 days after 1 October. The frequency distribution of this variable is similar to normal distribution (insignificant Shapiro-Wilk test).

Table 5. Main phenological stages of Cabernet Sauvignon vines grown at 28 sites in Hawke's Bay 1996/97 (site details presented in Table 2)

	The Number of Days from 1 October			
	to Flowering	to Véraison	to TSS=20°Brix	to Harvest
AIT	61	141	205	198
BOB	59	131	185	192
BPN	72	158	204	210
BEL	62	139	187	200
CVB	60	137	203	212
CVE	73	147	211	220
CRW	60	138	196	199
DRH	61	140	197	196
EVV	61	143	190	196
HHV	65	148	205	204
HTL	59	142	207	206
JRS	60	130	183	191
KNG	61	142	186	193
LEN	63	141	200	201
LND	62	141	208	212
MMR	74	152	209	216
MSV	61	141	196	198
MPV	67	143	200	203
NGW	63	138	189	203
PCW	62	139	196	200
RSW	63	144	194	212
RVV	68	144	192	192
RV2	69	146	192	192
ROB	57	131	188	192
RSG	65	147	199	206
RCT	65	145	193	200
SFV	60	142	192	201
SCR	59	132	178	193
Average	63.3	141.5	195.9	201.4

Leaf fall in this season occurred on average on 21 May (ranging from 221 to 244 days after 1 October), and 9 to 47 days after harvest.

Yield and Yield Components

Yield of grapes in this season varied markedly between sites from 0.489 to 1.384 kg/m^2 (mean 0.886 kg/m^2) (Table 6). These values are estimates of final harvest yield of grapes, but since cluster thinning was applied at many sites, potential yield (one estimated at véraison) was higher, 0.996 kg/m^2 (range 0.489 - 1.850 kg/m^2). Methods for yield estimation are shown in Chapter 2, page 30.

The number of clusters per square metre was 6.64 (range 3.99 to 9.85), while the estimate of average cluster weight was 135 g (range 87.7-189.3 g).

Berry weight at harvest was 1.48 g (range 1.16 to 1.85 g). The frequency distribution of this variable was similar to normal distribution (insignificant Shapiro-Wilk test).

Vigour and Canopy Properties

The estimated exposed leaf surface area (ESA, m^2 per hectare of vineyard, Table 7) was 11,613 m^2/ha (range 6,667 to 21,935 m^2/ha). The variation was primarily caused by differences in training systems, vine spacing and vineyard age, tending to be lower in very young vineyards. The frequency distribution of this variable differed from the normal distribution (Shapiro-Wilk test significant at $p<0.0025$), and was skewed to the left. That means the majority of sites (17) fell into the range of low ESA (from 8,000 to 12,000 m^2/ha). Canopy density scores ranged from 22 to 60 points.

Weight of vine prunings in winter (Table 7) was 0.396 kg/m^2 (range 0.105 to 0.790 kg/m^2). Yield/pruning weight ratio (defined in Chapter 2, page 34) was 2.66 (range 0.78 to 5.94). These values were lower than those recommended for optimum wine quality (Smart and Robinson, 1991) of approximately 5.0 or more, particularly considering the fact that the

frequency distribution of this variable was skewed to the left (Shapiro-Wilk significant at $p<0.0253$). This indicated that the majority of vineyards had unfavourable yield/pruning weight ratios.

Table 6. Yield and yield components of Cabernet Sauvignon grapevines grown at 28 sites in Hawke's Bay 1996/97

Site	Number of Clusters / m^2	Cluster Weight (g)*	Yield (kg/m^2)	Berry Weight (g)
Dartmoor / Puketapu				
BPN	8.0	135.6	1.090	1.5
RCT	5.3	152.6	0.804	1.4
RSW	6.8	149.2	1.016	1.2
Mean	6.7	145.8	0.970	1.3
Eskdale / Bayview				
CVB	7.6	128.0	0.970	1.5
EVV	7.0	158.6	1.112	1.5
LND	6.4	189.3	1.216	1.9
Mean	7.0	158.6	1.099	1.6
Fernhill / Ngatarawa / Ohiti				
BEL	4.3	166.2	0.713	1.4
BOB	5.6	87.7	0.489	1.4
CRW	5.8	116.7	0.675	1.5
HTL	8.4	100.2	0.843	1.5
JRS	6.7	121.4	0.819	1.7
KNG	8.1	112.1	0.904	1.3
NGW	6.8	126.2	0.857	1.4
PCW	8.9	100.6	0.898	1.3
ROB	9.6	138.5	1.323	1.4
SCR	7.3	119.2	0.873	1.5
Mean	7.2	118.9	0.839	1.4
Mangatahi / Maraekakaho				
RV2	6.6	116.6	0.775	1.8
RVV	5.4	139.8	0.749	1.6
Mean	6.0	128.2	0.762	1.7
Taradale / Meeanee / Brookfields				
MSV	4.0	175.5	0.700	1.7
SFV	4.0	152.0	0.614	1.7
Mean	4.0	163.8	0.657	1.7
Te Mata / Havelock North				
AIT	7.7	152.0	1.175	1.8
HHV	6.5	121.7	0.796	1.4
MPV	4.8	155.5	0.745	1.3
RSG	7.2	138.1	1.001	1.3
Mean	6.6	141.8	0.929	1.4
Te Mata / Havelock North (Haumoana / Te Awanga)				
CVE	4.1	128.6	0.528	1.5
DRH	9.8	140.6	1.385	1.4
LEN	4.5	110.0	0.495	1.4
MMR	8.5	146.9	1.249	1.4
Mean	6.7	131.5	0.914	1.4
Overall mean	6.6	135.0	0.886	1.5

* - Estimated

Vines at most sites had a yield/pruning weight ratio between 1.0 - 3.0. This indicates that vines were excessively vigorous at many sites, particularly when compared with European values that are commonly within the range 3 – 8 for cultivars that like Cabernet Sauvignon usually have long and/or thick canes (Champagnol, 1984, quotes Syrah and Grenache).

Table 7. Canopy properties of Cabernet Sauvignon grapevines grown at 28 sites in Hawke's Bay 1996/97

Site	ESA (m^2/ha)	Canopy Density	CDI	Pruning weight (kg/m^2)
		Dartmoor / Puketapu		
BPN	14,667	22	0.73	0.730
RCT	9,259	40	0.50	0.395
RSW	8,438	52	0.35	0.268
Mean	10,788	38	0.53	0.464
		Eskdale / Bayview		
CVB	10,192	46	0.43	0.370
EVV	11,034	34	0.58	0.536
LND	14,667	34	0.58	0.460
Mean	11,964	38	0.53	0.455
		Fernhill / Ngatarawa / Ohiti		
BEL	7,241	50	0.38	0.153
BOB	6,667	46	0.43	0.105
CRW	8,438	60	0.25	0.247
HTL	9,286	56	0.30	0.249
JRS	14,667	60	0.25	0.348
KNG	12,241	54	0.33	0.152
NGW	11,290	40	0.50	0.344
PCW	9,643	48	0.40	0.342
ROB	11,429	52	0.35	0.251
SCR	8,846	50	0.38	0.262
Mean	9,975	52	0.36	0.245
		Mangatahi / Maraekakaho		
RV2	16,071	36	0.55	0.515
RVV	16,071	40	0.50	0.669
Mean	16,071	38	0.53	0.592
		Taradale / Meeanee / Brookfields		
MSV	10,185	28	0.65	0.537
SFV	9,000	34	0.58	0.790
Mean	9,593	31	0.61	0.664
		Te Mata / Havelock North		
AIT	21,000	52	0.35	0.754
HHV	11,667	40	0.50	0.335
MPV	8,333	46	0.43	0.321
RSG	10,625	32	0.60	0.392
Mean	12,906	43	0.47	0.451

Te Mata / Havelock North (Haumoana / Te Awanga)				
CVE	8,393	46	0.43	0.314
DRH	21,935	56	0.30	0.467
LEN	9,200	58	0.28	0.339
MMR	14,667	34	0.58	0.533
Mean	13,549	49	0.39	0.413
Overall mean	11,613	45	0.40	0.396

Mean total dry weight production of vines (summation of estimated dry weight of grapes and of the vine prunings) was 0.440 kg/m^2 (range 0.180 to 0.709 kg/m^2). This range therefore shows a large variability of vineyard productivity between sites in the 1996/97 season. In addition to numerous factors of vineyard management and environment, this variability can also partly be ascribed to different vine age at studied sites.

Nutrient Status of Grapevines

The content of the five major macronutrients in leaf petioles collected at véraison, varied markedly among sites (Table 8).

Mean nitrogen content was 0.67% (range 0.41 to 1.10%). These values were within the range normally recommended as being adequate for successful vine growth (page 68). Cabernet Sauvignon as a cultivar is classified as intermediate in terms of petiole nitrogen content at flowering according to Christensen (1989). Nitrogen content in leaf petioles is often not considered a fully reliable indicator of grapevine nitrogen status (Robinson, 1992).

Phosphorus in leaf petioles varied from 0.05 to 0.44% (mean 0.17%). Compared to literature values for P at véraison, these results indicate that some vineyard blocks exhibited a moderate deficiency in this nutrient.

Potassium content was 1.88% (range 0.63 to 3.54%). Most vineyard blocks seemed to have been well supplied with this nutrient.

Calcium content in leaf petioles varied from 1.19 to 3.42% (mean 1.85%). Since optimal value for this nutrient in leaf petioles at véraison is about 1.2-2.8%, many vineyard blocks probably had a slight Ca deficiency.

Magnesium content was 0.32% (ranging from a deficient 0.02% to a maximum 0.76%). Because the optimal Mg value for grapevines is 1.1%, vines at almost all observed sites were probably deficient in Mg. However, slight visual symptoms of Mg deficiency were observed on vine leaves at only one site (RCT).

Table 8. Leaf petiole content of N, P, K, Ca and Mg at véraison in Cabernet Sauvignon grapevines grown at 28 sites in Hawke's Bay 1996/97

Site	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Dartmoor / Puketapu					
BPN	1.05	0.26	1.76	3.13	0.02
RCT	0.81	0.10	1.24	2.07	0.37
RSW	0.89	0.13	1.14	2.32	0.39
Mean	0.92	0.16	1.38	2.51	0.26
Eskdale / Bayview					
CVB	0.61	0.21	1.01	1.65	0.17
EVV	0.65	0.15	1.89	1.31	0.37
LND	0.56	0.06	1.89	1.74	0.43
Mean	0.61	0.14	1.60	1.57	0.32
Fernhill / Ngatarawa / Ohiti					
BEL	0.54	0.11	0.63	1.22	0.25
BOB	0.60	0.05	1.22	1.43	0.23
CRW	0.65	0.19	1.11	1.48	0.31
HTL	0.65	0.11	1.85	1.71	0.24
JRS	0.53	0.20	1.69	1.95	0.27
KNG	0.53	0.07	1.15	1.25	0.29
NGW	0.65	0.07	3.35	1.43	0.28
PCW	0.68	0.05	2.78	1.62	0.37
ROB	0.67	0.10	0.91	1.64	0.25
SCR	0.55	0.14	1.40	1.41	0.33
Mean	0.61	0.11	1.61	1.51	0.28
Mangatahi / Maraekakaho					
RV2	0.61	0.17	1.78	1.66	0.25
RVV	0.59	0.19	3.29	1.81	0.29
Mean	0.60	0.18	2.54	1.74	0.27
Taradale / Meeanee / Brookfields					
MSV	1.10	0.21	3.38	3.42	0.73
SFV	0.99	0.09	1.31	2.69	0.32
Mean	1.05	0.15	2.35	3.06	0.53
Te Mata / Havelock North					
AIT	0.63	0.07	1.91	2.33	0.76
HHV	0.63	0.20	1.39	1.74	0.11
MPV	0.62	0.45	3.54	2.98	0.62
RSG	0.61	0.20	3.02	1.50	0.28
Mean	0.62	0.23	2.47	2.14	0.44

Te Mata / Havelock North (Haumoana / Te Awanga)					
CVE	0.63	0.21	1.69	1.31	0.33
DRH	0.64	0.38	1.09	2.02	0.13
LEN	0.41	0.26	1.84	1.19	0.20
MMR	0.57	0.37	3.36	1.89	0.24
Mean	0.56	0.31	2.00	1.60	0.23
Overall mean	0.67	0.17	1.88	1.85	0.32

Berry Composition at Harvest

A number of attributes of berry composition were measured and there was considerable variation among sites (Table 9 and Table 10). Mean total soluble solids content (TSS) was 20.9 °Brix and it varied from 19.3 to 22.5 °Brix. Mean titratable acidity (TA) was 9.3 g/L and ranged from 6.1 to 11.9 g/L.

At harvest there was a considerable variation in the index of ripeness (IR), which is an expression of berry ripeness that ranged from 17.1 to 35.4 (Figure 6). Fruit at most sites reached an IR of 20 or more; this can be loosely considered as "technological ripeness", the level of ripeness at which grapes for table wine production can be harvested. IR values across the sites were not normally distributed as shown by a significant Shapiro-Wilk test. At only six vineyard blocks very high values (>26) of IR were achieved, and that fruit can be considered to have a potential for high wine quality (Du Plessis, 1984). The remaining 22 vineyards achieved the lesser IR values.

Similar variability occurred with the IRA index, which accounts for anthocyanin concentration in extracts of berry skins in addition to TSS and TA. Mean IRA was 27, but it varied from 15.7 to 47.5 (Table 9). The highest values of IRA were almost exclusively reached in the Fernhill/Ngatarawa/Ohiti sub-region.

The pH value of juice at harvest was 3.3 (range 3.15 to 3.46), which is very suitable from an oenological standpoint.

Total and extractable anthocyanin content in berry skins varied remarkably from 838 to 1857 mg/kg (mean 1263 mg/kg), and from 364 to 880 mg/kg (mean 626 mg/kg), respectively. The extractability of anthocyanins (the ratio between the anthocyanin content in synthetic wine and in 2% HCl – method presented in Chapter 2, page 33) was 50% (range 29 to 69%). The content of total and extractable polyphenols, which was very closely related to anthocyanin content (r=0.84, similar to correlation established in cv Shiraz by Gray *et al.*, 1997), varied from 3471 to 5716 mg/kg (mean 4322 mg/kg), and 1052-2852 mg/kg (mean 2106 mg/kg), respectively.

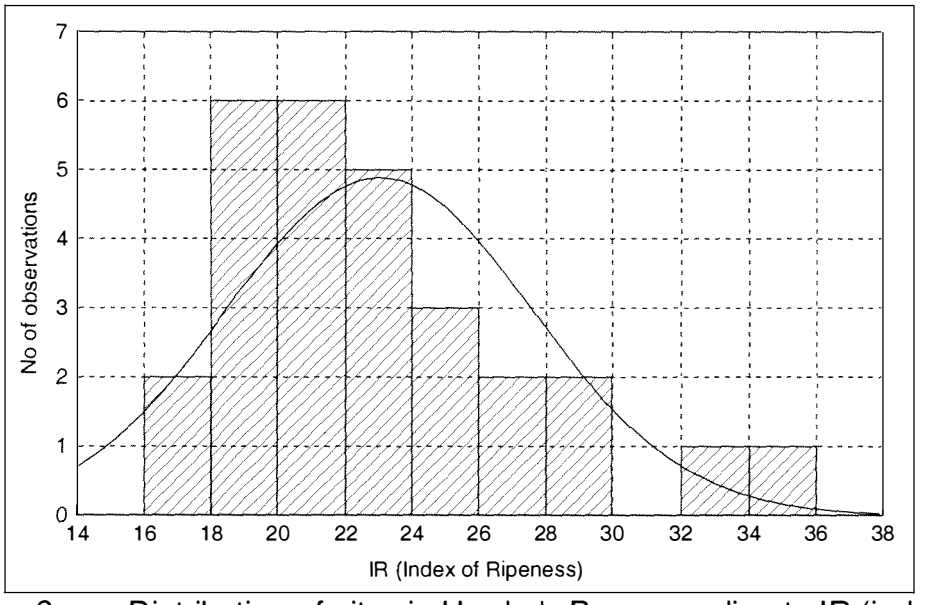

Figure 6. Distribution of sites in Hawke's Bay according to IR (index of ripeness) at harvest 1996/97

Organic acids were relatively high in this particular season, with mean malic acid concentration being 5.25 g/L (range 3.08 to 7.90 g/L), and mean tartaric acid being 6.85 g/L (range 3.86 - 9.38 g/L). Mean potassium content in juice was 1.72 g/L (range 1.10 to 2.80 g/L).

There was a positive correlation (r=0.58) between yield/pruning weight ratio and IRA with the highest IRA values being associated with sites in Fernhill / Ngatarawa / Ohiti sub-region. This confirms findings of other authors (Hepner *et al.* 1985, Bravdo *et al.* 1985) who have established a positive

relationship between yield/pruning weight ratio and content of sugar and wine colour in Cabernet Sauvignon, and a negative relationship between yield/pruning weight ratio and total acids in juice.

Sites in Fernhill / Ngatarawa / Ohiti sub-region differed significantly from those in other sub-regions in most of the observed parameters of phenology, cropping and particularly berry composition. Véraison occurred earlier at Fernhill than at Havelock North or Mangatahi. Juice attained TSS of 20 °Brix later at Havelock North than in other sub-regions. Number of clusters per unit surface area, as well as estimated cluster weight varied markedly between the sub-regions observed.

Table 9. Total soluble solids (TSS), titratable acidity (TA), index of ripeness (IR), pH, and index of ripeness adjusted for anthocyanins (IRA) at harvest 1996/97

Site	TSS (°Brix)	TA (g/L)	IR	pH	IRA
Dartmoor / Puketapu					
BPN	20.3	9.8	20.7	3.3	23.8
RCT	20.8	10.4	20.0	3.3	23.8
RSW	22.4	8.8	25.5	3.4	35.1
Mean	21.2	9.7	22.1	3.3	27.6
Eskdale / Bayview					
CVB	22.0	7.9	27.8	3.5	33.1
EVV	20.8	9.4	22.1	3.4	25.7
LND	20.5	9.7	21.1	3.4	21.2
Mean	21.1	9.0	23.7	3.4	26.7
Fernhill / Ngatarawa / Ohiti					
BEL	22.5	8.8	25.6	3.3	27.5
BOB	20.9	7.8	26.8	3.2	33.4
CRW	20.7	8.9	23.3	3.4	25.4
HTL	20.2	10.5	19.2	3.2	22.8
JRS	21.0	7.4	28.4	3.3	33.3
KNG	20.9	7.3	28.6	3.4	32.0
NGW	22.3	9.3	24.0	3.3	26.2
PCW	20.5	9.3	22.0	3.3	27.2
ROB	20.4	6.1	33.4	3.3	47.5
SCR	22.3	6.3	35.4	3.4	41.8
Mean	21.2	8.2	26.7	3.3	31.7
Mangatahi / Maraekakaho					
RV2	19.8	11.0	18.0	3.2	20.2
RVV	19.9	10.0	19.9	3.2	25.0
Mean	19.9	10.5	19.0	3.2	22.6
Taradale / Meeanee / Brookfields					
MSV	20.2	11.8	17.1	3.3	20.0
SFV	21.8	9.0	24.2	3.5	28.9
Mean	21.0	10.4	20.7	3.4	24.5

Te Mata / Havelock North					
AIT	19.3	9.8	19.7	3.3	20.5
HHV	19.9	10.5	19.0	3.2	21.6
MPV	20.7	8.7	23.8	3.3	28.9
RSG	21.2	10.8	19.6	3.2	22.8
Mean	20.3	10.0	20.5	3.3	23.5
Te Mata / Havelock North (Haumoana / Te Awanga)					
CVE	21.0	10.2	20.6	3.2	25.5
DRH	20.5	9.6	21.4	3.3	24.7
LEN	20.3	10.0	20.3	3.3	23.3
MMR	20.7	11.9	17.4	3.2	15.7
Mean	20.6	10.4	19.9	3.3	22.3
Overall mean	20.9	9.3	23.0	3.3	27.0

Table 10. Polyphenol and anthocyanin content in berry skin extracts, anthocyanin extractability, malic and tartaric acid, and potassium in juice at harvest 1996/97

Site	Extractable Polyphenols (mg/kg)	Extractable Anthocyan. (mg/kg)	Total Polyphenols (mg/kg)	Total Anthocyan. (mg/kg)	Extractability of Anthoc.	Malic Acid (g/L)	Tartaric Acid (g/L)	K (g/L)
Dartmoor / Puketapu								
BPN	2100	611	4288	1223	50%	5.0	8.0	1.6
RCT	2348	650	4656	1246	52%	4.8	7.3	1.5
RSW	2655	839	5716	1857	45%	5.0	6.3	2.2
Mean	2368	700	4887	1442	49%	4.9	7.2	1.8
Eskdale / Bayview								
CVB	2186	649	4428	1280	51%	3.5	7.2	1.7
EVV	2000	623	4476	1359	46%	5.5	7.0	1.9
LND	1529	464	3726	1109	42%	3.1	7.1	2.3
Mean	1905	579	4210	1249	46%	4.0	7.1	2.0
Fernhill / Ngatarawa / Ohiti								
BEL	1856	536	4794	1375	39%	4.5	7.3	1.5
BOB	2155	706	4814	1544	46%	4.6	4.7	1.5
CRW	2078	552	4665	1183	47%	4.6	7.2	1.5
HTL	2084	643	4244	1254	51%	6.0	7.5	1.5
JRS	1894	635	4202	1400	45%	4.2	4.8	1.2
KNG	2284	578	3487	838	69%	4.2	5.3	1.5
NGW	1833	554	4051	1141	49%	5.2	9.4	2.4
PCW	2330	696	4455	1278	54%	4.9	8.6	1.7
ROB	2852	880	4822	1463	60%	5.1	4.7	1.7
SCR	2023	640	3922	1265	51%	4.3	3.9	1.1
Mean	2139	642	4346	1274	51%	4.8	6.3	1.6
Mangatahi / Maraekakaho								
RV2	1929	584	3471	1066	55%	6.8	6.0	1.3
RVV	2636	717	4117	1164	62%	7.4	6.5	2.1
Mean	2283	651	3794	1115	59%	7.1	6.3	1.7
Taradale / Meeanee / Brookfields								
MSV	2178	628	3960	1072	59%	7.9	8.1	2.8
SFV	2195	654	4520	1223	53%	5.4	6.4	1.7
Mean	2187	641	4240	1148	56%	6.7	7.3	2.3

				Te Mata / Havelock North				
AIT	1770	499	4210	1177	42%	3.5	6.0	1.3
HHV	2041	601	3769	1151	52%	6.5	8.0	1.1
MPV	2133	676	4758	1443	47%	4.5	7.0	2.0
RSG	2058	620	4272	1249	50%	6.3	8.7	1.9
Mean	2001	599	4252	1255	48%	5.2	7.4	1.6
				Te Mata / Havelock North (Haumoana / Te Awanga)				
CVE	2461	696	4317	1195	58%	5.5	6.8	1.6
DRH	2200	617	4157	1145	54%	6.0	8.0	2.0
LEN	2115	610	4998	1379	44%	5.9	7.3	1.8
MMR	1052	364	3724	1274	29%	6.8	7.0	1.7
Mean	1957	572	4299	1248	46%	6.1	7.3	1.8
Overall mean	2106	626	4322	1263	50%	5.3	6.9	1.7

Havelock North, Fernhill and Dartmoor where characterised by smaller berries than other sub-regions in 1996/97. Vines at Mangatahi were harvested at significantly lower °Brix and higher acidity than those at Fernhill, with the pH of juice significantly lower than in all other sub-regions. Vine sites around Fernhill stood out by fruit ripeness, particularly when compared to Havelock North and Mangatahi sub-regions.

In summary, vine sites in the Fernhill / Ngatarawa / Ohiti sub-region had markedly earlier ripening in the 1996/97 season compared to other sub-regions, though a number of significant differences were also observed between other five sub-regions. High gravel content at Fernhill (details on sub-regional soils are presented in Appendix 11, page 269) and the associated low soil moisture retention capacity are considered the most important factor causing these differences between sub-regions.

Results by Training System

To assess the possible effect of different training systems on cropping, growth, and berry composition, results were organised by training systems and analysed by ANOVA. Due to highly unbalanced design of this post-hoc analysis and the exclusion of interactions, it can serve only as an indication of the potential effect of training systems on vine and grape attributes.

Sites were placed into five groups according to training system: DIV (divided canopies, like GDC or U); SHN (Scott-Henry); SYL (Sylvoz); CAN (cane

pruned VSP, including two Scott-Henry sites in the process of vine training); and COR (horizontal cordon). Means for major variables are given in Table 11.

Table 11. Phenology, cropping and berry composition in cv Cabernet Sauvignon grown at six sites in Hawke's Bay 1996/97, presented by training system

Phenology and Cropping									
Training system	Number of sites	1 Oct to véraison	1 Oct to TSS=20 °Brix	Number of clusters/m^2	Cluster weight (g)	Grape yield (kg/m^2)	CDI	ESA	Pruning weight (kg/m^2)
DIV	2	141	201	8.79a	146.3	1.280a	0.33	21.5a	0.610
COR	2	137	189	4.81b	119.9	0.551c	0.49	7.8c	0.447
CAN	14	141	196	6.47ab	135.4	0.854bc	0.44	9.9c	0.367
SYL	5	144	200	6.56ab	143.0	0.941ab	0.46	10.8c	0.340
SHN	5	143	192	7.06ab	127.4	0.899bc	0.44	14.7b	0.428
Mean		142	196	6.64	135.0	0.886	0.44	11.6	0.396

Berry Composition						
Training system	Berry weight (g)	TSS (°Brix)	TA (g/L)	pH	Phenolics (mg/kg)	Anthocyan (mg/kg)
DIV	1.592	19.9	9.7	3.26	4184ab	1161
COR	1.535	21.4	8.4	3.32	4667a	1384
CAN	1.444	21.0	9.2	3.30	4441a	1284
SYL	1.439	20.9	9.7	3.30	4430a	1310
SHN	1.557	20.5	9.5	3.27	3800b	1148
Mean	1.481	20.9	9.3	3.29	4322	1263

Training systems: DIV – divided canopy; COR – horizontal cordon; CAN – cane pruned VSP; SYL – Sylvoz; SHN – Scott-Henry

Significant effects of training systems occurred with cluster number, where DIV had a higher cluster number than COR (Table 11). The highest occurred on DIV and SYL vines, with the lowest yield from COR, CAN and SHN vines. As expected, estimated exposed leaf surface area was the highest in the divided training systems (analogous to results of Mabrouk and Sinoquet, 1998), being significantly higher than SHN that in turn was significantly higher than the other systems.

Grapes from SHN had a significantly lower total polyphenols content than COR, CAN and SYL. There were no significant differences between sites for the other attributes measured.

Results by Row Orientation

This post-hoc analysis does not allow the assessment of potential interactions and its results can serve only as an indication of the potential effect the row orientation had on measured vine attributes. Row orientation appears to have affected cluster weight with those from vines with an N-S orientation having a mean weight of 147.8 g, significantly larger than those from vines with a SE-NW orientation (mean 122.9 g). Furthermore, berries in clusters from N-S oriented vine rows had a mean weight of 1.587 g, being significantly larger than those from vines with a SE-NW orientation (1.393 g).

Juice pH at harvest varied between the sites with different row orientation. The mean pH values measured were 3.27ab (N-S), 3.20b (SW-NE), 3.33ab (SE-NW), and 3.34a (W-E). (Values followed by the same letters were not statistically different for $p<0.05$ by LSD test).

Vine vigour was one important attribute that varied between sites with different row orientations. Both pruning weights and canopy density scores were significantly different depending on vine orientation. The values in order of increasing vigour (or decreasing canopy density scorecard points) were 52.6a (SE-NW), 46.0ab (SW-NE), 42.2b (N-S), and 40.5b (W-E). (Different letters denote significant differences).

Discussion

Phenology

The range of mid-flowering dates that occurred in 1996/97 demonstrates that, even within a relatively small region such as Hawke's Bay, there can be lack of uniformity of flowering which contrasts with the assertion of Coombe (1988) stating the relative uniformity in flowering dates with a region. Cooler than normal conditions during this growing season may have influenced timing of this developmental event. However, normal environmental and climatic conditions in Hawke's Bay are quite different

from those in the Australian grape growing regions that were the major source of phenological data used by Coombe (1988) in his study. Further results (Chapter 6) do tend to support Coombe's contention, for in a warmer season the range of inter-site variation in flowering dates decreased significantly.

Canopy density index was significantly correlated with mid-véraison date (r=0.64), with a clear linear relationship (FD_V=127.0+33.2*CDI, SE = 4.8 days, p=0.0002). These results confirm the significance of the source-sink concept in viticulture. Strong vegetative growth at and after véraison slows berry ripening, shoots and berries being the competitive sinks for carbohydrates (Carbonneau, 1996). This is supported by the significant correlation between véraison date and pruning weight (r=0.48).

Air temperature in all months preceding véraison, except January, had a significant effect on the date of mid-véraison (r=–0.45, –0.49, –0.42, and –0.40 for October, November, December, and February, respectively). For January r=–0.37, and an F test gave p=0.054 so January GDD was on the brink of significance in this season. Multiple regression of all GDD variables on date of véraison indicated that GDD for December gave the most significant effect. Partial correlations for the independent variables differed considerably from the respective simple correlation coefficients discussed above (see Table 12).

It can be concluded that the estimated GDD for the month of December had a decisive impact on the timing of véraison in this season, as multiple correlation between GDD for that month and véraison date was the highest and most significant. Therefore, warm temperatures during fruit set and green berry development appear to have contributed to the earlier onset of fruit ripening.

The number of days from 1 October until a TSS of 20 °Brix was attained was significantly correlated with both the number of days from 1 October to flowering (r=0.50) and to véraison (r=0.63). It was also closely correlated with days from 1 October to harvest, even though fruit at the majority of

sites was picked after TSS had reached 20 °Brix (mean Brix at harvest was 20.85 °).

There was significant correlation between the number of days from 1 October to TSS of 20 °Brix and monthly GDD summations during the season, with an exception of March (–0.52, –0.44, –0.41, –0.46, and –0.49, for November, December, January, February, and April, respectively).

Table 12. Multiple regression between monthly GDD and the number of days from 1 October to véraison

Variables currently in the Equation

	Beta in	Partial Cor.	Semipart Cor.	Tolerance	R-square	t(23)	p-level
GDDOCT	0.720	0.098	0.063	0.008	0.992	0.460	0.650
GDDNOV	-1.926	-0.243	-0.162	0.007	0.993	-1.176	0.252
GDDDEC	-6.786	-0.599	-0.485	0.005	0.995	-3.512	0.002
GDDJAN	3.255	0.295	0.200	0.004	0.996	1.448	0.161
GDDFEB	4.287	0.323	0.221	0.003	0.997	1.598	0.124

If a simple model was to be developed on the basis of GDD for January, to predict the date when TSS in berries will reach 20 °Brix in any year, it would have an SE of 7.97 days. Use of a polynomial regression of the fourth order would reduce this SE only slightly to 7.30. Based on the estimated data for average temperatures and GDD in 1996/97, it is not possible to produce a model for prediction of grape ripeness that would be of any practical value.

A breakdown of data by geographical sub-region shows significant differences in phenology and ripening between sub-regions. Using number of days from 1 October to véraison as a discriminant, sub-regions fall into two groups; one with Dartmoor, Mangatahi, Havelock North and Taradale where the number of days until véraison was 142 to 149; and a second group consisting of Fernhill and Eskdale, where it was 136 and 140. It appears that light soil texture of sandy and gravelly soils in the second group of sub-regions was related to earliness of véraison.

Little difference existed between sub-regions when comparing number of days from 1 October to attaining TSS of 20 °Brix in fruit. Fernhill with 190

days had a significantly shorter period than the rest. Similarly, TSS at harvest was significantly higher, and TA lower, only between the Fernhill sub-region and others. As CDI for Fernhill was significantly lower than for all other sub-regions, except Havelock North (see Table 7), the positive effect of open canopies at Fernhill on fruit composition is clear.

Yield

Since this was an eco-physiological study of the effect of environment on behaviour of the Cabernet Sauvignon grapevine as a whole, no attempt was made to manipulate yield of grapes. Growers at certain sites had applied bunch thinning at varying intensities as a part of their regular viticultural practice. In addition, number of buds per unit surface differed according to the pruning system adopted by growers, and this was normally a function of the individual training systems used.

It would have been preferable if all sites had been planted at the same time, with the same spacing, training system and pruning treatments. However, it would be unrealistic to expect to find this in any viticultural region. Escalera *et al.* (1996) found that the training system had little effect on fruit composition of cv Chardonnay grown in California, although it did affect grape yield significantly. Pruning treatments exhibited smaller effect than vineyard site with respect to Cabernet Sauvignon cluster size (Rosner and Cook, 1983).

Carbonneau *et al.* (1987) established the effect of training system on gross photosynthesis of Cabernet Sauvignon on SO4 rootstock to be very significant. Training systems with shaded canopies had reduced gross photosynthesis, and those with most exposed canopies generated moderate water stress which increased photosynthetic water use efficiency and markedly stimulated anthocyanin synthesis.

Ough and Nagaoka (1984) found minimal composition differences in wines of cv Cabernet Sauvignon from three different crop thinning treatments, with a slight increase in quality by thinning in two of the three years. On the other

hand, they established that vineyard location had a generally consistent effect on wine quality. In this study crop per unit surface area generally reflected the overall vegetative capacity of vines as illustrated in the relationship between yield of grapes and ESA (Figure 7).

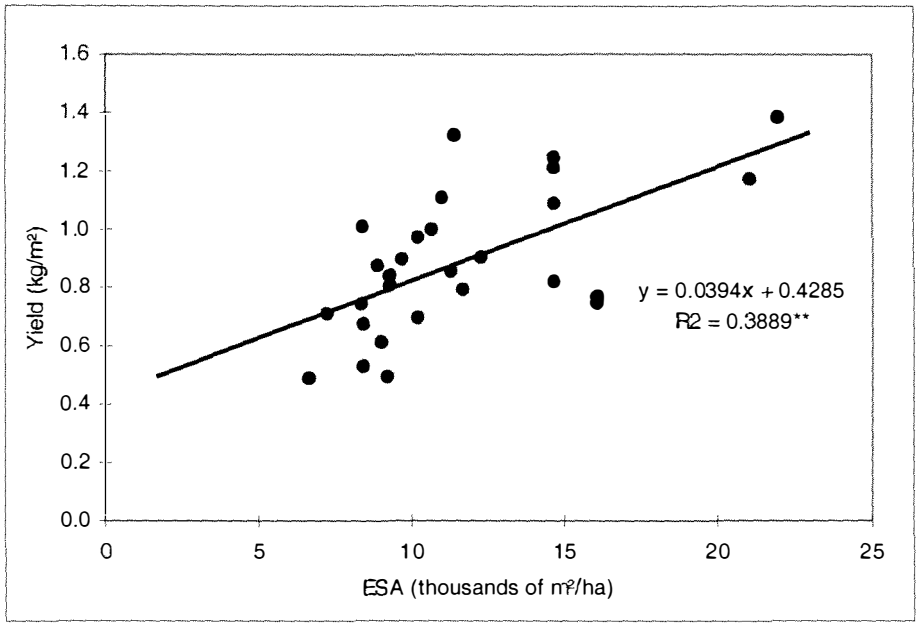

Figure 7. Relationship between the yield of grapes and estimated exposed leaf surface area (ESA)

At many sites in this season a varying degree of "shanking" (or waterberry, bunch stem necrosis - BSN) was observed. In conditions with lower than normal solar radiation (See Appendix 7) and relatively cool summer temperatures, photosynthetic capacity will be reduced (Huglin, 1986). In addition some vineyard managers removed significant number of leaves because of the seasonal characteristics; a combination of these two effects would have reduced carbohydrate availability that in turn could have contributed to shanking (Koblet, 1996; Caspari and Lang, 1996).

Cluster number was significantly correlated with estimated exposed leaf surface area (ESA), r=0.49. Average cluster weight was not correlated with ESA, but was positively correlated with pruning weight (r=0.44). Large clusters had higher potassium concentrations in juice (r=0.52) than small clusters, and they were associated with sites that had higher calcium and

magnesium contents in leaf petioles at véraison (r= 0.45 and 0.48, respectively).

The amount of rainfall had a diverse effect on average cluster weight depending on the month. November rainfall (during the beginning of flowering) had a negative effect on cluster weight ($r=-0.45$, $p<0.05$), while amount of rain in February and March (during ripening) influenced cluster weight positively ($r=0.53$, and 0.44, respectively, $p<0.05$).

Berry weight was also correlated with ESA ($r=0.45$, $p<0.05$) and rainfall ($r=-0.41$ for November, and $r=0.41$ for March, $p<0.05$). It seems likely that rainfall affected cluster weight by influencing berry weight, it being lower with higher November rainfall, and higher with increased March rainfall.

Vigour

ESA was positively correlated with yield (both potential, $r=0.70$, and yield after bunch thinning, $r=0.62$), but negatively affected TSS in juice at harvest ($r=-0.53$). It is important to emphasise that these two variables, yield and TSS, were not correlated between themselves. The effect of ESA on yield was a result of a relatively high vegetative potential of vines with high ESA values. Association of high ESA values with dense canopies (as presented further on) could account for a negative relationship between ESA and TSS.

Although a simple correlation between ESA and CDI was not significant, a quadratic regression of ESA on CDI (Figure 8) was significant ($R=0.47$, $p=0.047$). This curvilinear relationship was a result of favourable, ie. low, CDI values in two vineyards that had divided canopies ("U" and GDC training systems), and had ESA values that were higher than those at all other sites. If these two observations are excluded, the linear relationship between ESA and CDI becomes more obvious, and is positive and significant ($r=0.43$).

ESA had a negative correlation with the content of total polyphenols ($r=-0.49$) and total anthocyanins ($r=-0.40$) in juice at harvest. Higher canopy density in vines with higher ESA could explain this effect, as total

polyphenols and total anthocyanins were also negatively correlated with CDI, although not significantly (r=–0.31 and –0.20, respectively). Poor exposure of fruit to sunlight in very dense canopies decreases content of polyphenols and anthocyanins in red wine grapes (Smart and Robinson, 1991).

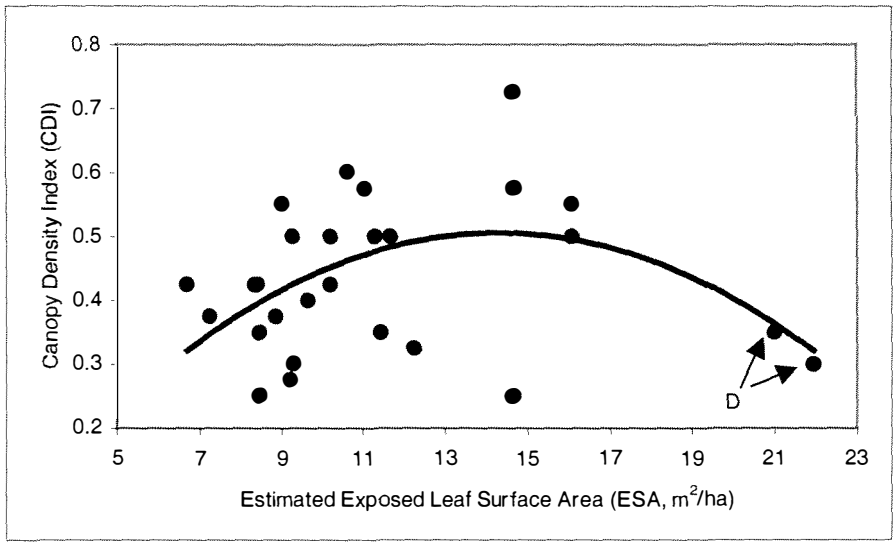

Figure 8. The relationship between estimated exposed leaf surface area (ESA) and canopy density index (CDI) of Cabernet Sauvignon vines grown at 28 sites in Hawke's Bay.
D denotes sites with divided canopies.

As expected, ESA had a positive correlation with the pruning weight (r=0.57) and dry production (r=0.73).

Canopy density index (CDI), derived from the scorecard assessment done at véraison (Table 7), varied from 0.25 to 0.72 (mean 0.44). Most vineyards had their canopies in the higher range, indicating that canopy density was greater than is usually recommended (such vineyards achieve values below 0.35).

CDI at véraison significantly affected phenological stages up to véraison. Increased canopy density at véraison was associated with later flowering and delayed onset of ripening. The association of CDI with berry ripening is weaker, although it is noteworthy that the correlation between CDI and Véraison-to-Harvest Index (VHI) was positive and significant, although weak

(r = 0.39). This indicates a trend of vines with denser canopies to require higher air temperatures for fruit ripening.

CDI was also positively correlated with N and K content in leaf petioles at véraison. The relationship between N content and vigour is expected, as the increase in N nutrition stimulates vegetative growth; the relationship between K content and vigour was probably a result of the fact that those sites in which a marginal potassium deficiency was observed (BEL, ROB, CVB, CRW, DRH, KNG, RSW, BOB had K below 1.2%), were also the sites with a lower vegetative vigour. Higher than optimal potassium content is not associated with an increased vigour (Huglin, 1986).

Correlation between the yield/pruning weight ratio and index of ripeness (IR) at harvest was positive and significant (r=0.62). Yield/pruning weight ratio is generally believed to be a good indicator of the potential for the preferred wine attributes or 'quality' (Bravdo *et al.*, 1985). The low yield/pruning weight ratios commonly occur with very high pruning weights, ie they are associated with an unbalanced grapevine growth. Such growth reduces the amount of assimilates available for berry development and increases shading of fruit.

Pruning weight was positively correlated with nitrogen and calcium content in leaf petioles at véraison (r=0.48 and 0.57, respectively). The effect of N nutrition on pruning weight is very similar to the relationship between N content and CDI, as discussed previously. Increased Ca content in vines with high vegetative potential is expected, as elevated Ca in leaf petioles of Cabernet Sauvignon were shown to be associated with more intensive metabolism of grapevines (Boselli *et al*. 1998).

The weight of vine prunings was positively correlated with berry weight (r=0.53). The chief factor behind this relationship was probably water availability to grapevines; increased water supply stimulates both vegetative growth (reflected in pruning weights) and generative growth (increased berry weight) particularly during the stage of development of green berries (Stevens *et al.,* 1995, McCarthy, 1997).

Pruning weights were correlated positively with TA (r=0.45), and negatively with TSS (r=–0.38) at harvest. This is expected, as excessive shoot growth increases carbohydrate demand from shoots (therefore lower TSS in berries), and it also considerably increases the percentage of shaded grape clusters, which contributes both to lower TSS and higher TA of fruit.

Dry matter production (defined in Chapter 2, page 30) was positively correlated with content of nitrogen and calcium in leaf petioles at véraison, which is mostly due to the effect of pruning weights. Dry matter production increased with higher ESA value (r=0.73), which is entirely expected as more developed vine canopies (higher ESA values) would naturally have more pruned wood and can bear higher crops.

Fruit composition

Index of ripeness adjusted for anthocyanins (IRA, page 32) was negatively correlated with malic acid content (r=–0.42), tartaric acid (r=–0.64), and K content in leaf petioles at véraison (r=–0.47). This is expected as titratable acidity represents one of the components of IRA and is at the same time, an approximate summation of tartaric and malic acid.

Increased canopy density and pruning weight negatively affected IRA (r=–0.40 and –0.45, respectively). The increased amount of GDD accumulated in the period from véraison to TSS of 20°Brix had a positive influence on the values of IRA (r=0.54). The average air temperatures for October, November and April acted similarly, while the rainfall in January and March showed a negative correlation with IRA.

TA was significantly affected by timing of phenological stages (flowering - r=0.59, véraison - r=0.71 and harvest date - r=0.41). Mean degree-day from véraison to harvest (MDVH) affected TA value significantly (r=–0.67). TA was correlated with extractable anthocyanins content (r=–0.45), but not with the extractability of anthocyanins. Potassium content in leaf petioles at véraison had a positive correlation with TA (r=0.50).

Most monthly GDD summations affected TA negatively (–0.45, –0.49, –0.41, –0.40, –0.46, for October, November, December, February, and April, respectively). The seasonal GDD also had a negative correlation with TA (–0.41). Rainfall had a positive correlation with TA, r=0.39 for the season, and 0.44 and 0.51 for January and March, respectively. It appears that rainfall increased TA, possibly by encouraging vegetative growth and by reducing air temperatures.

A positive correlation existed between GDD and pH of juice, significant for the monthly GDD of October (r=0.45), November (r=0.43), and April (r=0.48). Relationship of pH to rainfall was less clear, being negative for rainfall in January (r=–0.45) and positive for that of February (r=0.48). Overall, certain effects of weather conditions on pH could possibly be attributed to its effect on TA.

Berry weight was correlated negatively to total polyphenols (r=–0.49) and total anthocyanins (r=–0.40) in berry skin extracts. This relationship is expected, as fruit with smaller berries has a relatively larger proportion of skin.

None of the observed meteorological factors showed no significant correlation with content of anthocyanins and polyphenols. It is possible that the overall meteorological variability across Hawke's Bay during 1996/97 was too low to affect these fruit characteristics significantly.

Malic and tartaric acid in juice at harvest showed relationships to other variables generally similar to those of TA. Tartaric acid was positively correlated with potassium content in both juice and leaf petioles. Malic acid showed a significant and positive correlation only with the latter, although a negative correlation between K in Cabernet Sauvignon berries and malic acid was observed by Hepner *et al.* (1985).

Tartaric acid was negatively correlated with mean monthly and seasonal air temperatures and GDD, and it was not correlated with rainfall. Malic acid had positive correlations with monthly rainfall in October, December, January and March, as well as with the seasonal rainfall, while it was not

correlated with air temperatures. Overall site-to-site variability in rainfall and air temperatures in 1996/97 was perhaps too small to enable extraction of clear relationships between these variables.

Nutritional Status

A review of literature (Robinson, 1992; Anon., 1997; Christensen, 1989; Boselli and Vaio, 1996) showed than standard N concentration in leaf petioles at flowering ranges from 0.8 to 1%; at véraison around 0.7%; and 0.5% before harvest. Optimal P level at flowering ranges from 0.2 to 0.5%, >0.12% at véraison, and is about 0.06% before harvest. Optimal K concentration in leaf petioles at flowering should be 1.5-3.5, at véraison 1.2-3%, and about 3.3% before harvest. Standard Ca levels at flowering range from 1.2 to 2.5%, at véraison 1.2-2.8%, and 1.2-3% before harvest. Optimal Mg content in leaf petioles at flowering should be 0.3-0.8%, at véraison 1.1%, and about 1.2% before harvest.

Based on leaf petiole analysis, nitrogen nutrition was optimal at most sites. The only sites that showed some symptoms of a mild nitrogen deficiency were SCR and JRS. It is likely that water stress caused by very permeable soil at these sites was related to this lower nitrogen content. The relationship between leaf petiole nitrogen and vine water status is evident from the results of Freeman and Kliewer (1983) who established that petiole nitrate levels were significantly lower in unirrigated than in irrigated cv Carignane vines.

The largest variability in nutrient content between sites occurred with phosphorus (CV=59%) although considerable variability also occurred with magnesium (CV=51%) and potassium content (CV=46%). Calcium content varied moderately between sites (CV=31%), as did nitrogen (CV=24%). This variability in nutritional status of grapevines between sites is not surprising given that 28 sites observed in the initial study were located on 14 distinctively different soil types. Naturally, vineyard management factors, particularly type and amount of fertiliser application would have a large impact on this variability.

Grapevine rootstocks are known to affect rate of potassium uptake from the soil (May, 1994). Increased potassium content in grapevines may decrease the uptake of magnesium (Robinson, 1993; Champagnol, 1984). Since the rootstock SO4 has been shown to increase uptake of potassium by grapevines (Boselli and Volpe, 1993; Brancadoro *et al.*, 1995), it may have contributed to low magnesium content observed. Lower magnesium absorption by SO4 than by several other commonly used grapevine rootstocks has been reported by Badour *et al.* in 1982 (cit. Champagnol, 1984).

Among eight rootstocks tested by Loué and Boulay 1984 (cit. Huglin, 1986) SO4 had the second highest K content and the second lowest Mg content in leaf blades. These authors also demonstrated that Cabernet Sauvignon on SO4, compared to six other cultivars, had the lowest Mg content and the third highest potassium content.

Row Orientation

The differences observed between sites with different row orientation can be explained by their different sunlight interception. A significant effect of row orientation on vigour and yield was observed by Intrieri *et al.* (1996) in cv. Chardonnay grown in the conditions of Bologna, Italy. N-S oriented vineyard rows were found to be most efficient in light interception by Carbonneau and Loth (1985) and Smart (1973). Daudet *et al.* (1987) observed differences in stomatal conductivity, water potential and net assimilation between the western and eastern arms of the double lyre trained Cabernet Sauvignon vines. Therefore, some effect of different row orientation on vine growth and development at studied sites could be expected.

In 1996/97, N-S vineyards were found to have larger berries and clusters compared to SE-NW group of sites. However, in the process of selection of sites for further study, the issue of row orientation was not taken into account because it would mean a further significant reduction in a number

of potential suitable sites. By chance, most of the short-listed sites had a W-E row orientation, with one being SE-NW and another N-S orientated.

Site selection

In order to separate sites observed in 1996/97 into more or less distinctive groups or categories, their vegetative vigour was contrasted with ripening capacity by calculating a ratio of Canopy Density Index (CDI) vs Index of Ripeness (IR).

CDI/IR ratio was used as a guideline for selecting 6 vineyards for more detailed studies in subsequent years (Table 13). The rationale behind this approach is that it is relatively simple to identify those vineyards with good ripening potential and at the same time optimal canopy density (although the two indices are also inter-correlated). To simplify further, a lower ratio seems to indicate sites that will have grapes with more favourable juice composition and vines with lower vigour problem. Higher ratios were found at sites with excessively vigorous vines and reduced ripening capacity. In effect, this ratio of two inter-correlated variables actually amplifies differences between sites with regard to their generative and vegetative attributes.

The resulting CDI/IR values were arbitrarily grouped into six categories, with values below 1.5 forming Category 1, values 1.5-2.5 forming Category 2, values 2.5-2.7 forming Category 3, values 2.7-3 forming Category 4, values 3-3.5 forming Category 5, and ending with Category 6 where CDI/IR >3.5. From each of these categories one site for detailed study was to be selected (Table 13).

Category 1. Many among the sites in this group are located around Hastings. The selected site **JRS** (for characteristics of selected sites see Table 14) is in the Gimblett Road area, in the sub-region of Fernhill / Ngatarawa / Ohiti, along with ROB, SCR, CRW, KNG, and BEL. LEN and DRH belong to Haumoana / Te Awanga sub-region, and RSW is in Dartmoor / Puketapu. Most of the sites here are on well-drained soils

(*Omahu* and *Tukituki* gravels, *Omarunui* and *Pakowhai* sandy/silt loams), and the average air temperature in this group is slightly higher than that across Hawke's Bay.

Category 2. In this group, HTL, BOB, PCW, and NGW are also located in the Fernhill sub-region (which was one of the reasons why they were excluded from the selection). AIT, MPV and CVE are located in Haumoana or Havelock North sub-regions, RCT in Dartmoor sub-region, CVB in that of Eskdale / Bayview, and the selected **SFV** in Taradale / Meeanee sub-region. The soils here are similar to the first group, but perhaps little heavier (like *Te Awa* clay loam, *Poporangi*, *Waipukurau* and *Matapiro* sandy loams) and less free draining. The large number of sites in the first two groups comes as no surprise, since those groups represent sites where it is possible to ripen Cabernet Sauvignon in most years, regardless of seasonal variations.

Table 13. Selection of six sites for detailed study

CDI/IR*	Site	Comment
Category I		
0.88	JRS	SELECTED
1.05	ROB	too young
1.06	SCR	less accessible
1.07	CRW	outer row in the vineyard (only one row with the clone)
1.14	KNG	too young
1.35	LEN	possible pull-out or re-grafting
1.38	RSW	Not UCD7
1.40	DRH	unsuitable training system (divided canopy)
1.47	BEL	Not UCD7
Category II		
1.53	CVB	too close to selected site (LND)
1.56	HTL	too close to selected site (JRS)
1.59	BOB	Not UCD7
1.78	AIT	unsuitable training system (divided canopy)
1.79	MPV	too close to selected site (MMR)
1.81	PCW	outer row in the vineyard (only one row with the clone)
2.06	CVE	too close to selected site (MMR)
2.09	NGW	too close to selected site (JRS)
2.27	SFV	SELECTED
2.50	RCT	too young
Category III		
2.51	RVV	SELECTED
2.60	EVV	too close to selected site (LND)
2.64	HHV	too close to selected site (MMR)
Category IV		
2.72	LND	SELECTED
2.92	MSV	Not UCD7

Category V		
3.06	RV2	Not on SO4
3.06	RSG	suitable, but not selected
3.31	MMR	SELECTED
Category VI		
3.50	BPN	SELECTED

*Canopy Density Index / Index of Ripeness

Category 3. EVV is a site in the Eskdale sub-region, HHV is in Havelock North sub-region, while the selected site **RVV** is located in the Mangatahi / Maraekakaho sub-region west of Hastings. Soils are little heavier (silt and sandy loams) and more fertile in this group with sites cooler than in other subregions, being either closer to the sea or higher in altitude.

Category 4. From the two sites in this group, MSV, which is in the Taradale / Meeanee / Brookfields sub-region was discarded from further study because the clone was not UCD7. The selected site, **LND** is located in Eskdale sub-region. These sites are on soils well supplied with moisture (like *Okawa* silt loam) through most of the growing season.

Category 5. RV2 is another site in Riverview vineyard, in Mangatahi sub-region, along with RVV, but on a slightly more humid soil (on a lower terrace, with a shallower water table and a deeper topsoil), planted with Cabernet Sauvignon on Teleki 5C, which was the reason for this site not being selected. The remaining sites RSG and MMR in the neighbouring sub-regions of Havelock North and Haumoana, were both suitable for further study, and **MMR** was selected primarily because it was further southeast, thus providing a broader cover of the Hawke's Bay region.

Category 6. **BPN** is the only site in this group, and it represents sites on very fertile soils, well supplied with moisture throughout the season (a recent alluvial *Omarunui* silt loam on sand in case of BPN). Most vineyards planted on similar sites in Hawke's Bay are not planted with Cabernet Sauvignon, but rather with the earlier ripening varieties, and those less prone to excess vigour. This site is located in Dartmoor sub-region.

Table 14. Selected sites and their main characteristics

Site	Sub-Region	Year Planted	Soil Type (Local Soil Name)	Training System and Pruning	Irrigation
RVV	Mangatahi / Maraekakaho	1991	Ngatarawa sandy loam	Spur-pruned Scott-Henry	135 mm in 1997/98
JRS	Fernhill / Ngatarawa / Ohiti	1990	Omahu stony gravels	Spur-pruned Scott-Henry	about 130 mm in every season
BPN	Dartmoor / Puketapu	1990	Omarunui silt loam on sand	Four canes VSP	Nil
SFV	Taradale / Meeanee / Brookfields	1988	Pakowhai silt loam	Spur-pruned Horizontal Cordon	Nil
LND	Eskdale / Bayview	1991	Esk sand	Cane pruned Sylvoz	Nil
MMR	Haumoana / Te Awanga	1990	Waipukurau sandy loam	Spur-pruned Scott-Henry	54 mm in 97/98, 17 mm in 1998/99

Canonical Discriminant Analysis (Cruz-Castillo *et al.*, 1994) of the berry composition data for the above categories (excluding Category 6 that was omitted from this analysis since it has only one case) clearly differentiates among them (Table 15, Figure 9).

Table 15. Canonical Discriminant Analysis of selected variables in 1996/97

Factor Structure Matrix (season1.sta)
Correlations Variables - Canonical Roots
(Pooled-within-groups corre ations)

	Root 1	Root 2	Root 3	Root 4
TSS	-0.094	0.228	-0.058	-0.421
TA	0.297	-0.426	-0.255	0.192
PH	-0.088	0.320	0.494	-0.119
PHENOLS	-0.159	0.202	0.150	0.533
ANTHOC	-0.138	0.190	0.054	0.417
TPHENOLS	-0.158	0.333	-0.031	0.082
TANTHOC	-0.118	0.126	-0.104	-0.064
MAL_AC	0.063	-0.526	-0.084	0.118
TAR_AC	0.144	-0.071	-0.110	0.383
K_MUST	0.208	-0.007	0.542	0.064

Standardized Coefficients (season1.sta)
for Canonical Variables

	Root 1	Root 2	Root 3	Root 4
TSS	0.364	0.385	-0.684	-0.684
TA	2.684	0.346	-0.640	0.158
PH	-0.278	-0.335	0.534	0.428
PHENOLS	-6.404	-3.457	1.974	1.157
ANTHOC	7.740	4.060	-2.435	-0.118
TPHENOLS	1.497	2.978	-0.872	-1.196
TANTHOC	-4.564	-4.067	1.371	1.271
MAL_AC	-1.843	-1.109	0.213	-0.355
TAR_AC	-1.254	-0.463	-0.163	1.069
K_MUST	1.221	0.185	0.893	-0.362
Eigenval	7.090	1.997	0.764	0.267
Cum.Prop	0.701	0.898	0.974	1.000

Variables described in the Appendices (page 242).

The most important factors for discriminating between sites according to this statistical procedure are TA (in Root 1), and malic acid contents (in Root 2). With respect to Root 1, the distance is particularly obvious between the first and the fourth category, while the others are in between them. This is significant as total acidity and particularly malic acid content in juice are correlated with the preferred wine attributes (or 'wine quality'). According to Hepner *et al.* (1985) the relationship between malic acid in juice and wine quality of Cabernet Sauvignon is not straightforward in warm climates; conversely, in cool climates (1996/97 was a rather cool season), high malic acid content can be regarded as a negative quality factor.

This distinction between the arbitrary categories assigned to sites on the basis of their canopy properties and ripening abilities, shows that sites from different categories produced grapes having quite dissimilar attributes.

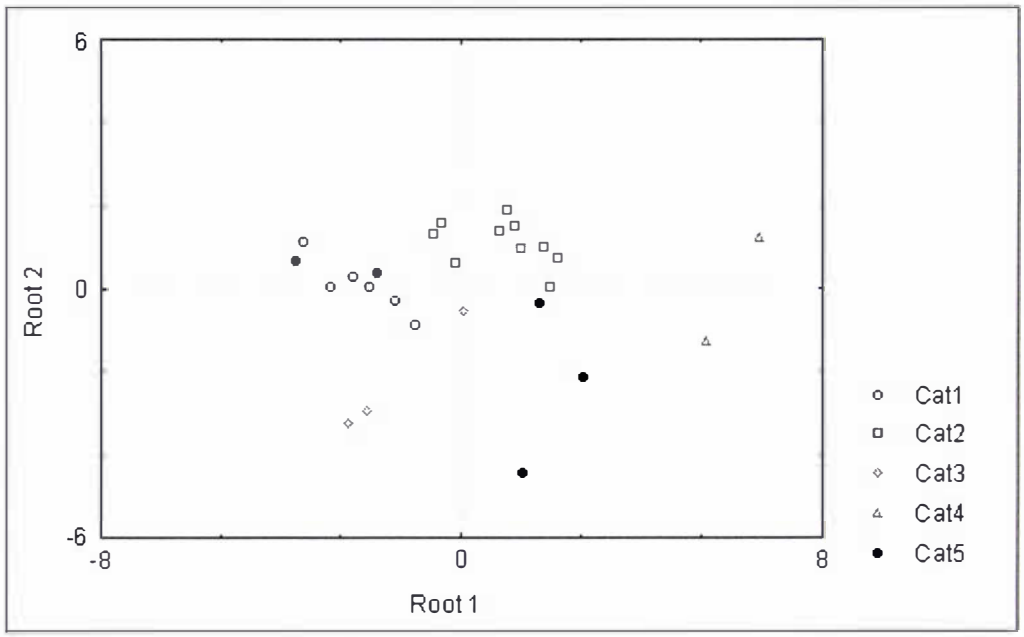

Figure 9. Scatterplot of canonical scores for selected variables collected at five site categories in 1996/97.
Cat1 through Cat5 refer to Categories 1-5.

The number of categories assigned was of an arbitrary nature. From the practical standpoint, it was suitable to limit this number to six, enabling adequate data collection, while still providing enough cases for subsequent statistical analysis. Later analyses of soil properties at selected sites, along

with the slight variation in their climate, aspect, and altitude, have proven convincingly that these are genuinely different grape-growing environments

Summary

Observations of Cabernet Sauvignon grapevines growing on 28 sites in Hawke's Bay during the 1996/97 growing season have shown a large variability of phenology, cropping potential, and fruit composition across the region. Mid-flowering ranged from 57 to 74 days from 1 October. Mid-véraison from 130 to 158 days from 1 October, where sites on sandy and gravelly soils were characterised by earlier véraison than sites on heavier soils. It took from 178 to 211 days for grapes at observed sites to reach a TSS of 20 °Brix. Yield of grapes also varied markedly between the sites (from 4.9 to 13.8 t/ha), and this was caused by variable fertility (cluster number) and cluster size. Estimated exposed leaf surface area (ESA) was very different between sites because of the difference in training systems and site potential. Canopy density was one of the most variable attributes observed, with a majority of sites having unfavourably dense canopies. The measure of canopy density (Canopy Density Index, CDI) was strongly correlated with pruning weight. Vegetative vigour, assessed using those attributes was highly correlated with fruit composition indices, particularly titratable acidity (TA).

Based primarily on vegetative properties and level of ripeness attained, the observed sites were categorised arbitrarily into six categories, representing more or less distinctly different grape-growing environments. Out of each of these groups, one representative vineyard site was selected (based on viticultural but also on practical criteria) for further and more detailed study. A post-hoc multivariate analysis of data, broken down by categories, has shown some significant differences between them, particularly with regard of phenology and ripening capacity. Canonical discriminant analysis, using several fruit composition attributes, has shown a clear distinction between the categories.

CHAPTER 4. CHARACTERISATION OF SELECTED VITICULTURAL ENVIRONMENTS

Introduction

The effect of the environment on vine growth and development is crucial to the success of wine grape growing. It is difficult, however, to assess the importance of individual environmental factors that have a prevailing impact on the attributes of grapes and wines, and, moreover, to quantify their effects. There has been a considerable debate about the effect of environmental factors. An example is the 'climate debate' between certain Australian and New Zealand scientists disagreeing on the relative importance of climate and vineyard site in determining grape quality (Due, 1994; Due, 1995; Gladstones, 1996). It is hoped that eventually there will be a holistic picture of environmental requirements for production of grapes with desired attributes on the one hand, and development of a practical tool for predicting the behaviour of grapevines at a given site or region on the other.

This study aims to characterise the environments of certain Hawke's Bay localities or potential 'terroirs' for growing the wine grape cv Cabernet Sauvignon. Similar studies have been done in various viticultural regions throughout the world. Falcetti and Iacono (1996) conducted an ecophysiological study of sites and their importance for the characteristics of grapes and wine in the conditions of the NE Italy. They concluded that different vine responses were caused by site related influences, such as slope, sun exposure and soil characteristics. Costantini *et al.* (1996) established similar environmental effects in their study around Siena in Italy, with even more emphasis on the influence of different soils. Egger *et al.* (1996) after studying 22 vineyard environments with cv Sangiovese, stress

the importance of water availability in terms of soil water retention for the quality of grapes. Carbonneau (1982) established for Cabernet Sauvignon on SO4 in France that dry gravelly soil contributed to higher TSS and lower TA content in juice compared to moist sandy loam. Vines on the latter soil had a higher crop yield than those on dry gravel.

Consistent production of high-quality grapes is made difficult by high inter-seasonal variability in the conditions of Hawke's Bay, New Zealand. This makes vineyard site selection critical if the desired wine quality is to be sustained. Sub-regions of Hawke's Bay are characterised by markedly different environmental conditions. Identifying and characterising these conditions, or potential 'terroirs', is of both scientific and commercial interest.

Material and Methods

Soil Properties

Soil profiles at each of the six sites were determined in pits opened with a mechanical digger in August 1998. Excavation was done until harder soil or pan was reached. At several sites a hand auger was used to sample the soil from deeper layers.

Soils were described after Milne *et al.* (1995). Soils were classified according to two systems: New Zealand Soil Classification (Hewitt, 1992), and the US soil classification system (United States Department of Agriculture, Anon. 1992).

Soil samples for basic texture analyses and pH measurement were taken from the soil layers in the major rooting zone (usually 30-70 cm). Soil texture was determined by gravimetric method and boundaries were as follows: gravel > 2 mm; sand from 2 to 0.05 mm; silt from 0.05 to 0.002 mm; and clay < 0.002 mm.

Meteorological Data

Meteorological data at selected sites were collected with Li-Cor LI1000 data loggers equipped with the appropriate temperature and solar radiation sensors (for details see Chapter 2). Technical details regarding the programming of data loggers, the set-up values and coefficients used are presented in Appendix 4 (page 246).

Growing degree-days (GDD) were calculated by methodology described in Chapter 2 (page 25).

Results

Soil Description and Classification

Differences exist in the most important characteristics in the soil profile at the six selected sites (Table 16). A detailed soil description and classification is included in Appendix 5 (page 248).

Site RVV, located on the highest terraces of the Ngaruroro in Mangatahi/Maraekakaho sub-region, has a sandy loam soil of Ngatarawa type. An important characteristic of this soil is the presence of about 40% gravel in deeper soil layers. Vine roots are very well spread in the profile up to 1.1 m. A particularly high concentration of roots was observed in the first 20 cm of soil, because of the sub-surface drip irrigation installed. Although the irrigation system was used only during periods of severe drought, it was presumably used more frequently in the period of vineyard establishment, hence it is likely the majority of fibrous roots were formed around irrigation lines. Horizon Bw (from 30 to 45 cm) was on the borderline between slightly acid and normal with a pH of 6.5. Its texture was 58% sand, 10% silt and 32% clay, making it a sandy clay loam.

Of the six sites investigated, the soil profile at JRS is unique in that its entire soil profile has a very high percentage of coarse and very coarse gravels and hence is extremely permeable. Viticulture in this area is not possible without irrigation, as the water table is >10 m (Jim Hamilton, pers. comm.) If

irrigation on such soils were stopped, grapevines would suffer irreversible damage. This is shown in anecdotal evidence in cases when the irrigation line has been damaged (for example, by rabbits).

Table 16. The main soil properties at six selected sites

SITE: RVV		SOIL NAME: Ngataraiwa sandy loam					
Horizon	Depth	Texture	Gravel %	Strength	Roots	Est.permeability	Mottles
A1	0 - 0.10	sandy loam		mod. weak	many thick horizontal	mod. rapid	
A2	0.10 - 0.19	sandy loam		mod. weak	many thick horizontal	mod. rapid	
A/B	0.19 - 0.30	sandy loam		mod. weak	common 2mm thick	mod. rapid	
Bw	0.30 - 0.45	sandy loam		mod. firm	common 2mm thick	moderate	
2B	0.45 - 0.70	heavy sandy loam	40 medium - fine	mod. weak	common very fine	mod. rapid	
2Bt	0.70 - 0.92	sandy clay loam	40 coarse - very coarse	mod. weak	common very fine	mod. slow	
2BCgp	0.92 - 1.08	heavysandy loam	40 coarse - very coarse		common very fine	moderate	common fine
2BCx	1.08 - 1.15+	gravelly sandy loam	40 medium - fine			slow	
SITE: JRS		SOIL NAME: Omahu stony gravels					
Horizon	Depth	Texture	Gravel %	Strength	Roots	Est.permeability	Mottles
A	0 - 0.07	loamy fine sand	50 coarse - very coarse		many thick	rapid	
C1	0.07 - 0.73	gravels w. sand	70 coarse - very coarse		many 2-8 mm	very rapid	
C2	0.73 - 0.85	gravels	70 coarse - very coarse		many 1-2 mm	extremely rapid	
C3	0.85 - 1.20+	gravels w. sand	70 coarse - very coarse		common 1mm		
SITE: BFN		SOIL NAME: Omarunui silt loam on sand					
Horizon	Depth	Texture	Gravel %	Strength	Roots	Est.permeability	Mottles
A	0 - 0.19	silt loam		mod. weak	fine grass	moderate	
A/B	0.19 - 0.35	silt loam	few	mod. firm	many fine grass	moderate	
bA	0.35 - 0.43	sandy loam		mod. weak	many fine grass	moderate	
C	0.43 - 0.96	loamy fine sand		very weak	common 3 mm thick	mod. rapid	
bA1	0.96 - 1.11	silt loam		mod. weak	common 3 mm thick	moderate	decomp.roots
bA2	1.11 - 1.35	silty clay		mod. weak	common 3 mm thick	moderate	decomp.roots
Cu(f)1	1.35 - 1.70	silt loam				moderate	many medium
Cu(f)2	1.70 - 1.90	loamy fine sand				mod. rapid	many medium
Cu(f)3	1.90 - 2.40+	heavy silt loam				moderate	many medium
SITE: SFV		SOIL NAME: Pakowhai silt loam					
Horizon	Depth	Texture	Gravel %	Strength	Roots	Est.permeability	Mottles
A1	0 - 0.15	silt loam		mod. weak	many 3-10 mm	moderate	
A2	0.15 - 0.26	heavy silt loam		mod. firm	many 3-10 mm	mod. slow	
C	0.26 - 0.32	loamy fine sand		very weak	many 3-10 mm	moderate	
bA	0.32 - 0.45	heavy silt loam		mod. weak	many 3-10 mm	moderate	
bA/B	0.45 - 0.51	silty clay		mod. firm	common 2 mm thick	moderate	
Bgg	0.51 - 0.71	silty clay		mod. weak	common 2 mm thick	moderate	common fine
Cu(f)1	0.71 - 1.15	fine sandy loam		mod. weak	common 2 mm thick	moderate	many medium - fine
Cg	1.15 - 1.90	silt loam		mod. firm	common 2 mm thick	mod. slow	common medium
Cu(f)2	1.90 - 2.10+	loamy fine sand		very weak		moderate	
SITE: LND		SOIL NAME: Esk sand					
Horizon	Depth	Texture	Gravel %	Strength	Roots	Est.permeability	Mottles
A	0 - 0.10	loamy sand		mod. weak	many very fine	mod. rapid	
Ap	0.10 - 0.27	loamy sand		very weak	common very fine	mod. rapid	
C	0.27 - 0.78	sand		very weak	common very fine	rapid	
Cg	0.78 - 1.30	loamy sand		very weak	common very fine	rapid	common medium
SITE: MMR		SOIL NAME: Waipukurau sandy loam					
Horizon	Depth	Texture	Gravel %	Strength	Roots	Est.permeability	Mottles
Ap	0 - 0.18	sandy loam		mod. weak	few 5 mm thick	moderate	
Bgp	0.18 - 0.34	clay loam		mod. firm	few 5 mm thick	moderate	common medium
Bw(gp)	0.34 - 0.60	sandy clay loam		mod. weak	few 5 mm thick	moderate	many medium
Bx	0.60 - 0.65+	very hard duripan				slow	

The root system is very well spread exploring the soil for water, although it is most dense in the upper soil layers because of regular irrigation. Horizon C1 (from 7 to 73 cm) was of a normal pH (6.8), and consisted of 84% gravel and 16% sand.

BPN had a very deep soil that created the potential for extremely vigorous vegetative growth. Near the experimental block very large walnut (*Juglans sp.*) and *Ficus* trees were growing without irrigation, and also nettles (*Urtica dioica* L.) grew in abundance (see photographs in Appendix 14, page 276). Horizon C (from 43 to 96 cm) was slightly acidic (pH 6.0), with texture being sand 90%, silt 2% and clay 8%. The analysed horizon C was not representative of texture of this soil, which has been classified as a silt loam on sand.

Grapevine roots were concentrated mainly in the layer 0.4 – 1.4 m, with the roots from grasses dominating in surface soil layers. At this site the permanent grass cover was very vigorous and resistant to dry conditions, probably due to high available water content. Grass grew throughout the season, almost regardless of rainfall; it was mown several times during the season giving high yields of grass. Regardless of significant water and nutrient usage by the cover crop, grapevines were excessively vigorous (see Chapter 5).

There is more than 40% of silt in soil at this site giving this it a high readily available water content. Since the site is located about two hundred meters from the Tutaekuri River at the same altitude, it is very likely that the water table is not very deep. A significant degree of mottling was observed at this site confirming this suggestion.

The soil at site SFV was a silt loam containing some clay and hence slightly heavier than soil at BPN. The soil profile is also very deep and vine roots are found throughout the profile up to 1.9 m. This soil has only a moderate estimated permeability, creating a relatively high soil moisture retention capacity. The water table rises up to about 1 m judging by the signs of

mottling observed. This is not surprising, as this vineyard is located on the banks of the Tutaekuri River. Horizon bA (from 32 to 45 cm) was slightly acidic (pH 6.3), consisting of 38% sand, 20% silt, and 42% clay.

LND had a very sandy soil ('Esk sand') and estimated permeability was high. However the water table could have been accessed by the roots as mottling occurred at about 1m. This vineyard was close to the Esk River, and was at the same altitude. Vine roots filled most of the soil profile, as irrigation was not practiced and there were no obstacles to root growth. Horizon C (from 27 to 78 cm) was almost a pure sand (94% sand, 2% silt and 4% clay), and moderately alkaline (pH 7.8).

The soil at site MMR was located on a thick and impermeable clay pan ('duripan'). This affected its viticultural characteristics very significantly. Vine roots grew only in the top 60 cm of this sandy clay loam. Mottling occurred at 18 cm depth; this indicates that during certain periods (winter) this soil is almost saturated with water. In dry seasons this site may require irrigation, as the rooting zone is shallow with very low soil moisture content (as low as 10%) by mid-summer. Horizon Bw(gp) was slightly acidic (pH of 6.4) consisting of a sandy clay loam with 47% sand, 12% silt and 41% clay.

Duripan has a remarkable effect on soil water availability to grapevines. Humid seasons commence with a waterlogged soil that very slowly dries out, retaining a high soil moisture content throughout the growing period. In dry seasons the shallow rooting zone dries out quickly; roots, restricted by duripan, are unable to reach the moisture reserves in subsoil. This causes the difference between rainy and dry seasons with regard to vine growth, development, and fruit composition at this site to be much more significant than at other sites.

Environmental Conditions

Estimates of average air temperatures in 1996/97 (Table 17) are based on regressions (Table 3) and show a variability in air temperatures over the region (standard deviation of the seasonal GDD is 59.2 °D between sites).

An overview of meteorological data from the Horticulture and Food Institute of New Zealand (HortResearch) network of weather stations for 1996/97 is in Appendix 7.

Air temperatures at selected sites in 1997/98 and 1998/99 are shown from Table 18 through to Table 22. Average temperature at the JRS and LND sites were generally warmer than at other sites. One unusual characteristic of 1998/99 was that the average temperature in October was higher than in November. In both 1997/98 and in 1996/97 the average temperature in February was greater than in January, normally the warmest month of the year in the Southern Hemisphere. Overall, small variability in air temperature was observed between sites, similar to that found between three orchard sites in the Kerikeri district (North Island of New Zealand) by McAneney *et al.* (1995).

April is usually the last month in which grape ripening occurs. In 1997/98 April was 1.7 °C warmer (16°C) than normal (14.3°C for Hastings, Thompson, 1987). In this season GDD during the period October-April was about 1650°D compared with an average GDD for this time of 1360°D, making 1997/98 a warm season. This resulted in one of the most acclaimed vintages in Hawke's Bay and New Zealand. The following season of 1998/99 was also above average in terms of GDD (1472°D on average).

No frosts were recorded in any of the six vineyards in which weather stations were placed during periods of vegetative growth in 1998/98 and 1998/99 (Table 20).

Table 17. Average air temperature estimates and seasonal GDD (°D) at 28 vineyard sites in Hawke's Bay in the 1996/97 season

Site	Oct	Nov	Dec	Jan	Feb	Mar	Apr	GDD Oct-Apr
Dartmoor / Puketapu								
BPN	13.2	14.3	16.9	16.8	18.6	15.9	12.3	1163
RCT	13.1	14.2	16.7	16.6	18.4	15.7	12.2	1128
RSW	13.2	14.3	16.9	16.8	18.6	15.9	12.3	1163
Mean	13.2	14.3	16.8	16.7	18.5	15.8	12.3	1151
Eskdale / Bayview								
CVB	13.6	14.7	17.2	17.2	18.9	16.3	12.7	1231
EVV	13.6	14.7	17.2	17.2	18.9	16.3	12.7	1231
LND	13.6	14.7	17.2	17.2	18.9	16.3	12.7	1231
Mean	13.6	14.7	17.2	17.2	18.9	16.3	12.7	1231

Fernhill / Ngatarawa / Ohiti								
BEL	13.1	14.1	16.7	16.6	18.4	15.7	12.2	1124
BOB	13.6	14.7	17.4	17.3	19.2	16.3	12.7	1256
CRW	13.0	14.1	16.6	16.5	18.2	15.6	12.2	1105
HTL	13.4	14.5	17.2	17.1	18.9	16.2	12.4	1212
JRS	13.6	14.7	17.4	17.3	19.2	16.3	12.7	1256
KNG	13.6	14.7	17.4	17.3	19.2	16.3	12.7	1256
NGW	13.4	14.5	17.3	17.2	19.0	16.3	12.5	1227
PCW	13.5	14.6	17.3	17.2	19.1	16.3	12.6	1238
ROB	13.3	14.4	17.0	16.9	18.7	16.0	12.4	1181
SCR	13.6	14.7	17.4	17.3	19.1	16.3	12.6	1252
Mean	13.4	14.5	17.2	17.1	18.9	16.1	12.5	1211
Mangatahi / Maraekakaho								
RV2	13.3	14.4	17.0	17.0	18.8	16.1	12.4	1189
RVV	13.3	14.4	17.0	17.0	18.8	16.1	12.4	1189
Mean	13.3	14.4	17.0	17.0	18.8	16.1	12.4	1189
Taradale / Meeanee / Brookfields								
MSV	13.4	14.4	17.0	16.9	18.7	16.1	12.5	1188
SFV	13.4	14.4	17.0	16.9	18.7	16.1	12.5	1189
Mean	13.4	14.4	17.0	16.9	18.7	16.1	12.5	1189
Te Mata / Havelock North								
AIT	13.0	13.9	16.8	16.7	18.4	15.9	12.0	1124
HHV	12.8	13.9	16.5	16.4	18.1	15.7	11.9	1085
MPV	12.9	13.9	16.5	16.4	18.1	15.7	11.9	1087
RSG	12.8	13.8	16.6	16.6	18.3	15.8	11.8	1098
Mean	12.9	13.9	16.6	16.5	18.2	15.8	11.9	1099
Te Mata / Havelock North (Haumoana / Te Awanga)								
CVE	13.0	14.1	16.7	16.6	18.3	15.9	12.1	1124
DRH	12.9	14.0	16.5	16.3	18.1	15.7	12.0	1093
LEN	12.9	14.0	16.5	16.3	18.1	15.7	12.0	1093
MMR	13.2	14.2	17.0	17.0	18.7	16.2	12.2	1172
Mean	13.0	14.1	16.7	16.6	18.3	15.9	12.1	1121
Overall Mean	13.3	14.3	16.9	16.9	18.7	16.0	12.3	1174

Average maximum temperatures were slightly lower at sites RVV and MMR than at the other four sites (Table 21). This can be attributed to higher altitude in case of RVV (about 100 m a.s.l, compared to 10-40 m at other four sites) and MMR (67 m a.s.l.). Air temperatures decrease with height above sea level by about 0.6°C for each 100 m increase in elevation (Thompson, 1987). In the case of MMR the difference can also be ascribed to exposure to sea breezes as average temperature maxima are cooler along the coast than inland, while minima are higher.

Table 18. Average air temperatures in 1997/98 and 1998/99

	1997/98							1998/99						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct	Nov	Dec	Jan	Feb	Mar	Apr
RVV	13.3	16.4	18.5	19.6	21.6	19.3	16.0	15.5	14.2	17.7	19.5	17.6	17.9	13.6
JRS	13.5	17.1	19.0	20.0	21.9	19.7	15.9	16.5	15.0	18.6	20.1	18.4	18.4	14.1
BPN	13.4	16.6	18.2	19.4	20.8	19.1	16.0	16.1	14.5	17.9	19.4	17.6	17.8	13.7
SFV	13.6	16.8	18.3	19.2	21.0	19.2	15.6	16.4	14.8	18.2	19.6	17.8	18.0	13.9
LND	13.7	17.0	18.5	19.7	21.2	19.4	16.0	16.3	14.9	18.3	19.6	18.0	18.3	14.0
MMR	13.1	16.0	18.1	19.3	21.3	19.5	16.4	15.6	14.7	18.0	19.7	18.2	18.4	13.9
Average	13.4	16.6	18.4	19.5	21.3	19.3	16.0	16.1	14.7	18.1	19.6	17.9	18.2	13.9

Table 19. Average minimum air temperatures in 1997/98 and 1998/99

	1997/98							1998/99						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct	Nov	Dec	Jan	Feb	Mar	Apr
RVV	7.2	9.5	11.0	11.9	14.4	12.6	9.7	10.1	9.2	11.3	13.2	11.0	12.2	9.0
JRS	6.8	9.3	11.3	12.2	14.6	12.3	9.5	9.5	9.2	11.7	13.9	11.3	12.4	8.7
BPN	6.5	8.6	9.6	10.9	13.0	10.5	7.9	9.3	8.4	10.5	12.8	9.9	11.1	7.8
SFV	7.0	9.0	10.0	11.2	13.4	11.4	8.5	9.8	8.8	10.9	13.3	10.4	11.8	8.2
LND	7.6	9.4	10.5	12.0	14.4	12.1	9.7	9.6	9.2	11.9	13.8	11.5	12.4	9.1
MMR	7.7	9.6	11.2	12.6	15.2	13.9	10.3	10.1	10.2	12.3	14.7	12.9	13.9	9.8
Average	7.2	9.2	10.6	11.8	14.2	12.1	9.3	9.7	9.2	11.4	13.6	11.2	12.3	8.8

Table 20. Absolute minimum air temperatures in 1997/98 and 1998/99

	1997/98							1998/99						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct	Nov	Dec	Jan	Feb	Mar	Apr
RVV	4.1	2.2	3.3	4.9	6.9	7.8	3.6	2.5	6.0	4.7	7.3	7.1	7.4	4.7
JRS	2.5	1.4	2.8	2.8	6.2	6.6	2.4	2.0	4.6	4.5	6.7	6.4	7.2	3.7
BPN	2.4	2.2	0.9	1.9	4.1	4.2	1.7	0.4	3.7	3.6	4.7	4.8	5.6	3.1
SFV	2.4	2.5	0.6	2.4	3.9	4.9	2.4	1.3	5.1	4.8	5.8	5.5	6.3	3.4
LND	3.0	2.8	3.4	4.2	6.3	5.4	3.8	1.7	5.5	6.7	8.4	7.1	7.2	4.8
MMR	3.7	2.4	4.5	4.8	7.5	8.8	4.4	4.6	5.8	4.9	9.5	8.8	9.9	5.5

Table 21. Average maximum air temperatures in 1997/98 and 1998/99

	1997/98							1998/99						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct	Nov	Dec	Jan	Feb	Mar	Apr
RVV	19.7	23.0	26.2	27.9	29.7	27.2	22.6	21.0	20.3	25.4	27.5	26.0	25.6	20.0
JRS	20.5	24.5	26.8	28.5	30.1	27.8	23.2	22.6	21.2	26.3	27.6	26.7	26.1	20.4
BPN	20.5	24.4	27.0	28.7	30.0	27.7	23.0	22.8	20.5	25.4	26.9	26.3	26.3	20.6
SFV	20.1	23.8	26.0	27.4	29.1	27.0	22.6	23.0	21.0	25.6	26.5	26.0	25.3	20.1
LND	20.1	24.2	26.2	27.7	28.5	26.8	22.7	22.8	20.9	25.3	26.4	25.4	25.5	20.1
MMR	18.8	22.8	25.6	27.5	28.8	26.6	22.0	21.3	20.2	24.8	26.3	24.9	24.8	19.4
Average	19.9	23.8	26.3	28.0	29.4	27.2	22.7	22.3	20.7	25.5	26.9	25.9	25.6	20.1

Table 22. Absolute maximum air temperatures in 1997/98 and 1998/99

	1997/98								1998/99							
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mean	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mean
RVV	26.3	29.4	33.4	33.9	36.2	31.5	27.8	31.2	27.4	28.6	32.5	37.0	30.2	30.7	27.0	30.5
JRS	27.3	32.6	36.5	35.5	35.7	32.2	28.7	32.6	29.3	30.2	34.9	40.2	34.1	30.8	27.8	32.5
BPN	27.0	31.5	35.2	36.1	36.3	31.9	28.1	32.3	28.4	30.5	32.5	37.6	33.0	31.1	28.7	31.7
SFV	26.4	31.3	34.6	33.7	34.8	30.8	27.1	31.2	28.1	28.4	32.0	36.0	31.5	29.3	26.9	30.3
LND	27.3	31.3	34.1	34.9	33.6	31.6	27.7	31.5	28.8	30.1	31.2	36.8	31.5	30.8	26.4	30.8
MMR	24.1	31.2	33.4	34.7	35.8	31.4	27.2	31.1	27.0	26.3	30.2	36.1	32.1	28.5	25.5	29.4

Absolute maxima (Table 22) were particularly high at JRS with maximum temperatures being the highest in 9 of the 14 months studied. The extreme maximum of 40.2°C occurred on 7/01/1999 between 1 and 2pm.

Average night temperatures (8pm – 7am) in 1997/98 and 1998/99 were relatively high, particularly in summer of 1998 (Table 23). During the first part of both seasons (from October to December), night temperatures were the highest at JRS (13.82°C, compared to 13.1-13.75°C at other sites). This was probably an effect of the stony soils at this site reflecting the heat accumulated during daytime. In the second part of the season, however, the highest night temperatures were recorded at MMR (15.71°C). That can be attributed to the proximity of the Pacific Ocean. Night-time temperatures at JRS during this period were very similar (15.6 °C; other sites were in the range 14.6-15.5°C). In both the seasons site BPN was consistently cooler during night than other sites.

Table 23. Average night temperatures in 1997/98 and 1998/99

	1997/98							1998/99						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct	Nov	Dec	Jan	Feb	Mar	Apr
RVV	10.6	13.9	15.4	16.0	18.2	16.5	13.4	13.8	11.8	14.5	16.1	14.2	15.2	11.9
JRS	10.6	14.2	15.9	16.3	18.7	16.8	13.6	14.3	12.5	15.4	17.1	15.1	15.7	11.9
BPN	10.4	13.3	14.7	15.4	17.0	15.7	12.6	13.9	11.9	14.4	16.2	13.9	14.8	11.2
SFV	10.9	14.0	15.0	15.4	17.5	16.3	13.2	14.3	12.3	14.8	16.7	14.3	15.4	11.6
LND	10.9	14.2	15.3	16.0	18.2	16.7	13.5	14.2	12.5	15.4	16.9	14.9	16.0	11.9
MMR	10.5	13.4	15.2	15.9	18.4	17.0	13.4	13.7	12.7	15.2	17.2	15.6	16.4	11.8
Average	10.7	13.9	15.2	15.8	18.0	16.5	13.3	14.0	12.3	15.0	16.7	14.7	15.6	11.7

Neither wind run nor wind speed was measured at any of the selected sites. Some wind direction and wind speed data were available from the Havelock North weather station (see Appendix 7). However, Havelock North has the

calmest conditions in Hawke's Bay and long term data (Thompson, 1987) show that wind speeds at Napier Airport are about three times higher than in Havelock North (yearly average of 17 km/h vs 6 km/h). Site LND is located approximately 10 km north from Napier Airport, and MMR is about 4 km southeast from Havelock North weather station. However, site LND is quite sheltered from S and SW winds (which are the most frequent). Therefore it can be assumed that wind speed at LND is considerably lower than at Napier Airport. In a study of three orchard sites in the Kerikeri district by McAneney *et al.* (1995) clear differences between sites were observed with respect to mean wind speed at 2 m height. It is also likely that some differences in wind speed existed between six selected sites in this experiment.

Based on data from Havelock North there was very little difference in windiness in the region between experimental seasons (168.5, 156.5 and 162.1 km of total wind run per day for 1996/97, 1997/98 and 1998/99 respectively).

Table 24. Average soil temperatures at 15 and 30 cm in 1997/98 and 1998/99

	1997/98							1998/99						
	At 15 cm													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct	Nov	Dec	Jan	Feb	Mar	Apr
RVV	15.2	18.5	20.1	20.5	22.2	20.3	16.6	16.8	17.5	18.7	20.5	18.7	18.5	15.9
JRS	17.1	22.0	25.0	26.1	27.9	24.6	19.4	19.2	20.0	23.4	25.3	24.3	22.2	18.4
BPN	15.3	18.4	20.7	20.5	21.8	19.2	16.8	17.1	18.4	19.2	20.7	18.6	18.7	16.5
SFV	15.6	20.0	22.5	22.8	24.6	21.4	17.6	18.4	19.4	21.3	23.5	21.8	20.6	16.7
LND	15.8	19.8	22.1	22.8	23.9	21.6	17.7	18.1	19.1	21.2	22.7	21.6	20.1	16.9
MMR	15.3	17.4	20.2	21.5	23.9	21.5	16.7	17.6	19.4	20.2	22.7	21.0	19.0	15.8
Average	15.7	19.4	21.8	22.3	24.1	21.4	17.5	17.9	19.0	20.7	22.6	21.0	19.9	16.7
	At 30 cm													
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct	Nov	Dec	Jan	Feb	Mar	Apr
RVV	14.7	17.8	19.7	20.4	22.0	20.4	16.5	16.4	17.5	18.4	20.4	19.0	18.8	16.1
JRS	16.9	21.8	24.9	25.9	27.8	24.5	19.5	19.1	20.0	23.1	25.2	24.2	22.3	18.6
BPN	15.0	18.2	20.4	20.3	21.7	19.3	16.9	16.6	18.2	19.0	20.8	19.3	18.9	16.8
SFV	15.1	19.3	21.8	22.0	24.0	21.1	17.4	17.7	19.3	20.8	23.2	21.7	20.5	16.7
LND	15.4	19.4	21.7	22.4	23.7	21.5	17.6	17.4	18.9	20.5	22.4	21.3	20.2	17.0
MMR	15.4	17.8	20.4	21.3	23.8	21.2	16.8	16.6	18.7	19.3	21.9	20.6	20.0	16.1
Average	15.4	19.1	21.5	22.0	23.8	21.3	17.4	17.3	18.8	20.2	22.3	21.0	20.1	16.9

Soil temperatures (Table 24) varied markedly between sites, with JRS having the highest average monthly soil temperature of 27.9°C recorded at

15 cm. The absolute maximum soil temperatures at 15cm recorded in these two seasons occurred at JRS, with 31.4°C on 17/02/1998 and 30.4°C on 8/01/1999. The soil at JRS contained a high percentage of gravel (50-70%) that undoubtedly contributed to its thermic characteristics. In addition, it was better exposed to direct sunlight than soils at other sites because of a sparse vine canopy and poor sward growth (probably because of the low soil moisture content). Bare vineyard soil temperatures were shown to be higher than that of grassed vineyard soils by Pradel and Pieri (2000).

Solar radiation was highest at LND and JRS sites (Table 25), although the overall variability between sites was relatively small (coefficient of variation between sites varied from 3 to 4%). Small differences in solar radiation were also observed between three orchard sites in the Kerikeri district by McAneney *et al.* (1994). Total solar radiation was similar in the 1997/98 and 1998/99 seasons.

Table 25. Monthly averages for solar radiation (mol/m^2) in 1997/98 and 1998/99

	1997/98							1998/99						
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct	Nov	Dec	Jan	Feb	Mar	Apr
RVV	39.0	44.7	46.7	48.4	43.7	37.4	28.8	38.2	39.5	46.9	44.8	44.0	35.0	27.2
JRS	40.3	45.6	47.5	49.0	44.6	38.7	30.7	39.5	40.8	47.7	45.7	45.0	36.5	29.8
BPN	37.8	42.7	44.5	46.0	41.8	36.3	28.8	37.1	38.2	44.7	42.8	42.2	34.3	27.4
SFV	36.7	41.0	42.6	43.8	40.2	35.4	28.8	36.0	37.1	42.7	41.1	40.5	33.6	27.6
LND	40.5	45.8	47.7	49.3	44.9	39.0	30.6	39.8	41.1	48.0	46.0	45.3	36.9	29.6
MMR	39.1	43.7	45.4	46.7	42.9	37.8	30.8	38.5	39.6	45.5	43.8	43.2	35.9	29.7
Average	38.9	43.9	45.7	47.2	43.0	37.4	29.7	38.2	39.4	45.9	44.0	43.4	35.4	28.6

Total rainfall in 1996/97 and 1998/99 (Table 27) was relatively normal for Hawke's Bay, 461 mm being the long-term sum of rainfall from October to April for Hastings, 516 mm for Napier (Thompson, 1987). Note that the rainfall data for 1996/97 are estimates based on regressions between sites and weather stations throughout Hawke's Bay. In 1997/98 the wine-growing region of Hawke's Bay had a severe drought, as did most of New Zealand. There were at least four “dry-spells” (15 days or more with less than 1 mm per day), two of them lasting for more than 30 days. Three of these periods qualified as ‘meteorological droughts’ having 15 or more days with no measurable rain.

Even in 1997/98 three of the vineyards studied were not irrigated at all (Table 27). Because of high soil moisture holding capacity at BPN and SFV (high silt content) and deep soils (at all three sites) there was no sign of water stress on vines, and even the sward culture was maintained throughout the season to some extent (photographs included in Appendix 14, page 276). JRS was normally irrigated daily due to extreme soil permeability, and RVV and MMR were also irrigated in this season. At both these sites growers applied irrigation in accordance with RDI (Regulated Deficit Irrigation, McCarthy *et al.*, 1992) practice, which means that only about half of the water lost through evapotranspiration was replaced by irrigation.

Estimated potential evapotranspiration (ET) data indicated that the sheltered sub-region of Havelock North (Table 26) had a considerably lower ET than the more exposed site at Napier Airport (1127 mm, Thompson, 1987.). Because the 1997/98 season had approximately 75% less seasonal rainfall and 30% greater heat summation than average for the region it is to be expected that in that season the ET values across the Hawke's Bay region were significantly greater than normal.

Table 26. Water balance summary for Havelock North (1952 – 1983)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
AWC							250 mm						
ET	136	108	85	47	27	17	20	34	58	89	112	133	866
DE	67	58	33	8	1	0	0	0	0	0	1	24	192
RO	0	0	1	1	1	9	33	41	16	5	0	0	107
FDE	81	88	91	52	15	3	0	0	0	0	3	59	100
FRO	0	0	3	3	3	27	48	67	53	22	0	0	77

Legend: AWC – Available water content; ET – Penman potential evapotranspiration (mm); DE – Evapotranspiration deficit (mm); RO – Runoff (mm); FDE – Frequency (%) of months with deficit; FRO – Frequency (%) of months with runoff. From Thompson, 1987.

Soil moisture content for soil profiles from 0 to 30 and from 0 to 60 cm in seasons 1997/98 and 1998/99 (Figure 10) were the most variable of all the environmental attributes monitored in this study. They were very variable between sites, both within and between seasons. Presented are the percentages of water in soil relative to estimated field water capacity (Chapter 2, page 25) in the 30 and 60 cm deep profiles. It is clear from the

study of soil profiles (Table 16) that both the soil and the rooting depths at most sites were much deeper than that.

Table 27. Rainfall (mm) and irrigation (mm) at six selected sites in the experimental period

		Season 1996/97							
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	Sum
RVV	r	16.4	32.1	121.8	49.5	89.8	95.9	40.7	446.2
JRS	r	16.4	32.1	121.8	49.5	89.8	95.9	40.7	446.2
	i	17.0	16.5	17.0	17.0	15.4	17.0	16.5	
	Σ	33.4	48.6	138.8	66.5	105.2	112.9	57.2	562.8
BPN	r	14.8	21.1	122.4	59.0	136.6	119.1	36.9	509.9
SFV	r	14.8	21.1	122.4	59.0	136.6	119.1	36.9	509.9
LND	r	14.8	21.1	122.4	59.0	136.6	119.1	36.9	509.9
MMR	r	15.9	16.7	142.1	84.1	97.1	108.9	54.4	519.2
		Season 1997/98							
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	Sum
RVV	r	50.8	17.5	9.0	36.5	45.5	3.0	25.2	187.5
	i	0.0	0.0	0.0	46.5	42.0	46.5	0.0	
	Σ	50.8	17.5	9.0	83.0	87.5	49.5	25.2	322.5
JRS	r	50.8	15.5	8.5	26.0	29.5	4.5	25.3	160.1
	i	17.0	16.5	17.0	28.0	15.4	17.0	16.5	
	Σ	67.8	32.0	25.5	54.0	44.9	21.5	41.8	287.7
BPN	r	56.6	24.0	13.5	33.0	25.3	8.1	29.7	190.2
SFV	r	56.6	27.0	9.0	35.0	23.0	9.0	29.7	189.3
LND	r	56.6	40.5	9.0	28.5	20.0	8.2	29.7	192.5
MMR	r	56.1	14.0	15.0	19.0	25.0	18.9	33.5	181.5
	i	0.0	0.0	0.0	18.6	16.8	18.6	0.0	
	Σ	56.1	14.0	15.0	37.6	41.8	37.5	33.5	235.5
		Season 1998/99							
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	Sum
RVV	r	34.8	87.7	44.5	176.6	20.4	143.1	112.6	619.7
JRS	r	21.0	45.1	39.3	202.4	15.1	111.5	101.6	536.0
	i	15.9	16.8	24.7	26.4	15.4	17.0	16.5	
	Σ	36.9	61.9	64.0	228.8	30.5	128.5	118.1	668.9
BPN	r	42.8	68.0	59.0	260.4	22.6	123.4	101.5	677.7
SFV	r	21.8	46.3	64.0	225.1	20.1	80.3	94.0	551.6
LND	r	29.3	101.9	77.5	270.0	13.0	152.5	94.0	738.2
MMR	r	14.4	33.8	57.0	171.2	17.0	74.2	125.6	493.2
	i	0.0	0.0	0.0	0.0	16.8	0.0	0.0	
	Σ	14.4	33.8	57.0	171.2	33.8	74.2	125.6	510.0

Legend: r – rainfall; i – irrigation; Σ – water influx (rainfall + irrigation)

Considerable seasonal variation in soil moisture content existed between 1997/98 and 1998/99, and there is variability between the sites in both seasons (Figure 10). All the selected sites started the season with higher soil moisture content in 1997/98 than in 1998/99. In contrast through most

of 1997/98 the soil moisture content was considerably lower than in 1998/99. Therefore, the two seasons studied in detail had very different patterns of soil moisture availability at all sites.

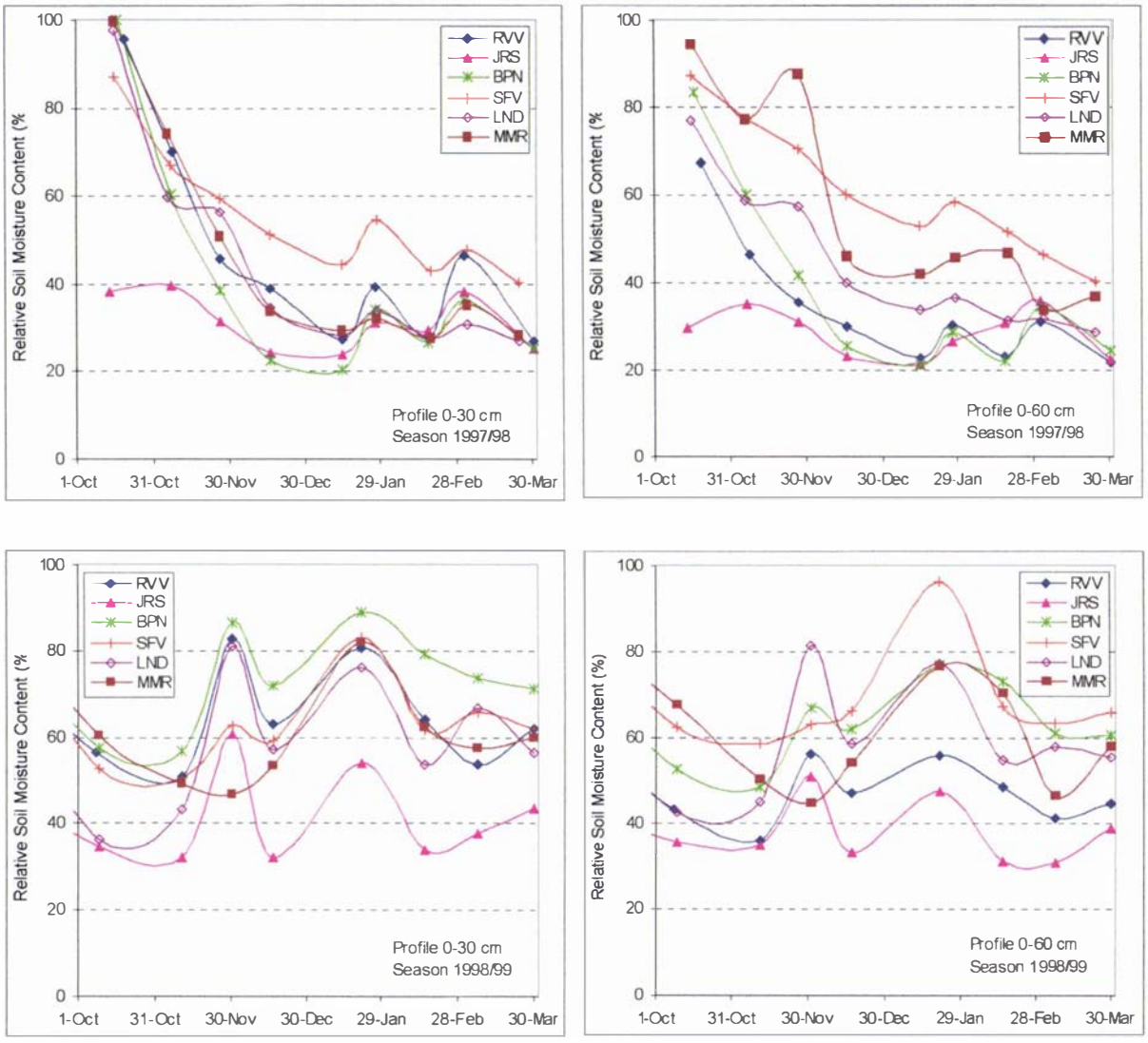

Figure 10. Soil moisture content relative to estimated field water capacity at six selected sites in Hawke's Bay

In 1997/98 soil moisture content at the RVV site declined constantly because of lack of any significant rainfall; irrigation was applied in accordance with the RDI practice. In 1998/99 soil moisture content had two peaks: the first towards late November being the result of > 70 mm of

rainfall in the last week of November, and the second resulting from a very significant rainfall (>170 mm) in the second half of January. The two peaks in soil moisture in 1998/99 at the JRS site correspond to that indicated above.

Soil moisture dynamics at BPN were very different between the two seasons. In the dry 1997/98 season, soil moisture content in the 0-30 cm profile fell to very low levels, although it must have been higher in deeper (over 2 m) layers of this very deep soil. Since mottling occurs in this soil at all depths below 1.35 m, and since it is a recent fluvial soil (about two hundred meters away from the Tutaekuri River), it is very likely that the water table is within the reach of vine roots although this was not determined. If this were so then this would explain why grapevines at BPN did not exhibit any sign of water stress. On the contrary, growth was excessive even in 1997/98, continuing long after véraison (see Chapter 5, page 107). In addition, soil at this site is a silty loam with a silty clay layer at 1.11m. Based on the amount of available water held by soils of different textures (McCarthy *et al.*, 1992) it is estimated that the soil at BPN had up to 50% more available water at the same absolute soil moisture content compared to soils at the JRS or LND sites.

Soil moisture content at the SFV site remained relatively high in both seasons. An important difference was that the 1997/98 growing season began with about 10% higher soil moisture content than in 1998/99; this had a significant impact on vegetative growth of the vines as shown in Chapter 5. The sandy soil at the LND site had a lower soil moisture content throughout the 1997/98 season than in 1998/99. November and January rainfall in 1998/99 increased the soil moisture content significantly again.

Soil moisture dynamics were very different between the two seasons at the MMR site. The November rainfall in 1998/99 mentioned above all but bypassed the sub-regions of Havelock North and Haumoana and the soil moisture content only peaked once, following high rainfall in the second half of January. High soil moisture content at the beginning of season was characteristic of MMR, which has an impermeable pan at about 60-65 cm.

Discussion

Wind speed and soil temperature were the climatic elements that varied most over small distances in orchards of the Kerikeri district, New Zealand, (McAneney *et al.*, 1995) and in vineyards of the Franconia region in Germany (Wahl, 1988). It is however debatable whether soil temperature is a climatic or an edaphic characteristic. It can be stated with certainty that although soil temperature is affected by the above-ground weather conditions, it is also very strongly related to soil physical characteristics. For the purposes of the present study soil temperature will be treated as one of the below ground factors. Soil temperature was found to vary markedly between sites in the Hawke's Bay region, while wind speed was not measured.

The Concept of 'Soil Factor'

Based on observations of grapevine phenology, cropping and fruit characteristics at different sites, it is suggested that a single, integrated variable could be used to characterise a vineyard site in general, or characterise it over a given period of time. This period could be a vegetative season, or a period between two phenological stages, or any single month within the season.

This compound factor would be analogous to 'climatic' or 'bioclimatic' indices that are commonly used to characterise viticultural regions, such as Branas's and Huglin's heliothermic indices (Huglin, 1986; Giomo *et al.*, 1996). These indices use climatic variables, such as temperature summation, rainfall, or sunshine hours to characterise a viticultural region in general (using long-term climatic records), or over any given period, such as season or phenological phase. In addition, many of these indices utilise various coefficients, which are numerical constants that serve to adjust the resulting value so that it fits better with actual vineyard observations. An example of such a coefficient is found in Huglin's heliothermic index; it represents a factor that adjusts the value of heliothermic index for different latitudes.

However, while the existing climatic and bioclimatic indices used in viticulture serve their purpose on a global scale, where they are used to match cultivars to regions, they are of little use on a regional level (Giomo *et al.*, 1996). The variability in climatic characteristics between sub-regions is often quite low, so the resulting indices are not able to distinguish between environments that appear to be significantly different for viticulture.

In the work by Stevens *et al.* (1995) water stress indices were calculated by integrating the daily values of soil water availability over specific periods with which declines in both fruit and vegetative growth were linearly correlated. The authors used a root-weighted measure of soil matric potential to calculate those indices.

To base a similar 'below-ground' index on data available from the present research the term 'Soil Factor' (SF) is introduced. The aim of SF is to integrate several soil-related variables that have been found, by trial and error, to characterise the environmental conditions at a given site reasonably well. In order to be representative of the soil conditions the value of SF should integrate the following:

- Soil temperature at a given depth (30 cm)
- Volumetric soil moisture content (0-30 cm)
- The depth of main rooting zone
- Soil texture index

The soil texture index can be represented as an average of the soil texture class in the rooting zone (as estimated at the soil profile description), or more precisely as a compound index comprising the percentages of sand, silt, clay and gravel in any specific soil. Water availability index is very closely related to soil texture index (or soil texture class) and can be indexed comparatively based on the known percentages of readily available water in different soil types. Based on various literature values (Northcote, 1988; McCarthy *et al.*, 1992) water availability indices were set at 1.0 for sandy, 1.4 for silty and 1.3 for clayey soils. These particular values were derived through the model optimisation phase (Hardisty *et al.*, 1993) which

adjusts the values of coefficients to increase the goodness of fit between the parameters of the model and the actual data.

As soil depth and texture are relatively constant over time for a given site, the value of SF has to be calculated individually for each combination of soil temperature and moisture measured.

The proposed formula for the calculation of SF is as follows:

$$SF = \frac{St}{Sm \times TI \times RD}$$

Where: *SF* = the 'soil factor'
St = soil temperature at 30 cm
Sm = soil moisture content (vol %)
TI = the soil texture index (values are 1.0 for sand, 1.4 for silt, and 1.3 for clay)
RD = rooting depth (m).

It is suggested that SF numerically represents expected relationship between soil water regime and grape and wine attributes. This effect of soil is summarised by Mérogue *et al.* (1998) who stated that the nature and depth of soil, its texture and structure represent important factors that directly influence water reserves and its distribution with time and, through that, growth and development of the grapevine.

Variables St and Sm were generally correlated in most of months during the season. The strongest relationship was established for St at 30 cm and Sm for the 0-30 cm soil profile. Coefficients of correlation between these variables were: for October –0.85, for November –0.67, for December –0.70, for February –0.74, and for March –0.66. However, correlation for the month of January was weak and insignificant (r=–0.30).

Further analysis of the relationship between Sm and St for this month showed that outliers belong to sites BPN and SFV. At both of these sites, located on the banks of the Tutaekuri River, very obvious mottling was observed in the soil profile. This indicated that the water table was within the

reach of vine roots at least some time during the year. It appeared that the water infiltrating from the subsoil affected the relationship between soil temperature and soil moisture.

Furthermore, it is most likely that the depth of the water table varied markedly between the very dry 1997/98 season and the 1998/99 season where overall rainfall was average. It is probable that higher evapotranspiration and demands for irrigation water resulted in the water table being deeper than normal in this year. That would explain, at least in part, the considerable difference in soil moisture content that occurred at the non-irrigated BPN site between the 1997/98 and 1998/99 seasons (Figure 10).

Because of the lack of a consistently strong and significant correlation between the variables St and Sm throughout the season, both of them were used for calculation of SF. It is acknowledged that the utilisation of only one variable, for example soil temperature at 30 cm, would be simpler. However, where both soil temperature and soil moisture data are available, they should be used in conjunction to calculate SF more accurately.

Soil Temperature Modelling

Environmental data collected in the 1997/98 and 1998/99 seasons together with soil texture in main rooting zone may be used for simple modelling of soil temperature. This calculated soil temperature at 30 cm could be potentially used in cases when no soil temperature data are available.

Soil temperature at 30 cm showed a good relationship with both mean air temperature for the period of summer (months November through February) and with the ratio of clay and silt in main vine rooting zone (approximately 30-60 cm). The regression equation between mean soil temperature at 30 cm (ST30) from November through February, clay/silt ratio in main vine rooting zone (C/S) and mean air temperature for the same period (AT) is:

$$ST30 = 16.929 - 1.1886 \times C/S + 0.4375 \times AT$$

Coefficient of multiple correlation between these variables is R=0.869, coefficient of determination R^2=0.755, and SE=1.079 °C. F test of the regression coefficients showed high significance ($p=1^{-10}$). This regression (Figure 11) may be used for the calculation of soil temperature at 30 cm with approximately ±2°C tolerance (±2 standard errors) if accuracy of 95% is wanted.

Since soil temperature at 30 cm was found to have a good relationship with many grapevine attributes (such as canopy characteristics or fruit composition) observed in this study, the above model, as well as the SF value, for a given site may be a useful indication of its viticultural potential. This will be discussed into more detail in Chapter 9.

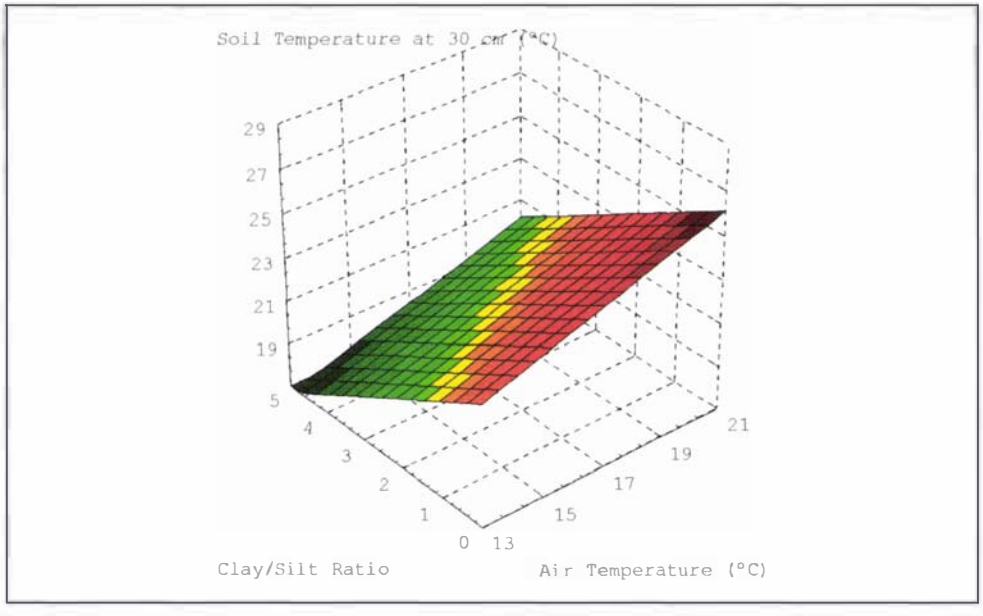

Figure 11. Soil temperature at 30 cm from November through February, clay/silt ratio in main vine rooting zone and air temperature for the same period

Summary

A detailed analysis was performed in order to ascertain the extent of variability in environmental factors at six vineyard sites in the Hawke's Bay wine region, selected in a previous study based on observed differences in vine performance. Selected viticultural environments were characterised by

air temperature, solar radiation, rainfall (above-ground factors) and soil temperature, soil moisture, soil profile characteristics and soil texture (below-ground factors). Mean, minimum and maximum air temperatures varied slightly and differences between sites were mostly within 1°C. Some differences were observed between sites in air temperature amplitudes, attributable to landscape factors such as maritime influence or sheltered vineyard position. Soil thermic properties and proximity to the sea caused slight differences in night-time air temperatures between sites. Wind speed data were not collected at the observed sites, but data available from other meteorological stations in Hawke's Bay suggest that wind speed across the region is variable. Rainfall during three seasons showed a slight variability between sites and large differences between seasons. Variability between sites in solar radiation was low. Average monthly soil temperatures varied > 5°C between sites. Soil temperatures were higher in gravelly and sandy and lower in silty and clayey soils. Soil temperature at 30 cm was strongly correlated with clay to silt ratio at the same soil depth and with air temperature. This relationship enables calculation of soil temperature based on mentioned variables with ±2 °C tolerance. To integrate several soil-related variables that have been found to characterise viticultural performance of Cabernet Sauvignon well, a compound index designated 'soil factor' (SF) is proposed. SF is based on soil temperature, soil moisture volumetric content, depth of topsoil and a water availability index that is based on soil texture class. Further studies showed that SF correlates with many attributes of vine vegetative growth, fruit composition and wine quality.

CHAPTER 5. BUDBURST AND VEGETATIVE GROWTH

Introduction

A variety of definitions of the term 'vigour' have been used by viticultural authors worldwide. In some cases it is viewed as rate of shoot growth, sometimes average length and thickness of internodes, occasionally as the number of matured internodes, and frequently as total weight of shoots per vine (May, 1994). According to Huglin (1986), a scientifically valid definition of this physiological concept is lacking.

By the end of the growth period shoots can reach three to four meters in length in cv Cabernet Sauvignon (Champagnol, 1984). Vigorous vines are characterised by high metabolic activity such as increased intensity of respiration, high rates of protein synthesis, high meristematic cell activity, and a hormonal equilibrium that favours growth (Ibid.). Continued shoot growth after véraison is unfavourable as it delays ripening through fruit shading by the leaves and through competition between shoots and fruit for carbohydrates (Hepner *et al.*, 1985). Extended shoot growth, often resulting from excessive nitrogen supply, usually demands repeated 'green' or 'summer' pruning. Keller *et al.* (1999) established that high nitrogen availability combined with repeated trimming can decrease fruit and wine quality in Pinot Noir grapevines grown in conditions of the Finger Lakes region in New York State. Observation of shoot elongation dynamics is useful as it serves as a good indication of grapevine water status and potentially of water stress (Van Zyl, 1982; Kliewer *et al.*, 1983; Hardie and Martin, 2000).

The objective of this work was to determine the effect of selected sites in the Hawke's Bay wine region on phenology of budburst, the dynamics of vegetative growth and canopy density in cv Cabernet Sauvignon Clone UCD7 on SO4 rootstock. Dense canopies have been shown to adversely affect all major components of fruit and wine quality (Smart and Robinson, 1991). Many factors, apart from rootstock and cultivar, can contribute to stimulate vigour, including soil properties, climate and applied viticultural practices (Smart *et al.*, 1985). Low vine vigour, on the other hand, is most commonly caused by water stress or root growth restriction caused by unfavourable soil characteristics (Smart and Robinson, 1991). A detrimental effect of dense canopies on fruit quality occurs through excessive shading of fruit and leaves and through competition between actively growing shoot tips and the developing/ripening berries for carbohydrates (Carbonneau, 1996).

Material and Methods

Vines were observed weekly during the early part of the growing season in 1997/98 and 1998/99 to determine the phenological stage of budburst. Definitions used were described in Chapter 2. Data obtained allowed estimation of budburst percentage dynamics, based on activated to total buds ratio recorded at each observation.

Shoot elongation was measured weekly on 20 de-fruited shoots on 6-10 vines at each site from early November through January; this latter date coincided with the beginning of véraison at most sites. Hardie and Martin (2000) showed that shoot growth rates of de-fruited vines are more sensitive to soil water deficit compared with fruit-bearing vines. It is likely that this difference in responsiveness to soil water deficit may also be valid to some extent in the case of de-fruited shoots vs. fruit-bearing shoots. Shoots for elongation measurement were de-fruited on the assumption that their growth would be thus more indicative of the plant water status. Shoots to be measured were tagged and protected from accidental damage by tying to wires. Because some shoots were tipped inadvertently during the growing

seasons, the final shoot sample size was about 15 in most cases. Shoots were selected on both sides of the canopy, and from both the upper and lower parts of the canopy.

Canopy density was determined using the scorecard method outlined in Chapter 2 (Smart and Robinson, 1991). A detailed example of the scorecard used is shown in Appendix 1 (page 239).

During the later part of the growing season, from véraison onwards, grapevine growth was assessed by counting the number of growing shoot tips of 6-10 vines in the experimental block.

A method used to determine leaf petiole nutrient status as well as statistical methods for data analyses are presented in Chapter 2, page 21.

Results

There was considerable variation in dates of budburst in both the 1997/98 and 1998/99 seasons (Table 28). Mid-budburst date ranged from 21 September in 1998/99 at the site MMR to 11 October in 1997/98 at BPN. Correlations between the variables observed in the 1997/98 and 1998/99 seasons are presented in Appendix 12, and correlations between the variables in all three seasons are in Appendix 10.

Table 28. Cabernet Sauvignon budburst dates at six vineyard sites in Hawke's Bay in the 1997/98 and 1998/99 seasons and environmental conditions for 10-20 September

	Start (5%)	Mid (50%)	End (95%)	Air t	Soil t - 15cm
			Season 1997/98		
RVV	28/09/97	4/10/97	11/10/97	10.6	12.7
JRS	30/09/97	7/10/97	13/10/97	11.1	12.8
BPN	6/10/97	11/10/97	16/10/97	10.8	12.7
SFV	28/09/97	4/10/97	10/10/97	11.2	12.3
LND	1/10/97	10/10/97	15/10/97	11.3	12.6
MMR	28/09/97	3/10/97	9/10/97	10.8	12.5
Average	30/09/97	6/10/97	12/10/97	11.0	12.6

		Season 1998/99			
RVV	15/09/98	23/09/98	2/10/98	12.1	13.4
JRS	17/09/98	26/09/98	5/10/98	12.1	14.7
BPN	28/09/98	10/10/98	20/10/98	12.1	11.9
SFV	17/09/98	25/09/98	4/10/98	12.4	13.6
LND	19/09/98	5/10/98	16/10/98	12.9	13.3
MMR	13/09/98	21/09/98	30/09/98	12.0	13.4
Average	18/09/98	28/09/98	7/10/98	12.2	13.4

Legend: t - temperature

Characteristic for 1998/99 was the heterogeneity in bud movement (Table 29), which quite often occurs in New Zealand conditions, but was especially noticeable in this season characterised by mild winter, especially July (Figure 12).

Table 29. The heterogeneity of budburst at site LND on 23 September 1998

Category	Budburst (%)
Cane - proximal node	6.25
Cane - distal node	29.69
Spur - proximal node	44.85
Spur - distal node	67.28
Overall budburst percentage	27.28

The vines at LND which are trained as Sylvoz and pruned to 10-bud canes and 2-bud spurs had a considerably slower bud movement (counted at 27% budburst, Table 29) on canes, particularly on proximal nodes (about 6%), compared to that on distal nodes on spurs and canes.

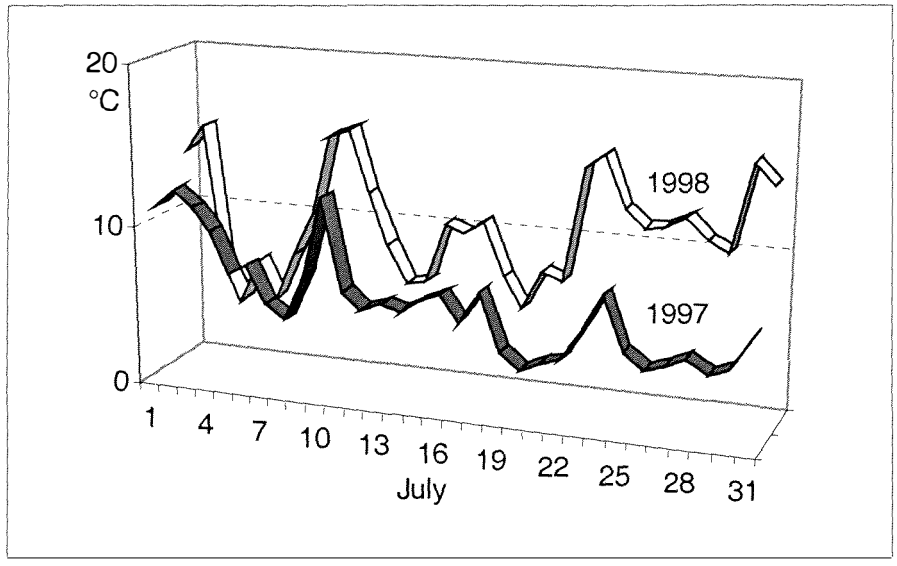

Figure 12. Mean air temperatures (°C) in July 1997 and 1998 at Havelock North

Shoot Elongation

Marked differences in shoot elongation dynamics existed between sites and seasons (Figure 13). Differences in shoot growth were observed at key stages of development: at the beginning of shoot growth; at flowering; at fruit set; and at the beginning of véraison, all during the 1997/98 and 1998/99 seasons (Table 30).

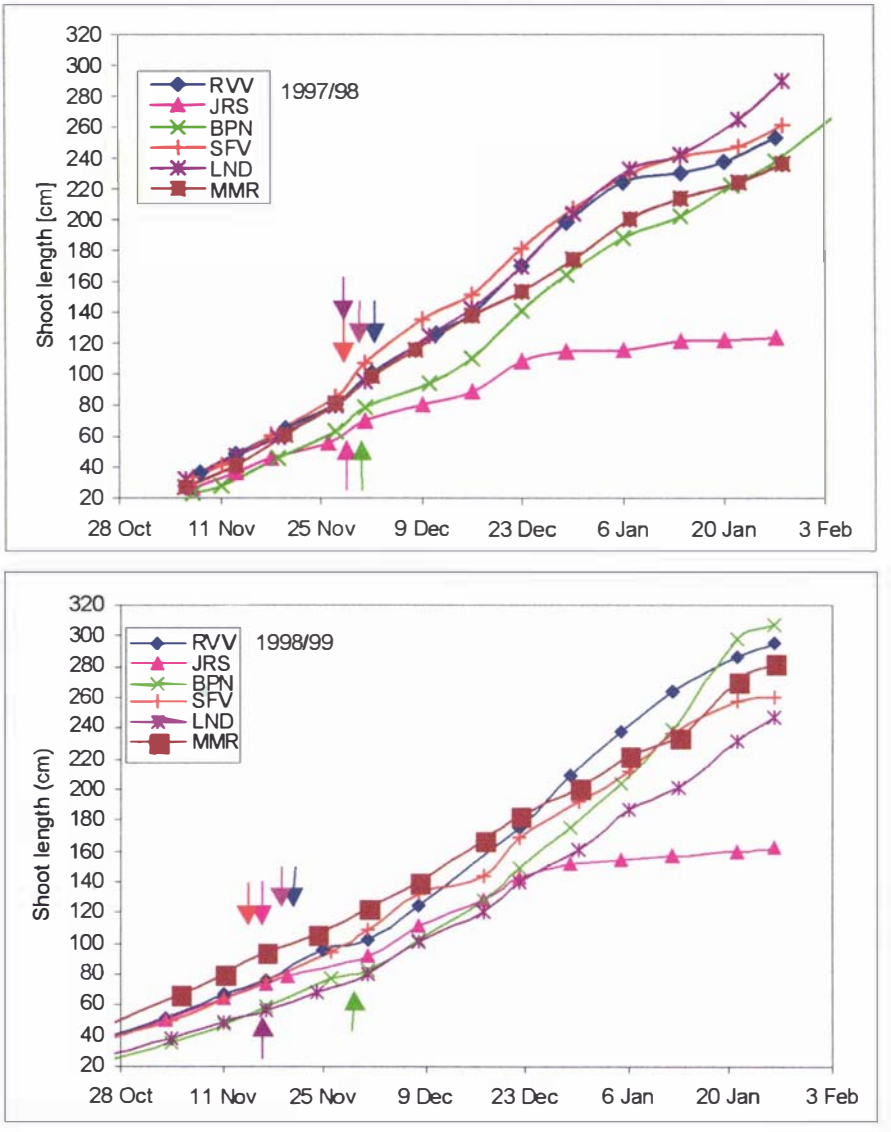

Figure 13. Shoot elongation (cm) at six selected sites in Hawke's Bay. Coloured arrows denote mid-flowering at respective sites.

Mean seasonal shoot length at 5 November in 1997/98 was significantly less than at the same time in 1998/99, but the difference did not persist at later times through development. Shoot length varied significantly between sites at all stages. On 13 January shoots at JRS were significantly shorter than those at the other five sites, among which there were no significant differences.

Daily shoot elongation rates were very variable between weeks, particularly in 1997/98 (Figure 14). Rates of elongation at JRS were always least, being close to zero before véraison. Rates at SFV and RVV were similar, particularly in 1997/98. Shoot elongation rates at BPN in 1998/99 were increasing throughout the observed period. All sites, except JRS, had lower daily rates during November and December in 1998/99. The lower soil moisture content in early spring in 1997/98 compared with 1998/99 (Figure 10) should be noted.

Table 30. Shoot length at several stages of development at six vineyard sites in Hawke's Bay during the 1997/98 and 1998/99 seasons

Shoot length at 5 November (growth of green shoots)							
	RVV	JRS	BPN	SFV	LND	MMR	Mean
1997/98	36.4d	26.2e	23.1e	33.6d	32.2d	27.1de	29.8A
1998/99	51.6b	49.8bc	35.4cd	50.4b	38.25c	66.4a	48.6B
Mean	44.0A	38.0B	29.2C	42.0AB	35.2BC	46.8A	
Shoot length at 2 December (flowering)							
	RVV	JRS	BPN	SFV	LND	MMR	Mean
1997/98	100.8b	69.8d	78.5cd	107.0a	93.4b	98.4b	91.6A
1998/99	102.0ab	92.2b	82.8bc	108.8a	80.0c	123.4a	98.2A
Mean	101.4A	81.0B	80.7B	107.9A	87.7B	110.9A	
Shoot length at 30 December (green berry development)							
	RVV	JRS	BPN	SFV	LND	MMR	Mean
1997/98	197.9a	114.4c	164.2b	206.9a	203.7a	173.9ab	176.8A
1998/99	208.8a	151.5b	175.1a	183.2a	159.1b	215.3a	182.2A
Mean	203.3A	132.9C	169.6B	195.0A	181.4A	194.6A	
Shoot length at 13 January (close to véraison)							
	RVV	JRS	BPN	SFV	LND	MMR	Mean
1997/98	230.1a	121.1c	202.1a	223.0a	241.6a	213.3a	205.2A
1998/99	233.8a	156.7bc	252.7a	273.0a	191.9ab	253.6a	221.0A
Mean	232.0A	138.9B	227.4A	230.0A	216.7A	233.5A	

Note: Values with the same capital letters are not significantly different for the factors Season and Site. Values marked with the same lower case letters are not significantly different for the interaction Season x Site. Significance determined by LSD test for $p<0.05$.

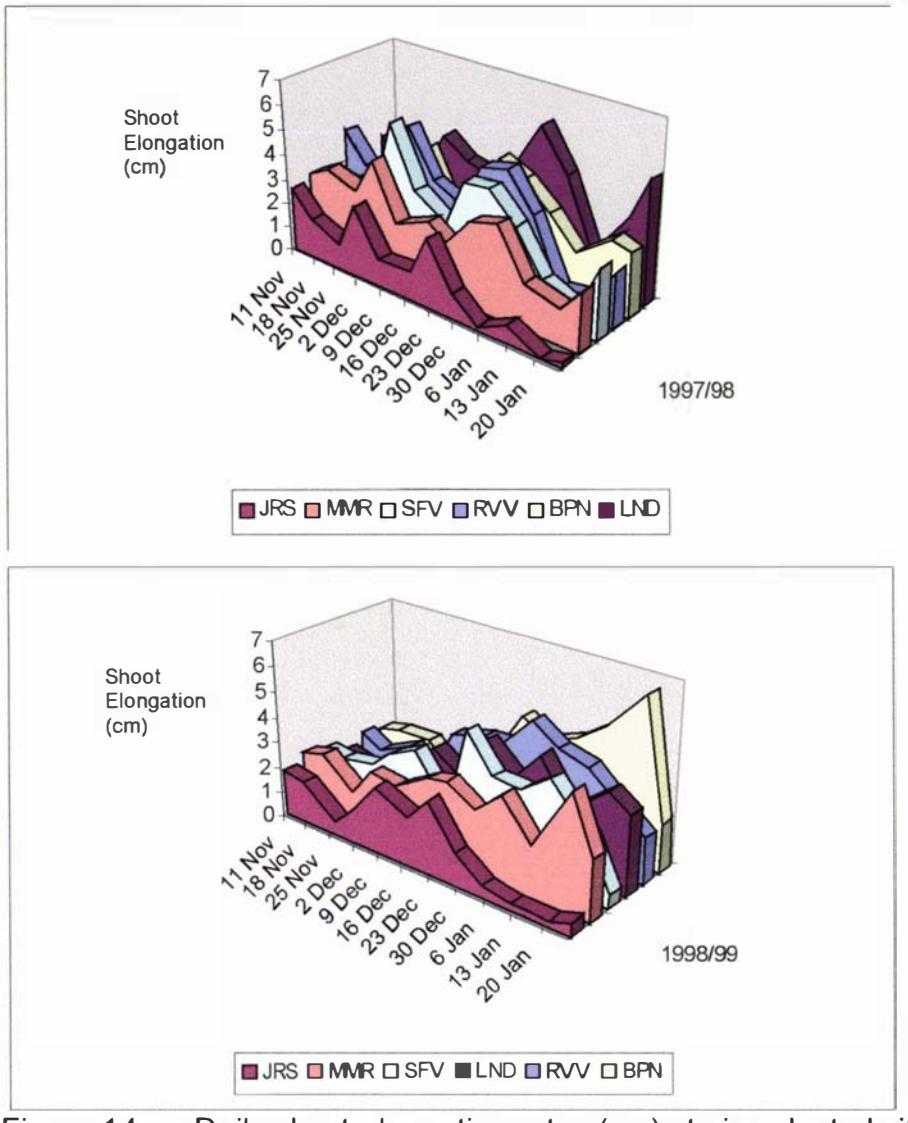

Figure 14. Daily shoot elongation rates (cm) at six selected sites in Hawke's Bay during the 1997/98 and 1998/99 seasons

The maximum rate of shoot elongation was 6.6 cm/d at the BPN site in 1998/99 (the week 12/1-21/1/1999). In 1997/98 the maximum of 5.5 cm/d was achieved at the SFV site (the week 27/11-1/12/1997). Both these maxima are larger than the maximum of 4.4 cm/d established in early May (November in the Southern Hemisphere) in cv Cabernet Franc grown under continual irrigation in California (Matthews *et al.*, 1987). This indicates that the maximum shoot elongation at the BPN site in 1998/99 was reached very late in the season.

In the 1997/98 season shoot elongation rates increased for the first time around 2 December (flowering). From 9-16 December there was a decrease in shoot elongation rates, attributable to shoot trimming applied at most sites at that time (Table 31). The next increase in shoot elongation rates at most sites occurred around 23 December. This peak could be ascribed to resumed growth after the first summer pruning. Daily shoot elongation rates started to decrease during January, additionally reduced by summer pruning conducted at some sites around 13 January. However, a noticeable increase in shoot growth occurred late in January (except at the JRS site where shoot growth had ceased), which was aided by up to 24 mm of rainfall that fell in the week before 20 January.

Table 31. Summer pruning dates at six vineyard sites in Hawke's Bay during the 1997/98 and 1998/99 seasons

	Trimming/Slashing	Partial defoliation
	Season 1997/98	
RVV	16/12/97	
JRS		
BPN	19/12/97	21/01/98
SFV	20/12/97	30/12/97
LND		17/01/98
MMR	7/01/98	13/01/98
	Season 1998/99	
RVV	25/11/98	
JRS		
BPN	24/01/99	
SFV	26/11/98	26/01/99
LND	24/11/98	26/01/99
MMR		26/01/99

In 1998/99 the first decline in shoot elongation rates was observed around 25 November and was caused by summer pruning at most sites. Note that in 1998/99 flowering was finished at most sites late November. Thereafter shoot elongation rates mainly increased, with the notable exclusion of the JRS site where shoot growth almost stopped in early January 1999. In December 1998 shoot elongation rates peaked because of 64-105 mm of rainfall that fell in the first half of December. Significant rainfall in mid-January 1999 caused a strong increase in shoot elongation rates measured at some sites, particularly BPN which peaked to the maximum of 6.6 cm/d, the highest shoot elongation rate in the observed period.

Canopy Density

Canopy density scorecard points at véraison between seasons 1996/97 and 1998/99 vary (Table 32) with differences between sites being relatively consistent (with the exception of MMR in 1997/98).

Overall, 1996/97 was characterised by densest canopies, even though the vines were younger (only six years old at RVV, BPN, and LND). In contrast canopy density was least in 1997/98, with an intermediate density occurring in 1998/99.

A more detailed insight into individual canopy density assessment items (canopy density scorecard form is presented in Appendix 1, page 239) shows significant differences in canopy properties between seasons in two particular scorecard items. Canopy gaps (mean score 4.8 which corresponds to about 25% of canopy gaps) were significantly lower in 1996/97 (mean score 2.7) than in the 1997/98 and 1998/99 seasons (means 6.3 and 5.3 respectively). Leaf size (mean score of 5.3 indicates leaves were slightly large) was assessed as significantly larger in 1998/99 (score 3.7 – lower values denote larger leaves) than in 1996/97 and 1997/98 (mean scores 6 and 6.3 respectively).

Table 32. Canopy density scorecard points for six Cabernet Sauvignon vineyard sites in Hawke's Bay during three seasons

	Canopy Density Scorecard Points		
	Season 1996/97	Season 1997/98	Season 1998/99
RVV	40	46	36
JRS	60	62	66
BPN	22	38	28
SFV	36	44	48
LND	34	42	42
MMR	34	62	32
Average	37.7	49.0	42.0

Note that high scorecard values reflect low canopy density and *vice versa*.

Mean seasonal scores for other canopy density assessment items did not show significant differences between seasons. During three years of observation leaf colour was shiny dark green or shiny yellowish, mean leaf layer number was > 2, fruit exposure was about 50%, shoot length was 10-20 nodes, lateral growth was moderate to very vigorous, and there were about 20% of growing tips in the canopy.

During three years of research, canopy gaps percentage was significantly higher at JRS (about 50%) than at BPN (about 15%), with intermediate values at four remaining sites. Leaf size was assessed as large at BPN and as average at JRS, with no significant differences between other sites. Mean leaf layer number was lower (about 2) at the JRS site than at all others. Fruit exposure was worse at SFV and BPN (approximately 40%) than at other four sites (50% or better). There was almost no lateral growth at the time of assessment (around véraison) at the JRS site in all seasons, while at other sites it was very vigorous. Finally, the number of growing tips was very low at JRS (about 5%), significantly lower than at all other sites.

Post-véraison Growth

A considerable amount of vine growth, measured as actively growing shoot tips per unit ground surface area (Figure 15), occurred post-véraison at most sites in both seasons, particularly 1998/99. At JRS in both seasons there was practically no growth after véraison commenced. In contrast shoot growth at BPN continued long after véraison and even through to harvest in 1998/99. Week-to-week variations in number of growing tips observed primarily in 1998/99 were caused by irregular summer pruning. As newly formed shoot tips were mainly found on laterals results indicate that significant numbers of laterals developed at some sites (particularly BPN) in both seasons.

The Content of Major Nutrients in Leaf Petioles

Nitrogen concentration in leaf petioles at flowering (Table 33) varied from 0.74 to 1.28%, which was mostly in the standard range (for standard nutrient values see Chapter 3, page 68). As in the 1996/97 season, N content at véraison was generally within the normal range, ranging from 0.48 to 0.87%. Nitrogen concentration in leaf petioles before harvest varied from 0.39 to 0.69%, comparable to values found in the literature. Overall, N concentration was the highest at flowering (1.01%), significantly ($p<0.05$) lower at véraison (0.66%), and still lower pre-harvest (0.51) (Figure 16).

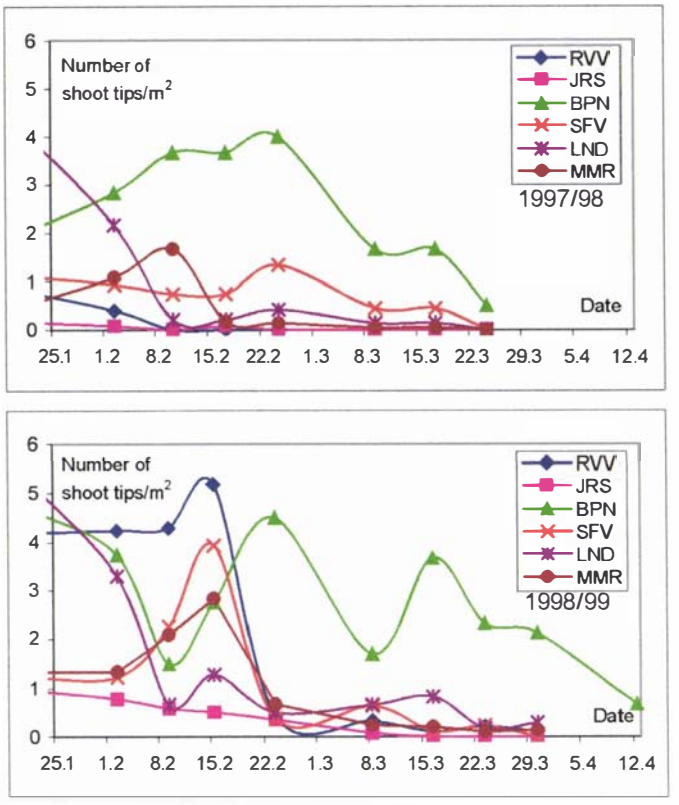

Figure 15. Number of growing shoot tips per m^2 at six Cabernet Sauvignon vineyard sites in Hawke's Bay after véraison during the 1997/98 and 1998/99 seasons

Table 33. Leaf petiole content of N, P, K, Ca and Mg at flowering, véraison, and before harvest in 1997/98 and 1998/99 for six selected sites

	Season 1997/98						Season 1998/99					
	RVV	JRS	BPN	SFV	LND	MMR	RVV	JRS	BPN	SFV	LND	MMR
	Flowering						Flowering					
N	1.02	0.91	1.08	1.14	0.96	0.96	0.91	0.94	1.28	1.10	0.74	1.09
P	0.26	0.32	0.31	0.38	0.23	0.41	0.23	0.36	0.32	0.28	0.14	0.24
K	3.39	3.14	6.15	2.57	2.05	1.66	2.53	2.89	4.01	2.28	2.86	1.84
Ca	2.30	2.15	2.10	2.29	1.81	1.89	1.47	1.27	1.60	1.81	2.01	1.33
Mg	0.23	0.26	0.18	0.23	0.26	0.48	0.12	0.12	0.14	0.22	0.19	0.21
	Véraison						Véraison					
N	0.62	0.60	0.87	0.86	0.67	0.74	0.50	0.49	0.51	0.60	0.59	0.48
P	0.19	0.32	0.18	0.26	0.20	0.34	0.05	0.34	0.26	0.29	0.07	0.09
K	4.59	3.81	5.88	3.03	1.65	3.13	5.12	2.12	4.34	4.35	4.49	3.10
Ca	2.08	1.34	0.90	1.48	1.78	1.52	2.23	0.76	1.72	2.52	2.15	1.98
Mg	0.36	0.38	0.14	0.32	0.48	0.50	0.35	0.12	0.17	0.34	0.31	0.42
	Before harvest						Before harvest					
N	0.52	0.50	0.57	0.69	0.51	0.65	0.39	0.39	0.39	0.47	0.51	0.52
P	0.14	0.08	0.17	0.25	0.19	0.18	0.23	0.16	0.16	0.12	0.15	0.21
K	3.25	2.62	6.28	2.88	1.50	1.76	2.39	3.26	3.99	2.15	2.70	1.72
Ca	5.59	2.52	1.58	2.28	1.72	1.81	3.60	1.93	2.80	4.29	3.78	3.09
Mg	0.55	0.47	0.23	0.54	0.69	0.81	0.48	0.33	0.32	0.52	0.47	0.59

Phosphorus concentration at flowering ranged from 0.14 to 0.41%, which is similar to P content in leaf petioles of 0.16-0.33% established during three seasons and at two sites in unfertilised cv Shiraz grown in Eden Valley, Australia (Dundon *et al.*, 1984). Potassium concentration in leaf petioles at véraison in the 1997/98 and 1998/99 seasons ranged from 0.05 to 0.34%, similar to that established in 1996/97, and overall in the optimal range (Chapter 3, page 68). Before harvest in 1997/98 and 1998/99, P concentration varied from 0.08 to 0.25% between sites. Phosphorus content was highest at flowering (0.29%), significantly lower at véraison (0.21%) and pre-harvest (0.17%), with no significant difference at the two latter developmental stages (Figure 16). In 27 cultivars grown in California studied by Christensen (1984), leaf P showed very little change between flowering and véraison.

Potassium content at flowering was generally high, ranging 1.66-6.15%. The maximal K content surpasses that determined by Dundon *et al*. (1984) in an experiment with cv Syrah, which ranged 1.89-3.18% in non-fertilised vines. The maximal K content in Syrah vines fertilised with KCl in the same trial was 4.23%. Potassium concentration at véraison again reached maximal levels (range from 1.65 to 5.85%) above the optimal 3% suggested by Coombe and Dry (1992). High levels of K were also established in leaf petioles before harvest (range from 1.50 to 6.28%). Under excessive K fertilisation K content >5% in petioles collected at harvest of cv Concord (*Vitis labrusca*) was measured by Morris *et al.* (1983). In this study average K content was similar at all stages being 2.95, 3.27 and 2.88% at flowering, véraison and before harvest, respectively (Figure 16). Slightly higher K found at véraison corresponds to that established by Lafon *et al.* in leaf blades of cvs Ugni blanc and Charente (cit. Champagnol, 1984). Christensen (1984) found K to decline from flowering to véraison in petioles of most cultivars, similar to what Hepner and Bravdo (1985) established in Cabernet Sauvignon.

Calcium concentration in leaf petioles at flowering varied from 1.27 to 2.3%, therefore in the normal range for this element (Chapter 3, page 68).

Véraison level of calcium in leaf petioles varied from 0.76 to 2.52%, somewhat lower than established in the 1996/97 for 28 vineyard sites and than the optimal Ca of 2.8% (Robinson, 1992). Ca content before harvest ranged from 1.58 to 5.59% in the 1997/98 and 1998/99 seasons.

Magnesium concentration in leaf petioles at flowering ranged 0.12-0.48%, being somewhat lower in 1998/99 than in the 1997/98 season. Dundon *et al*. (1984) found that Mg content in leaf petioles of cv Syrah in the above mentioned trial ranged 0.31-0.82% in non-fertilised vines. Cabernet Sauvignon is known to be lower in Mg content than some other grapevine cultivars (Loué and Boulay 1984, cit. Huglin, 1986). Mg was also relatively low in the 1997/98 and 1998/99 seasons in petioles collected at véraison (range 0.12-0.50%), similar to the concentration found at 28 sites in the 1996/97 season (Chapter 3, page 50). Mg content was considerably lower than the optimal of 1.1% (Coombe and Dry, 1992). Before harvest Mg concentration rose to a range 0.23-0.81%.

Concentration of both calcium and magnesium increased through the season (Figure 16) being 1.84 and 0.22%, respectively, at flowering, increasing slightly to 1.87 and 0.30% at véraison, and then significantly towards pre-harvest (2.92 and 0.50%).

Pruning Weights

There was no significant effect of season or interaction between season and site on pruning weights at six selected sites (Table 34). The greatest pruning weights were at BPN, followed by those at SFV, RVV and MMR, then LND, with the lowest occurring at JRS.

Table 34. Pruning weights (kg/m^2) at six selected sites in Hawke's Bay over three seasons

	Season 1996/97	Season 1997/98	Season 1998/99	Average
RVV	0.669	0.611	0.686	0.655b
JRS	0.348	0.218	0.334	0.300d
BPN	0.730	0.880	0.833	0.814a
SFV	0.790	0.695	0.617	0.700b
LND	0.460	0.376	0.590	0.475c
MMR	0.533	0.591	0.660	0.595b
Average	0.588	0.562	0.620	

NB: Values with the same letters are not significantly different by LSD test at $p<0.05$

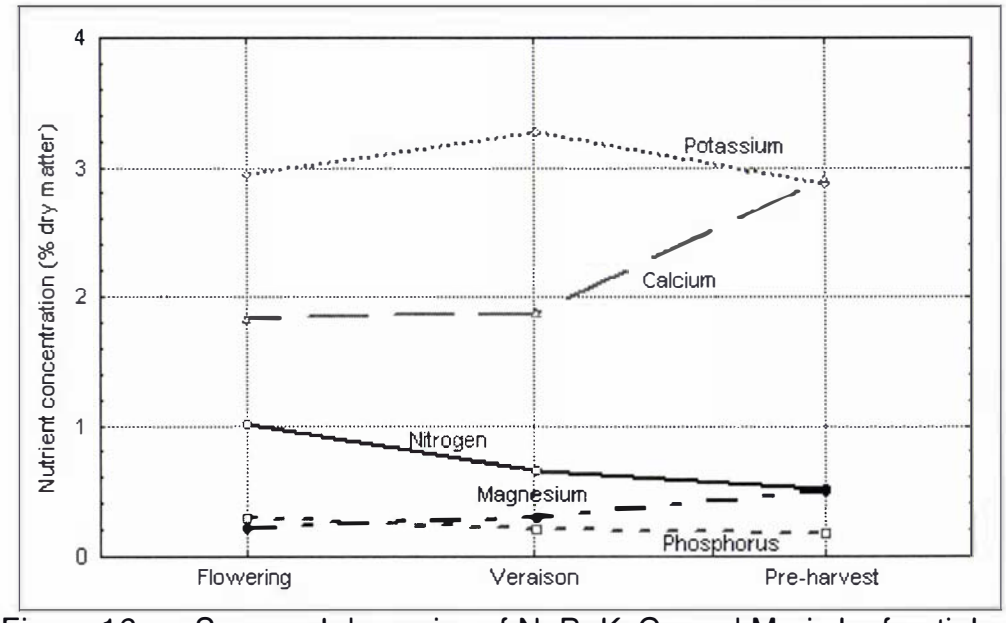

Figure 16. Seasonal dynamics of N, P, K, Ca and Mg in leaf petioles. Each point represents an average for six sites over 2 seasons for flowering and pre-harvest stages, and 3 seasons for véraison.

Mature Cane Properties

Detailed cane properties were observed during the 1997/98 season (Table 35). The greatest number of canes was at the MMR and RVV sites, with lowest at BPN and LND with the others intermediate. Individual cane weight was two to almost five times heavier at the BPN site compared to other sites. Only canes at the JRS and MMR sites were of 'medium' vigour (20-40 g) based on boundaries given by Smart *et al.* (1992), while the remaining vineyards had canes of 'high' vigour (>60 g). Vines at site BPN also had a

significantly higher number of nodes per cane than did canes at LND and JRS sites.

At the two sites with Scott-Henry training systems (RVV and MMR, JRS was not observed in this regard) differences in cane weight between upper and lower tier occurred. Lower tier canes were lighter (56.9 and 53.9 g respectively for sites) than those from upper tier (67.2 and 77.2 g). Because only two replicates with this training system were observed for differences in cane weight between tiers, it is not possible to determine if the differences between tiers or sites were significant. However, downward pointing shoots were shorter and with less internodes developed than upward oriented shoots in cv Nebbiolo (Schubert *et al.*, 1999).

Table 35. Cane properties at six Cabernet Sauvignon vineyard sites in Hawke's Bay 1997/98

Site	Pruning weight (g/m^2)	Canes per m^2	Cane weight (g)	Nodes per cane	Cane diameter (mm)	Dry matter %
RVV	610.6b	9.84b	62.1c	17.2ab	8.90	62.79
JRS	218.4c	6.65cd	33.1d	11.8c	8.59	64.89
BPN	880.0a	5.67d	158.2a	20.0a	9.92	62.30
SFV	694.6b	7.74c	89.7b	16.3ab	10.05	62.72
LND	375.5c	5.93d	63.6c	15.3bc	9.56	63.61
MMR	590.9b	11.72a	51.2c	18.0ab	9.44	61.64

Values with same letters are not statistically different at p=0.05 by LSD test. Cane diameter gave insignificant F test. Dry matter % was not statistically tested because it had only one replicate per site.

Yield/Pruning Weight Ratio

The ratio of yield and vegetative growth (either in terms of leaf surface area, or more commonly, winter pruning weights) is most commonly known in viticultural literature in English language as 'crop load' (Bravdo *et al.*, 1985) or yield/pruning ratio (Smart and Robinson, 1991). Yield/pruning weight ratio at the JRS and LND sites was consistently higher than at other sites, with averages >3 over three seasons (Table 36). Sites SFV in 1996/97 and BPN in 1998/99 were severely undercropped, with yield/pruning weight ratio <1. In the first case, considerable 'shanking' of grape clusters was noted at harvest, and in the second low berry set percentage contributed to yield reduction, thus lowering the yield/pruning weight ratio. Over three seasons

and six sites yield/pruning weight ratios ranged from one to four (average 2.2).

Table 36. Yield/pruning weight ratio at six Cabernet Sauvignon vineyard sites in Hawke's Bay over three consecutive seasons

Site	1996/97 (estimated)	1997/98	1998/99	Average for 1997/98 and 1998/99
RVV	1.16	2.94	1.97	2.46b
JRS	2.44	4.10	3.02	3.56a
BPN	1.49	1.98	0.74	1.36bc
SFV	0.78	1.65	1.22	1.44c
LND	2.64	4.16	2.70	3.43a
MMR	2.55	1.84	1.69	1.77bc
Average	1.84	2.78	1.89	

Note: ANOVA done only for the 1997/98 and 1998/99 seasons; seasonal differences not significant. Averages with the same letter are not significantly different at p=0.05 by LSD test.

Discussion

Phenology of Budburst

Cabernet Sauvignon is a cultivar particularly prone to uneven or heterogeneous budburst (Anon, 1980). The occurrence of an uneven budburst is important, since the heterogeneity once initiated will have an impact on subsequent phenological stages including shoot growth and flowering. The problem of irregular budburst is common to many temperate horticultural crops grown in warm regions (Lavee and May, 1997).

Average air temperature for the winter period June-August 1998 varied from 9.0 to 9.4 °C between sub-regions, while the average July temperature range was from 10.8 to 11.1 °C. This is considerably higher than normal July temperature for this region (from 8.5 to 8.9 °C). It is likely that these higher than usual winter temperatures negatively affected the uniformity of budburst. Nir and Spieler (1988) and Lavee and May (1997) also mentioned mild winters as a cause of the erratic budburst in grapevines. Dokoozlian *et al.* (1999) experimentally showed that chilling temperatures improve budburst in cv Perlette cuttings.

Certain fruit species require exposure to low temperatures (chilling) to terminate the state of dormancy. In grapevines a chilling period of at least seven consecutive days with a mean daily temperature <10 °C is needed for this to occur in cv Merlot (Pouget, 1988). The requirement for chilling may not be obligatory for breaking dormancy in all grapevine cultivars (Lavee and May, 1997). Chilling requirement in grapevines is low and in the absence of chilling and other dormancy-breaking mechanisms, grapevine buds will still burst, albeit irregularly and with a delay (Lavee and May, 1997).

According to Janick (1986), *Vitis vinifera* is classified intermediately between the non-cold requiring plants (e.g. *Olea europea, Punica granatum*) and cold requiring plants (e.g. *Prunus communis, P. persica*), along with *P. dulcis* and *Cydonia oblonga*. Nashimoto *et al.* (1995) established that potted vines of cv Kyoho (a complex interspecies hybrid) had a chilling requirement of 290 h (number of hours <7 °C), compared with 740 h for peach (*Prunus persica*) or 952 h for pear (*Pyrus communis*). Similar literature values for cv Cabernet Sauvignon are not available. Nevertheless, as ancestry of cv Kyoho consists mainly of American *Vitis* species, which are cold-requiring (Janick, 1986), it can be assumed that chilling requirement of *V. vinifera*, including Cabernet Sauvignon, will be lower than that of cv Kyoho as determined by Nashimoto *et al.* (1995). The mentioned finding of Pouget (1988) that cv Merlot requires at least seven consecutive days with a mean temperature <10 °C to break dormancy translates to 168 h of temperatures <10 °C.

Daily mean temperatures in July 1997 and 1998 at Havelock North (data from the Horticulture and Food Research Institute of New Zealand weather station) show that the chilling requirement described by Pouget (1988) for cv Merlot was not met in July 1998 (Figure 12). July 1997 had 21 consecutive days with daily mean temperatures <10°C. However, the longest sequence of consecutive days with daily mean temperatures <10°C in July 1998 was only five days (3-7 July 1998). Although August 1998 had two sequences of seven and more consecutive days with <10°C (data from the same weather

station) it appears that this August chilling was already post-dormancy, as budburst in 1998/99 season was irregular and slow at some sites (Table 29).

Uneven budburst led to uneven shoot growth as well as to differences in flowering of inflorescences positioned on different shoots (see photographs in Appendix 14, page 276). Uneven shoot growth is unfavourable as it causes marked variation in canopy density: while gaps occur in canopy at places where budburst on canes was poor, shoots growing from spurs tend to be excessively vigorous, and cause very dense patches in vine canopy. Buds positioned on canes had a markedly lower percentage activation rate compared to buds on spurs (Table 29). Proximal buds had a lower percentage of budburst than distal both on spurs and on canes, analogous to the results of Tesic (1995) for several white wine grape cultivars.

Because of the higher winter temperatures in the 1998/99 season budburst was eight days earlier on average than in 1997/98. This effect of higher winter temperatures on earliness of budburst is in accordance with several authors from different countries as quoted by Coombe (1988). Costantini *et al.* (1996) established strong positive correlation between budburst earliness and maximum temperature of the previous month for cv Prugnolo gentile in conditions of Italy. In Hawke's Bay the month preceding budburst is usually August. The present data showed no correlation between maximum temperature for August and budburst date, although there was a significant ($p<0.05$) correlation between mean July temperature and both budburst date ($r=-0.59$) and budburst duration (which in effect represents the heterogeneity of budburst) ($r=0.82$). This indicates that warm winter causes budburst to be early, slow and erratic.

In both the seasons vines at the MMR site were the first to reach mid-budburst, followed by those at RVV. The BPN site was the last to reach mid-budburst in both seasons. This did not appear to be correlated with average air temperatures at budburst, particularly at MMR, which was always among the coolest sites during September. However, mean soil

temperature for 10-20 September showed a strong and significant correlation with earliness of budburst (r=–0.71).

Thus higher than normal air temperatures in early spring and particularly the soil temperatures resulted in early budburst, while warm mid-winter temperatures had a negative effect on budburst uniformity. A linear regression model has been developed to predict budburst date and duration (Figure 17). Several authors (Baldwin, 1966; Pouget, 1966 and 1967; Williams *et al.*, 1985) based their budburst models on temperature summation following the period of vine dormancy.

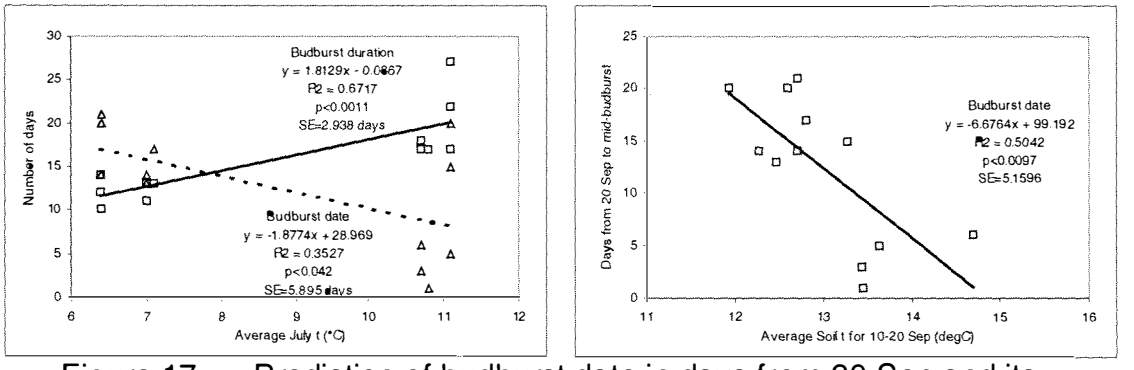

Figure 17. Prediction of budburst date in days from 20 Sep and its duration.
Based on July air temperature (left) and soil temperature (right); *t* denotes temperature.

The effect of soil temperature on budburst is consistent with the findings of Kliewer (1975) who showed that budburst in Cabernet Sauvignon was 3-8 days earlier at root temperatures 25-30 °C than at 11 °C. Zelleke and Kliewer (1981) determined increased cytokinin activity in the xylem sap of Cabernet Sauvignon plants subjected to high root temperature. Cytokinins are hormones that promote cell division and bud activation in plants generally (Gladstones, 1992). The above model is based on vine pruning done in the second half of June. Martin and Dunn (2000) stressed the importance of pruning time for temperature based phenology models. In addition, Williams *et al.* (1985) and Calo *et al.* (1996) state that temperatures during dormancy and the state of vine reserves also affect the accuracy of budburst prediction models.

The Effect of Site on Growth and Yield/Pruning Weight Ratio

Of all above-ground environmental variables measured, average air temperature for November had the most significant effect on rate of shoot growth at flowering (r=0.79). Zelleke and Kliewer (1979) showed that high ambient temperatures significantly increase shoot growth in potted Cabernet Sauvignon vines. Shoot length at 12-13 January was strongly correlated (r=–0.82) with average soil temperature at 30 cm (indicating water stress) and with mean soil moisture content in the 0-30cm profile for December (r=0.68). CDI was also significantly correlated with soil moisture in the 0-30 cm profile during February (r=0.66) and the March soil temperature at 15 cm (r=–0.84). Dry production (defined in Chapter 2, page 30) was negatively correlated with soil temperature at 30 cm, particularly during January (r=–0.86). This can be ascribed to water stress (as assessed by shoot elongation), obvious at some sites during 1997/98.

Yield/pruning weight ratio was negatively correlated with soil moisture, indicating that the balance between vegetative and reproductive growth was in favour of the former when soil was moist. Mean monthly soil moisture contents were negatively correlated with yield/pruning weight ratio each month of the growing season, with the strongest correlation (r=–0.85) occurring in 0-60 cm profile in March in the 1997/98 and 1998/99 seasons. The values of 'soil factor' (SF), an attribute defined and examined in Chapter 4 (page 92), for all months from October through March were strongly correlated with shoot length in mid-January, winter pruning weights, yield/pruning weight ratio, CDI, and to lesser extent with dry production (Table 37). There is a strong correlation between SF values throughout the season and all measured components of vegetative growth. This indicates that 'soil factor' is related to vine vegetative potential of Hawke's Bay 'terroirs'.

Table 37. Correlation between the 'Soil Factor' and growth attributes

Month SF	Shoot Length on 13/01	Pruning Weight	Yield/pruning weight ratio	CDI
October	−0.76*	−0.71*	0.53	−0.55
November	−0.82*	−0.84*	0.69*	−0.64*
December	−0.79*	−0.82*	0.80*	−0.66*
January	−0.71*	−0.83*	0.83*	−0.69*
February	−0.70*	−0.86*	0.84*	−0.75*
March	−0.67*	−0.87*	0.85*	−0.70*

Correlation coefficient values followed by * are significant at $p<0.05$

Since the extent of vegetative growth influences fruit composition through source-sink competition and shade effects, differences in soil properties such as texture, rooting depth, water and thermic balance, are likely to be important sources of variation in fruit composition and wine quality between potential 'terroirs'. The relationship of vegetative growth indices, for example pruning weight, with wine quality in cv Cabernet Sauvignon was shown by Hepner *et al.* (1985).

Positive correlation of CDI and shoot growth with soil moisture content, and absence of such correlation in the case of crop yield, corresponds to the results of Bravdo and Naor (1996). They stated that irrigation of cv Cabernet Sauvignon (ie increased soil moisture) affects vegetative growth proportionally more than it affects yield. This indicates the shift of vine balance to vegetative growth evident in potential 'terroirs' with low SF values, for example the BPN site. This disproportionate increase in vegetative and generative growth characteristic of cultivars such as Cabernet Sauvignon or Sauvignon Blanc may be related to their genotype. 'Sauvignon' was derived from 'sauvage', the French for 'wild'. Although there are opinions this relates to strong 'herbaceous' or methoxypyrazine aroma present in grapes of these two closely related (Bowers and Meredith, 1997) cultivars, it is much more likely that this relates to their growing habit (Ibid.).

Luis Ravaz in 1906 (Maccarrone *et al.*, 1996) found that quality of wine produced closely correlates with ratio of yield and vegetative growth (Milosavljevic, 1985). Ravaz established that an increase in yield followed by a proportionate increase in vegetative growth favours wine quality. Further increases in yield above an appropriate balance or 'plateau' lead to

a significant decrease in quality. Yield/pruning weight ratio is also called the 'Ravaz index' (Maccarrone *et al.*, 1996). Yield/pruning weight ratio has been shown to closely correlate with grape and wine quality (Bravdo *et al.*, 1985; Smart and Robinson, 1991). Yield/pruning weight ratio indicates 'vine balance': low values (<3) denote excessive vigour of grapevines, high values (>12) mean overcropping, while a yield/pruning weight ratio between 5 and 10 is considered optimal for fruit quality (Smart and Robinson, 1991).. Williams and Arnold (1999) cited the range of 3.5-4.5 as a yield/pruning weight ratio favourable for optimal wine quality in Cabernet Sauvignon from a vineyard in Oakville, California, provided that yields of grape do not exceed 17.5 t/ha. Bravdo *et al.* (1985) found slightly reduced wine quality in Cabernet Sauvignon grown in Israel if yield/pruning weight ratios were above 10. The present work shows (Table 36) that studied sites, except JRS and LND, are prone to excessive vigour of Cabernet Sauvignon grapevines.

The above discussion supports the view that yield/pruning weight ratios at investigated sites reflected their potential 'terroir' specificity. Therefore, a potential criticism that a comparison of grapevine viticultural and oenological performance between sites should be based on vines with the same yield/pruning weight ratio does not stand. Even if such a trial would be warranted, an attempt to set up an exact yield/pruning weight ratio is not realistic. Yield/pruning weight ratio represents a ratio between grape yield and winter pruning weight. Yield of grapes is determined not only by the number of buds per vine at winter pruning, but also by bud fertility, berry set and berry size. Cluster thinning as an additional means of yield/pruning weight ratio control is of limited value, as the proportion of thinned clusters does not equate reduction in yield at harvest. Shoot number, length and diameter will determine the winter pruning weight. All these variables cannot be completely controlled in field trials. Therefore establishing a trial with vines having the exact same yield/pruning weight ratios at different sites would not be achievable. As the standard deviation of yield/pruning weight ratios at six sites in three seasons (Table 36) was <1 it appears that overall variability in yield/pruning weight ratios was not very high. In conclusion,

while there cannot be doubt that different yield/pruning weight ratios at six studied sites may have affected fruit composition, that effect is not to be considered an obstacle for a 'terroir' study, simply because it represents an intrinsic attribute of 'terroir'. A similar soil-induced variability in vine vegetative growth and yield/pruning weight ratio was observed by Scienza *et al.* (1996).

Nutrient Status, Fruit Cropping and Composition

In the 1997/98 and 1998/99 seasons véraison levels of nutrients were slightly higher than standard for N, P and K, and somewhat lower for Ca and Mg (for standard nutrient concentrations see Chapter 3, page 68). No visible symptoms of nutrient deficiencies were observed, which is in accordance with intensive vegetative growth observed as well as mean cropping levels >10 t/ha in both seasons (see Chapter 7, Table 54). Expressed year-to-year fluctuations evident in K concentrations in leaf petioles collected at all three stages are common in grapevines (Christensen, 1984).

A trend of decrease in N in petioles through the season was expressed at all six sites. The highest N levels in leaf petioles were observed at the BPN and SFV sites. P concentration tended to decrease through the season at all sites, with concentrations of this element being highest at the MMR site. K concentration was the highest at BPN, up to 3% above other sites. Levels of Ca showed a similar pattern at all sites, with a high pre-harvest content at RVV. Mg increase from flowering occurred at all six sites. However, the BPN site had particularly low Mg content at all three stages. This appears to be a result of K-Mg antagonism, as BPN also had the highest K concentration in leaf petioles.

Boselli *et al.* (1998) established that Ca concentration in leaf petioles of Cabernet Sauvignon was dependent on soil moisture status throughout the season. Thus in a dry season Ca content in petioles varied around 1%, with a slight increase occurring between flowering and véraison, with little further change towards harvest. In a wetter season, Ca in leaf petioles increased,

being about 1.7% at flowering, 2.6% at véraison, and nearly 3% before harvest. Therefore, the Ca pattern of change during a wet season in Northern Italy (Boselli *et al.*, 1998) was reasonably similar to mean values found in Hawke's Bay. The dry 1997/98 season in this study has also shown overall Ca content in leaf petioles was less (2.06%) than in the more humid 1998/99 season (2.24%).

Calcium content at flowering was positively correlated with berry set percentage (r=0.67) and probably because of that also with cluster weight (r=0.68). Mg concentration was also significantly correlated (r=0.70) to berry set percentage. Improvement in berry set and/or reduction in rachis necrosis as affected by foliar applications of Mg were established in various cultivars by Dabas and Jindal (1985), Theiler (1986) and Cline (1987). A similar effect of Ca on reducing the extent of rachis necrosis was also found by Cline (1987).

Nitrogen concentration in leaf petioles at flowering was negatively correlated with yield/pruning weight ratio (r=–0.64). This is not surprising, since the increased N status in vines is commonly associated with the shift of balance to an increased vegetative production, which is exactly what the yield/pruning weight ratio indicates. No relationship between K and Mg levels and yield/pruning weight ratio was established, contrary to the results of Hepner and Bravdo (1985).

Levels of N in leaf petioles at véraison showed a significant and positive correlation with malic acid concentration in berries at harvest (r=0.58). This relationship appears to be related with an increase in vigour caused by N, and increased vigour may have indirectly caused elevated malic acid in berries via fruit shading.

Potassium concentration at véraison was positively correlated with pruning weight (r=0.62). This correlation was mainly a product of high pruning weights at BPN, which also had the highest K. According to Smart *et al.* (1985), a shaded microclimate can cause K accumulation in shoots before véraison, and high pH levels in the fruit. It is suggested that this happened

at the BPN site, which was characterised by excessive vigour and prolonged shoot growth. High K level is usually associated with low tartaric acid (Champagnol, 1984) which is, again, lower in shaded than in well-exposed berries (Crippen and Morrison, 1986). K level in leaf petioles at flowering and before harvest was strongly correlated with the pH (r=0.71 and r=0.77, respectively) and tartaric acid (r= – 0.77 and r=–0.82, respectively) in juice at harvest. High K before harvest was also negatively correlated with wine sensory evaluation score (Table 60, Chapter 8). Potassium at véraison was also correlated with tartaric acid (r=–0.71). Similar regressions were also observed between K/Mg ratio (at véraison) and pH (r=0.82), tartaric acid (r=–0.84), malic acid (r=0.71) and tartaric/malic acid ratio (r=–0.72).

Calcium content at véraison was correlated negatively with total anthocyanins at 22-24 March (r= – 0.58), and with total phenolics at harvest (r= – 0.58), which could potentially be related to the mentioned relationship between Ca and soil moisture content. Magnesium at véraison and before harvest was significantly correlated with pH at harvest (r= – 0.66 for both Mg at véraison and harvest), with tartaric acid at harvest (r=0.61 and 0.66, respectively), and with malic acid (r= –0.61 and –0.63). It can be assumed that correlations between Mg and juice constituents arose from K/Mg antagonism. Mg concentration throughout the seasonal cycle was positively correlated with wine sensory evaluation scores (see Table 60, Chapter 8).

Summary

A considerable variability in budburst dates existed between six Cabernet Sauvignon sites across Hawke's Bay and between the 1997/98 and 1998/99 seasons. Uneven budburst was characteristic for 1998/99. A regression model for budburst date and duration based on air and soil temperatures is given. At several stages of development significant differences in shoot growth were found between sites. Early November shoots were significantly longer in the 1998/99 season when October temperature was markedly higher than in 1997/98. Daily shoot elongation rates were to some extent related to summer pruning operations and occurrences of rain. Canopy

density scores showed a seasonal variability as affected by soil moisture and soil temperature, with densest canopies observed in 1996/97 and most open in 1997/98. Vineyard sites were relatively consistent with respect to canopy density, however, a striking seasonal variability in canopy density was observed at the MMR site. This variability was ascribed to soil at this site, characterised by a shallow impermeable clay pan. The difference in soil moisture content between a wet and a dry season at this site, believed to be an effect of the clay pan, is proportionally much higher than at other sites. Post-véraison shoot growth was observed at some sites, particularly the BPN site. Concentration of macronutrients in leaf petioles collected at flowering, véraison and before harvest was analysed in detail, with most values found to be within the normal range. Mg concentration in leaf petioles was found to be below optimal in some cases, which could partly be the effect of cultivar, as Cabernet Sauvignon is known to be relatively low in Mg. Selected sites were significantly different in winter pruning weights, which were positively correlated with canopy density. In 1997/98 pruned canes were shown to be of high vigour (their individual weight was > 60 g) at all sites except JRS and MMR. Over three seasons yield/pruning weight ratio was higher at the JRS and LND sites that have gravelly and sandy soils than at others. Monthly values of 'soil factor' (SF), a compound variable defined and examined in Chapter 4, were strongly correlated with several attributes of vine vegetative growth: mid-January shoot length, pruning weight, canopy density and yield/pruning weight ratio. It is suggested that SF could characterise the vegetative potential of a vineyard site. If further results show a good relationship between SF and fruit composition and wine quality then such an index could be potentially useful for vineyard site selection.

CHAPTER 6. FLOWERING, BERRY SET AND THE DEVELOPMENT OF GREEN BERRIES

Introduction

At flowering grapevines are sensitive to environmental factors (Champagnol, 1984) and viticultural practices. Environmental factors during this stage have a particularly strong effect on berry set. Percentage berry set (the ratio of berries to flowers in a cluster) is a significant quantitative variable that has a major influence on cluster size and therefore crop yield. Weather conditions at berry set may affect fertilisation of ovules (Kliewer, 1977), and thus the number of seeds in berries (Ewart and Kliewer, 1977). This will have an effect on crop yield, as seed number was shown to be positively correlated with berry weight (Koblet, 1987). Seed number per berry also has an effect on fruit quality (Cawthon and Morris, 1982).

Flowers in cv Cabernet Sauvignon are perfect and berry set is usually satisfactory (Avramov, 1996). According to Mullins *et al.* (1992), maximal berry percentage for cv Cabernet Sauvignon is 65%, but normally it is from 20 to 30%. Most *Vitis vinifera* cultivars are autogamous and autofertile, and berry set is poor only under unfavourable or stress conditions. Percentage berry set has a direct influence on grape yield. Environmental conditions during this period may also adversely affect the composition of berries, either through the quality of berry set (ie. seed number per berry), or by influencing timing and duration of this stage.

The aim of this study was to examine the effect of both above-and below-ground environmental factors on phenology of flowering and berry set in Cabernet Sauvignon grapes grown at six sites in Hawke's Bay. In addition, this study evaluated the variability in berry set and berry weight during early

development. This variability strongly affects crop heterogeneity, which is very important from the oenological standpoint (Trought, 1996; Torok and Muller, 1985). Uneven berries have undesirable effects on wine quality in cv Merlot (Rabion *et al.*, 1987). The causes of crop heterogeneity can be attributed to phenological differences between vines or different parts of one vine (Due, 1994), to internal competition between clusters (Coombe, 1980), and to berry to berry variation arising from uneven exposure, weather at flowering, or cluster tightness (Long, 1997). Some or all of these effects have their onset before and during flowering, or during berry set and early development.

Material and Methods

Material for this study were vines of cv Cabernet Sauvignon, Clone UCD7 grafted on SO4 rootstock. These vines were planted 1988-1991 in six commercial vineyards in the Hawke's Bay wine region. Sites were selected based on their canopy properties and fruit composition at harvest (described in Chapter 3). Most materials and methods have been described in Chapter 2 (page 21). Some methods specific for flowering and berry set will be presented here.

Weekly estimation of flowering percentage began at the first signs of cap-fall, ending when flowering had completely finished. This was done by associating scores (0-4) with a degree of cap-fall for each inflorescence counted (200-300 at each site), as previously described in Chapter 2 (page 26).

It is important to note that in the 1996/97 season pruning dates differed between sites. Different pruning dates can have a strong effect on the phenological stages (Mullins *et al.*, 1992; Martin and Dunn, 2000) and probably influenced mid-flowering dates in 1996/97. For this reason only flowering dates for the 1997/98 and 1998/99 seasons were included in statistical analysis.

Berry set percentage – the ratio of berry number per cluster to flower number per inflorescence – was determined by enclosing 8-10 inflorescences in white mesh bags before flowering. These bagged clusters were picked after berries had reached pea size. Berry set percentage was then obtained from the number of berries and flower caps retained in bags.

Statistical methods for data analysis were previously described in Chapter 2 (page 21).

Results

Environmental Conditions during Flowering

Environmental conditions during October and November influenced phenological stage of flowering (Table 38). During November 1997 and October 1998 warm air temperatures were recorded with GDD being 199.3°D and 180.2°D respectively compared with 140.2°D and 107.0°D for November 1998 and October 1997. Solar radiation in October 1997 and 1998 was similar, while November 1997 was considerably higher in solar radiation than November 1998. Correlations between the variables observed in the 1997/98 and 1998/99 seasons are presented in Appendix 12, and correlations between the variables in all three seasons are in Appendix 10.

Soil temperatures followed a similar pattern to that of GDD, though in the 1998/99 season November had higher soil temperatures than October. Of all environmental variables presented, soil moisture content showed the highest variability between sites and seasons.

Flowering Dynamics

There was large variability in date and duration of flowering (Table 39). Flowering dates were significantly correlated with GDD for October (r=–0.81). Soil temperature at 15 cm during October, as well as soil moisture content in the 0-30 cm profile for the same month, were both significantly

correlated with flowering date (r=–0.82 and r=0.63, respectively) and with air temperatures (r=0.89 and r=–0.60, respectively). Therefore it appears that air temperature during October was the dominant environmental factor affecting flowering date.

Table 38. GDD, solar radiation, soil temperature and soil moisture at six selected vineyard sites in Hawke's Bay during October and November 1996-1998

Site	GDD (°D)		Solar Radiation (mol/m²)		Soil t 15 cm (°C)		Soil t 30 cm (°C)		Soil Moisture % 0-30 cm		Soil Moisture % 0-60 cm	
	Oct	Nov	Oct	Nov	Oct	Nov	Oct	Nov	Oct	Nov	Oct	Nov
					Season 1996/97*							
RVV	104	134	-	-	-	-	-	-	-	-	-	-
JRS	113	144	-	-	-	-	-	-	-	-	-	-
BPN	102	131	-	-	-	-	-	-	-	-	-	-
SFV	106	135	-	-	-	-	-	-	-	-	-	-
LND	112	141	-	-	-	-	-	-	-	-	-	-
MMR	102	128	-	-	-	-	-	-	-	-	-	-
Average	106.5	135.5	-	-	-	-	-	-	-	-	-	-
					Season 1997/98							
RVV	104	191	1209	1340	15.2	18.5	14.7	17.8	34.0	20.6	24.0	14.5
JRS	109	212	1248	1367	17.1	22.0	16.9	21.8	8.4	7.9	6.6	7.3
BPN	107	199	1171	1282	15.3	18.4	15.0	18.2	33.6	16.6	24.6	15.0
SFV	112	203	1136	1230	15.6	20.0	15.1	19.3	32.9	23.9	33.1	28.0
LND	115	210	1256	1374	15.8	19.8	15.4	19.4	23.2	13.8	18.4	13.8
MMR	95	181	1213	1311	15.3	17.4	15.4	17.8	38.8	24.3	36.7	32.1
Average	107.0	199.3	1206	1317	15.7	19.4	15.4	19.1	28.5	17.9	23.9	18.5
					Season 1998/99							
RVV	172	125	1184	1186	16.8	17.5	16.4	17.5	20.0	18.1	15.3	12.8
JRS	201	148	1225	1223	19.2	20.0	19.1	20.0	7.6	7.1	7.9	7.7
BPN	192	135	1149	1147	17.1	18.4	16.6	18.2	21.0	20.7	19.1	17.8
SFV	198	144	1117	1112	17.7	19.4	16.8	19.2	19.9	19.1	23.6	22.1
LND	194	147	1235	1233	18.1	19.1	17.4	18.9	8.7	10.3	10.1	10.7
MMR	172	142	1192	1187	17.6	19.4	16.6	18.7	23.4	19.1	26.3	19.5
Average	188.2	140.2	1184	1181	17.8	19.0	17.2	18.8	16.8	15.7	17.1	15.1

* - Estimated data.

Shoot length (Table 30) at flowering time was approximately the same in both 1997/98 and 1998/99 seasons (shoot growth was not measured in 1996/97). Therefore it appears that a relationship exists between shoot length and the occurrence of flowering. Flowering date was negatively correlated with shoot length at 12 November (before the onset or at early stages of flowering) (r=–0.70).

Duration of flowering varied considerably between 1997/98 and 1998/99, which was strongly related to GDD for November (r=–0.97).

Daily increase in percentage of flowering during the period when 20-80% of flowering was taking place, varied sharply between seasons, ranging 12.3-17.9% in 1997/98, and 4.9-7.7% in the 1998/99 season.

Table 39. Flowering dates and duration at six Cabernet Sauvignon vineyard sites in Hawke's Bay over three seasons

Site	Start	Mid-flowering	End	Days from 1 Nov to mid-flowering	Duration (days)
			Season 1996/97		
RVV	-	8/12/96	-	37	-
JRS	-	30/11/96	-	29	-
BPN	-	12/12/96	-	41	-
SFV	-	30/11/96	-	29	-
LND	-	2/12/96	-	31	-
MMR	7/12/96	14/12/96	-	43	-
			Season 1997/98		
RVV	27/11/97	1/12/97	8/12/97	30	11
JRS	25/11/97	28/11/97	5/12/97	27	10
BPN	26/11/97	30/11/97	7/12/97	29	11
SFV	23/11/97	28/11/97	3/12/97	27	10
LND	25/11/97	29/11/97	4/12/97	28	9
MMR	25/11/97	30/11/97	7/12/97	29	12
			Season 1998/99		
RVV	17/11/98	23/11/98	5/12/98	22	18
JRS	11/11/98	18/11/98	30/11/98	17	19
BPN	18/11/98	30/11/98	8/12/98	29	20
SFV	8/11/98	16/11/98	26/11/98	15	18
LND	12/11/98	18/11/98	30/11/98	17	18
MMR	13/11/98	21/11/98	30/11/98	20	17

Berry Set and its Variability

The number of flowers and berries per cluster and berry set percentage varied between sites and seasons (Table 40). Season, site and their interaction all affected berry set percentage. Average berry set in 1997/98 (42.8%) was significantly higher than in 1998/99 (28.2%). Berry set at SFV and MMR was higher than at the LND, RVV and JRS sites, which was higher than at BPN. The lowest overall berry set percentage was recorded at BPN in 1998/99 (15.9%) and the highest at MMR in 1997/98 (55.6%).

The number of flowers per inflorescence in the sample observed did not differ significantly between sites, but it was significantly higher in 1998/99 (mean 454) than in 1997/98 (mean 261). Berry number did not differ

significantly between seasons (106 and 121 for 1997/98 and 1998/99 respectively), while the effect of site and the interaction of site and season was significant. Variability of flower and berry numbers between clusters was higher in 1998/99 than in 1997/98.

Table 40. Berry set and its variability (SD – standard deviation)

Site	Flower caps	SD	Berries	SD	Berry set percent	SD
			Season 1997/98			
RVV	232	47	112b	26	48.3ab	5.0
JRS	231	50	69c	23	31.8c	11.8
BPN	282	73	107bc	31	39.0bc	10.3
SFV	227	85	102bc	19	48.8a	13.5
LND	328	91	109bc	45	33.5c	13.7
MMR	266	108	139ab	65	55.6a	12.4
Average	261A	76	106A	35	42.8A	11.1
			Season 1998/99			
RVV	554	270	101bc	52	18.2e	3.6
JRS	531	260	163a	73	31.6cd	5.1
BPN	446	160	65c	32	15.9e	6.6
SFV	295	84	108bc	41	35.2c	9.6
LND	443	128	170a	44	40.9b	11.6
MMR	455	163	120b	39	27.4de	4.9
Average	454B	178	121A	47	28.2B	6.9

NB: Different upper case letters denote significant effect of season, lower case of the interaction site and season (LSD test at $p<0.05$)

Variability of Weight in Green Berries

On 5-7 January in the 1997/98 and 1998/99 seasons all differences in berry weight between sites were significant, except those between MMR and RVV, and MMR and JRS (Table 41). Season and interaction of season and site showed no effect on berry weight.

Table 41. Cabernet Sauvignon berry weight at six sites in Hawke's Bay on 5-7 January in the 1997/98 and 1998/99 seasons

Site	Season	Valid N	Mean	Minimum	Maximum	Standard Deviation	Skewness
RVV		100	0.392	0.020	0.801	0.173	0.199
JRS		100	0.301	0.022	0.637	0.133	0.577
BPN	1997/98	100	0.458	0.035	0.860	0.177	-0.128
SFV		100	0.521	0.093	0.961	0.163	-0.132
LND		100	0.624	0.025	1.090	0.210	-0.411
MMR		100	0.348	0.037	0.739	0.160	0.281
RVV		50	0.372	0.126	0.644	0.114	0.013
JRS		50	0.355	0.144	0.732	0.168	0.655
BPN	1998/99	50	0.439	0.131	0.823	0.124	0.397
SFV		50	0.554	0.182	1.059	0.157	0.809
LND		50	0.571	0.286	1.143	0.148	1.061
MMR		50	0.374	0.112	0.780	0.142	0.782

NOTE: Skewness above 1 indicates distributions significantly different from normal.

Coefficients of variation in berry weight decreased throughout development and ripening of berries from 33-46% in January to about 25% at harvest (Figure 18). The variability of berry weight at harvest at six sites was similar to that found in early January, with the exception of SFV and RVV. Relatively high berry weight variability at JRS can be related to skewness of its berry weight distribution (Table 41). Such a distribution indicates a relatively high proportion of smaller berries (as distribution was skewed to the left) that appear to have remained relatively small and increased the overall variability of berry weight at this site as berries were enlarging.

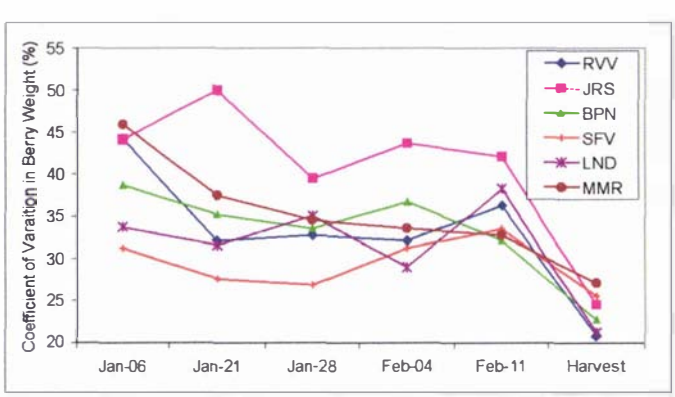

Figure 18. Changes in coefficient of variation (%) of berry weight during development and ripening of berries at six sites in Hawke's Bay 1997/98

There was some variability in berry and rachis dry matter content (Figure 19) as established in samples collected 6-7 January 1999. Site JRS had the highest, and sites RVV and BPN the lowest dry matter percentage both in berries and in rachides. Dry matter content in berries and rachides was significantly correlated with soil moisture content in the 0-30 cm profile for December (r=–0.84 and r=–0.90, respectively).

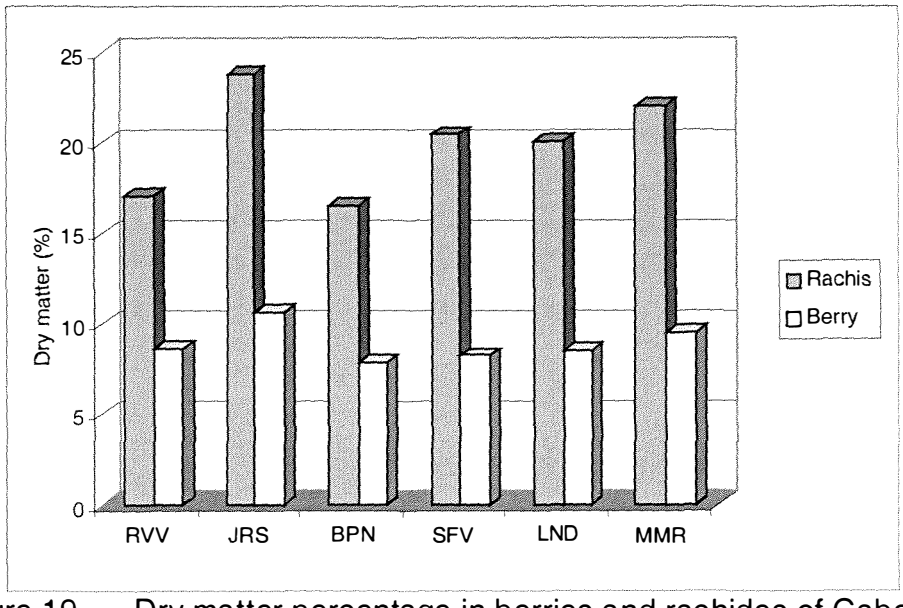

Figure 19. Dry matter percentage in berries and rachides of Cabernet Sauvignon collected 6-7 January 1999 at six selected sites in Hawke's Bay

Discussion

Air temperature was found to be the main factor affecting the date of flowering in the present study, which is in accordance with results published by many authors (Calo, 1972; Alleweldt and Hofacker, 1975; Yu, 1979; Huglin, 1986; Haba-Ejarque, 1989; Calo *et al.*, 1994).

Flowering date was positively correlated with harvest date (r=0.74), confirming the results of Costantini *et al.* (1996) for cv Prugnolo gentile, and also those of Barbeau at al. (1998a) for cv Cabernet Sauvignon. In addition, mid-flowering date was also correlated with mid-véraison date (r=0.85), closely corresponding to the relationship between these two phenological

events in Cabernet Sauvignon established by Barbeau *et al.* (1998a) in conditions of the Loire Valley in France.

Flowering date was positively correlated with rainfall for October (r=0.87) in the 1997/98 and 1998/99 seasons agreeing with Costantini *et al.* (1996) for cv Prugnolo gentile in Italy. These authors also found a similar correlation between flowering date and rainfall for November, but this did not occur in the present study.

These relationships of weather and flowering suggest there is potential to affect timing of flowering and overall phenology by vineyard management practices (for example, by timing winter pruning) and particularly site selection.

A trend of reduction in berry weight variability with increased duration of flowering was observed. This was somewhat surprising, since increased duration of flowering was also shown to reduce berry set. It is suggested that prolonged flowering influenced by cool weather augmented the drop of small poorly fertilised berries, thus reducing overall variability in berry size. Based on Coombe's (1984) study on developmental changes in individual berries, it is possible that berry weight variability can be a relative indication of synchronicity in development within the population of berries. Berry weight variability in 1997/98 was lowest at the JRS site. Overall, it was lowest at RVV in 1998/99. This is some indication that a poor berry set in this season at RVV actually caused a good synchronicity in berry development in the remaining berry population. As 100 mm of rain fell during the period from 21 November to 10 December (from 40% to full flowering) at RVV, it is hypothesised that most berries were fertilised before this change in weather, hence their relative uniformity. This will be discussed further in Chapter 7 (page 173).

Flowering rates (Figure 20) were strongly influenced by air temperatures during flowering (R^2=0.941) as previously reported by Milosavljevic *et al.* (1972) for several other grape cultivars. Williams *et al.* (1985) found that it took 5-6 days for flowering to go from 10 to 90% in cv Thompson Seedless

during a week with reportedly high temperatures in Californian conditions. That would amount to a daily rate of about 14%, and is close to flowering rates observed during the 1997/98 season in this study, when mean temperature during flowering was 18.5 °C. Detailed data for cool flowering conditions are not available, although Williams *et al.* (1985) noted earlier onset of flowering in warmer than in cooler vineyards. It is likely that rates of flowering determined in 1998/99 would be more typical of Cabernet Sauvignon in Hawke's Bay. Mean temperatures during flowering in 1998/99 (15.4 °C) were closer to normal for this region (15.4 °C for November and 17.5 °C for December at Napier, mean for 1973-1990, the National Institute of Water and Atmospheric Research, New Zealand).

Air temperatures during flowering were positively correlated with at harvest measurements of cluster weight (r=0.62), TSS (r=0.86), tartaric/malic acid ratio (r=0.61) and total phenolic and anthocyanin concentration in berry skins (r=0.69 in both cases). Tartaric/malic acid ratio was also positively correlated with wine sensory evaluation score (see Chapter 8, page 184). McAneney *et al.* (1995) found that delayed flowering in mandarin (*Citrus unshiu*) caused both flowering and the early stages of fruit development to take place during periods of higher air temperatures, which lead to higher juice quality. The authors explained this effect of warm weather during flowering on fruit quality through higher initial rates of sugar accumulation. Whether these findings can explain the positive correlation established between higher air temperatures during flowering and fruit quality in this study on grapevines is not clear. No apparent differences in initial rates of TSS accumulation between seasons with higher and lower flowering temperatures were observed in this study.

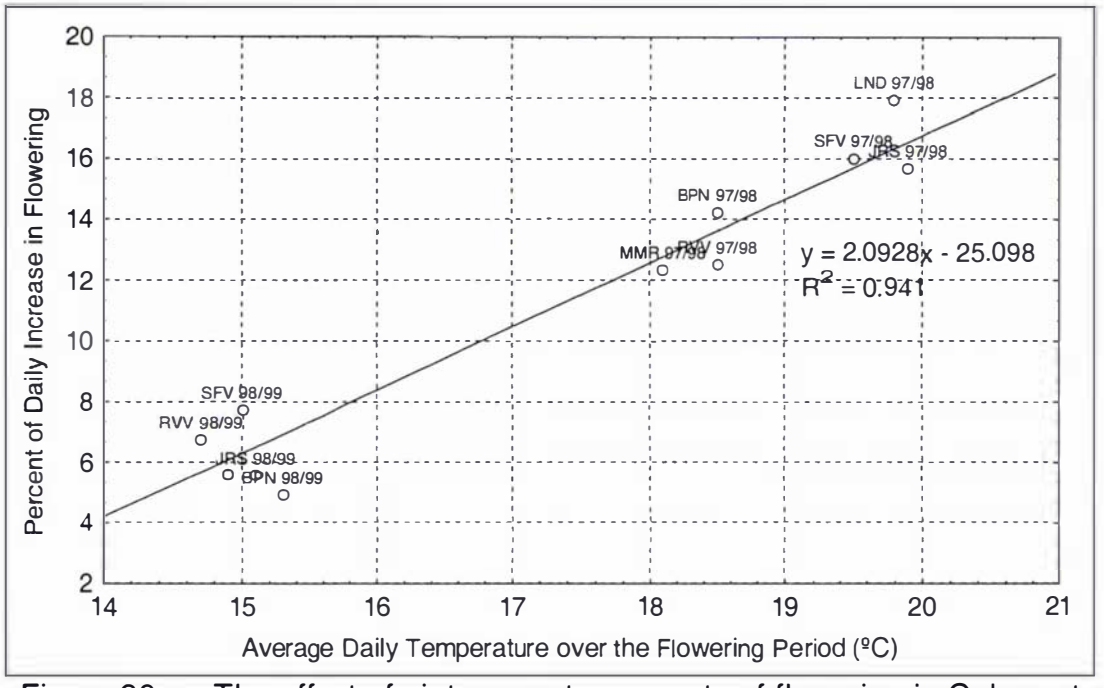

Figure 20. The effect of air temperature on rate of flowering in Cabernet Sauvignon grown at six sites in Hawke's Bay during the 1997/98 and 1998/99 seasons

Koval and Pavlenko (1976) and Pratt and Coombe (1978) found a relationship between shoot growth (expressed by number of nodes developed) and flowering date. Present results show a positive correlation between shoot length at mid-flowering and the number of underdeveloped inflorescences at that time. The binomial regression between the two variables (Figure 21) shows a reduction in number of underdeveloped inflorescences with increased shoot length. A zero percentage of underdeveloped inflorescences would indicate full synchronicity in flowering, and would be ideal from the management point of view. Poorly developed shoots at flowering were those approximately 25-40 cm long at that time and noticeably thinner in diameter than most shoots. According to present results, such shoots are more likely to bear less developed inflorescences. This delay in development may be of a hormonal nature, as low gibberellins were associated with poor shoot growth (Gladstones, 1992). This finding is in a good accordance with the recommendation by Long (1997) to remove fruit on short shoots, as they are one of the causes of poor uniformity of clusters in Cabernet Sauvignon. Present results indicate that if most shoots

within a block of Cabernet Sauvignon were about 100 cm long at flowering, that would favour synchronicity in the phenology of flowering.

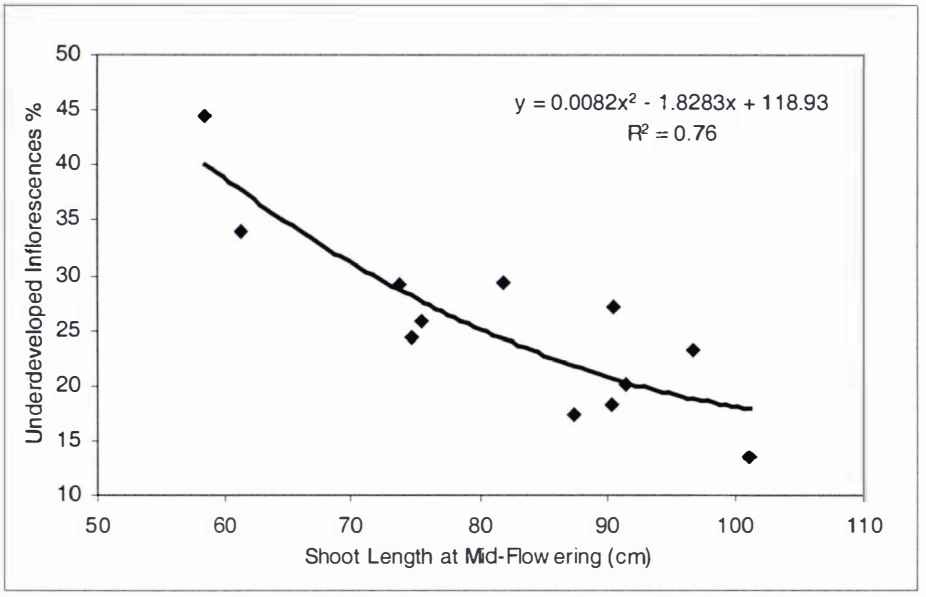

Figure 21. The relationship between shoot length at mid-flowering and the proportion of underdeveloped inflorescences (those with no flowers open) at approximately 50% of flowering

A negative correlation between shoot elongation rate and berry set was found by Wagner *et al.* (1987) in cultivars Grenache and Merlot, while there was no such correlation in cv Cabernet Sauvignon, which is in agreement with the overall results of this study. Shoot elongation rates in 1997/98 were positively correlated with berry set. Dry soil conditions in 1998/99 during flowering (Table 38) appear to have caused low shoot elongation rates, as shoot length at flowering was positively correlated with soil moisture in the 0-30 cm profile in November (r=0.71). Rainfall occurring towards the end of flowering in the same season (1998/99) had a detrimental effect on berry set percentage, presumably by negatively affecting pollen germination. This probable direct effect of rainfall on berry set may have affected the above-mentioned relationship between shoot elongation rate and berry set.

A significant curvilinear regression occurred between GDD for November and the percentage berry set (Figure 22). Ewart and Kliewer (1977) found no relationship between temperature regime during flowering and berry set in cv Cabernet Sauvignon grown in a controlled environment. When GDD

for November exceeded 180 °D there appeared to be a negative effect on berry set. This relationship may be related to an early occurrence of water stress at some sites. Analysis of air temperatures for November in the dry 1997/98 season, shows that daily maximum temperatures were positively correlated with soil temperatures at 15 cm (r=0.74), and negatively with soil moisture content in the profile 0-30 cm (r= – 0.42). Soil moisture content in November fell to about 7% at JRS in both the 1997/98 and 1998/99 seasons, and to about 10% at LND in 1998/99. It appears that in some season and sites with sandy or gravelly soils water stress can occur as early as flowering. A clear reduction in shoot elongation rates – an indication of water stress – occurred at JRS throughout November in both the 1997/98 and 1998/99 seasons (Figure 14, Chapter 5).

Duration of flowering was negatively correlated with percentage berry set. Sites with late and prolonged flowering in 1998/99 (RVV, BPN) had not reached 50% flowering when a significant rain fell (more than 100 mm over two weeks). By that time other sites had mostly finished flowering and even berry set, resulting in a large difference in berry set percentage between these sites and those affected by rainfall. In 1997/98 a positive correlation (r=0.83) was found between flowering rates and seed/berry number. Ewart and Kliewer (1977) found a significant positive correlation between temperature during flowering and seed/berry number in controlled environment. Although a similar relationship was not significant in this study, positive correlation between flowering rate and seed number indicates that seed number was affected by conditions of flowering.

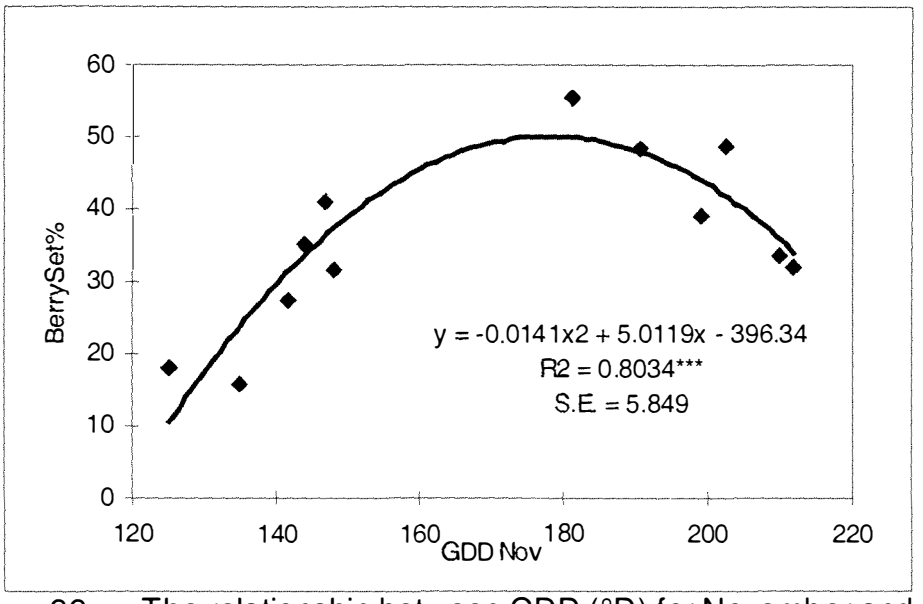

Figure 22. The relationship between GDD (°D) for November and the percentage berry set in Cabernet Sauvignon at six sites in Hawke's Bay during 1997/98 and 1998/99

Warm temperatures and abundant light (open canopies caused by low water availability) in the 1997/98 season during the period of formation and differentiation of flower primordia in buds appear to have increased the flower number in 1998/99. Although improved light and temperature conditions associated with open canopies have been shown to positively affect bud fertility (Casteran *et al.*, 1987), mean number of inflorescences per bud (ie bud fertility) was very similar between 1997/98 and 1998/99 (1.17 and 1.15 respectively).

Based on the present study it can be stated that relatively small differences in meteorological conditions may have a considerable effect on timing and duration of flowering, as well as fruit set percentage. Some differences in GDD during spring were observed between the Fernhill and the Tuki Tuki areas (represented by the JRS and MMR sites). Sites characterised by early flowering are likely to have an early harvest, which can be a significant advantage for Cabernet Sauvignon grapes grown in Hawke's Bay. An important factor for flowering and berry set as shown by present results is rainfall, a meteorological factor whose variability between sub-regions is considerable and difficult to predict. Along with windiness (not measured in

this study), the rainfall represents possibly the most inconsistent sub-regional meteorological factor.

Sites with gravelly and sandy soils were characterised by low soil moisture and higher soil temperature early in the season and during flowering. These conditions were reflected in an increased berry and rachis dry matter content early in fruit development stage. At the site on gravelly soil (JRS) these fruit characteristics remained through to harvest (Figure 28, Chapter 7).

Although significant effects of season on flowering date occurred, in most seasons sites on fertile silts (such as BPN) are likely to flower later than those on moderately fertile and light soils.

Observations of flowering rates and their relationship with meteorological factors may ultimately be used for the production of reliable flowering models (Williams *et al.*, 1985), particularly useful for vineyard pest and disease management. In order for such models to be produced studies will have to be undertaken on more vineyard sites and over periods considerably longer than in this study.

Summary

Flowering and berry set and its effect on early berry development were studied in cv Cabernet Sauvignon grown at six sites selected in Hawke's Bay based on their canopy and fruit characteristics as reported in Chapter 3. Environmental conditions before and during flowering and berry set were analysed, including air temperatures, solar radiation, soil temperatures at two depths, and soil moisture content. Soil-related conditions showed the highest variability between sites and seasons.

Small differences in meteorological conditions between sites had a considerable effect on timing and duration of flowering and fruit set percentage. Sites characterised by early flowering are likely to ripen early, which can be a significant advantage for Cabernet Sauvignon grapes grown

in Hawke's Bay. An important factor for flowering and berry set as shown by present results is rainfall, a meteorological factor whose variability between sub-regions is considerable and difficult to predict. Sites on fertile and moist silts are likely to flower later than those on gravelly and sandy soils in most seasons.

Precocity of flowering was positively correlated with GDD for October and with shoot length before flowering, and negatively with October rainfall. Duration of flowering was negatively correlated with GDD for November and percentage berry set. Daily flowering rates were highly correlated with air temperatures during flowering. Short shoots have been found to carry inflorescences that are less developed and flower later than those on long shoots. High variability in shoot length at flowering therefore appears to promote heterogeneity in flowering.

There was a significant polynomial relationship between GDD for November and berry set. Warmer November temperatures improved berry set up to GDD of 180 °D thereafter showing a reduction in berry set. November GDD>180°D were recorded at sites that exhibited early water stress shown by a reduction of shoot elongation rates during this month. Berry weight variability, as an expression of synchronicity in berry development, at early stages was low in conditions of poor berry set. If favourable weather conditions are limited only to a short period during berry set, percentage set will be low. However, berries that were set in that relatively short period appear to be more synchronised in their development compared to a situation with favourable conditions throughout the setting period. Sites with gravelly and sandy soils were characterised by low soil moisture and higher soil temperature early in the season and during flowering. These conditions were reflected in an increased berry and rachis dry matter content early in fruit development stage.

CHAPTER 7. VÉRAISON AND BERRY RIPENING

Introduction

The onset of ripening in grapevines is termed *véraison* (from French, referring to colour change) and it encompasses several important concurrent or sequential events occurring at that stage in the grape berry. These events include: acceleration of growth and softening of the pericarp, accumulation of glucose and fructose, decrease in concentration of acids, especially malate, loss of chlorophyll from the skin and, in coloured cultivars, accumulation of anthocyanins, and increased activity of some enzymes (Coombe, 1984).

Berry ripening therefore occurs from véraison onwards, with significant changes occurring in berry volume and weight, and a further increase in hexoses and decrease in organic acids. Each of the constituents of berries and juice has its own dynamics of ripening, with a synchronicity of these dynamics largely dependent on environmental conditions during this period. These ripening dynamics are important in determining fruit quality at harvest, and ultimately wine quality.

Detailed observations of véraison and ripening dynamics of berry weight and various berry compounds during the ripening period were made to examine the effect of viticultural environment, or potential 'terroir' on expression of fruit quality in cv Cabernet Sauvignon grown at six sites in Hawke's Bay. The attributes of fruit composition observed were TSS, dry matter percentage, juice yield, TA, tartaric, malic acid, pH, potassium, plus anthocyanins and phenolics in berry skin. Fruit quality at harvest is mostly determined by TSS, TA and pH of berries, their aroma and skin colour. Quantitative expression of these qualitative elements will primarily be determined by the interaction between environmental conditions and

genotype and, as Calo *et al.* (1996) noted, fruit quality will therefore be highly variable between seasons and sites.

Material and Methods

Most of the methods concerning fruit ripening were outlined earlier (Chapter 2, page 21). Some specific methods for fruit analyses applied during the 1997/98 and 1998/99 seasons are presented here.

Berry weight (and its variability) was measured at several stages during fruit development in 1997/98 and 1998/99 using an electronic scale with ±0.001 g resolution. Berries were removed from selected clusters with scissors, and generally were weighed immediately after picking. On some occasions they were stored in a refrigerator (approximately 5°C) for up to 24 hours before weighing.

Berry dry weight was obtained by drying a minimum of 50 berries in a drying oven at 65 °C until constant weight, which usually took about two weeks.

Ten representative clusters were used to determine stem and berry percentage in clusters, and the number and weight of seeds in berries. Clusters were weighed, then berries on each cluster removed and counted, and stems were then weighed. One hundred berries were systematically selected from all the berries picked from clusters by taking every fifth berry in a row. Selected berries were weighed, their seeds extracted, placed at room temperature for several days to dry, and then counted and weighed.

Results

Results of observations of véraison and of analyses of fruit composition presented here were obtained during the 1997/98 and 1998/99 seasons, with some additional results included from the 1996/97 season. Correlations between variables observed in 1997/98 and 1998/99 are presented in Appendix 12, and correlations between the variables in all three seasons are in Appendix 10.

Véraison date and dynamics (Figure 23) varied considerably between seasons. On average, mid-véraison was seven days earlier in 1998/99 than in 1997/98. Véraison was always earliest at the JRS site and latest at BPN. The order in which other four sites went through véraison was different in each season, as was the time span between the earliest and latest site.

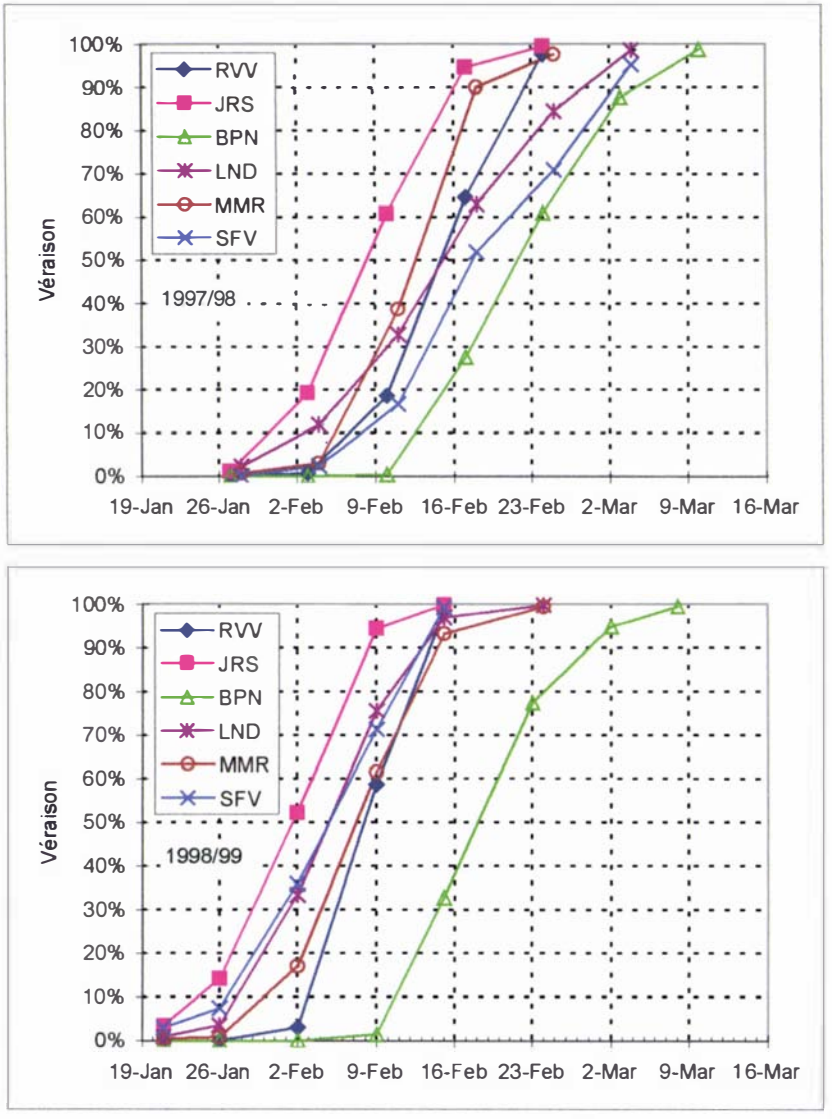

Figure 23. Véraison dynamics in cv Cabernet Sauvignon in the 1997/98 and 1998/99 seasons at six selected sites in Hawke's Bay

Duration of véraison (the period from 5 to 95% véraison) varied markedly between sites and seasons. The JRS site went fastest through véraison in

1997/98 in just 12 days, while véraison at LND in the same season lasted for 32 days.

Development and Ripening of Berries

Berry growth curves (Figure 24) expressed similar double sigmoid patterns between sites with periods of intensive growth pre- and post-véraison, with a reduction of growth at the beginning of véraison in the second half of January at most sites, and a variable berry size in final weeks of ripening. Berries at the LND site were the largest throughout development and ripening in both the 1997/98 and 1998/99 seasons. The growth reduction phase at BPN was delayed in comparison to other sites, which indicates delayed phenological development at this site.

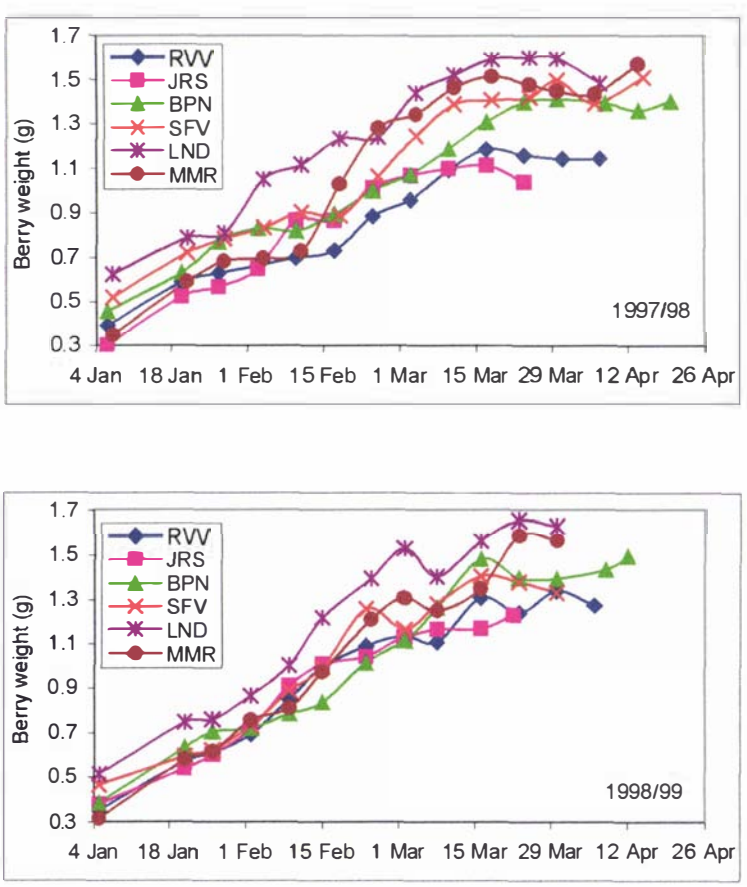

Figure 24. Berry weight at six Cabernet Sauvignon vineyard sites in Hawke's Bay during ripening in the 1997/98 and 1998/99 seasons

Berry weight increase was studied in detail in the 1997/98 season. Differences between sites in berry weight were often significant (Table 42).

Table 42. Cabernet Sauvignon berry weight at six sites in Hawke's Bay at several stages of development in the 1997/98 season

	6-7 Jan	20-21 Jan	27-28 Jan	3-4 Feb	10-11 Feb	Harvest
RVV	0.392b	0.588b	0.628ab	0.662ab	0.698ad	1.185b
JRS	0.301a	0.523a	0.565a	0.648a	0.866bc	0.995a
BPN	0.458c	0.632b	0.769c	0.832c	0.820be	1.347c
SFV	0.521d	0.721d	0.784d	0.834c	0.903ce	1.461cd
LND	0.624e	0.787e	0.808d	1.049d	1.115f	1.671e
MMR	0.348b	0.591d	0.682b	0.695b	0.727d	1.608de
Average	0.441	0.640	0.706	0.787	0.855	1.378

NB: Different letters denote significant differences by LSD test for $p<0.05$

Overall berry weight at harvest at the JRS and RVV sites was smaller than at other four sites. In 1996/97 mean berry weight was 1.48 g for all 28 sites observed and 1.62 g for six selected sites (see page 47); this was larger than mean berry weight at selected sites in 1998/99 (1.42g) and 1997/98 (1.31g).

In the 1997/98 season seed weight was greatest at MMR and smallest at JRS (Table 43). Berry weight was strongly and positively correlated with seed weight (r=0.95) and seed weight per berry (r=0.98). Number of seeds per berry was similar at all sites in 1997/98 (range 1.36 to 1.62 seeds per berry), the largest seed number being at the LND site, and the lowest at RVV.

Table 43. Seed number per berry and seed weight (g) at harvest in 1997/98

	RVV	JRS	BPN	SFV	LND	MMR
Seeds in Berry	1.36	1.47	1.44	1.49	1.62	1.47
100 Seed Weight	2.62	2.25	2.82	2.79	3.08	3.26

Note: Data were not statistically analysed because there was only one replicate per each site

Total soluble solids (°Brix) in juice varied markedly both between sites and seasons (Figure 25). Throughout ripening in the 1997/98 and 1998/99 seasons, TSS values were consistently highest at the JRS site and lowest at BPN, with the remaining four sites midway between these two extremes. The weekly TSS values on a per berry basis are presented in Appendix 13 (page 271).

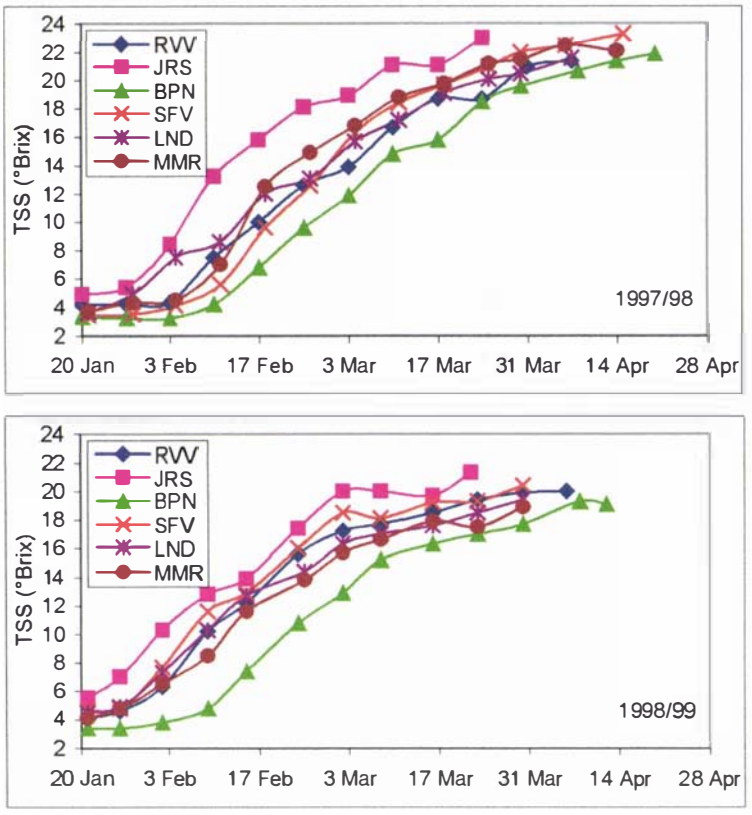

Figure 25. Total soluble solids (TSS) in berries of Cabernet Sauvignon at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

TSS values were higher in 1997/98 and lower in the 1996/97 and 1998/99 seasons (Table 44). Fruit from the JRS and SFV sites was harvested with consistently higher TSS in juice compared to the other four sites. In both seasons there was a noticeable difference between sites in the timing of the TSS increase. In early February TSS varied between sites from 3 to 10 °Brix. In early March the range was from about 12 °Brix (at BPN) to almost 20 °Brix (at JRS).

Titratable acidity (TA) in juice varied considerably between sites (Figure 26). The JRS site had the lowest TA throughout ripening both in 1997/98 and 1998/99, while fruit at BPN generally had the highest TA. The weekly rates of change of TA per berry (see Appendix 13, page 271) were highest in the first half of February in both seasons, with the maximum weekly decrease of –9.7 mg TA/berry recorded at the JRS site in 1998/99. The high TA weekly

change rates tended to persist at the BPN site up to early March in both seasons.

Table 44. TSS (°Brix) in Cabernet Sauvignon juice at harvest at six selected sites in Hawke's Bay over three seasons

	1996/97		1997/98		1998/99		Average
	TSS	Harvest date	TSS	Harvest date	TSS	Harvest date	TSS
RVV	19.9	11/04/97	21.4	7/04/98	20.0	6/04/99	20.4
JRS	21.0	10/04/97	23.0	24/03/98	21.3	22/03/99	21.8
BPN	20.3	29/04/97	21.9	20/04/98	19.1	12/04/99	20.4
SFV	21.8	20/04/97	23.3	6/04/98	20.4	31/03/99	21.8
LND	20.5	1/05/97	21.6	7/04/98	19.4	2/04/99	20.5
MMR	20.7	5/05/97	22.1	14/04/98	18.9	2/04/99	20.6
Average	20.7		22.2		19.9		

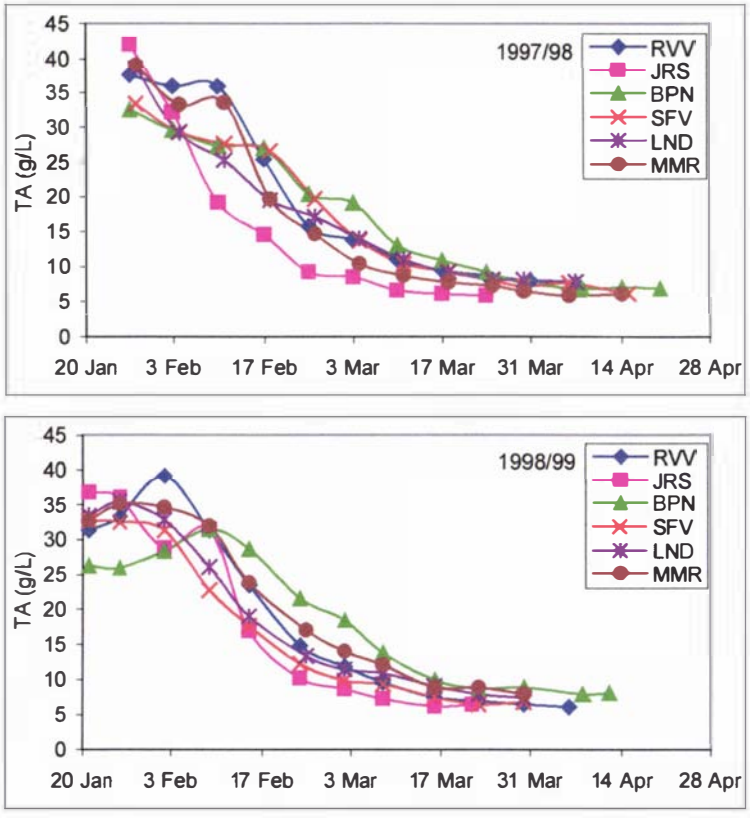

Figure 26. Titratable acidity (TA) in Cabernet Sauvignon juice at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

Mean TA concentration at harvest in 1996/97 was considerably higher (9.6 g/L) than in the 1997/98 and 1998/99 seasons when they were relatively similar (Table 45). In all three seasons TA was significantly correlated with mean January air temperature (r=–0.80) and CDI (r=–0.61).

Table 45. TA (g/L) in Cabernet Sauvignon juice at harvest at six selected sites in Hawke's Bay over three seasons

	1996/97	1997/98	1998/99	Average
RVV	10.0	7.6	6.1	7.9
JRS	7.4	5.8	6.4	6.5
BPN	9.8	6.8	8.1	8.2
SFV	9.0	6.1	6.8	7.3
LND	9.7	7.8	7.4	8.3
MMR	11.9	6.1	8.0	8.7
Average	9.6	6.7	7.1	

Juice pH during berry development and ripening differed between sites, and was highest at JRS at all stages during the 1997/98 and 1998/99 seasons (Figure 27).

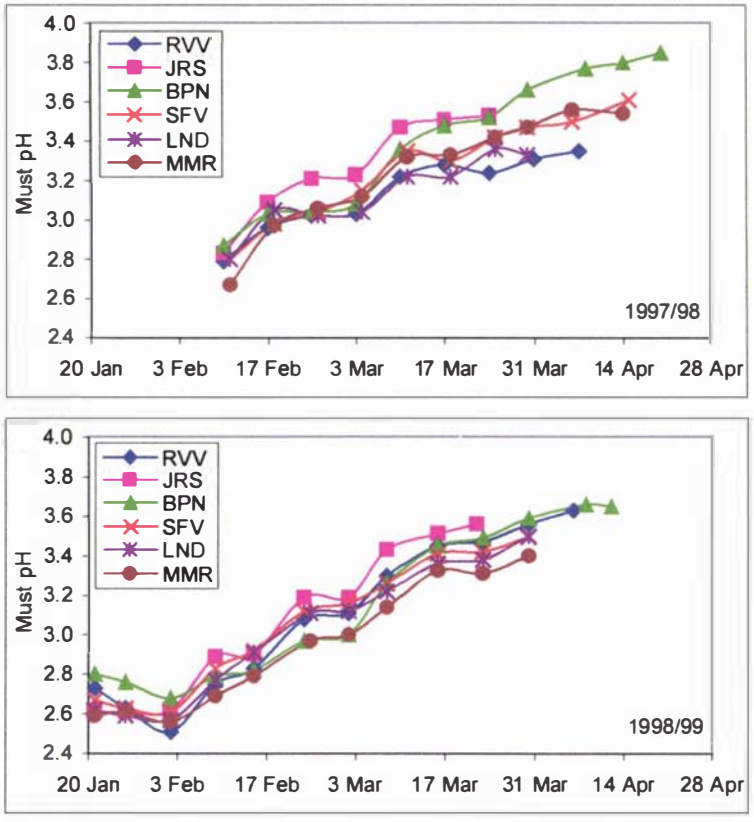

Figure 27. Juice pH of Cabernet Sauvignon at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

Juice pH at harvest (Table 46) was lower in the 1996/97 season (average 3.32) than in 1997/98 and 1998/99 (averages 3.54 in both seasons).

Table 46. Juice pH in Cabernet Sauvignon at harvest at six selected sites in Hawke's Bay over three seasons

	1996/97	1997/98	1998/99	Average
RVV	3.23	3.35	3.63	3.40
JRS	3.34	3.53	3.56	3.48
BPN	3.30	3.85	3.65	3.60
SFV	3.46	3.61	3.50	3.52
LND	3.35	3.36	3.50	3.40
MMR	3.22	3.54	3.40	3.39
Average	3.32	3.54	3.54	

Juice yield percentage varied little during berry ripening (Figure 28) being mostly between 65 and 70%. It was only slightly higher in 1998/99 than in 1997/98, particularly the samples from the MMR and LND sites.

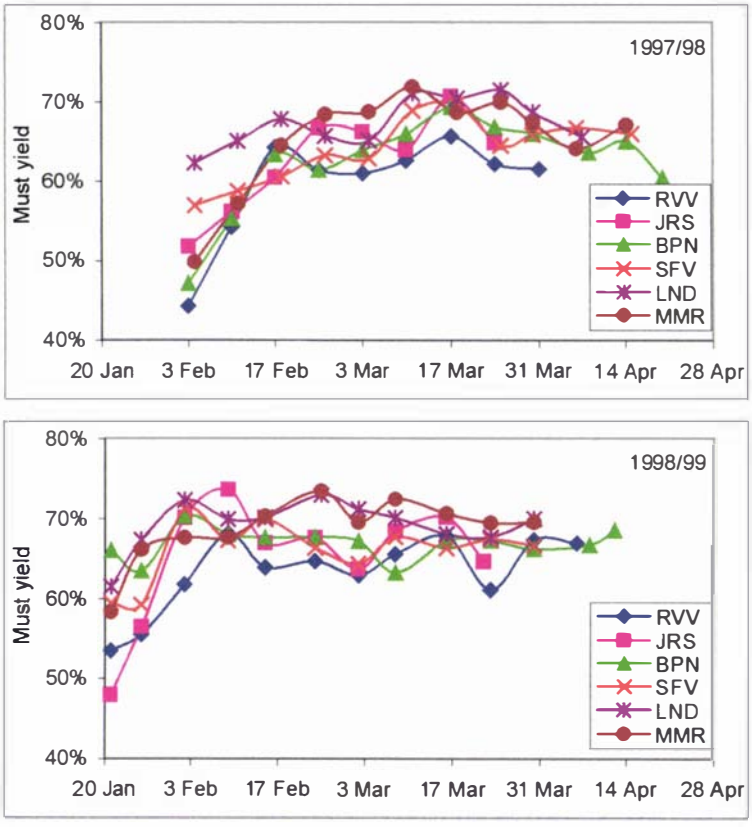

Figure 28. Juice yield percentage in Cabernet Sauvignon at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

Juice yield increased from late January when it was 40-50% to 70% in mid-February, and that level was maintained throughout the rest of fruit ripening. Throughout the ripening, sites characterised by comparatively small berries

(JRS and RVV) tended to have a slightly lower juice yield than the other sites. Berry weight on 23 March was positively correlated with juice yield on the same date ($r=0.67$, $p<0.05$)

Juice turbidity values during berry development and ripening (Figure 29) varied considerably between seasons. The juice from 1997/98 had a considerably higher proportion of sediment compared to 1998/99.

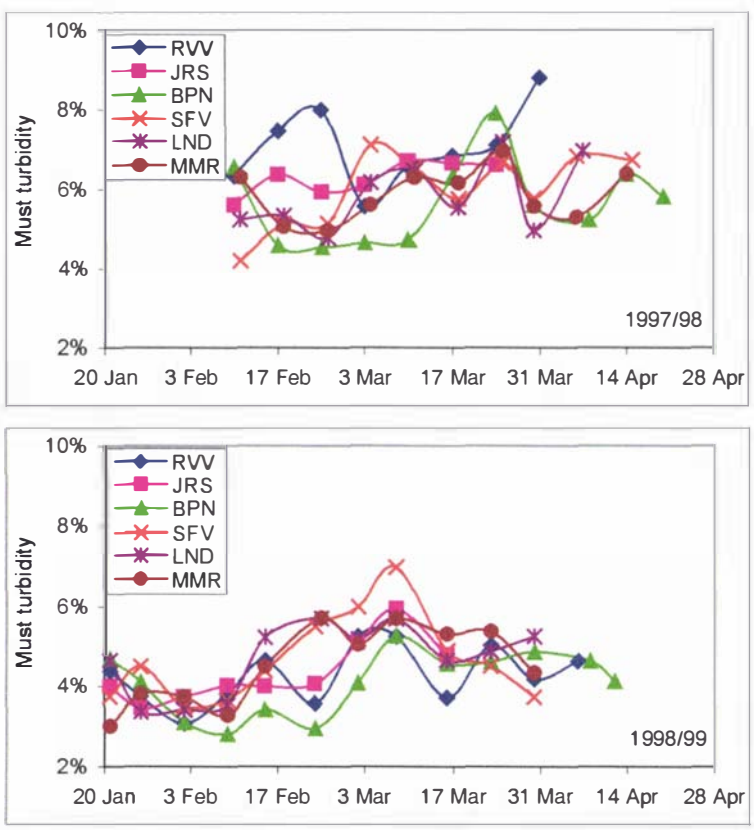

Figure 29. Turbidity of Cabernet Sauvignon juice at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

Juice turbidity was affected by air temperatures, soil moisture and rainfall (including any irrigation). Juice turbidity on 23 March was positively correlated with mean air temperature in February ($r=0.91$, $p<0.05$) and negatively with the total seasonal rainfall + irrigation ($r=-0.93$). Neither juice yield nor turbidity showed any significant effect on fruit quality attributes.

Tartaric acid content in juice during berry ripening was considerably higher at the beginning of sampling period in 1998/99, particularly on 20-21 January, compared to 1997/98 (Figure 30).

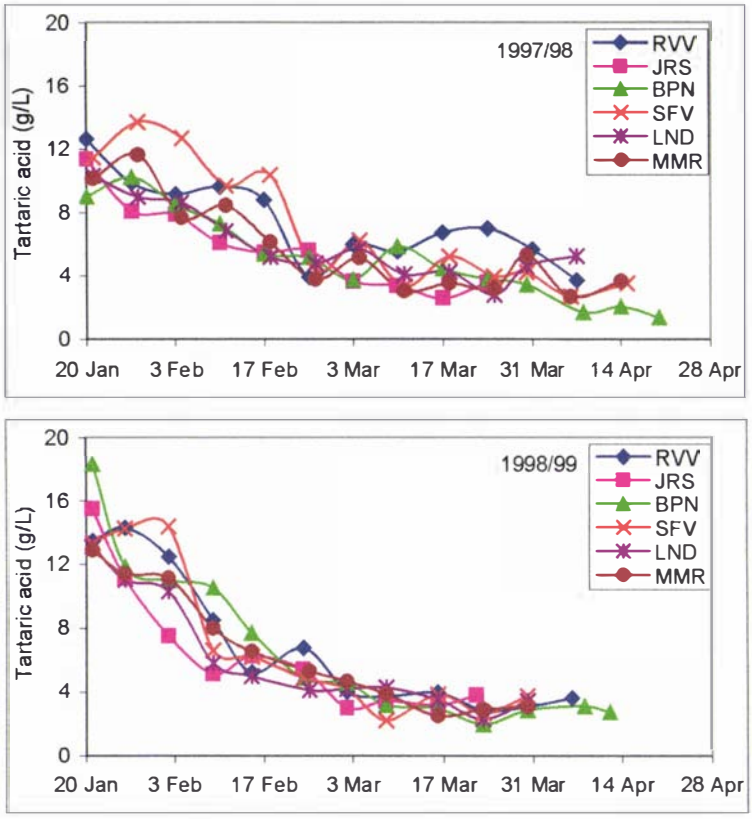

Figure 30. Tartaric acid (g/L) concentration in Cabernet Sauvignon juice at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

Tartaric acid concentration in juice at harvest (Table 47) was similar in the 1997/98 and 1998/99 seasons (averages 3.49 and 3.38 g/L respectively), and considerably higher than that in 1996/97 (average 4.41 g/L).

Malic acid concentration in juice during berry development and ripening varied considerably between sites, with the JRS site consistently having the lowest malic acid content and BPN the highest (Figure 31).

Table 47. Tartaric acid (g/L) concentration in Cabernet Sauvignon juice at harvest at six selected sites in Hawke's Bay over three seasons

	1996/97	1997/98	1998/99	Average
RVV	2.86	3.69	3.60	3.38
JRS	3.33	3.56	3.77	3.55
BPN	5.17	1.35	2.71	3.08
SFV	5.75	3.49	3.71	4.32
LND	3.72	5.23	3.41	4.12
MMR	5.61	3.64	3.06	4.10
Average	4.41	3.49	3.38	

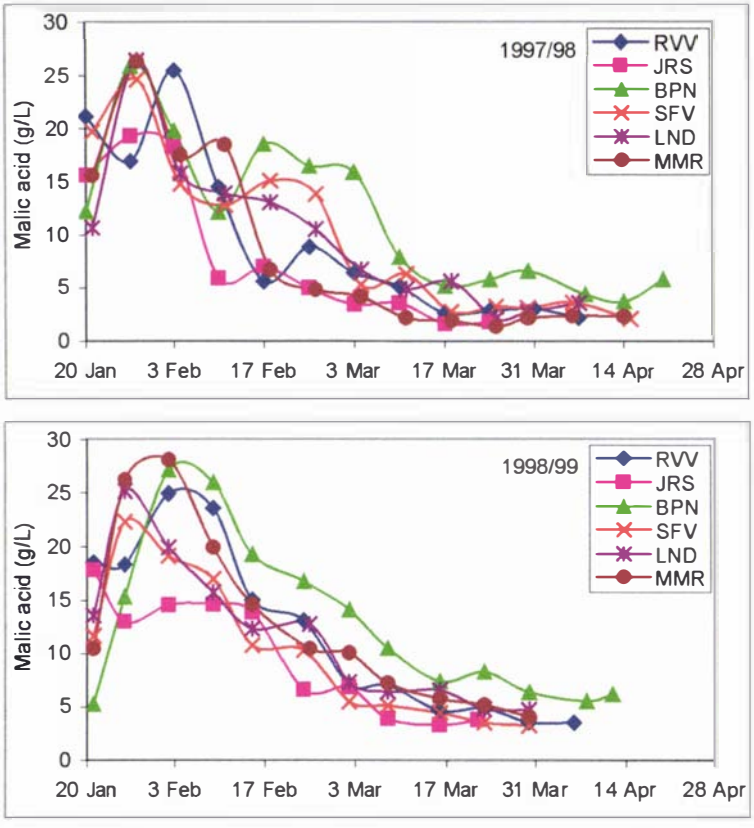

Figure 31. Malic acid (g/L) concentration in Cabernet Sauvignon juice at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

Malic acid concentration in juice at harvest varied considerably between seasons (Table 48). High malic acid content was characteristic of the 1996/97 season (average 5.29 g/L). Site BPN was characterised by high content of malic acid in juice at harvest even in the 1997/98 and 1998/99 seasons, when the overall malic acid content was lower than in 1996/97.

Table 48. Malic acid (g/L) concentration in Cabernet Sauvignon juice at harvest at six selected sites in Hawke's Bay over three seasons

	1996/97	1997/98	1998/99	Average
RVV	7.36	2.16	3.48	4.33
JRS	4.38	1.76	3.72	3.29
BPN	5.00	5.79	6.14	5.64
SFV	5.08	2.07	3.22	3.46
LND	3.08	3.53	4.68	3.76
MMR	6.85	2.26	4.02	4.38
Average	5.29	2.93	4.21	

Potassium concentration in juice during berry development and ripening showed a marked variation between sites and seasons (Figure 32). Sites BPN and JRS were characterised by high juice potassium throughout the observed period, particularly in the 1997/98 season. Changes in K concentration over the period of development and ripening was relatively slow with a steady rate of increase at most sites.

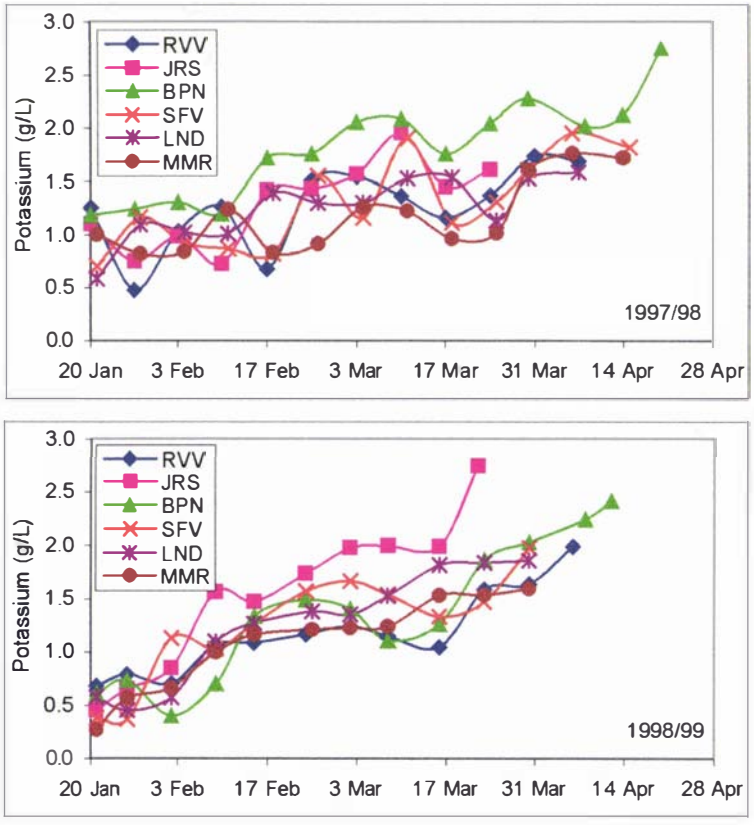

Figure 32. Potassium (g/L) concentration in Cabernet Sauvignon juice at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

There were few differences in potassium concentration in juice at harvest between the 1996/97 and 1997/98 seasons (Table 49), while it was the highest in 1998/99 at most sites. Overall, site BPN had the highest K concentration in juice, the lowest was at MMR, with little differences between the other four sites.

Table 49. Potassium (g/L) concentration in Cabernet Sauvignon juice at harvest at six selected sites in Hawke's Bay over three seasons

	1996/97	1997/98	1998/99	Average
RVV	2.14	1.69	1.99	1.94
JRS	1.22	1.61	2.75	1.86
BPN	1.60	2.75	2.41	2.25
SFV	1.68	1.82	1.98	1.83
LND	2.30	1.58	1.86	1.91
MMR	1.73	1.72	1.59	1.68
Average	1.78	1.86	2.10	

In the 1997/98 and 1998/99 seasons and at six selected sites mean potassium content was about 0.3 mg/berry before véraison. It increased sharply after véraison to exceed 1.0 mg/berry by late February. At harvest, K content was about 1.5 mg/berry, with values above 2.0 mg achieved in cases of late harvest.

Total anthocyanin concentration in juice was markedly higher in 1997/98 than in the 1998/99 season (Figure 33), particularly at the JRS site. Anthocyanin concentrations were measured from véraison (during February at most sites) onwards.

Anthocyanin concentration in berry skins at harvest enables the calculation of Index of Ripeness adjusted for Anthocyanins (IRA, defined in Chapter 2, page 32) (Table 50).

Table 50. Index of Ripeness adjusted for Anthocyanins (IRA) at harvest for six selected sites in Hawke's Bay in the 1997/98 and 1998/99 seasons

	RVV	JRS	BPN	SFV	LND	MMR
Season 1997/98	28.9	46.3	32.5	39.9	25.1	38.1
Season 1998/99	32.8	31.7	19.7	24.9	22.0	20.3

Differences in both extractable and total anthocyanin concentrations in berry skins between sites was high (Table 51), with the highest concentration at the JRS site. Both in the 1996/97 and 1998/97 seasons total anthocyanins

were > 1 g/kg at most sites. In 1998/99 total anthocyanin concentration was > 1g/kg only at the JRS site, while all other sites had a relatively low anthocyanin concentration.

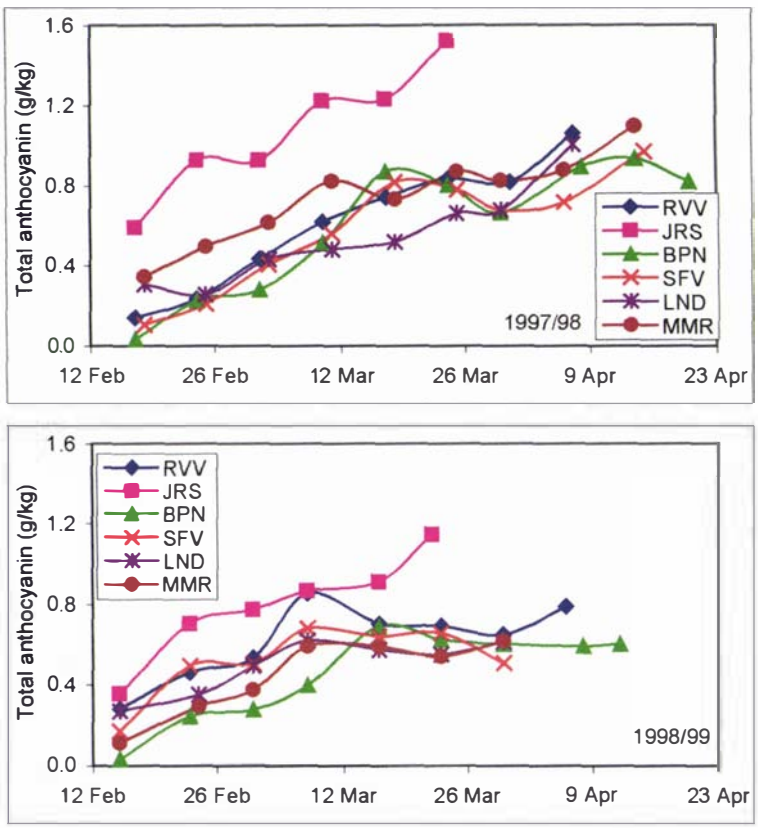

Figure 33. Total anthocyanin (g/kg) concentration in Cabernet Sauvignon juice at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

During the course of ripening overall range of anthocyanins on a per berry basis was 0.03 to 1.47 mg. The maximum of 1.47 mg/berry was higher than that reported by Yokotsuka *et al.* (1999) for Cabernet Sauvignon grown in Japan in test vineyards with modified soil, where it was up to 1.0 mg/berry.

Total concentration of polyphenols in berry skin extracts over the period of berry development and ripening showed a clear difference between the 1997/98 and 1998/99 seasons (Figure 34). Site JRS had the highest concentration of polyphenols throughout the observed periods in both seasons, particularly in 1997/98 with differences between the other five vineyard sites being relatively small. Total phenolic compounds normally

increase from véraison onwards in red grapes, while in white cultivars there is little change in their content during the same period (Kanellis and Roubelakis-Angelakis, 1993).

Table 51. Concentration of total and extractable anthocyanins (mg/kg of fresh weight) in Cabernet Sauvignon berry skins at harvest at six selected sites in Hawke's Bay in the 1997/98 and 1998/99 seasons

	1996/97			1997/98			1998/99		
	Total	Extractable	Ext. %	Total	Extractable	Ext. %	Total	Extractable	Ext. %
RVV	1164	717	62	1060	486	46	789	458	58
JRS	1400	635	45	1523	631	41	1146	414	36
BPN	1170	611	52	821	473	58	605	295	49
SFV	1223	654	53	970	500	52	508	284	56
LND	1109	464	42	1005	367	37	613	294	48
MMR	1274	364	29	1096	508	46	620	314	51
Average	1223	574	47	1079	494	47	714	343	50

NB: Ext. % - percentage extractability of anthocyanins

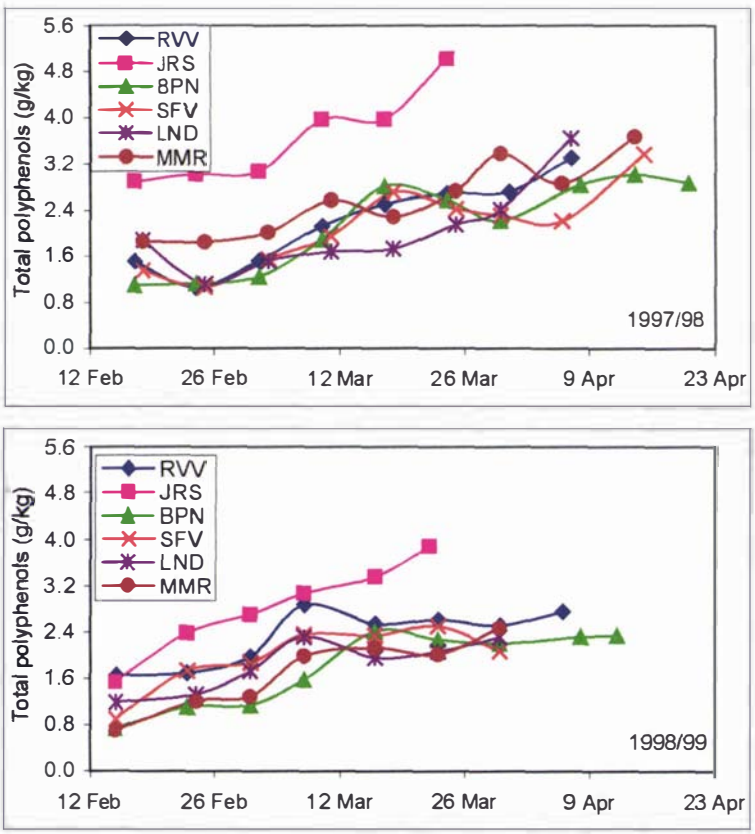

Figure 34. Total polyphenols (g/kg) concentration in Cabernet Sauvignon berry skin extracts at six selected sites in Hawke's Bay during berry development and ripening in the 1997/98 and 1998/99 seasons

There were also considerable differences in concentration of extractable polyphenols in berry skin extracts at harvest between sites and seasons (Table 52). Berry skins collected in 1998/99 had a considerably lower concentration of extractable polyphenols compared with previous two seasons. Over the period of three seasons, the LND and MMR sites were mostly lower than average in extractable polyphenols, while the others were mostly above the seasonal average. Percentage of extractable polyphenols varied between sites; RVV tended to have a relatively good extractability of polyphenols, while JRS and LND were mostly lower than the seasonal average. Overall, the lowest extractability of polyphenols was measured in the MMR berries in 1996/97 (28%). An obvious similarity existed between the percentage extractability of polyphenols and that of anthocyanins (Table 51).

Table 52. Concentration of total and extractable polyphenols (mg/kg of fresh weight) in Cabernet Sauvignon berry skins at harvest at six selected sites in Hawke's Bay in the 1997/98 and 1998/99 seasons

	1996/97			1997/98			1998/99		
	Total	Extractable	Ext. %	Total	Extractable	Ext. %	Total	Extractable	Ext. %
RVV	4117	2636	64	3296	1411	43	2752	1555	56
JRS	4202	1894	45	5020	2114	42	3870	1470	38
BPN	4107	2100	51	2867	1669	58	2339	997	43
SFV	4520	2195	49	3359	1634	49	2068	1064	51
LND	3726	1529	41	3634	1254	35	2307	1045	45
MMR	3724	1052	28	3665	1703	46	2473	1182	48
Average	4066	1901	46	3640	1631	45	2635	1219	47

NB: Ext. % - extractability percentage of polyphenols

Total polyphenol concentration had an overall range 0.61 - 5.74 mg per berry, the latter being considerably higher than the maximum of about 2.4 mg reported by Yokotsuka *et al.* (1999) for Cabernet Sauvignon grown in experimental vineyards in Japan.

Yield and Yield Components

Bud and cluster number varied little between seasons and more between sites (Table 53). The RVV site was characterised by relatively high bud fertility (number of clusters per bud) in both the 1997/98 and 1998/99 seasons.

Table 53. Bud and cluster number in Cabernet Sauvignon grapevines at six vineyard sites in Hawke's Bay in the 1997/98 and 1998/99 seasons

	1997/98				1998/99			
Site	Buds / m^2	Clusters / m^2	Clusters / bud	Clusters / shoot	Buds / m^2	Clusters / m^2	Clusters / bud	Clusters / shoot
RVV	8.6	12.4	1.4	1.3	9.5	14.8	1.6	1.8
JRS	8.3	10.1	1.2	1.5	8.5	10.5	1.2	1.4
BPN	7.6	11.3	1.5	2.0	7.8	7.8	1.0	1.0
SFV	6.6	7.4	1.1	1.0	9.8	7.6	0.8	0.9
LND	10.5	9.9	0.9	1.7	11.7	12.5	1.1	1.6
MMR	11.0	9.3	0.8	0.8	11.0	14.1	1.3	1.8
Mean	8.8	10.1	1.2	1.4	9.7	11.2	1.2	1.4

Yield of grapes varied significantly between seasons and sites (Table 54). Yield was higher in 1997/98 than in 1998/99, and at RVV and LND than at other four sites.

Table 54. Grape yield (kg/m^2) in Cabernet Sauvignon at six sites in Hawke's Bay in the 1997/98 and 1998/99 seasons

Site	Season 1997/98	Season 1998/99	Average
RVV	1.799a	1.352ab	1.576A
JRS	0.893c	1.007bc	0.950B
BPN	1.746a	0.618bd	1.182B
SFV	1.145b	0.753cd	0.949B
LND	1.566a	1.590a	1.578A
MMR	1.087b	1.118b	1.102B
Average	1.373A	1.073B	

Note: the values marked with a different capital letter are significantly different for the factors Season and Site. Those with different lower case letters are significantly different for the interaction Site x Season. Tested by LSD test and significant at $p<0.05$.

Yield in 1997/98 was higher than in 1996/97 (Table 55) because of increased cluster number (10.1 and 6.5 clusters/m^2 respectively). On the other hand, yield was higher in 1997/98 than in 1998/99 primarily as a result of different cluster weight (136.6 and 95.4 g respectively). Yield was correlated with cluster weight ($r=0.73$) and not with cluster number per unit surface area in the 1997/98 and 1998/99 seasons. Yield at BPN in the 1998/99 season was highly affected by poor berry set at this site (Chapter 6, Table 40).

Berry weight was relatively high at all sites in 1996/97 (mean 1.62 g), while in 1997/98 and 1998/99 RVV and JRS sites were characterised by lower berry weight than at the other four sites. Low cluster weight in 1998/99

(mean 95.4 g) was associated with a relatively poor berry set in that season (28.2%).

Table 55. Cluster number and weight, berry weight and grape yield in Cabernet Sauvignon at six selected sites in Hawke's Bay over three seasons

	1996/97*				1997/98				1998/99			
	Cluster weight (g)	Cluster number / m^2	Yield (kg/m^2)	Berry weight (g)	Cluster weight (g)	Cluster number / m^2	Yield (kg/m^2)	Berry weight (g)	Cluster weight (g)	Cluster number / m^2	Yield (kg/m^2)	Berry weight (g)
RVV	139.8	5.4	0.749	1.58	145.3	12.4	1.799	1.14	91.3	14.8	1.352	1.27
JRS	121.4	6.7	0.819	1.74	88.3	10.1	0.893	1.04	95.5	10.5	1.007	1.23
BPN	135.6	8.0	1.089	1.46	155.2	11.3	1.746	1.39	79.2	7.8	0.618	1.50
SFV	152.0	4.0	0.614	1.66	155.2	7.4	1.145	1.39	99.7	7.6	0.753	1.33
LND	189.3	6.4	1.215	1.85	158.6	9.9	1.566	1.48	127.1	12.5	1.590	1.63
MMR	146.9	8.5	1.249	1.40	116.8	9.3	1.087	1.43	79.3	14.1	1.118	1.57
Mean	147.5	6.5	0.956	1.62	136.6	10.1	1.373	1.31	95.4	11.2	1.073	1.42

* - Estimated cluster weight and yield

Weight, TSS and Seed Number Variability in Berries

At harvest in 1997/98 a sample of 40 berries from the JRS site was analysed for individual TSS, berry weight and seed number (Table 56). Berry weight was strongly correlated with seed number (r=0.72).

Table 56. Berry weight, seed number and TSS at the JRS site at harvest 1997/98

Variable	Mean	Minimum	Maximum	Standard Deviation
Berry weight (g)	0.99	0.38	1.52	0.24
TSS (°Brix)	22.73	20.40	26.00	1.54
Seed Number	1.58	1.00	3.00	0.59

There was no correlation between berry weight and TSS. When berries were grouped into three categories based on weight (small <0.8 g, medium 0.8-1.2 g, large > 1.2 g), small and medium berries had larger TSS level, but differences were not statistically significant. Large berries had a mean of 2.25 seeds, medium 1.48, and small berries had 1 seed on average.

Discussion

A large number of variables observed during fruit ripening and of correlations between those variables (presented in Appendix 10, page 262)

make it difficult to determine the major factors that contributed to differences in fruit composition of Cabernet Sauvignon grapes observed in this study.

Principal Component Analysis (PCA) was utilised in order to extract the most important factors that would explain the site-related effects on fruit composition. PCA was applied to 61 variables observed at six Cabernet Sauvignon vineyard sites in the 1997/98 and 1998/99 seasons. These variables represented vine vegetative growth, phenology, yield components, fruit composition and environmental characteristics of the observed sites.

PCA extracted two factors (Table 57) that were able to explain 63% of the total variance in data. The percentage of variance unaccounted for is suggested to have originated from vineyard management practices that were not analysed, as well as from certain environmental conditions that were not monitored, such as the water table level.

Table 57. Factor loadings calculated by the Principal Component Analysis (PCA) of data obtained at six vineyard sites in the 1997/98 and 1998/99 seasons (rotation: Varimax Normalised)

Variable	Factor 1	Factor 2	*Description*
CLWG	-0.266	0.650	*Cluster weight*
NOCL	-0.022	-0.204	*Number of clusters*
YLD	-0.232	0.395	*Yield*
IPF	0.494	0.024	*Index of precocity for flowering (defined in Chapter 2, pg 27)*
IPV	0.777	0.035	*Index of precocity for véraison (defined in Chapter 2, pg 27)*
IPCY	0.735	0.035	*Index of precocity for the cycle (defined in Chapter 2, pg 27)*
BWG	-0.510	-0.295	*Berry weight*
SHL	-0.818	-0.108	*Shoot length in mid-January*
PRWG	-0.867	-0.139	*Pruning weight*
YPRAT	0.641	0.384	*Yield to pruning weight ratio*
CDI	-0.773	-0.293	*Canopy Density Index*
NF	-0.522	0.020	*N in leaf petioles at flowering*
PF	0.137	0.375	*K in leaf petioles at flowering*
KF	-0.214	0.094	*P in leaf petioles at flowering*
CAF	-0.082	0.672	*Ca in leaf petioles at flowering*
MGF	0.065	0.621	*Mg in leaf petioles at flowering*
PHE	0.816	0.160	*Total polyphenols in berry skin*
AC	0.779	0.319	*Total anthocyanins in berry skin*
TAR	0.043	0.548	*Tartaric acid in juice*
MAL	-0.508	-0.608	*Malic acid in juice*
TMR	0.312	0.744	*Tartaric / malic acid ratio*
KJCE	0.321	-0.519	*Potassium in juice*
TSS	0.736	0.417	*TSS in juice*
TA	-0.753	0.160	*TA in juice*
PH	0.396	-0.221	*Juice pH*
IR	0.830	0.069	*Index of Ripeness*
MI	0.480	0.608	*Maturity Index TSS/malic acid*pH*

SFO	0.814	-0.349	*Soil Factor for October*
SFN	0.881	-0.116	*Soil Factor for November*
SFD	0.779	0.392	*Soil Factor for December*
SFJ	0.732	0.479	*Soil Factor for January*
SFF	0.749	0.437	*Soil Factor for February*
SFM	0.744	0.401	*Soil Factor for March*
TO	0.047	-0.931	*Mean air temperature for October*
TN	0.197	0.877	*Mean air temperature for November*
TD	0.732	0.400	*Mean air temperature for December*
TJ	0.773	-0.226	*Mean air temperature for January*
TF	0.181	0.930	*Mean air temperature for February*
TM	0.279	0.892	*Mean air temperature for March*
TAL	0.102	0.937	*Mean air temperature for April*
WIO	0.190	0.766	*Rainfall + Irrigation for October*
WIN	0.043	-0.782	*Rainfall + Irrigation for November*
WID	0.137	-0.908	*Rainfall + Irrigation for December*
WIJ	0.000	-0.909	*Rainfall + Irrigation for January*
WIF	0.086	0.487	*Rainfall + Irrigation for February*
WIM	0.019	-0.859	*Rainfall + Irrigation for March*
WIA	0.055	-0.911	*Rainfall + Irrigation for April*
WIS	0.060	-0.912	*Rainfall + Irrigation for October-April*
STO	0.553	-0.741	*Soil temperature in October*
STN	0.786	0.055	*Soil temperature in November*
STD	0.816	0.292	*Soil temperature in December*
STJ	0.884	-0.117	*Soil temperature in January*
STF	0.735	0.541	*Soil temperature in February*
STM	0.845	0.358	*Soil temperature in March*
SMO	-0.838	0.240	*Soil moisture content in October*
SMN	-0.742	0.370	*Soil moisture content in November*
SMD	-0.228	-0.811	*Soil moisture content in December*
SMJ	-0.359	-0.821	*Soil moisture content in January*
SMF	-0.385	-0.777	*Soil moisture content in February*
SMM	-0.342	-0.817	*Soil moisture content in March*
Expl.Var	18.857	18.814	*Explained Variance*
Prp.Totl	0.314	0.314	*Proportion of the Total Variance*

This analysis shows that Factor 1 mostly corresponds to the below-ground environmental conditions and is associated with many important attributes of vine growth, phenology and fruit composition. Factor 2 mostly corresponds to the above-ground conditions and, with respect to fruit attributes, is associated with malic and tartaric acids in juice and their ratio.

A scatterplot of these two factors (Figure 35) shows a grouping of certain variables that closely corresponds to their mutual correlations; the closer the variables are in this graph, the stronger their positive correlation is, and the further they are, the stronger their negative correlation is. Furthermore, the closer variables are to the values of 1 or –1 for each of the Factors, the

stronger their correlation is with the respective Factor. Prominent similarities are noticeable between this analysis and the PCA done by Barbeau *et al.* (1998b) using 23 variables of phenology, growth and fruit composition collected at 11 Cabernet Franc vineyard sites of the Loire Valley (France).

In quadrant 1 (Figure 35) the most important fruit quality attributes are found along soil-related environmental attributes. Indices of maturity, yield to pruning weight ratio and mean air temperature for December are found in the large group on the right hand side of this quadrant. This section appears to represent 'fruit quality variables'. The association between fruit attributes such as TSS and air temperatures is in accordance with the findings of Zelleke and Kliewer (1979).

As Calo *et al.* (1996) stated, although the positive effect of temperature on sugar accumulation has been clearly demonstrated, this relationship is always dependent on the crop level and the amount of water available to vines. Therefore the negative relationship between soil moisture content and TSS can be explained through a reduction of water available to grapevines. Ferrini *et al.* (1996) found a significant increase in TSS in grapes of cv Sangiovese grown with various cover crops that reduced available soil water and nutrients.

Although there is a similarity between TSS curves in 1997/98 and 1998/99 those for JRS and BPN sites are clearly different, with other four sites in between (Figure 25). The maximum weekly increase in TSS content per berry occurred at JRS relatively early in both seasons (39.3 mg/berry in the week 10-17/2/1998, and 34 mg/berry in the week 26/1-2/2/1998). The maximum weekly increase in TSS at the MMR site in 1997/98 also occurred early in the week 4-11/2/1998 (53.7 mg/berry). At other sites maximal changes in TSS content were observed later in both the 1997/98 and 1998/99 seasons, and they usually occurred in the last week in February or the first week in March.

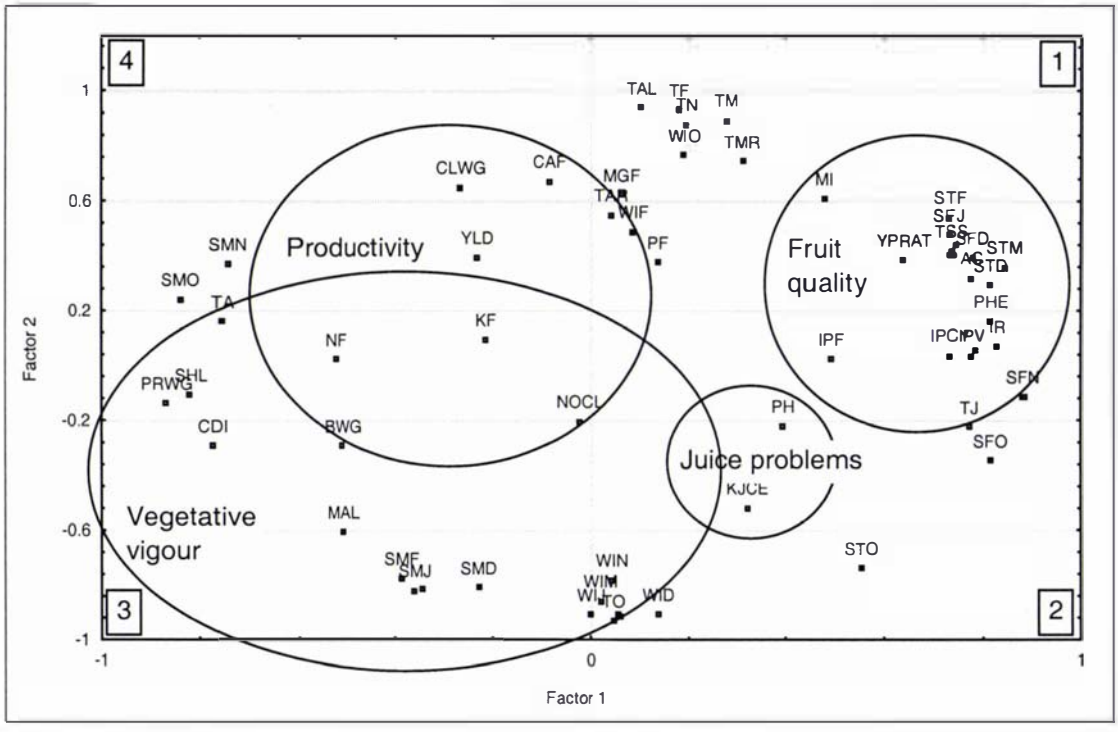

Figure 35. Principal component analysis (PCA) of 61 variables collected at six vineyard sites in the 1997/98 and 1998/99 seasons

At most sites decreases in the weekly TSS per berry accumulation rates occurred simultaneous with weekly rainfall > 25 mm. A decrease in the weekly TSS accumulation rate also occurred at the BPN site in 1998/99 in the period 18 February-11 March. In the same period the number of actively growing shoots at that site peaked twice (see Chapter 5, page 103). This indicates that the competition for carbohydrates between shoots and berries at this site affected fruit ripening unfavourably.

On the other hand, the weekly TSS per berry accumulation rate decreased twice during 1997/98 and once in 1998/99 at the JRS site. These decreases coincide with reduced soil moisture content at that site (Chapter 4, Figure 10). It is suggested that this decrease in sugar accumulation in berries was caused by excessive water stress evident at this site in that period. Meriaux *et al.* (1979) found a decrease in berry sugar in Cabernet Sauvignon when water stress occurred during véraison. Low levels of available soil water are known to cause stomatal closure and inhibition of photosynthesis (Liu *et al.*, 1978). This can reduce the amount of carbohydrates available for berries,

although it has been experimentally shown that grapevines can retranslocate their carbon reserves from the permanent vine parts to fruit under stress conditions (Candolfi-Vasconcelos *et al.*, 1996).

Soil moisture content and soil temperatures both affected TSS accumulation significantly (Figure 36). The quadratic surface shows that both high and low levels of soil moisture appear to have affected TSS accumulation negatively. This was the case at the RVV and BPN sites in 1997/98 when it was dry and in 1998/99 when it was moist. It is suggested that a relatively high crop level in 1997/98 at these sites affected TSS negatively. Sites JRS, MMR and SFV were characterised by high soil temperatures and low soil moisture content and hence achieved the highest TSS level by 23 March. Freeman and Kliewer (1983) established that TSS was reduced by irrigation in cv Carignane compared to non-irrigated vines, which is analogous to the effect of increased soil moisture content on TSS observed in this study.

Quadrant 1 also shows that Soil Factor (SF) variables were quite close to those representing total anthocyanin concentration in berry skins (Figure 35). Simple linear regression between SF for January and total anthocyanins at harvest (Figure 37) is significant ($y=0.5756+0.2533*x$, $R^2=0.75$, $p<0.0001$) and value of SE is 0.154 g/kg. This relationship is very similar in the case of total polyphenols and SF. The JRS site stands out by its high anthocyanin concentration, while those with low January SF value were low in anthocyanins (for example SFV and BPN).

Maccarrone *et al.* (1995, cit. Scienza *et al.* 1996) found that soil type has a significant effect on anthocyanin content in Cabernet Sauvignon wines produced in Tuscany, Italy. Wine anthocyanins were higher from grapes grown on a sandy soil (A) than from a silty-clayey soil (B). Although soil temperature or moisture data for the mentioned experiment are not available, it can be assumed that the SF value was greater at A than at B. This corresponds to the findings of Bourzeix *et al.* (1977) that water stress increased anthocyanins and phenolics in cv Cabernet Sauvignon, and of Freeman and Kliewer (1983) that unirrigated cv Carignane vines had

significantly more anthocyanins in berry skins than fruit from irrigated vines. Also, Freeman (1983) established that irrigation reduced anthocyanins in cv Shiraz. Presumably this effect of soil water status on anthocyanin content in fruit arises mostly from clusters being shaded by increased vegetative growth that is associated with high soil water availability. Scienza *et al.* (1996) stated that these shading effects resulting in lower anthocyanin concentration in berries and in juice can be overcome by appropriate anthocyanin extraction techniques during winemaking. To some extent the effect of site on skin pigments was through different berry size, as total anthocyanin concentration was negatively correlated with berry weight. Therefore smaller berries with their higher skin to volume ratio had increased anthocyanin concentration compared to larger berries. A similar relationship was established in cv Shiraz by Freeman (1983) and Gray *et al.* (1997). Certain aspects of the effect of site on extractability of anthocyanins will be discussed in Chapter 8 (page 190).

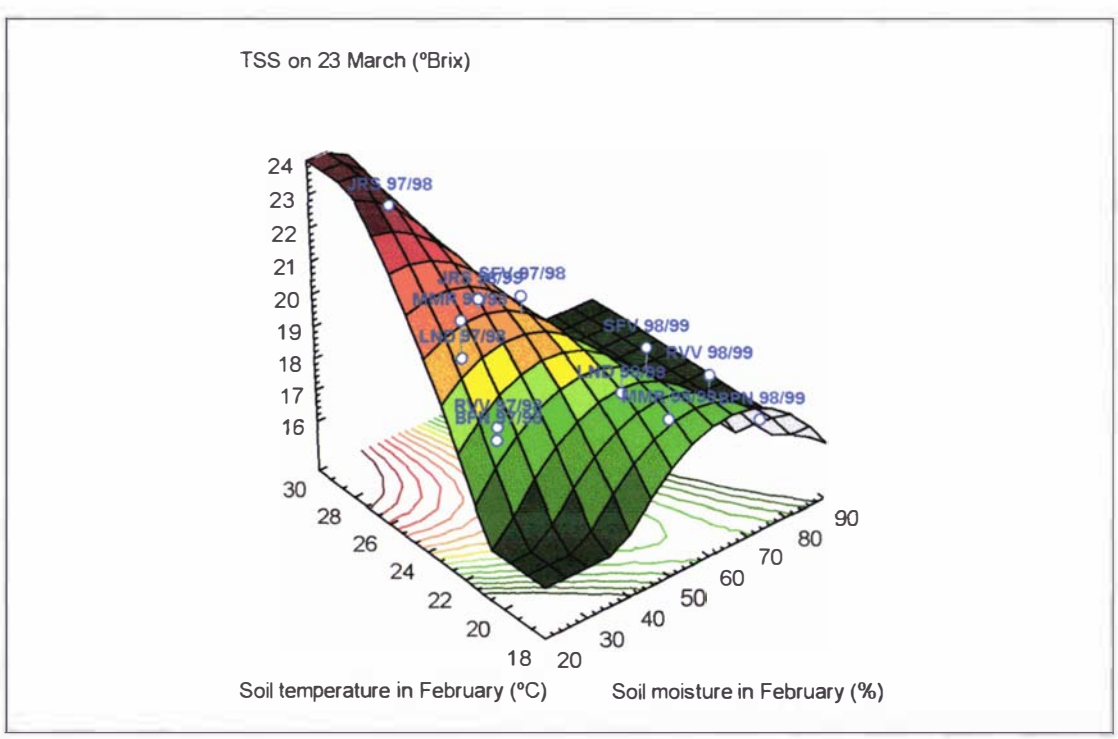

Figure 36. The relationship between soil moisture content in the 0-30 cm profile and soil temperature at 30 cm in February and TSS in juice measured on 23 March, based on data collected at six vineyard sites in the 1997/98 and 1998/99 seasons

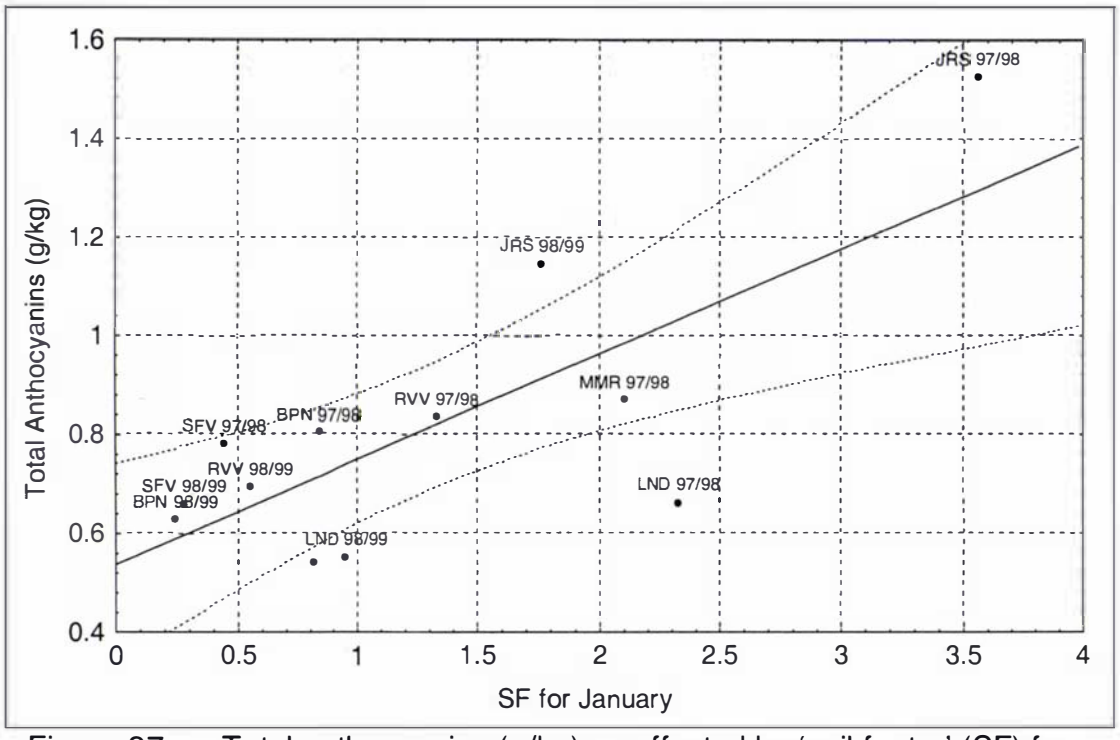

Figure 37. Total anthocyanins (g/kg) as affected by 'soil factor' (SF) for January. Regressions are based on data for six Cabernet Sauvignon vineyard sites in the 1997/98 and 1998/99 seasons.
Dotted lines show 95% confidence boundaries

Regressions between SF, which represents soil physical characteristics, temperature and moisture and total polyphenols and anthocyanins accumulated in berry skins at harvest exhibit the effect of 'terroir' and season on this aspect of fruit maturation and quality. SF for February and March exhibit similar relationships with berry skin anthocyanins and polyphenols, however the regression of SF for January onto these berry skin compounds could be potentially more useful for forecasting than those of subsequent months.

Anthocyanin accumulation in berries starts at or shortly after the increased accumulation of sugars (Kanellis and Roubelakis-Angelakis, 1993), although trace levels of anthocyanins were detected in berries before that (Hrazdina *et al.*, 1984). The present results show a marked difference between sites in total anthocyanin concentration measured after mid-véraison. Quadrant 1 shows a large distance between CDI and

anthocyanins and polyphenols (Figure 35). This corresponds to the effect of shoot density and leaf area on concentration of anthocyanins and phenolics in berries of cv Merlot established by Mabrouk and Sinoquet (1998). Carbonneau *et al.* (1987) found a marked increase in anthocyanin synthesis in Cabernet Sauvignon grapevines on SO4 rootstock in training systems with exposed canopies compared to systems with shaded canopies. The authors suggest that this effect of exposed canopies occurred as a result of moderate water stress being generated in such vines. In comparison, vines with shaded canopies had low stomatal conductance with a subsequent reduction in gross photosynthesis.

CDI and berry weight were two variables with a similar effect on skin anthocyanins (Figure 38). The regression of CDI and berry weight on total anthocyanin concentration in berry skin can be expressed as AC=2.37–0.88*BW–0.85*CDI (R^2=0.793, $p<0.001$, SE=0.14 g/kg), where AC = total anthocyanins in g/kg of fresh weight and BW = berry weight (g). AC and BW were measured on 23-25 March and CDI was determined at véraison. This relationship indicates that small berries in combination with sparse vine canopies appear to be favourable for accumulation of anthocyanins in berry skins, while dense canopies and large berries will result in poor anthocyanin concentration. There appears to be a synergetic effect of sparse canopies and low berry weight on increase in skin anthocyanins: the multiple coefficient of correlation between these variables was R=0.89, while coefficients of partial correlations were r=–0.54 (with berry weight) and r=–0.46 (with CDI). Berries at JRS, a site characterised by low both the CDI and berry weight, attained the highest concentration of anthocyanins. Low anthocyanins were at BPN (a site with high CDI) and LND (a site with large berries). At the MMR site large difference in characteristics of canopy, berry weight and anthocyanins are noticeable between the 1997/98 and 1998/99 seasons. The results of wine sensory evaluation presented in Chapter 8 will also show that wines from respective seasons differed significantly. It is likely that less favourable canopy density, larger berry weight and lower anthocyanins in 1998/99 than in 1997/98 contributed to the mentioned difference in wine sensory characteristics.

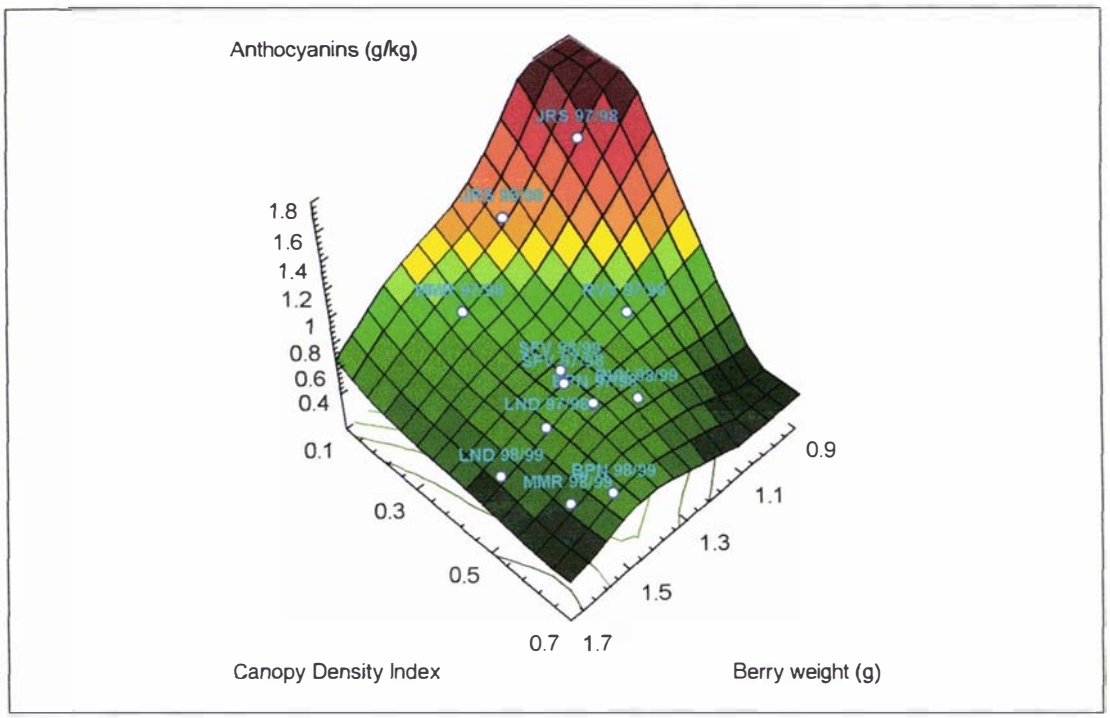

Figure 38. The relationship between berry weight (g), Canopy Density Index (CDI) and total anthocyanins in berry skins (g/kg fresh weight) based on data collected at six vineyard sites in the 1997/98 and 1998/99 seasons

As Calo *et al.* (1996) pointed out, canopy properties and soil physical characteristics are often overlooked factors when considering environmental influences on sugar accumulation. Relationships established in the present study between TSS accumulation and CDI and SF indices clearly show that the above observation by Calo *et al.* (1996) is correct.

In quadrant 2 (Figure 35) pH and K concentration in juice are relatively close and they may point to 'problem musts', high pH and K both being unfavourable for winemaking. Morris *et al.* (1983), Hepner *et al.* (1985) and Ruhl *et al.* (1988) also determined a positive correlation between juice K and pH in different cultivars. A lack of correlation between the leaf petiole K and wine pH was observed by Dundon *et al.* (1984) in cv Shiraz, while present results for three seasons show a moderate correlation between leaf petiole K at véraison and juice pH at harvest.

Hardie (1981) found a lower K concentration in berries of cv Zinfandel that were subjected to water stress compared to berries from unstressed vines, and Freeman and Kliewer (1983) found that irrigation of cv Carignane increased K concentration in fruit. The high K concentration in berries at the BPN site could be thus explained by absence of water stress or, as Hardie (1981) stated, by strong vegetative growth that enhanced redistribution of this element from leaves to fruit. In the light of this, the relatively high K that was established in the JRS berry samples in 1998/99 might indicate that vines at this site were not highly water-stressed as in 1997/98.

In quadrant 3, vine vigour variables are dominant, and N status of vines is also close (Figure 35). Soil moisture variables are grouped together, close to those of rainfall and irrigation. Significant fruit attributes such as berry weight and malic acid concentration are also in this quadrant, which points out their mutual correlations. This quadrant can be viewed as to represent the 'potential for vegetative vigour'. A large distance between TSS and CDI (Figure 35) shows that fruit ripening and dense vine canopies were negatively correlated. A similar correlation was established by Mabrouk and Sinoquet (1998) between shoot density and sugar concentration in the must. From the results presented it appears that high SF enhanced TSS in fruit mainly through reducing excess canopy density as a result of reducing vine vigour. Spiegel-Roy and Bravdo (1964) and Kliewer *et al.* (1983) showed that increased water supply, which can probably be associated with high CDI values, delayed ripening in various grapevine cultivars.

Accumulation of malic acid in berries was similar to results from Hrazdina *et al.* (1984) for cv De Chaunac, where malic acid accumulation continued until late July (corresponding to late December in the Southern Hemisphere). In cv Cabernet Sauvignon malic acid accumulation lasted until late January, probably because of this cultivar is late maturing. The same authors found an overall decline in tartaric acid, interspersed with brief periods of renewed tartaric acid synthesis particularly during February. Tartaric acid concentration at several stages during ripening was generally not correlated with above-ground factors. Malic acid changes were positively correlated

with TA weekly change rates (r=0.49), indicating that TA changes were mostly due to changes in malic acid. Malic acid is known to be degraded with greater intensity during ripening compared to tartaric acid, which is relatively stable due to its slower metabolism (Calo *et al.*, 1996).

The relationship between tartaric acid content in ripening berries and the relief of water stress by irrigation or rainfall described by Hardie (1981) has been confirmed in this study. In many cases rainfall >20 mm per week caused an increase in tartaric acid content on a per berry basis. In 1997/98 for every 10 mm of rainfall that fell during the week, tartaric acid content increased by 0.6 mg/berry. In the 1998/99 season, when water stress was less severe at most sites than in 1997/98, every 10 mm of weekly rainfall increased tartaric acid by 0.2 mg/berry.

Malic acid concentration in juice at harvest was correlated with air and soil temperatures (large distances between variables, Figure 35) and rainfall (relatively close). According to Kanellis and Roubelakis-Angelakis (1993), the relationship between malic acid and temperatures during ripening is due to increased respiratory rates and to switching the main respiratory substrate from glucose to malic acid. The increase in malic acid with increased soil water supply (Figure 39) was noted by Hardie (1981), and can be ascribed to the indirect effect of increased vegetative growth associated with higher soil water supply. Stevens (1995) observed a decline in malate concentration with increasing water stress in cv Colombard, which closely corresponds to our findings in cv Cabernet Sauvignon.

Quadrant 4 (Figure 35, page 162) is characterised by early-season soil moisture variables, titratable acidity, N and K concentration in leaf petioles at flowering. It also has yield and cluster weight variables, and hence can be referred to as the 'productivity' section of this graph.

Fruit quality attributes were clearly opposed to those of vegetative growth and soil moisture (Figure 35). In the 1997/98 and 1998/99 seasons grape yield did not appear to have had a negative effect on fruit attributes as it is frequently assumed. Phenology, as expressed by indices of precocity, was

a clear indicator of the potential fruit quality. The large distance between the early-season soil moisture content (Smo, Smn) and fruit quality attributes shows that seasons that start off with a high soil moisture content, which is common after significant winter rainfall, have less potential to produce quality fruit than those with dry soil conditions in spring.

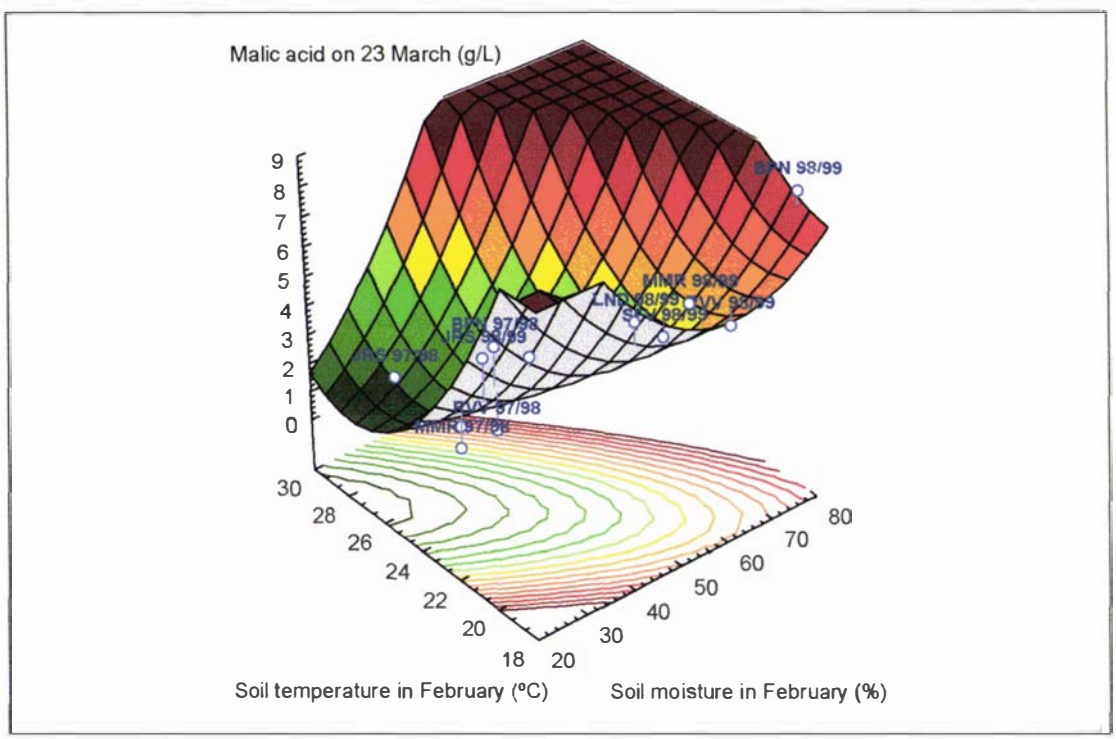

Figure 39. The relationship between malic acid in juice (g/L) on 23 March and soil temperature at 30 cm and soil moisture in the 0-30 cm profile in February based on six sites in the 1997/98 and 1998/99 seasons

The most relevant finding of this analysis is the association between the 'Soil Factor' (SF) and soil temperatures on the one hand, and fruit quality attributes on the other. The SF values for December through March were significantly correlated with fruit composition attributes expressed by the Maturity Index TSS/malic acid*pH measured on 23-25 March (Figure 40). This index will later be shown to correlate well with wine sensory evaluation scores (Chapter 8, page 185). However, the regression of the January SF on fruit composition is most useful for the potential modelling purposes, as it

is stronger than with the December SF, and applicable earlier in the season than when SF for subsequent months are used. This regression equation was $y=8.17+11.52*x$ ($R^2=0.62$, $p<0.01$, SE=9.55). Sites with high SF values, such as JRS, exhibited a high potential for fruit quality, while those with low SF values, as BPN, exhibited the opposite. This relationship is, however, not completely consistent; in 1998/99 the SFV site achieved the best wine sensory characteristics as will be shown in Chapter 8, while its SF was always relatively low.

It could be argued that the inclusion of vine physiological status and processes could greatly improve the accuracy of ripening models presented in this study that are regression-based and empirical. Williams *et al.* (1985) offered a model of sugar accumulation in cv Thompson Seedless. Although essentially based on GDD, this model takes into account the total mass of carbohydrates available for fruit growth from reserves and daily photosynthesis (supply) and the maximum potential for fruit growth (demand). By incorporating photosynthesis into the model, Williams *et al.* (1985) have in effect added solar radiation to degree-days as the environmental factor of ripening. The authors note that significant factors of fruit ripening such as yield/pruning weight ratio and water availability were not included in their fruit maturation model. It should be emphasised that the regression-based ripening models in the present study primarily attempt to quantify the effect of 'terroir' on Cabernet Sauvignon fruit maturation in the Hawke's Bay wine region. Unlike the model of Williams *et al.* (1985) they were not intended to provide a generic model of fruit ripening in grapevines.

Giomo *et al.* (1996) established that there is a lack of direct linear relationship between climatic indices and fruit composition parameters. As bioclimatic indices were aimed at defining the suitability of macroclimate for grapevines, they cannot differentiate between vineyard sites in terms of their qualitative potential. The 'soil factor' (SF), a compound index proposed in the present study (page 92, Chapter 4) appears to offer an assessment of quality potential of vineyard sites. SF is based on soil variables (soil moisture, soil temperature and soil physical characteristics) that are

relatively easy to measure with the aid of modern technology. The SF index is not meant to replace the existing bioclimatic indices, since it was not designed to characterise viticultural regions nor even sub-regions. The concept of 'soil factor', however, offers the potential to be used as an addition to the existing climatic indices in order to characterise the qualitative potential of vineyard sites or 'terroirs'.

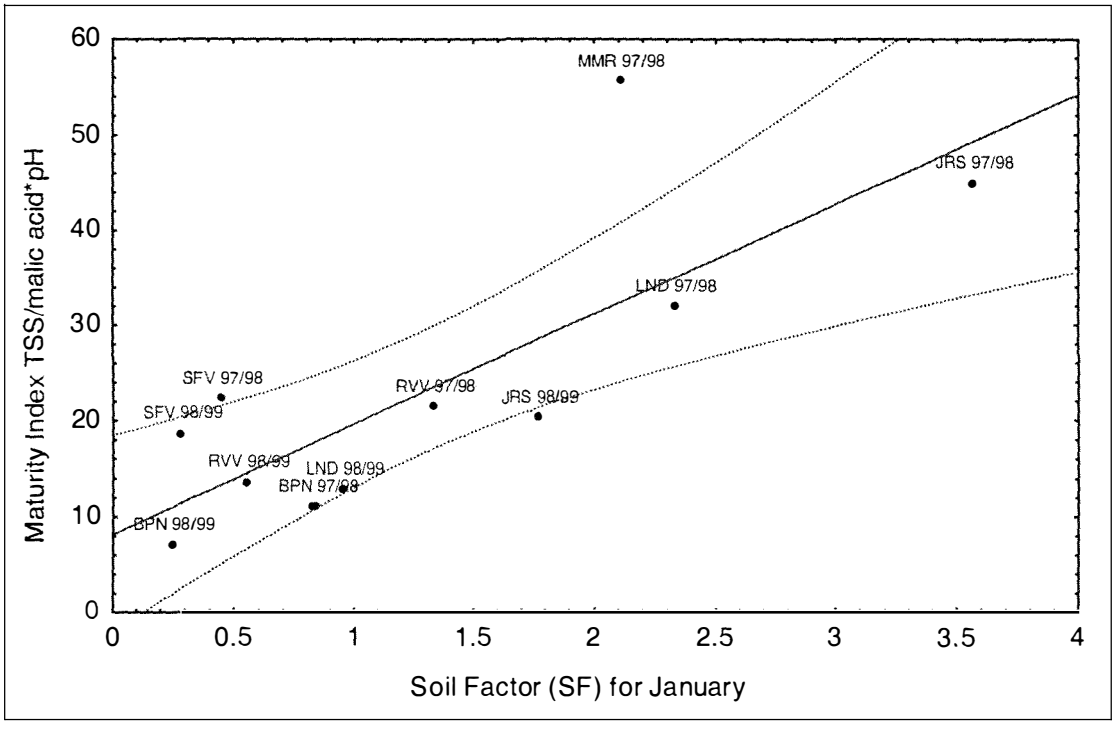

Figure 40. The relationship between the Maturity Index TSS/malic acid*pH and the Soil Factor (SF) for January, based on data for six vineyard sites in the 1997/98 and 1998/99 seasons. Dotted lines show 95% confidence boundaries.

The novel technological approach to viticulture termed 'precision viticulture' (Lamb, 1999) is capable of repeated collecting of large amounts of vineyard information over vast areas: soil electric conductivity, soil moisture, soil depth, impervious layers, and even grapevine canopy characteristics. Overlaying such information with the existing soil maps and applying the concept of 'soil factor' in subsequent analysis could provide a relatively simple and fast method to define local 'terroirs' on a scientific basis. An

analogous method was already applied to define 'terroirs' in the Nyons-Valreas Basin in France by Vaudour *et al.* (1998) (further discussed in Chapter 9, page 211).

Factors that caused fruit variability observed in this study were diverse. That it only took 11 days for véraison to go from 5 to 95% at RVV in 1998/99 was probably the result of poor berry set (18.2%). This poor fruit set resulted in a grape yield of 1.35 kg/m^2, relatively low compared to yield of 1.8 kg/m^2 in 1997/98 at this site. It is hypothesised that the poor berry set at the RVV site in 1998/99 reduced berry-to-berry variability in ripening dynamics by significantly reducing the population of berries from normal, as discussed in Chapter 6 (page 132). This reduction in berry-to-berry variability could explain a relatively short 5-95% véraison period at RVV in 1998/99. Coombe (1989) showed that after the inception of softening in an individual cv Muscat Gordo Blanco berry, its volume and glucose and fructose concentration increased abruptly. According to Coombe, sampling of a population of berries tends to represent these changes as smooth curves due to an unsynchronised berry development. A strong correlation between seed weight and berry weight that was found in this study (page 144) also indicates that conditions during fruit set may have contributed significantly to berry-to-berry variability.

Summary

Phenology of véraison and berry ripening dynamics were studied in cv Cabernet Sauvignon grown at six sites in the Hawke's Bay wine region. Mid-véraison date varied markedly between seasons. Véraison was always earliest at the JRS site and latest at BPN. Phenology of véraison and ripening was significantly affected by soil and air temperatures in January. Berry weight differed between sites significantly throughout ripening and at harvest it was positively correlated with seed weight. Data representing 61 variables of vine vegetative growth, phenology, yield and fruit composition collected at six vineyard sites over the 1997/98 and 1998/99 were analysed by a Principal Component Analysis (PCA). PCA extracted two factors that

explain 63% of the variance in the data. The first factor mostly corresponds to the below-ground environmental conditions and is associated with many attributes of vine growth, phenology and fruit composition. The second factor corresponds to the above-ground conditions and is associated with malic and tartaric acid concentration in fruit. Fruit quality attributes have been found closely associated with soil temperature and the 'Soil Factor', the variable defined and examined in Chapter 4. Soil moisture content in the 0-30 cm profile and soil temperature at 30 cm affected TSS of juice and total anthocyanins and polyphenols concentration in berry skins. Relationships established between SF, which corresponds to soil physical characteristics, and fruit quality attributes exhibit effects of 'terroir' and of season. It appears that high SF values enhanced fruit quality mainly by reducing excess canopy density through a reduction in vine vigour. Grapevine phenology, expressed by indices of precocity, appeared to be a good indicator of the potential fruit quality.

CHAPTER 8. EVALUATION OF CABERNET SAUVIGNON WINES FROM DIFFERENT SITES

Introduction

Most grape characteristics that are relatively easy to determine in a laboratory (such as TSS, TA, or pH), or indices derived from them, are not always well correlated with wine characteristics or wine quality (Du Plessis, 1984; Van Rooyen *et al.*, 1984). To adequately evaluate differences between treatments in viticultural trials it may be necessary to produce wines from small amounts of grapes from each treatment. This procedure is termed microvinification or small-lot winemaking. The microvinification procedure needs to be the same for each treatment, so that all conditions during crushing, fermentation and racking remain the same across all treatments and/or seasons in a trial. It is also desirable for wine lots to be replicated in such studies to allow assessment of winemaking consistency between lots. Therefore the aim of microvinification is to uncover the oenological potential of grapes.

High quality or 'premium' wine is a product with very complex attributes that have several dimensions, including that of time. A simple parameter that would contain the entire information about wine quality does not exist and it is only wine itself that can be used to assess oenological potential of grapes. Scienza *et al.* (1996) stated that wine sensory analysis is the key to integration of viticultural and oenological research with grape and wine production. In principle, fruit expression requires minimal impact of oenological techniques. Some exceptions are 'chaptalisation' or adding sugar to the must in case of very low sugar levels, pH adjustments, and sometimes adding oak chips to assess the effect of oak on flavour expression.

Next to full-scale winemaking, microvinification is the best method to obtain small quantities of wine that can then be used to assess wine organoleptic quality as affected by various viticultural treatments. Reynolds *et al.* (1995) employed the microvinification procedure to assess the effect of vineyard location and leaf removal. Tesic (1996) used sensory and chemical analyses of wines produced by microvinification to assess the merit of different pruning treatments. Costantini *et al.* (1996) used microvinification of cv Prugnolo gentile grapes to characterise different growing environments, while Barbeau *et al.* (1998b) used small-scale winemaking to assess the effect of 'terroir' on wine 'typicity'.

It has been demonstrated in previous chapters (5-7) that viticultural potential for 'terroir' as defined by Morlat (1996, cit. Barbeau *et al.*, 1998a) significantly affected phenology, vegetative growth, fruit development and ripening of cv Cabernet Sauvignon in Hawke's Bay. The aim of this study was to assess whether this 'terroir' effect can be determined by sensory analysis of wines produced by microvinification of grapes picked at selected sites in the 1997/98 and 1998/99 seasons. Assessment of the effect of site-related factors, including harvest date, on wine quality of cv Cabernet Sauvignon in a region that is considered to be marginal for this cultivar (Gladstones, 1992) is of scientific and commercial interest.

Material and Methods

Microvinification

Wines for this evaluation were made from about 40 kg of Cabernet Sauvignon grapes hand-picked at six selected sites (RVV, JRS, BPN, SFV, LND and MMR) during the 1997/98 and 1998/99 seasons immediately prior to general harvest at each site (for harvest dates see Table 58). Grapes were picked from vines in the inner two rows (two bays of vines), from a varying number of vines as vine spacing differed between sites, and until the total weight of picked grapes reached about 40 kg.

Clusters were counted and yield weighed individually for each vine, or from each tier (in two-tiered Scott-Henry vines) or from each cordon sleeve (left and right) when grape yield per vine was very high. Further grape processing as well as the microvinification process are described in detail in Appendix 8 (page 255).

Microvinification (Figure 41) was conducted in the Microvinification Unit of the Horticulture and Food Institute of New Zealand, Havelock North Research Centre during 1998 and 1999.

The must obtained by crushing grapes was analysed for TSS, TA, pH, K and tartaric and malic acid (the last three analyses were done only in the 1997/98 season) prior to inoculation and fermentation. The must extraction procedure was therefore different from that for berry juice analysis (see Chapter 2, page 21). However, analytical procedures were the same as those applied in berry composition analysis.

FTIR Analysis

FTIR (Fourier Transform Infrared) analysis is still under development and evaluation for oenological purposes (Alistair Mowat, pers. comm.). Analysis of the 1997/98 wines was conducted at the Horticulture and Food Institute of New Zealand (HortResearch), Ruakura Research Centre. This analysis was conducted to objectively assess the extent of similarities or dissimilarities between wines from different growing sites. The results obtained are to be considered only as an indication of relative similarity between sites in wine attributes.

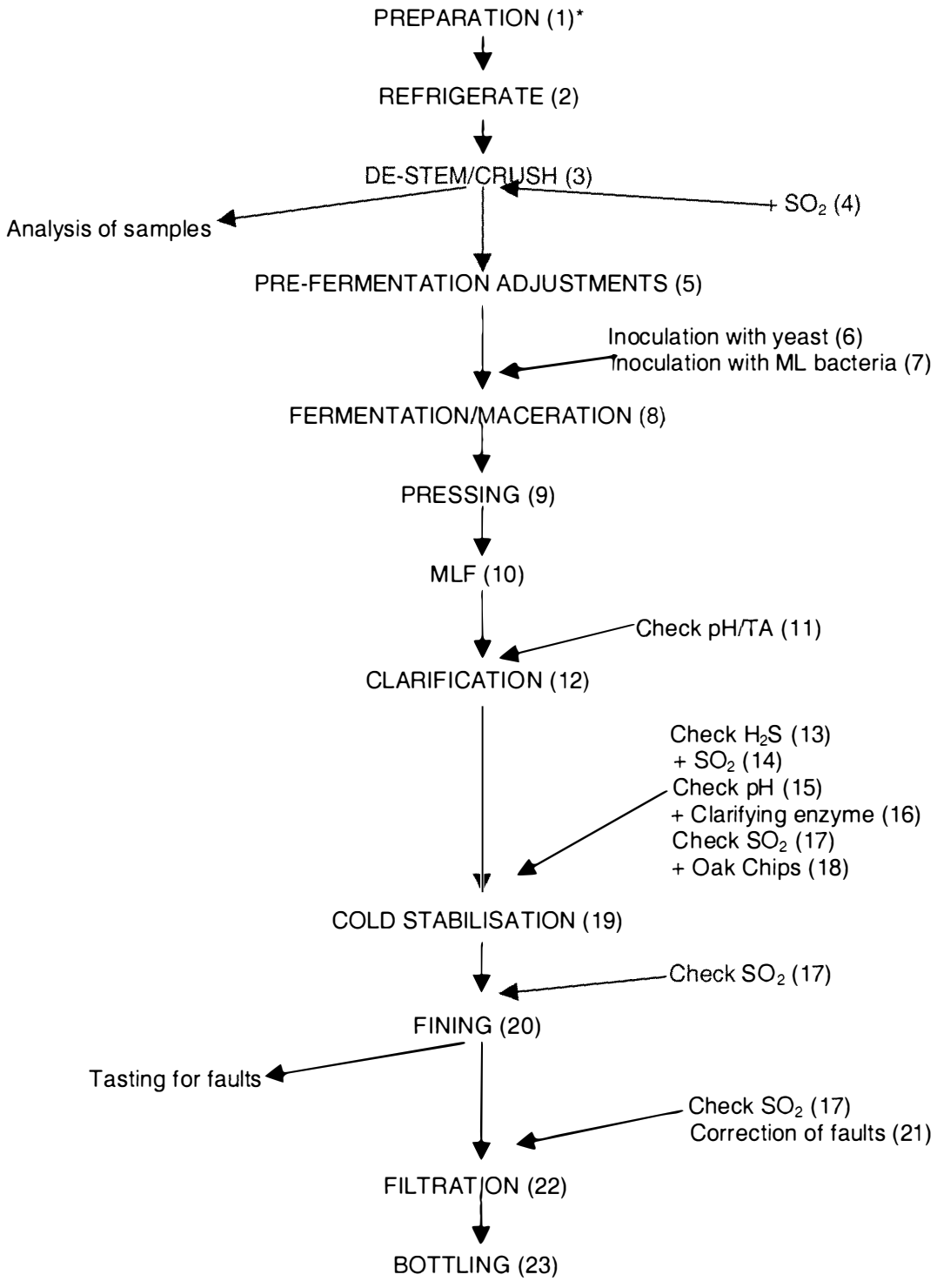

Figure 41. Flow diagram for microvinification of Cabernet Sauvignon grapes.
* - Numbers refer to notes in Appendix 8, page 255.

The FTIR analysis procedure and the statistical interpretation of obtained results were conducted as follows. A sample of wine was extracted from

each bottle using a syringe needle that was passed through the cork. Three drops of wine were placed on an Attenuated Total Reflectance (ATR) Crystal (ZnSe) accessory on a FTIR spectrometer. Spectra were collected from the 4000 to 650 wave number cm^{-1} region. Principal component analysis (PCA) was applied to the population of spectra from the wine samples. The first 20 principal components for the six red wine samples were used for a k-means clustering analysis.

Sensory Analysis of Wines

Descriptive analysis was performed in April 2000 using seven experienced tasters drawn from the School of Wine and Food Sciences staff at Charles Sturt University, Australia. Wines from the six selected sites produced in the 1997/98 and 1998/99 seasons were presented unlabelled as 50 mL samples in clear, tulip-shaped glasses. Each wine was presented in two replicates, each from a different bottle. The total number of wine samples presented was 24. Each wine sample was descriptively assessed for its appearance, nose and palate, and was scored on the common commercial scale 1-20.

Wine scores were statistically analysed as a complete randomised design with two factors (season and site). The factor season had two treatments (the 1997/98 and 1998/99 seasons) and the factor site had six treatments (six sites: RVV, JRS, BPN, SFV, LND and MMR). Each treatment combination was replicated seven times (the scores from seven tasters) with two sub-replicates (two different bottles), giving 14 replicates in all.

Aromatic characteristics of wines assessed by the tasters were summarised using the terminology from the Wine Aroma Wheel (Noble, 1995).

Results

Differences existed between values for TSS, TA, pH, K, tartaric and malic acid (Table 58) in the must used for microvinification and the juice obtained in berry composition analysis (presented in Chapter 7, page 143). They

resulted from different sample sizes and different juice extraction procedures applied in these two processes. Fruit condition at harvest was generally good, particularly in 1997/98. In the 1998/99 season *Botrytis cinerea* infected about 15% of berries at the BPN site. Slight shanking and berry splitting in the same season was noted at the BPN, SFV and MMR sites.

Harvest was later in 1997/98 (7 April on average) than in 1998/99 (2 April on average). TSS values in the must were also higher in the first season (mean 21.5 °Brix) than in the second (mean 20.2 °Brix). The must pH and TA at harvest were similar between seasons, but markedly different between sites, with the BPN site having the highest pH in both seasons, combined with a relatively high TA. Analysis of the must used for microvinification in the 1997/98 season show a markedly higher K content in the BPN must compared to other sites. The ratio of tartaric / malic acid in 1997/98 in the BPN must was lower (0.44) than in musts from other sites (range 0.96-1.74).

Table 58. Cabernet Sauvignon juice and wine analyses in the 1997/98 and 1998/99 seasons

Season 1997/98									
			Juice analysis					Wine analysis	
Sample	Harvest date	TSS (°Brix)*	pH	K (g/L)	TA (g/L)	Tartaric acid (g/L)	Malic acid (g/L)	O.D.** at 280 nm	O.D. at 520 nm
RVV	7/4/98	20.3	3.19	1.12	7.9	5.7	3.6	34	14
JRS	24/3/98	22.0	3.39	1.38	5.9	4.6	3.4	52	26
BPN	20/4/98	20.7	3.62	1.78	7.3	2.9	6.6	43	22
SFV	6/4/98	22.1	3.35	1.32	7.7	4.5	4.7	29	12
LND	7/4/98	21.3	3.15	1.22	8.7	5.3	4.6	30	10
MMR	14/4/98	22.4	3.30	1.18	6.3	4.0	2.3	44	23
Season 1998/99									
			Juice analysis					Wine analysis	
Sample	Harvest date	TSS (°Brix)	pH	K (g/L)	TA (g/L)	Tartaric acid (g/L)	Malic acid (g/L)	O.D. at 280 nm	O.D. at 520 nm
RVV	6/4/99	19.7	3.40	-	7.0	-	-	-	-
JRS	22/3/99	20.8	3.38	-	6.8	-	-	-	-
BPN	12/4/99	18.8	3.63	-	8.2	-	-	-	-
SFV	31/3/99	21.4	3.29	-	7.5	-	-	-	-
LND	2/4/99	20.1	3.21	-	8.6	-	-	-	-
MMR	2/4/99	20.1	3.29	-	8.0	-	-	-	-

* - Musts with TSS<22 °Brix were chaptalised to 22 °Brix; ** – Optical Density

FTIR Analysis Results

Based on the Fourier Transform Infrared (FTIR) analysis of wines (Figure 42), samples SFV and RVV appear similar to each other, but are distinctively different from the other four samples. Wine samples MMR and LND appear similar while the sample from JRS is dissimilar from the remaining samples in this group.

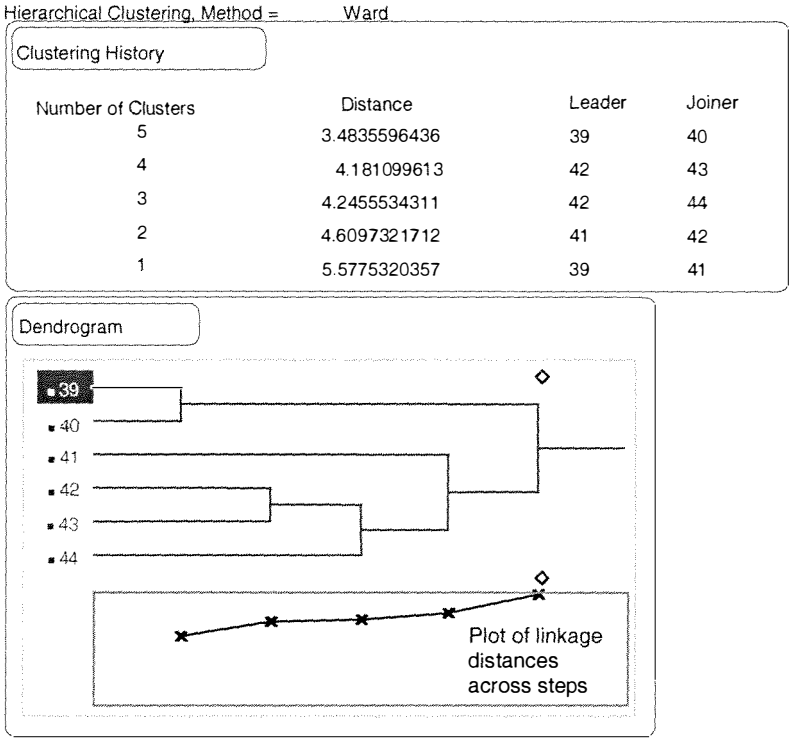

Figure 42. FTIR analysis of 1998 wines and the results of cluster analysis.
The sample numbers correspond to following sites: 39 = SFV; 40 = RVV; 41 = JRS; 42 = MMR; 43 = LND; 44 = BPN.

Wine Sensory Analysis Results

Sensory evaluation of wines showed a significant variability in wine scores between seasons and sites (Table 59). No significant differences were found between the wine replicates, indicating a relative uniformity in wine characteristics between bottles.

The MMR wine was rated the best of the 1997/98 wines, while SFV was ranked the highest among the 1998/99 wines. Season 1997/98 had a mean

score (15.1) significantly higher than 1998/99 (13.4). Site mean was the highest at MMR (15.6), not significantly different from JRS (15.0), LND (14.8) and SFV (14.6). The RVV wine score (14.0) was significantly lower than MMR, but higher than BPN (11.6), the latter being significantly lower than all other mean site wine scores.

Overall, the highest-ranking wines were the MMR 1997/98 wine and the JRS wine from the same season. In both seasons the least preferred was the BPN wine , which may be related to a slightly oxidised character in those wines as noted by some tasters.

Table 59. Wine sensory analysis and scoring of the 1997/98 and 1998/99 seasons' Cabernet Sauvignon wines from six sites in Hawke's Bay

Site and Harvest date	Appearance	Nose	Palate	Mean Score	Comments
		Season 1997/98			
RVV 7/04	Dark plum, cloudy	Stemmy, mild bell pepper, plummy	Short, green, little fruity, thin	14.2bc	
JRS 24/03	Dark plum	Blackberry but slightly grassy, burnt, chocolate	Fine tannins, not aggressive	17.1a	Complex
BPN 20/04	Dark plum, brown hue	Vegetative, cooked/burnt	Soft tannins, bell pepper, poor fruit	11.9d	Slightly oxidised, unbalanced
SFV 6/04	Medium cherry	Stemmy, strong bell pepper, burnt	Medium tannins, bell pepper, medium length, chocolate	14.2bc	
LND 7/04	Medium dark plum	Bell pepper, burnt, plums	Soft, light tannins, fruity (cherry), short, acidic	15.0b	
MMR 14/04	Medium dark plum	Relatively intense, licorice, caramels, bell pepper, blackberry	Soft, light tannins, fruity (cherry), good length	18.3a	Well balanced
		Season 1998/99			
RVV 6/04	Medium cherry	Burnt, licorice, mild dark fruit, strong bell pepper, grassy	Green tannins, short to medium length, medium fruit	13.8bc	
JRS 22/03	Plum	Vegetative (cut grass), burnt, dark cherries	Coarse tannins, short, little fruit, astringent, unripe	12.9c	
BPN 12/04	Dark plum, brown hue	Vegetative – bell pepper, burnt	Green tannin, light, bell pepper, poor fruit	11.4d	Slightly oxidised
SFV 31/03	Dark plum	Mint, burnt, licorice, slight bell pepper, black currant	Soft and fine tannins, short to medium length, licorice	15.0b	
LND 2/04	Dark plum	Mint, hint of grassiness, fruity	Soft tannins, fruity (black cherry), short, acidic	14.5bc	
MMR 2/04	Medium cherry	Mint, plum, burnt, bell pepper	Soft and light tannins, bell pepper, more acid, bitter aftertaste	12.9c	

Note: Scores with the same letter are not statistically different by LSD test at p=0.05

A number of relevant attributes of vine canopy, nutrient status, berry constituents and environmental conditions were significantly correlated with sensory evaluation scores for wines produced by microvinification from selected sites in Hawke's Bay (Table 60).

Wine scores were negatively correlated with grapevine phenology (véraison and date when must achieved IR=20), as well as with K concentration in leaf petioles before harvest. The correlation between wine scores and canopy density index (CDI) was moderately strong and negative. Wine scores were strongly positively correlated with Mg concentration in leaf petioles at all stages of sampling. Moderately strong correlations were found between TSS and TA during March, K, malic acid, and malic/tartaric acid ratio of juice on the one hand, and wine scores on the other. The 'soil factor' values (SF) for the January-March period were moderately positively correlated with wine scores, as was the soil temperature at 15 cm in March.

Table 60. Correlations between wine sensory evaluation score and vine growth, fruit and environmental attributes

Variable	Correlation with wine score (r)
Grapevine phenology	
Number of days from flowering to véraison	--0.643*
Number of days from 1 October to Index of Ripeness = 20	--0.589*
Canopy characteristics and nutrient content	
Canopy Density Index (CDI)	--0.657*
K concentration in leaf petioles before harvest	--0.595*
Mg concentration in leaf petioles at flowering	0.820**
Mg concentration in leaf petioles at véraison	0.734**
Mg concentration in leaf petioles before harvest	0.740**
Berry composition	
TSS in berries on 23 March	0.698*
TA in berries on 2 March	–0.671*
K concentration in berries at harvest	--0.642*
Malic acid content in berries at harvest	--0.761**
Tartaric / Malic acid ratio at harvest	0.776**
Maturity index TSS/malic acid*pH	0.914**
Environmental conditions	
Mean air temperature in March	0.587*
'Soil Factor' (SF) for January	0.647*
SF for February	0.611*
SF for March	0.605*
Mean soil temperature at 15 cm in March	0.659*

* denotes correlation significant at $p<0.05$, ** $p<0.01$

Discussion

Sites characterised by short flowering to véraison periods and by early attaining an index of ripeness (IR, defined in Chapter 2, page 32) of 20 produced wines that achieved high scores. Canopy density index (CDI, defined in Chapter 2, page 29) was positively correlated with both these phenological variables. Coefficients of correlation are r=0.63 between CDI and duration of the period flowering to véraison, and r=0.87 between CDI and the number of days required for grapes to attain an IR of 20. However, CDI was negatively correlated with wine scores. As increased CDI elevated malic acid content in berries at harvest (r=0.62), this, as well as the tartaric/malic acid ratio, had a significant effect on wine score (r=–0.76, r=0.78, respectively). Shaded clusters (associated with high canopy density) appear to have lower temperatures than those well exposed, which was reflected in their increased malic acid content, as discussed in Chapter 7 (page 169). Similar effect of shade on malic acid in Cabernet Sauvignon was established by Smart *et al.* (1988). Works by Jaquinet *et al.* (1982), Van Zyl (1982) and Pszczolkowski *et al.* (1985) on various cultivars associate increased grape quality with low malic acid. Hepner *et al.* (1985) also found a negative correlation between Cabernet Sauvignon wine quality and malic acid content in must.

The relationship between wine sensory score and vine nutrient status was found to apply only with K and Mg (and K/Mg ratio). Potassium concentration in leaf petioles before harvest, as well as K concentration in berries at harvest (positively correlated between themselves, r= 0.77), were both correlated negatively with wine score (r=–0.60 and –0.64 respectively). Similarly, K/Mg ratio at véraison was correlated with wine score (r= –0.64). Although levels of K in leaf petioles and juice were correlated with juice pH (as discussed in Chapter 7, page 167), pH and wine score were not correlated. A negative correlation between Mg concentration in leaf petioles with wine sensory evaluation scores indicates that the empirical association of SO4 rootstock with unfavourable wine characteristics of Cabernet Sauvignon, which is a common anecdotal observation among grape

growers in Hawke's Bay (as discussed in Chapter 2, page 21), may be well founded. It is believed that SO4 rootstock can potentially cause Mg deficiency in grapevines grown in New Zealand conditions, especially on sandy soils (Anon., 1997).

Wine scores were correlated with TSS on 23 March (r=0.70) and TA on 2 March (r=–0.67), but these juice compounds measured at harvest were not correlated with wine scores. It is possible that this occurred because harvest date was not a common date, and not based on the grapes attaining a common ripeness index or other common parameter connected with physiological ripening of grape berries. The fruit ripening season can be relatively long in cool climates, and the fruit is often subjected to unfavourable weather conditions and pests and diseases, which can lead to harvests earlier than optimal for the desired wine quality. It is also possible that those early TSS and TA values may be related to aroma development (not determined in this study), and then be expected to correlate well with wine scores (see Table 60). Strauss *et al*. (1987) established a good relationship between TSS and certain aromatic precursors in cv Riesling from early stages of fruit ripening through to harvest. A comprehensive literature overview regarding aroma compounds in grapes by Van Rooyen *et al*. (1984) showed variability in their behaviour during ripening. Coombe and McCarthy (1997) stated that the accumulation of aroma in the grape berry differs significantly from the accumulatory processes previously associated with berry ripening (ie sugar accumulation).

Overall the best correlation between fruit composition and wine sensory evaluation score was established when the maturity index TSS/malic acid*pH was used, where all the fruit composition variables were measured on 23-25 March. Values of this index ranged from 7.2 (at BPN in 1998/99) up to 55.8 (at MMR in 1997/98). The linear regression between this maturity index and wine score was significant at $p<0.0001$ (Figure 43).

Previously, Van Rooyen *et al*. (1984) reported that TSS/TA ratio and TSS*pH were useful juice composition indices to predict wine quality in cvs Pinotage and Cabernet Sauvignon, with the latter index giving better

predictions than the former. The present results show a significant correlation between TSS/TA ratio in the must and wine sensory scores ($r=0.689$, $p<0.05$), while correlation of TSS*pH with wine scores was not significant. The inclusion of malic acid in the maturity index formula in place of TA appears to be suitable for cool climate conditions, where malic concentration in the must would naturally vary more than in warm climates. Although there was no relationship between pH of the must and wine scores, occurrences of very high pH coincided with lowest wine scores at the BPN site in both seasons (Table 58 and Table 59).

The use of TSS/malic acid*pH as a maturity index is novel and appears to offer the potential to predict Cabernet Sauvignon wine quality in conditions of cool to warm climates. Comparatively dry and warm soil conditions at the onset of ripening increased the value of this maturity index, as it was positively correlated with SF for January ($r=0.79$, $p<0.05$).

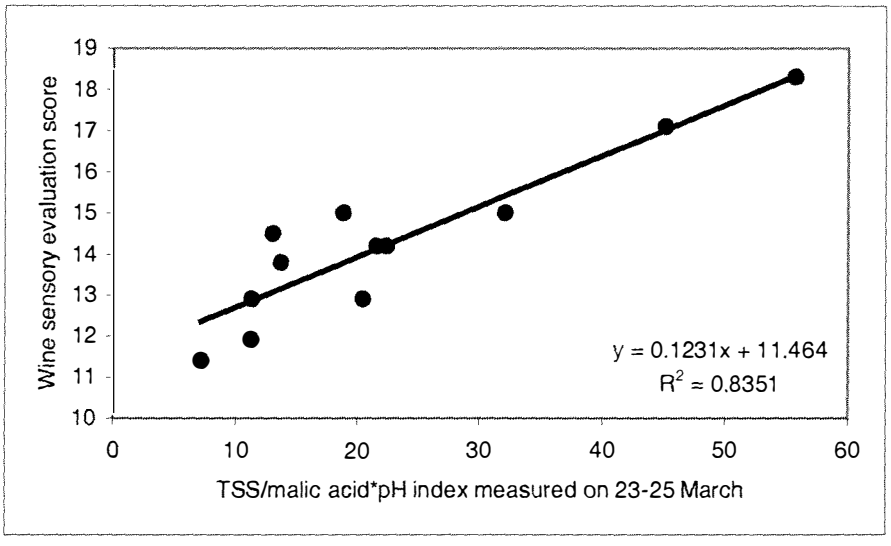

Figure 43. Regression between the TSS/malic acid*pH index in juice on 23-25 March and wine sensory evaluation score based on data for six sites in the 1997/98 and 1998/99 seasons

Harvesting grapes at different stages of maturity at different sites may have contributed to differences in sensory scores of respective wines, thus interfering with the effect of environmental conditions of the site on these

scores. The range of anthocyanins and polyphenols between sites when TSS reached 20 °Brix at all sites was lower than when sampled at harvest, while there was very little difference in ranges of other juice compounds measured. If fruit were harvested at a common TSS this could hypothetically produce wines with less variability in their final scores than was found in this study, due to having similar sugar levels and to the mentioned lower anthocyanin range at a common TSS.

It could be argued that this could have been avoided by harvesting grapes at approximately same TSS level (for example, at 20 °Brix). However, in the cool season of 1996/97 TSS of 20 °Brix was reached, on average, 196 days after 1 October, or on 15 April (Chapter 3, Table 5), therefore quite late in the season. It should also be noted that the date of achieving a TSS of 20 °Brix had to be extrapolated for four sites where the fruit never attained this level of sugar ripeness. Furthermore, in the 1998/99 season the vines at some of the six sites studied had difficulties in achieving 20 °Brix (Chapter 7, Figure 25). Anecdotal evidence from Hawke's Bay suggests that the production of premium Cabernet Sauvignon wines in Hawke's Bay is possible (Chapter 1, page 15). Juice analysis results (Chapter 7, Table 44) showed that an adequate sugar ripeness (for example, TSS of 22 °Brix), that would be expected to be associated with premium wine quality, was attained only at 3 sites in the 1997/98 (an exceptionally warm season for this region with GDD of approximately 1700°D compared to the long-term average of about 1300°D), and not at all in the 1996/97 and 1998/99 seasons. The trend of TSS accumulation, which is indicated by the growth curves (Chapter 7, Figure 25) in the 1998/99 season suggests that the value of 22 °Brix would not have been attained during April, and quite possibly not at all. This contention is supported by experiences of Hawke's Bay grape growers over many relatively cool seasons. Results from the 1996/97 season (Chapter 3, Table 9) show that only four out of 28 sites achieved TSS of 22 °Brix in this cool season, although some sites were picked as late as mid-May.

The above discussion indicates that the decision when to harvest Cabernet Sauvignon grapes based on a particular TSS value in the conditions of Hawke's Bay represents a risky strategy. This situation would be very different in warm or hot wine regions, where Cabernet Sauvignon grapes normally achieve TSS>22 °Brix in most seasons (Anon., 1995). In the conditions of Hawke's Bay, in certain seasons, TSS of 20 °Brix can be attained at most sites. However, it can be argued that this relatively low TSS value (for the production of high quality wines) could misrepresent the wine quality potential at those Hawke's Bay vineyard sites that would potentially achieve higher sugar ripeness than 20 °Brix. One of the main aims of this study was to determine the full oenological potential at the examined sites (Chapter 1, page 19), not only comparatively, but also in absolute terms. Harvesting grapes at TSS of 20 °Brix would not enable the realisation of this stated thesis objective, thus grapes were harvested at various TSS levels as dictated by the situation at each site.

Environmental conditions that significantly correlated with wine score were the 'soil factor' (SF), soil temperature and mean air temperature in March, in most cases the last ripening month. The SF values for January, February and March – the fruit ripening period – all had similar coefficients of correlation with wine scores (Table 60). Soil temperatures in February and March exhibited a similar relationship to wine scores, the correlation with soil temperature in March being the strongest (r=0.66). Overall, in the 1997/98 and 1998/99 seasons dry and warm soils during summer, as well as warm air temperatures during the final ripening month were favourable for wine quality.

Juice turbidity (Figure 29, Chapter 7) did not correlate with wine sensory evaluation scores. Du Plessis (1984) showed that must turbidity *per se* does not necessarily relate to wine quality (as previously stated by Sirota *et al.*, 1979, cited by Du Plessis, 1984), and that particle size of material in the must could be of more importance.

FTIR analysis and the sensory evaluation of wines from 1997/98 point to one common characteristic with respect to aroma or flavour. FTIR analysis

showed that SFV and RVV wines were most similar, and distinctly different from the remaining four wines. Characteristic of both these wines was a stemmy aroma, although they were also close in other characteristics except for wine colour, which was better in the RVV wine than in SFV. Of the remaining four wines, JRS was quite dissimilar, perhaps because it was the only wine with well expressed fruitiness and herbaceousness in aroma, and being higher in phenolics than the others. The BPN wine clearly differed from both LND and MMR wines as it was overly vegetative and received lower scores than the two in all observed aspects of wine quality. A relative similarity between the LND and MMR wines (though not as strong as in the pair RVV-SFV) detected by FTIR analysis may be related to these two wines both having expressed fruitiness on the palate.

The RVV Wines

The 1997/98 RVV wine was characterised by most tasters as having a vegetative nose and being green with a thin palate (Table 59). Harvest data for this site and season show that grapes were picked before an adequate fruit ripeness was reached, as TSS were rather low (Table 44), acidity high and pH very low. In addition, extractable polyphenols in berries sampled before harvest were the second lowest among sites in 1997/98. This would explain why this wine was perceived as thin by most tasters.

Wine from the RVV site in 1998/99 was produced from grapes with relatively similar attributes to 1997/98, and the site was picked almost on the same date (Table 44). The wine from 1998/99 was also characterised as green and short on the palate, and was perhaps only slightly better in relation to fruitiness than the wine from this site in 1997/98.

The JRS Wines

Although the JRS site was picked the earliest in 1997/98 (Table 44), grapes attained a high level of ripeness judging by TSS, TA and tannin contents. However, tasters found the 1997/98 JRS wine to be somewhat astringent. Besides having a blackberry attribute, a slight grassiness was noted in the

bouquet. Most tasters found this wine to be complex, rich, with fine tannins and good length (Table 59).

Vegetative nose and astringent, coarse tannins on the palate characterised the 1998/99 JRS wine. Fruit from this site was picked early in the season to avoid wet weather (Table 44), and a later harvest could have resulted in higher fruit and wine quality. Astringency is typical of wines made from early-picked red grapes, probably a result of the tannins having not yet condensed to their fully mature polymeric forms (Peynaud and Ribéreau-Gayon, cit. Gladstones, 1992). Two tasters sensed unripe fruit flavours on the palate with this wine.

Tannic and vegetative characters noted in the JRS wines could possibly also be related to high seed tannins, although concentration of tannins in seed was not established in this study. Glories (1995) noted the possibility that vegetal and tannic characters come from grapes with seeds rich in tannins from vines grown on gravel and sand in Saint-Emilion (Bordeaux, France). The author did not mention cultivars, but it is safe to assume, because of the region, that they were probably Cabernet Sauvignon, Cabernet Franc and Merlot. In the light of this, JRS grapes, also coming from gravelly soil and presumably with seeds rich in tannins (which was not measured), could potentially produce wine with preferred attributes through a different extraction procedure during winemaking compared to standard microvinification procedure (Figure 41). Glories (1995) also mentioned that low anthocyanin extractability is also associated with grapes from gravel and sand. Berry skins from the JRS site indeed had below average anthocyanin extractability (see Chapter 7, page 155), 40.7% compared to a mean value of 48% for six sites over three seasons. Analysis of harvest data for total anthocyanins and their extractability (Figure 44) shows that although sites on sandy and stony soils had higher total anthocyanins, they also tended to have a lower extractability of anthocyanins than sites on heavy soils. This could be attributed to imperfect extraction methodology (described in Chapter 2). However, Yokotsuka *et al.* (1999) determined that soil type affects anthocyanin composition in Cabernet Sauvignon, therefore this

different composition could possibly had an effect on overall anthocyanin extraction percentage.

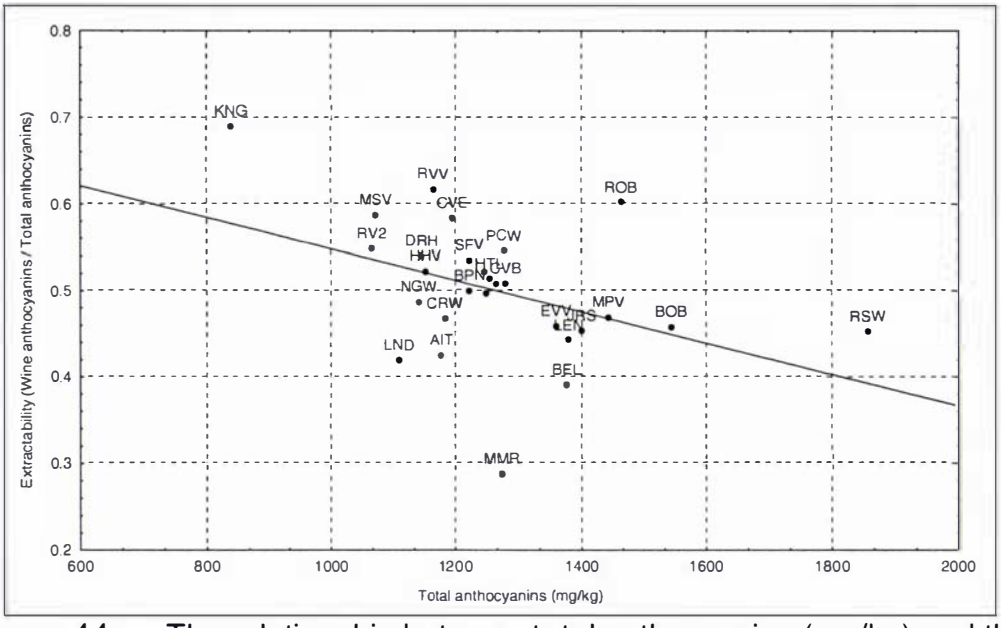

Figure 44. The relationship between total anthocyanins (mg/kg) and the extractability of anthocyanins based on data collected at 28 sites in 1996/97

The BPN Wines

Wine from the BPN site in 1997/98 ranked poorly with all tasters, however as the wine was oxidised that probably affected its scores. Therefore the sensory evaluation results obtained from this wine cannot be used for further analysis. The site was picked the latest in 1997/98, still with relatively low TSS (Table 44) and a high TA, but also with an unfavourably high pH. It is noteworthy that that the BPN juice in 1997/98 also had the lowest tartaric/malic acid ratio. During fermentation, pH increased to high levels and this required addition of tartaric acid as well as an additional cold stabilisation.

The 1998/99 BPN wine was evaluated as very vegetative, green and having poor fruit characteristics. These characteristics, along with an oxidised character in this wine may be related to the BPN 1998/99 grapes having a

Botrytis infection, which can be very harmful for wine quality (Du Plessis, 1984). Harvest data for this site in 1998/99 show that it was picked at low TSS content (Table 44), and with an unfavourable combination of relatively high TA and a high pH. High pH of the must is normally corrected by addition of tartaric acid, which in the presence of already high TA, causes wine to be acidic.

The SFV Wines

The 1997/98 SFV wine was characterised as "stemmy on the nose" by most tasters. This site was picked at an intermediate date and with relatively favourable TSS (Table 44), TA, pH and relatively low polyphenol levels. FTIR analysis showed some similarities between this wine and the 1997/98 RVV wine.

The 1998/99 SFV wine was ranked the best among the 1998/99 season wines (Table 59). On the nose this wine was described favourably by most tasters. This site was picked in 1998/99 with a reasonably favourable must composition, albeit with a relatively low concentration of extractable polyphenols in berry skins, that might be related to this wine being slightly short on the palate.

The LND Wines

Soft tannins were observed in wine from the LND site in1997/98 by most tasters. Tasted young it exhibited some bitterness on the palate that seemed to disappear with ageing. One unfavourable characteristic of this wine was its short palate, probably related to low extractable polyphenols in berries (see Chapter 7, Table 52).

Soft tannins also characterised the 1998/99 LND wine. Although the wine was short on the palate again, attributable to low polyphenol concentration in berry skins, and although the grapes were picked with relatively low TSS (Table 44) and high TA, this wine was the second best among the 1998/99 wines, perhaps because of its fruity characters.

The MMR Wines

The 1997/98 MMR wine was the best wine from both seasons (Table 59). Most tasters praised its soft tannins, good length and balance. It is noteworthy that in 1997/98 the MMR grapes were picked at a relatively high IR and tartaric/malic acid ratio (see Table 58). Furthermore, berries at this site had the second highest content of extractable polyphenols in 1997/98 (Chapter 7, Table 52).

The 1998/99 MMR wine was produced from grapes picked relatively early with a low TSS content (Table 44) and a high TA. Polyphenol and anthocyanin concentrations in the berries at MMR in 1998/99 were low. The nose of MMR wine from 1998/99 was minty and somewhat fruity, while tannins were soft as they were in the 1997/98 MMR wine. As in most of the 1998/99 wines, most tasters noted some acidity on the tip of tongue.

Different Wine Styles and Potential 'Terroirs'

Wines produced by microvinification from grapes picked at six selected sites in Hawke's Bay in the 1997/98 and 1998/99 exhibited the potential for grapes to be used for production of different styles of wines. While the seasonal variability was well expressed even if only over two experimental seasons, the range of variability in wine quality potential by sites was considerable. The wet autumn in 1999 exhibited one very significant potential problem for Hawke's Bay wine grape growing, namely the disease pressure that occurs with wet weather prior to harvest. Although Cabernet Sauvignon is less susceptible to Botrytis than other cultivars commonly grown in Hawke's Bay, it ripens late and needs to achieve not only adequate TSS levels, but also sufficient anthocyanin concentration, flavour and aroma. In case of a forced early harvest, full ripening is not possible, and phenolic compounds are such that grapes tend to give green, astringent wines, even if the more commonly observed must attributes (TSS, TA, pH) are favourable.

Long (1997) differentiated wine styles of Cabernet Sauvignon from different locations in Alexander Valley, California. The locations Lowlands, Uplands,

and Midlands were characterised by respectively 140, 130 and 120 days from flowering to harvest. Lowlands produced an elegant wine style, giving finesse and more fruit than tannin; Uplands was characterised by a powerful wine style, with a balance of tannin and fruit and with mid-palate while Midlands gave dense wines with very ripe fruit flavours and structure. In this study, the JRS site is comparable to Midlands, having a similar number of days from flowering to harvest (119 in 1997/98 and 124 in 1998/99), and also providing high tannin and fruit ripeness. Other sites all fit between Lowlands and Uplands, as they have 130-140 days from flowering to harvest, and are intermediate with regard to fruitiness and tannins. SFV is slightly closer to Lowlands (with 138 days from flowering to harvest in 1997/98 and 135 in 1998/99) than to Uplands, and the style (more fruit than tannins, shortness) tends to correspond to Lowlands.

Gravelly sites in the Fernhill / Ngatarawa / Ohiti sub-region, represented in this study by the JRS site, will achieve good TSS/TA balance in most seasons. From three years of study it seems likely that pH of the must will also be favourable. Owing to high soil temperatures, low soil water status, and therefore low canopy density, total polyphenols and total anthocyanins in Cabernet Sauvignon grown at the JRS site will usually attain good levels, however not necessarily a favourable extractability. For this site to give balanced wines it is necessary that the irrigation deficit strategy be applied carefully and judicially. From this study it can be concluded that excessive water stress throughout the development and ripening of fruit is not favourable for tannin characteristics. Seguin (1983, 1986, cit. Gladstones, 1992) and Zamboni *et al.* (1987) postulated that a steady, moderate availability of moisture is essential for production of the highest quality grapes. Based on these results, soil water availability at the JRS site was rather discontinuous throughout both the 1997/98 and 1998/99 seasons, particularly the former, and this adversely affected wine quality.

Sandy loams in the Mangatahi / Maraekakaho sub-region probably offer better potential for wine quality than can be concluded from the RVV wine from the 1997/98 and 1998/99 seasons. This is suggested, as it is likely that

grapes were picked before their optimal ripeness was attained in both these seasons. Provided that grapes are not damaged by Botrytis, higher TSS, tannins and anthocyanins could be achieved if harvest could be delayed more than they were in 1997/98 and 1998/99. In addition, in 1998/99 heavy rainfall in mid-flowering reduced berry set and caused millerandage – shot berries – which is known to produce wines with 'greener' tannins compared to regular-sized berries (Rabion *et al.*, 1987). Therefore green tannins on the palate sensed by tasters could at least partly be ascribed to the millerandage effect. For this site in Mangatahi / Maraekakaho it would be advisable to 'pick on tannins' (to harvest grapes with sufficient ripe tannins) rather than on TSS or similar index of ripeness.

Sandy loam on a pan in the Tuki Tuki area (in the Havelock North / Te Mata sub-region, the same soil type also present in the Dartmoor / Puketapu region), is represented by the MMR site and is sought after viticultural land in Hawke's Bay, particularly for red cultivars. Although in wet seasons the Cabernet Sauvignon performance is probably poor because of water logging of the soil, seasons in which soil is sufficiently dry and when autumn is sunny and warm, as occurred in the present study, is capable of producing great wines.

Sands with loam around Eskdale (the Eskdale / Bayview sub-region), represented by the LND site in this study, although sandy, can be hard to manage due to a certain percentage of silt and a very likely access to the water table by the vine roots. Relatively high available soil water during the development of green berries allows very large berries to be produced regularly (see Chapter 7, Table 42) and hence high yields at the LND site. Unrestricted vine root growth also means vigorous vine growth, particularly in wet seasons. This can be amended to an extent by grassing down. However even that is of little help when the vine roots will not compete for the same water and nutrients with sward culture, simply because vine roots are much deeper. Although this site can produce Cabernet Sauvignon wine with fruitiness and soft tannins in dry years and with adequate canopy

management, earlier ripening and less vigorous cultivars are perhaps a better choice for this site.

Silt loams around the Tutaekuri River were represented by two sites in this study, although they physically belong to two different topographical sub-regions of Hawke's Bay. These are the SFV site (the Taradale / Meeanee / Brookfields sub-region) and BPN (the Dartmoor / Puketapu sub-region). The SFV site is located on older and moderately fertile soil, however with ample water supply throughout the season, because of its high water retention capacity, and the likely influence from the water table. In the experimental period this consistent water supply was the most probable reason that Cabernet Sauvignon vines were in a considerable imbalance, judging by the low yield/pruning weight ratios at this site (see Chapter 5, Table 36). Although the vineyard management consisted of very rigorous canopy management, coupled with a sward of chicory in every second row, grapes at this site still achieved only relatively low levels of anthocyanins and phenolics (see Chapter 7, Table 51 and Table 52). Wines were somewhat stemmy, although soft tannins and certain fruitiness were also noted. Testing of alternative training and pruning systems, less vigorous rootstocks (for example 3309C), as well as the use of various cover crops, could potentially result in the production of enhanced quality Cabernet Sauvignon varietal wines.

Judging by the results of this three-year study, the BPN site located on a silt loam near the Tutaekuri River in the middle of the Dartmoor / Puketapu sub-region, is not suitable for successful production of high quality Cabernet Sauvignon wines. Fruit from this site, however, can potentially be used for blending, especially with very acidic musts that are low in pH. The soil at this site is very deep and fertile, and as such it stimulates vegetative growth in Cabernet Sauvignon, while yields remain average. In an average Hawke's Bay season, grapes at this site will not be able to achieve the desired level of ripeness determined by TSS, TA, tannins, colour, or flavour. However, pH was consistently high in every season, which represents an additional problem for winemaking, as already discussed (page 191). It is important to

note that the Dartmoor / Puketapu sub-region has sites favourable for Cabernet Sauvignon, such as those with Waipukurau sandy loam and gravel (for example, the RSW site studied in the 1996/97 season).

Summary

Wines produced in two consecutive seasons (1997/98 and 1998/99) in unreplicated lots by microvinification of grapes grown at six sites in Hawke's Bay were evaluated by sensory analysis. Significant differences in wine scores were found between seasons (1997/98 being significantly better than 1998/99) and between sites. A number of relevant vine canopy, nutrient status, berry composition and environmental conditions were correlated with wine sensory evaluation scores. High wine scores were associated with precocity in phenological stages, favourable canopy density and optimal Mg status of the vines. Wine scores were negatively correlated with malic acid in berries at harvest, and positively correlated with tartaric/malic acid ratio. The TSS/malic acid*pH index measured on 23-25 March appears to be the best predictor of wine sensory attributes. Therefore it has been proposed as a novel maturity index for Cabernet Sauvignon grapes grown in cool to warm climates. March temperatures of air and soil at 15 cm showed a positive correlation with wine scores. 'Soil factor' (SF), the variable described and examined in Chapter 4, during fruit ripening (January-March) was significantly correlated with wine scores. Previously (Chapter 5 and 7) it was reported that SF was significantly correlated with a number of variables relating to vine phenology, vegetative growth and fruit ripening. It appears that environmental characterisation of vineyard sites in Hawke's Bay would be possible based on SF, leading to determination of potential viticultural 'terroirs' for Cabernet Sauvignon. Overall, wines from soils of limited water capacity or limited root growth achieved highest sensory evaluation scores, probably by reducing vegetative growth and thus inducing canopy characteristics favourable for fruit development and ripening.

CHAPTER 9: GENERAL DISCUSSION AND CONCLUSIONS

Thesis Objectives

'Classical' climatic or bioclimatic indices used to delimit regions are no longer of great value for the New Zealand grape and wine industry. Viticulture in this country is beyond its stage of establishment and is currently entering the stage of development (Falcetti, 1997; refer to Figure 2 in Chapter 1, page 5). There is a need for a more sophisticated viticultural criterion to be used for further site selection than the macroclimate characterised by GDD and analogous indices.

Although less known grapevine cultivars also offer potential for future success, it is the performance of 'classic' cultivars such as Sauvignon Blanc, Chardonnay, Pinot Noir and Cabernet Sauvignon in different regions or sub-regions that is really important. This is not only because of the market value of their production, but even more as they are cultivars that are the basis of the international recognition of wines from any new viticultural country or region (Falcetti, 1997). For example, New Zealand became known internationally because of the quality of its Sauvignon Blanc wines from Marlborough (Cooper, 1993).

The knowledge of grapevine viticultural and oenological performance as influenced by site-related factors represents an immense value to grape and wine industry of a country or a region. Through an adequate site selection the highest value of the final product will be ensured. As Costantini *et al.* (1996) noted, the knowledge of natural resources of a 'terroir', beyond giving indications for zoning, permits the application of an appropriate

vineyard management that can optimise fruit and wine quality from a given area.

The overall aim of the present study was to increase understanding of the interaction between site-related factors, conditions of the season and Cabernet Sauvignon vines. Initially, the objective was to ascertain the magnitude of environmental effects on growth, development and fruit maturation of Cabernet Sauvignon vines within Hawke's Bay. To achieve this aim a significant number of Cabernet Sauvignon vineyards planted with the same clone and on the same rootstock was selected and investigated. This initial research undertaken at 28 Cabernet Sauvignon sites throughout Hawke's Bay concentrated primarily on attributes of phenology, vigour, cropping, and fruit composition.

In the next stage six sites were selected to represent the most distinct environmental conditions for a more detailed study. The aim of this study was to characterise precisely the mesoclimatic variations and their influence on grapevine vegetative and reproductive cycles.

The first requirement for this was to set-up weather stations at the six selected sites to collect air and soil temperature, solar radiation and rainfall. Soil moisture content was also measured frequently during the season. This detailed study also included analyses of grapevine leaf petiole tissues at key stages of development (flowering, véraison, and before harvest). Vegetative growth and canopy characteristics were observed closely and weekly analyses of fruit samples were done throughout berry development and ripening.

The final stage of study focused mainly on influences of the soil type on grapevine vegetative and reproductive cycles, as well as wine attributes. This included a detailed study of soil profiles and their physical characteristics.

The outcomes of this thesis are:

- Characterisation and quantification of major mesoclimatic and edaphic factors, and their effect on fruit attributes and grape yield in cv Cabernet Sauvignon in the Hawke's Bay region.
- Determination of the effect of grapevine vigour on major cropping and ripening attributes in this cultivar.
- Examination of the 'terroir' effect on attributes of vegetative growth, phenology, yield, development and ripening of berries and potential wine qualities.
- Increased understanding of the potential of Cabernet Sauvignon for fruit and wine quality in different seasons and at different sites in Hawke's Bay.
- Models of phenology, grape ripening and site environmental characterisation.
- The sensory evaluation of Cabernet Sauvignon wines produced by unreplicated microvinification of fruit from sites chosen to represent different viticultural environments.
- Identification of the potential viticultural 'terroirs' in Hawke's Bay as the basis for future viticultural zoning.

In the light of success of Hawke's Bay Cabernet-based red wines on the market, there can be little doubt that potential for future 'terroirs' exists in Hawke's Bay. There also exists a strong commercial interest to study the effect of site on Cabernet Sauvignon wine. The following example may illustrate the commercial interest for characterisation of future 'terroirs' for Cabernet Sauvignon in Hawke's Bay. In a tasting by an Australian wine magazine (Cooper, 1999), 41 Cabernet Sauvignon based wines were tasted, 29 of which were recommended by the panel of judges. Of those recommended 18 wines had their sub-region or area of origin clearly identifiable from the label. Of these 18, 11 were made from grapes

originating from the Fernhill / Ngatarawa / Ohiti sub-region, seven of these being from the Gimblett Road area. Of the remaining recommended wines three originated from the Dartmoor / Puketapu sub-region, another three from the Taradale / Meeanee / Brookfields sub-region, and one from the Havelock North / Te Mata sub-region.

The overall body of scientific knowledge about the effect of 'terroir' is relatively limited. As expected most studies so far have been done in France (Seguin, 1981 and 1986; Glories, 1995; Dumas *et al.*, 1997; Boidron, 1997; Bourguignon and Gabucci, 1997; Barbeau *et al.*, 1998a and 1998b; Boissenot, 1998; Morlat, 1992, 1997 and 1998; Salette *et al.*, 1998; Vaudour *et al.*, 1998). To lesser extent, 'terroir' studies were done in other European countries such as Italy (Battistutta *et al.*, 1996; Bertamini *et al.*, 1996; Costantini *et al.*, 1996; Falcetti and Iacono, 1996), Switzerland (Beguin and Macnamara, 1999) or Slovakia (Hronsky, 1999). In the New World countries similar studies are few (Elliott-Fisk, 1993; Trought, 1996; McCloskey *et al.*, 1996; Proffitt *et al.*, 2000). Some of the reasons why there was a lack of research interest in the effect of 'terroir' on grape and wine attributes in the New World countries will be addressed in this chapter.

A Review and Analysis of Outcomes

The initial study of 28 vineyard sites in 1996/97 as well as the detailed study of six selected viticultural environments enabled an analysis of vine phenology, cropping and fruit and wine attributes as they related to certain vineyard characteristics, local climate and soil properties at studied sites.

Phenology and 'Terroir' Definition

Vineyards on 14 different soil types in the Hawke's Bay wine region were included in this study in the 1996/97 season. As 28 sites were studied, some of those were on relatively similar soils, although in different sub-regions. Examples of this were:

- BEL and RSW, both on the *Tukituki* stony gravels, the first one in Fernhill / Ngatarawa / Ohiti, and the second one in the Dartmoor / Puketapu sub-region. These two vineyard plots had very similar canopy density (scores 50 and 52, respectively). Vine phenology at RSW was several days later than at BEL.

- CVE and MMR (both in Haumoana / Te Awanga) and RCT (in Dartmoor / Puketapu). All these sites were on the *Waipukurau* sandy loam (poorly drained with a hard pan). Canopy density was unfavourable for quality wine grape production in all these plots (canopy density scores ranged 34-46). Vine phenology at MMR was several days later than at CVE, probably because of higher altitude; RCT ripened earlier that CVE and MMR probably because it was further inland than other sites and hence warmer.

- DRH and LEN (both in Haumoana / Te Awanga) and NGW (Fernhill / Ngatarawa / Ohiti) and SFV (Taradale / Meeanee / Brookfields) were all on the *Pakowhai* soil type. However, the first two were on sandy loam sub-type and the last two on silt loam sub-type. Consequently, while the first two had favourable canopy density scores (56 and 58) and were similar in phenology, they were earlier than the second pair, which were again similar in phenology between themselves, and with unfavourable canopy density scores (40 and 34).

- PCW (Fernhill / Ngatarawa / Ohiti) and RSG (Havelock North / Te Mata sub-region) were both on the *Poporangi* sandy loam (poorly drained). PCW had a more favourable canopy density score (48) than RSG (32). This difference can explain somewhat earlier phenology at the PCW site. Canopy density was more favourable at PCW probably because vines were younger than at RSG (4 and 10 years respectively at the time of study).

These comparisons indicate that while soil type had a significant impact on phenology of grapevines, other site-related factors, such as altitude or proximity to the sea also had important influence. Significant differences

between 'terroirs' in timing of phenological stages exist in the Loire Valley (France) for cv Cabernet Franc Barbeau *et al.* (1998b). As determined in the present study, these authors found that phenological differences were reflected in fruit composition at harvest.

The analysis of phenology at investigated sites is based on 'indices of precocity' (IPF, IPV and IPCY) defined in Chapter 2 (page 27).

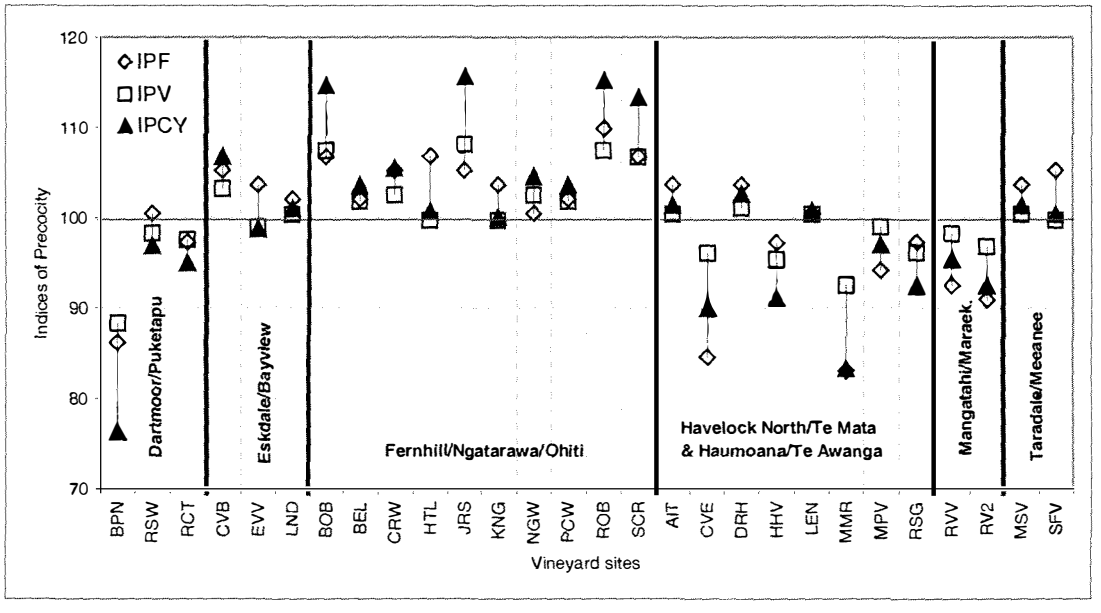

Figure 45. Indices of precocity for cv Cabernet Sauvignon at 28 sites in six sub-regions in 1996/97.
IPF, IPV, IPCY are indices of precocity for flowering, véraison and for the cycle, respectively.

In the 1996/97 season marked differences in indices of precocity existed between the 28 sites (Figure 45). Sub-regional differences in these indices were also pronounced. The BPN, CVE, HHV, and MMR sites stand out as 'very late'. BOB, JRS, ROB and SCR were the sites with very early phenology, and they were all located in the Fernhill / Ngatarawa / Ohiti sub-region, which was overall the earliest sub-region in the 1996/97 season. One reservation regarding phenology in 1996/97 was the different pruning times at the 28 investigated sites. Martin and Dunn (2000) showed that later

pruning (the difference between later and earlier being 40 days) delayed budburst, flowering and véraison by about 4-5 days in cv Cabernet Sauvignon grown in Victoria, Australia. It is therefore possible that a certain degree of variability in phenology in 1996/97 could have been caused by difference in pruning times. Overall variability in phenology between 28 sites in the 1996/97 season, however, was much higher than 4-5 days, being 17 days for mid-flowering and 28 days for mid-véraison.

All indices of precocity in 1996/97 were correlated with berry composition at harvest. IR was positively correlated with IPF (r=0.56), IPV (r=0.70) and IPCY (r=0.70), while malic acid concentration in berries was negatively correlated with the three indices (r=–0.39, r=–0.40 and r=–0.41, respectively). Similar correlations between IPCY and malic acid were established in cv Cabernet Franc by Barbeau *et al.* (1998a). Tartaric acid concentration was negatively correlated with IPV (r=–0.50) and IPCY (r=–0.49). No correlation between IPCY and tartaric acid in cv Cabernet Franc was found by Barbeau *et al*. (1998a). Canopy density index was negatively correlated with all the indices (IPF r=–0.55, IPV r=–0.64 and IPCY r=–0.65), indicating it had delayed phenology of flowering and véraison, as shown in Chapter 3 (page 64).

Principal component analysis (PCA) of the variables collected in the 1996/97 season extracted two factors. PCA showed that IPF, IPV, and IPCY were the principal components of Factor 1 (along with TA), while ESA, pruning weight and dry production were the principal components of Factor 2 (Table 61). This analysis clearly showed the importance of phenology in vineyard site characterisation.

Two-year averages for indices of precocity at six selected sites (Figure 46) show that there were considerable differences in phenological classification between flowering, véraison and the complete yearly cycle at the same sites. The largest difference was found at the BPN site where IPV was slightly late, while IPCY was very late. JRS was the only really early site, while SFV and LND were slightly early. Exception from the latter was an early IPF at the SFV site. MMR was intermediate, RVV slightly late, and

BPN was very late. There were little differences in indices of precocity between the 1997/98 and 1998/99 seasons.

Although done with a different cultivar and in a different hemisphere, the study of Barbeau *et al.* (1998b) with cv Cabernet Franc in the Loire Valley shows a similar classification of 'terroirs' based on indices of precocity compared to this study of cv Cabernet Sauvignon in six Hawke's Bay potential 'terroirs'. According to Barbeau *et al.* (1998b) early 'terroirs' correspond to sandy, sandy clayey or gravelly soils developed on various substrates, but all characterised by good drainage. Late 'terroirs' correspond to clayey and silty soils, as well as to sandy or clayey-sandy soils that have soil water problems ('*problèmes d'hydromorphie*'), for example water perching on the pan during winter.

Table 61. Principal component analysis of the variables observed in the 1996/97 season at 28 sites in Hawke's Bay

	Factor loadings (Varimax normalised)	
	Factor 1	Factor 2
IPF	**-0.764**	-0.041
IPV	**-0.803**	-0.192
IPCY	**-0.817**	-0.175
Number of clusters	-0.359	0.428
Cluster weight	0.246	0.416
Yield of grapes	-0.196	0.669
Berry weight	-0.030	0.604
TSS	-0.257	-0.462
TA	**0.834**	0.181
pH	-0.448	0.085
Total phenolics	-0.116	-0.524
Total anthocyanins	-0.150	-0.450
Malic acid	0.654	-0.022
Tartaric acid	0.618	0.015
K in juice	0.358	0.088
N in leaf petioles at véraison	0.377	0.198
P in leaf petioles at véraison	0.457	0.031
K in leaf petioles at véraison	0.594	0.141
Ca in leaf petioles at véraison	0.408	0.373
Mg in leaf petioles at véraison	0.043	0.212
CDI	0.609	0.310
ESA	0.011	**0.832**
Pruning weight	0.441	**0.728**
Yield/pruning weight ratio	-0.639	-0.328
Dry production	0.246	**0.877**
Explained Variance	5.968	4.418
Proportion of Total Variance	0.239	0.177

Note: Marked loadings > 0.700

The JRS site, an early 'terroir' according to this phenological classification of Barbeau *et al.* (1998b), was on a gravelly soil, while slightly early LND was on a sandy soil. The SFV site represents an exception to the above classification as it was on a silty soil. One explanation for a relative precocity at this site (particularly in 1998/99) could be found in low yield (see Chapter 7, Table 54) and yield/pruning weight ratios (Chapter 5, Table 36). In addition, air temperatures during October (the month preceding flowering) at SFV were slightly higher than average (see Chapter 4, Table 18).

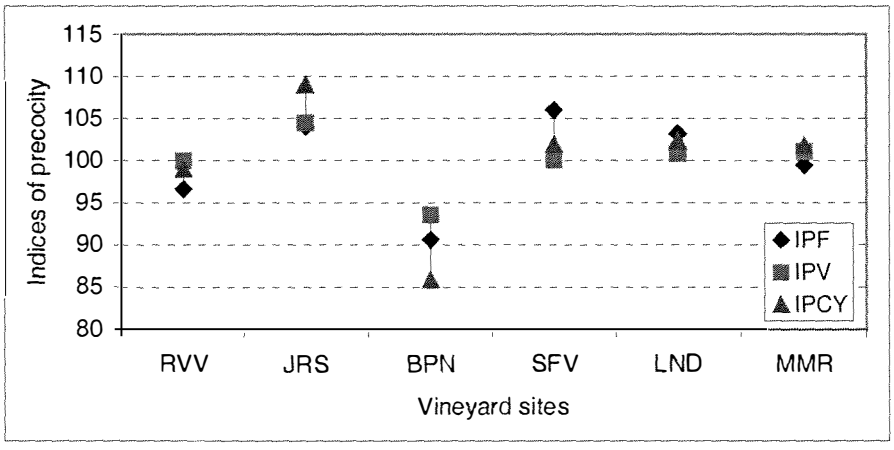

Figure 46. Indices of precocity for cv Cabernet Sauvignon at six sites – average for the 1997/98 and 1998/99 seasons. IPF, IPV, IPCY are indices of precocity for flowering, véraison and for the cycle, respectively.

MMR, with an overall intermediate precocity, was on a soil with impermeable water pan. In the 1998/99 season that was average in rainfall MMR was of intermediate precocity. It was slightly early in a very dry 1997/98, while it was very late in a wet 1996/97. Slightly late RVV is on a sandy loam, albeit with a considerable clay percentage (for detailed soil descriptions see Chapter 4, page 78).

IPCY was negatively correlated with CDI (r=–0.75) and pruning weight (r=–0.76), indicating that vigorous vine sites were late in phenology. Similar correlations existed between CDI, pruning weight and IPV, while IPF was not correlated with canopy vigour characteristics. Soil-related variables were well correlated with IPV and IPCY (Table 62), particularly soil temperatures at both depths and the 'soil factor' (SF). Soil type was established as a

major factor in affecting phenology of grapevines by Battistutta *et al.* (1996), Bertamini *et al.* (1996) and Barbeau *et al.* (1998a and 1998b).

Indices of precocity were also correlated with certain berry composition constituents and to wine sensory evaluation score (Table 63). These indices were strongly correlated with TSS at several stages during fruit ripening, but not to TSS content at harvest. Generally, most berry constituents were better correlated with indices of precocity when measured around véraison than later during ripening or at harvest. This could indicate that the effect of various environmental factors on berry composition became stronger as fruit approached ripeness.

Table 62. Coefficients of correlation between soil temperature at 15 cm (ST15), 'Soil Factor' (SF) and indices of precocity of véraison (IPV) and the cycle (IPCY)

Index	ST15 for Dec	ST15 for Jan	ST15 for Feb	ST15 for Mar	SF for Oct	SF for Nov	SF for Dec	SF for Jan	SF for Feb	SF for Mar
IPV	0.59	0.72	0.62	0.67	0.69	0.73	0.61	0.59	0.64	0.64
IPCY	0.60	0.72	0.61	0.64	0.64	0.67	-	-	-	-

Note: Presented correlation coefficients are significant at $p<0.05$

Table 63. Coefficients of correlation between TSS, tartaric and malic acid, juice pH, wine score and indices of precocity of flowering (IPF), véraison (IPV) and the cycle (IPCY)

Index	TSS at 9 February	TSS at 2 March	TSS at 23 March	Tartaric at 10 Feb	Malic at 10 Feb	Malic at harvest	T/M ratio at harvest	pH at 2 March	Wine score
IPF	0.61	0.64	-	–0.75	–0.58	-	-	0.63	-
IPV	0.85	0.84	0.66	–0.69	-	–0.67	0.58	0.66	0.65
IPCY	0.83	0.83	0.63	–0.74	-	–0.64	-	0.68	0.61

Note: T/M – tartaric/malic acid ratio. Presented correlation coefficients are significant at $p<0.05$

It is significant that there was a positive correlation between the wine sensory evaluation score and index of precocity of véraison ($r=0.65$). That indicates that distinction between potential 'terroirs' in Hawke's Bay is possible based on date of mid-véraison, and that it is reasonably related to potential wine quality. This outcome is similar to findings of Barbeau *et al.* (1998a and 1998b) for Cabernet Franc in conditions of France, on which studies the present analysis was based. Phenological dates as criteria for delimitation between sub-regions or 'terroirs' has not yet been used in New Zealand and Hawke's Bay.

Soil, Climate, Vineyard Management and the 'Terroir' Effect

Vine canopy management aims to copy canopy microclimate conditions characteristic of acclaimed vineyards, as it is not possible to duplicate their soil conditions elsewhere. This is achieved by various means of shoot devigoration (Smart and Robinson, 1991). This viticultural strategy is based, according to these authors, on the belief that soil, by affecting growth and thus properties of canopy microclimate, has an indirect effect on wine quality.

Findings of this study confirmed that soil type has a large effect on canopy properties such as shoot growth, number of laterals, canopy gaps, fruit exposure and canopy leaf layer number. A range of differences found in canopy density as affected primarily by soil type was so large that no reasonable amount of canopy management could manipulate canopies at different sites/soil types to become similar. Little work on the effect of 'terroir' has been done so far in viticultural areas that typically rely primarily on canopy management to improve fruit quality (ie New Zealand) therefore the present findings are relatively novel, particularly when the range of variability in canopy vegetative characteristics is concerned. For example, a study by Tomasi *et al.* (1999) on Cabernet Sauvignon/SO4 vines grown at two sites in Treviso, Italy, showed that shoot length before véraison was 100-125 cm. According to the present results over two seasons and at six Hawke's Bay sites, the corresponding shoot length varied 124-307 cm. This could mean, theoretically, that trimming of more than 150 cm of shoot length would be required to maintain similar canopies, indicating that canopy management has its limits in conditions of Hawke's Bay.

However, the statement by Smart and Robinson (1992) that all differences in fruit and wine quality caused by soil characteristics are an indirect effect of soil on canopy microclimate conditions does not hold true in all environments. For example, vine water status during development of green berries directly affected final berry size (McCarthy, 1997), which in turn influenced wine quality, particularly in red wines (Bravdo *et al.*, 1985; Bravdo and Naor, 1996). Soil water status, especially in dryland viticulture,

is largely dependent on depth and texture of rooting zone and potentially on the water table. Similarly, soil water availability has a direct influence on grapevine photosynthesis (Flexas *et al.*, 1998), regardless of canopy geometry.

Vineyard irrigation management can be as important as canopy management in being able to influence wine quality. The strategic timing of water deficits may be one useful method to improve wine quality (McCarthy, 1997), primarily through reduction of vegetative growth that represent a competitive sink with berries for photosynthetic assimilation products. In conditions of dryland viticulture water deficits occur 'naturally' through a specific combination of rainfall and overall weather patterns and numerous soil characteristics. Seguin (1981) established that in the great vineyards of Medoc in France drought never leads to severe water stress of the vines, but that the main problem is excess rainfall, particularly close to harvest. From the present results in Hawke's Bay drought caused a noticeable water stress only in grapevines grown on extremely permeable soils, or where an impervious layer restricted vine roots (such as the JRS and MMR sites). Similarly to Medoc, in Hawke's Bay excess rainfall can occur close to harvest. In Napier from 1900 to 1985 the highest recorded rainfall in March was >200 mm, and it was relatively frequently in the 100-150 mm range (Thompson, 1987).

Dryland wine grape production still represents a very important type of viticulture the world over. Many viticultural regions aim to produce premium wine quality without irrigation, and in the past it was usually the only available option. Vineyard irrigation may be relatively expensive to introduce in developing countries. In traditional wine producing countries (e.g. France) irrigation is not looked upon favourably by the wine industry, since it is not a part of the famed tradition and because of a potential to increase yields. In the major New World wine producing countries, such as Australia and the US (California) irrigation is essential for adequate grape production in most years and areas. However, water resources are increasingly becoming insufficient, and the associated problems of water quality are also on the

increase. Finally, in some countries or regions with high seasonal rainfall, vineyard irrigation management is not possible. For example, in many viticultural areas in New Zealand irrigation management cannot be successfully applied due to relatively high seasonal rainfall and/or soils with high moisture retention capacity. For all these reasons, in the future it can be expected that non-irrigated viticulture will still remain relevant, at least when it comes to production of super-premium or ultra-premium wines. For example, recently certain Margaret River (Western Australia) ultra-premium wine producers completely turned to dryland viticulture, although this resulted in yields as low as 2.5 t/ha (Broadfield, 1999). These yields, that are several times lower than in irrigated vineyards, reportedly enable the production of ultra premium wines (Ibid.).

Although soil characteristics have an important effect on wine quality in irrigated viticulture, they are a crucial factor in dryland viticulture. Gladstones (1992) acknowledged the difference in the relative importance of soil physical properties between irrigated and non-irrigated vineyards. In dry and/or warm areas and in non-irrigated vineyards, canopies mostly manage themselves – no particular canopy management operations may be necessary due to reduced vegetative growth. In viticultural regions with ample water supply throughout the season soil characteristics are particularly important exactly because vegetative growth will be enhanced, difficult to manage and hence creating a potential for canopy density problem. In such conditions, as mentioned, irrigation management is not possible and site selection and canopy manipulation are essential if excellent wine quality is to be achieved.

Even in cool climates with significant seasonal rainfall (>500 mm), irrigation management may be used on well drained soils with low water holding capacity and where vine roots cannot easily reach the water table. Such is the case in the Fernhill / Ngatarawa / Ohiti sub-region in Hawke's Bay, represented in this study by the JRS site. Some irrigation management should probably occur in dry seasons at other sites, particularly those where rooting zone is restricted. Such soils can hold a very limited amount of

water, and are quickly depleted in the absence of rainfall or irrigation. This situation can occur in the Tuki Tuki area of the Havelock North / Te Mata sub-region, represented by the MMR site in this study. From the present results it can be concluded that in seasons with normal rainfall and at most sites, vineyard irrigation will not be beneficial for grape and wine quality. However, as droughts are common in lowland Hawke's Bay (Thompson, 1987) irrigation to alleviate excessive water stress may be required during dry periods at sites that have soils of either high permeability or low soil moisture holding capacity. Likewise, irrigation will be beneficial at sites where vine roots are restricted by an impermeable pan (such as MMR). Vineyard sites located on the Omahu stony gravels (such as JRS) are entirely dependent on irrigation in order to achieve reasonable yields of good quality grapes.

Canopy, soil, irrigation management, choice of training system or rootstock, can all affect wine quality significantly. It is possible that the influence of 'terroir' can be negated to large extent, or even eliminated, by poor vineyard management techniques. The potential benefits that can be derived from a preferred terroir can also be overturned by inadequate oenological techniques, but these are not the subject of this study. Nonetheless, the statement by Gladstones (1992) that "the commercial cost of attaining a given wine quality level will be least where the vineyard environment is most suitable" is very true. In fact, application of correct vineyard management techniques will reinforce the notion of 'terroir'. When this occurs 'terroir' becomes the main discriminating factor in wine grape growing (Gladstones, 1992). Martin (2000) and Mondavi (1999) also emphasise the importance of vineyard management techniques in defining 'terroir'.

Major projects on 'terroir' definition conducted at Institut National Agronomique (INRA) in France by Vaudour *et al.* (1998) have as a starting point 'pedopaysages' or 'soil landscape units' that are considered to be 'potential terroirs'. Viticultural and oenological 'validation' of these 'potential terroirs' leads to their establishment as 'terroirs'. Validation of 'potential terroirs' is conducted through a statistical analysis of numerous fruit

composition data over ten years and more. 'Potential terroirs' for which discriminant analysis determines significant differences in fruit composition by this methodology are proclaimed as 'terroirs'.

The effect of 'terroir' is an outcome of both viticultural/oenological management and natural site characteristics ('potential terroirs'). Which of these two major factors takes precedence in determining wine quality remains to be determined unequivocally, and will vary with the 'cycle of viticulture' (establishment, development, maturity and decline, as defined by Falcetti, 1997; see Figure 2 in Chapter 1, page 5) in a given country. As viticulture in the New World wine growing countries is at an early phase in the cycle of development it is likely that, with time, overall vineyard management will become less important and 'terroir' will become the more important discriminating factor (Falcetti, 1997). Countries in the cycle of viticultural development are (in increasing order of closeness to reaching the cycle of 'maturity') New Zealand, South Africa, Australia, California and Germany. Falcetti (1997) states that New Zealand has just entered this cycle – until recently the New Zealand grape and wine industry was in the 'launching' stage.

If the contention of Falcetti is accepted, New Zealand will have a relatively long way to go before its viticulture reaches the cycle of maturity characterised by viticultural zoning and delimitations that bring about the concept of 'terroir'. It can be argued that the actual time required for that to occur will not necessarily be measured in centuries as in France, Spain and Italy. A good example of how the application of viticultural and wine science, along with a strong marketing initiative, can dramatically speed up this cycle of viticulture can be found in California. The Californian grape and wine industry is now in its early stages of viticulture zoning and exploration of its 'terroirs' (Elliott-Fisk, 1993; McCloskey *et al.*, 1996). To a lesser extent a similar emerging trend can be seen in Australia (Proffitt *et al.*, 2000).

The 'Soil Factor' and Grape and Wine Attributes

A study by Tomasi *et al.* (1999) on the effects of soil physical characteristics on fruit and wine quality in cv Cabernet Sauvignon grown in Treviso, Italy enables some relevant comparisons with this work. Cabernet Sauvignon vines in the trial of Tomasi *et al.* (1999) were of R5 Clone grafted on SO4 rootstock and were trained using the Sylvoz system.

Two plots were studied, one on stony – sandy (A) and the other on clayey – silty (B) soil. Soil conditions and textures for these two sites bear a resemblance to, respectively, the JRS and RVV sites from this study. JRS and RVV, both trained as Scott-Henry and spur pruned to 8-9 buds per m^2, can serve for comparisons with vines on A and B sites of Tomasi *et al.* (1999). Soil moisture content, also established by TDR, ranged from 7 to 15% at 20 cm depth at A and 10-30% at site B in the period flowering to véraison. Site A was irrigated 2-5 times during the season, although a strong water deficit occurred at that site throughout the season. This was reflected in shoot growth before véraison, being about 100 cm at A and 125 at B. For comparison, shoot length before véraison at JRS was about 140 cm and >230 cm at RVV (see Chapter 5, Table 30). Pruning weight was also low at A – about 1.2 kg/vine, while at B it was approximately 1.8 kg/vine. The corresponding pruning weights at JRS and RVV were 1.4 and 3 kg.

Contrary to results at the JRS and RVV sites, better fruit composition and wine quality was achieved at the B than at A site in Italy. Overall for all sites, TSS levels at the Treviso sites were markedly lower (16.9-20.6) than those in Hawke's Bay (20.4-21.8). Concentration of total anthocyanins at B in Treviso and at RVV in Hawke's Bay were similar (1000-1200 mg/kg), those attained at A in Treviso were very low (about 800 mg/kg), while JRS in Hawke's Bay had the highest concentration of anthocyanins (around 1400 mg/kg). Similar relationship existed regarding total polyphenols.

Wines produced from the B site in Treviso were of higher quality in all attributes measured than wines from site A. This is contrary to sensory

evaluation results from the present study, which show that wines from the stony-sandy soil (JRS) were of higher quality than those from RVV. Comparison of wines produced in the Treviso trial and in Hawke's Bay was not possible, as they were not evaluated by a common method.

Growth characteristics and fruit composition of the same cultivar on the same rootstock in these trials showed distinct differences between sites in the two wine regions. Excessive water stress that can occur in stony soils in conditions of little rainfall and insufficient irrigation (A) had a detrimental effect on fruit and wine quality in Cabernet Sauvignon. However, a relatively similar soil at JRS with a moderate water stress enabled production of fruit composition better not only than A, but also than that achieved in soils with good soil water retention capacity in both regions. That good fruit quality was achieved at the JRS site despite low soil moisture content throughout the season might be explained by the findings of Meriaux *et al.* (1976). They established that steadily intensifying drought conditions from an early stage of growth resulted in morphological adaptation of cv Cabernet Sauvignon leaves, enabling them to maintain optimum photosynthesis and fruit sugar content equal to that of the irrigated control.

Fruit quality in Cabernet Sauvignon on SO4 rootstock was positively affected when vines were grown on dry gravelly soil (Carbonneau, 1982). That author also found that Cabernet Sauvignon vines on a moist sandy loam (relatively similar to the soil at RVV) had higher yields but lower TSS than when grown on a dry gravelly soil. This finding was similar to the present results from grapes grown at the JRS and RVV sites. Boissenot (1998) also determined that limited water supply was beneficial for wine quality in Cabernet Sauvignon, since a high water supply was associated with the increased methoxypyrazine content through higher grapevine vigour. Both Merogue *et al.* (1998) and Costantini *et al.* (1996) noted variability of grapevine performance on stony and dry soils, as it is greatly dependent on water availability that (in non-irrigated vineyards) varied within and between seasons.

Unfavourable consequences of water stress at site A (Tomasi *et al.*, 1999) emphasise the importance of a remark made by Seguin (1983, 1986, cit. Gladstones, 1992) that a steady, moderate availability of moisture, whether coming from rainfall or irrigation, is essential for production of the highest quality grapes.

Another important conclusion that can be derived from the trial of Tomasi *et al.* (1999) relates to the proposed 'soil factor' (SF), the variable described and examined in Chapter 4. This variable was shown to significantly relate to a number of attributes of vegetative and generative growth, as well as with fruit and wine quality. Available data for site A in the Treviso trial indicate that a high SF value on that site probably occurred. If that were the case then that would mean that the effect of SF on attributes of fruit and wine quality is not linear, but that at very high SF values quality parameters deteriorate.

The occurrence of high SF levels would indicate that soil temperatures frequently exceeded 30°C, volumetric soil moisture content was 6-7% and a rooting zone depth was <0.5m. Under such conditions grapevines grown as relatively large plants (including systems like Sylvoz or Scott-Henry) would be excessively water-stressed, vegetative growth would be significantly reduced and fruit quality constituents would decrease. In such conditions where no irrigation or insufficient irrigation is available, grapevines would have to be grown as small plants (for example, the Goblet system) in high density plantations if reasonable fruit quality was to be achieved.

Potential Viticultural 'Terroirs' in Hawke's Bay

Based on the present study it is possible to propose potential viticultural 'terroirs' for Cabernet Sauvignon in Hawke's Bay (Figure 47). Sites on gravelly soils that are extremely permeable are termed "Gravels" in this study and are found west of Hastings, in Ohiti and, to lesser extent, close to Puketapu. Sites close to the Ngaruroro and Tutaekuri rivers (the Mangatahi / Maraekakaho and Dartmoor / Puketapu sub-regions), such as those on alluvial sandy or silty loams are termed "Terraces". "Shallowpans" represent

'potential terroirs' located on the Waipukurau sandy loam soil that commonly has a clay pan. These can be found close to the Tukituki River. 'Potential terroirs' on the Esk sandy soils are termed "Sands" and are found in Esk Valley. Based on the limited research conducted in 1996/97, sites in the close proximity of the Pacific Ocean and predominantly on the Waipukurau sandy loam, such as those in Haumoana, Te Awanga or Bayview areas, are probably different enough in most attributes and represent their own 'terroir', here termed "Oceanic".

Other viticultural areas in Hawke's Bay require a more detailed study for their 'terroir' effect to be ascertained. This is particularly true of the Meeanee-Brookfields area (south of Napier) that was not included in this study because the appropriate scion/rootstock combination was not available.

The value of 'soil factor' (SF), the variable defined and examined in Chapter 4, that has shown to be potentially useful for modelling of fruit ripeness (Chapter 7) was very different between these 'potential terroirs'. At véraison (early February), the "Gravels" SF would normally be 3, while at "Terraces" it would be <1. The "Shallowpans" SF would be <1 in wet and >2 in dry seasons. The SF values at "Sands" and "Oceanics" would mostly be between 1 and 2 (SF for "Oceanics" only being an educated guess). However, not only the soil-related factors are different between these 'potential terroirs': in Chapter 4 it was shown that above-ground conditions exhibit slight differences between sub-regions and hence between 'potential terroirs' in Hawke's Bay.

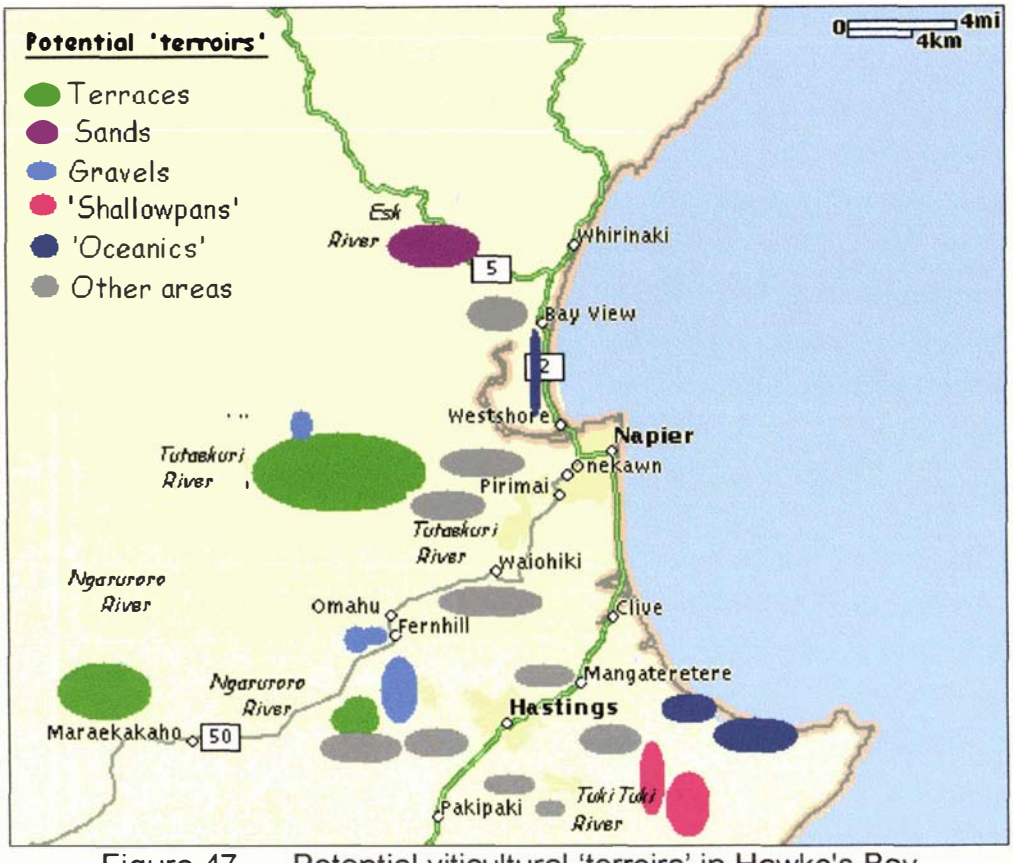

Figure 47. Potential viticultural 'terroirs' in Hawke's Bay

The most relevant outcome of this study is the effect of site or of 'potential terroir' on wine sensory attributes, presented in Chapter 8 in detail (page 193), although it is acknowledged that management practices might have had an effect on the sensory scores. The SF values during fruit ripening were significantly correlated with wine sensory evaluation scores. Wines originating from vineyard sites where soil had limited the water availability to grapevines either by low soil moisture retention capacity, or by limiting vine root growth, achieved highest scores and the most preferable organoleptic attributes. These sites represent "Gravels" and "Shallowpans". Therefore, these two 'potential terroirs' appear to be able to produce Cabernet Sauvignon wines with the most preferred attributes, particularly so in 'good seasons' (ie those that are warm, sunny and with a relatively dry summer and autumn).

Unlike "Gravels", "Shallowpans" are difficult to manage in wet and/or cool seasons due to excessive vegetative growth of grapevines, for example the

vegetative growth that occurred in 1996/97 (see Table 7, Chapter 3). From the present results it appears that canopy management (trellises with divided canopy, frequent shoot trimming and leaf removal) is not capable of substantially improving fruit quality at "Shallowpans" when seasons are excessively wet and cool (see Table 9, Chapter 3).

In-depth studies to determine the best vineyard irrigation management for obtaining the highest fruit and wine quality in "Gravels" are very much warranted and urgently required. Anecdotal evidence suggests that such studies are currently conducted 'in-house' within certain wine companies.

In most seasons "Terraces" and "Sands" will provide only average quality wines that can potentially be slightly improved with canopy management. This is mostly because their soil characteristics (relative fertility, depth, high available water content or presence of the water table) induce strong vegetative growth in Cabernet Sauvignon grapevines. It is likely that blending with Merlot and Cabernet Franc will be required in many seasons to sustain wine quality, with the percentage of Cabernet Sauvignon in these blends reducing with a decreasing SF value. (Low SF denoting soils that are deeper, cooler, and with more available moisture than when the SF values are high).

The 'terroir' effect of "Oceanics" on wine quality can only be guessed at, based on the results of initial study in 1996/97, and are probably midway between "Shallowpans" and "Terraces".

These results suggest that New Zealand and, more specifically, Hawke's Bay should establish its own 'terroirs'. According to the present understanding, the most suitable methodology for this would be the one based on the work of Vaudour *et al.* (1998) conducted at the Institut National Agronomique (INRA) in France. The present study presents a relatively rough delimitation of potential 'terroirs' in Hawke's Bay. As in the work of Vaudour *et al.* (1998) it will require ten or more years of fruit composition and wine quality data from a significant number of representative sites for 'potential terroirs' to be proclaimed 'terroirs'.

Potential benefits of delimitation based on thus defined 'terroirs' to the New Zealand grape and wine industry are quite significant. The adoption of the 'terroir' method in site selection and viticultural zoning does not imply that the New Zealand wine industry need to impose severe viticultural and winemaking restrictions, similar to the perhaps over-regulated *Appellation d'origine contrôlée* system of France.

If Falcetti's (1997) theory of cycles in viticultural development is accepted, even if a delimitation based on 'terroir' is not imposed from the wine industry bodies in the near future, the time will come when the need for viticultural zoning will be only too obvious. This process and the associated problems can currently be witnessed in the famous wine region of the Coonawarra in South Australia, where many grape growers are appealing against the proposed Coonawarra Geographic Indication (Anon., 2000c). Already established vineyards and wineries are now facing the possibility of not being able to use the lucrative Coonawarra name on their wine labels, as the recently established boundaries exclude their properties from the Coonawarra appellation. If an appropriate 'terroir'-based delimitation was done in that region a decade or two ago, the vineyards in question would have been established as certain appellation from their onset, and the current problems would probably be avoided. The New Zealand wine industry could learn valuable lessons from examples such as this one in Australia, as it will certainly face similar problems in the near future.

It is important to note that 'terroir' should be seen as a complex interaction of environment and viticulture. That effect can be associated with areas of varying physical size. As Martin (2000) stated, 'terroir' can be viewed at numerous different levels of physical space. Thus there exists a New Zealand 'terroir', 'terroir' of Hawke's Bay and of its sub-regions, and it can even be associated with rather small vineyard blocks, particularly so in Hawke's Bay, a region characterised by pronounced variability of soil and climate. Therefore a base 'terroir' will be associated with different size areas, primarily dependent on soil/subsoil variability and mesoclimatic conditions.

Conclusions and Future Prospects

Based on three years of study of phenology, growth, development, fruit composition and wine quality in cv Cabernet Sauvignon, Clone UCD7 grafted on SO4 rootstock at different sites in Hawke's Bay, detailed analysis of environmental data and a comprehensive review of relevant literature, the following conclusions can be drawn:

- Principal component analysis of variables collected in 1996/97 isolated phenology as one of the key attributes for characterisation of viticultural sites. 'Indices of precocity' (Barbeau at al., 1998b) were strongly correlated to important attributes of fruit and wine quality. Phenological indices could therefore provide the basis for a relatively simple determination of site categories (ie. early, intermediate, late) as a precursor to more detailed studies of site-related effects on vine growth and fruit and wine quality.

- Monitoring of weather and soil variables at selected sites enabled detailed analysis of viticultural environments. In addition, soil profiles were studied and soil samples taken from the rooting zone were physically analysed. Based on observed environmental factors it is concluded that overall variability of climate is less than the variability of soil across the Hawke's Bay winegrape producing region. That indicates that below-ground environmental conditions will be the dominant factor in determining 'terroirs' within a specific region.

- Vineyard sites were relatively consistent in canopy density, however, high seasonal variability in canopy density was observed at the MMR site. This variability was ascribed to soil at this site that has a shallow impermeable clay pan. Difference in soil moisture content between wet and dry seasons at this site, suggested that the effect was due to the presence of a clay pan, and that this difference will be proportionally higher than at other sites. This pronounced difference caused by seasonal conditions at MMR translates to distinct seasonal difference in potential for fruit and wine quality at this site. Increased attention to

canopy management in wet seasons is needed to reduce potentially significant decrease in fruit quality. However, excessive defoliation is not recommended, as it may additionally reduce fruit quality and increase 'shanking' through low carbohydrate status. Maintaining a relatively light crop yield in wet seasons at MMR and similar sites would seem warranted.

- Overall macronutrient concentration in leaf petioles was normal, as were seasonal dynamics. Mg concentration in leaf petioles was below optimal in some cases, and this could be due partly to the effect of cultivar, as Cabernet Sauvignon is known to be relatively low in Mg. In addition, SO4 has been reported as a rootstock associated with low Mg status. Soil fertility was not tested and Mg status in soil is not known, however high K levels as well as high K/Mg ratio indicates that the likely reason for low Mg is antagonism with K, rather than its low availability. Nonetheless, utilisation of rootstocks that may improve Mg status in Cabernet Sauvignon vines in Hawke's Bay could potentially be beneficial for wine quality.

- Vines at selected sites significantly differed in winter pruning weights, which were positively correlated with canopy density. Over three seasons yield/pruning weight ratio was higher at the JRS and LND sites that had gravelly and sandy soils than at others. Analysis of cane weight data showed convincingly that overall vigour of Cabernet Sauvignon vines grown in Hawke's Bay was excessive, as four out of six sites had canes with an average weight above optimum. Reduction of vine vigour at sites with deep and wet soils is essential for successful Cabernet Sauvignon growing in Hawke's Bay. Using moderately vigorous rootstocks, testing various training and pruning systems at different planting densities to determine a combination that stimulates vigour the least, growing different cover crops to compete with vines for water and nutrients at key stages of development are suggested methods for reducing vine vigour.

- Study of phenological phase of flowering showed that it is a crucial stage when to large extent grape yield is determined by berry set percentage. It also has an effect on fruit quality through crop variability that can result from different flowering times within a block. Removal of clusters from very short shoots at cluster thinning may prove beneficial by reducing unwanted crop variability. Seasons characterised by fast and early flowering may also be those that have an early harvest of a good crop of well-ripened grapes. Sites that have a warmer mesoclimate should benefit from slight advantage in flowering time and rate and thus should be the preferred sites for production of Cabernet Sauvignon grapes in Hawke's Bay.

- A Principal Component Analysis (PCA) of 61 variables of vine growth, phenology and fruit characteristics extracted two main factors that differentiated the six studied sites. The first factor mostly corresponds to below-ground environmental conditions and is associated with many attributes of vine growth, phenology and fruit composition. The second factor corresponds to above-ground conditions and is associated with organic acids in juice. Therefore, fruit quality attributes have been found to be closely associated with soil characteristics and to lesser extent with that of weather.

- Of all the observed fruit composition attributes, the TSS/malic acid*pH index measured on 23-25 March appears to be the best predictor of Cabernet Sauvignon wine quality in terms of its organoleptic value. This index is proposed in the present study as a novel maturity index for Cabernet Sauvignon grapes grown in cool to warm climates. Further validation of this maturity index on other cultivars and in other regions is warranted, as the potential benefit of a reliable and a relatively early maturity index for the grape and wine industry is significant.

- Based on available evidence from the Hawke's Bay wine industry (discussed on page 15, Chapter 1) it is clear that more than two seasons are needed to determine 'typicity' of wine as related to potential viticultural 'terroir'. However, a general pattern that emerged from this

study was such that wines originating from vineyard sites where soil limited water availability to grapevines, either by low soil moisture retention capacity or by limiting vine root growth, achieved highest scores and the most preferable organoleptic attributes. The biggest advantage of sites with soils restricted in water supply and/or root zone is that they discouraged vegetative growth and had an optimal crop yield ratio. Sites that did not have this relative advantage required higher levels of input in vineyard management in order to reach and maintain a satisfactory balance in vine growth. This balance may be easier to achieve at such sites with grapevine cultivars other than Cabernet Sauvignon.

- Analogous to existing climatic indices that characterise viticultural countries and regions, the 'soil factor' (SF) is proposed as an additional and valuable factor that can be used to characterise vineyard sites. SF integrates soil temperature, soil moisture volumetric content, depth of topsoil and water availability index based on soil texture class. SF exhibited strong correlations with many vine growth and development characteristics as well as with fruit and wine attributes. These attributes included: several indices of vegetative growth, mid-véraison date, TSS at some stages of ripening, tartaric and malic acid at early stages of ripening, total phenolics and anthocyanins in berry skins at harvest and, finally, wine sensory evaluation scores. It appears that environmental characterisation of vineyard sites in Hawke's Bay based mainly on SF could eventually lead to determination of potential viticultural 'terroirs' for Cabernet Sauvignon and perhaps other cultivars in the future. Further studies that would help 'fine tune' a model analogous to SF are required and could potentially be of great benefit to viticultural science and to the New Zealand wine industry.

- The present study indicates certain potential 'terroirs' in Hawke's Bay based on the three years of research on cv Cabernet Sauvignon. The definition of these potential 'terroirs' was synthetised out of the overall information on vineyard environment and fruit and wine composition

obtained in this study, with particular emphasis on the 'soil factor' (SF), which was found to be very dissimilar at different site types. These potential 'terroirs' are:

- "Gravels", located mostly west of Hastings. These sites will probably achieve good sugar/acid balance in most seasons. Irrigation management is of utmost importance at these sites, as excessive water stress caused by restricted irrigation can be unfavourable for fruit characteristics.

- "Terraces" represent river terraces of inland Hawke's Bay. From the results obtained it appears that the proper selection of harvest date is crucial for the success at these sites. This is particularly true of tannins that can taste overly green in wines when grapes were picked too early. "Terraces" may also include sites that are characterised by an extreme potential for vegetative vigour, probably due to a high water table. Such sites cannot be recommended for wine grape growing.

- "Shallowpans", mostly south of Havelock North. These sites will produce inconsistent fruit and wine quality between seasons. Seasons characterised by dry and sunny weather will produce outstanding vintages, while vintage from wet and cool seasons will be of a considerably lower value.

- "Sands", mostly around Eskdale. These sites may be characterised by relatively high vine vigour and high yield potential, probably due to the water table readily accessible by vine roots. In good seasons "Sands" may produce wines characterised by nice soft tannins and good fruitiness.

- In addition to the above, vineyard sites in the close proximity of the Pacific Ocean may represent a potential 'terroir' of their own ("Oceanic"). However, these sites were not studied into detail in the present work.

Future studies of potential 'terroirs' in various viticultural regions will be essential for understanding wine quality, style and typicity resulting from the interaction of mesoclimate and landscape, cultivar, clone, rootstock, soil and subsoil, water availability, all under influence of viticultural and oenological strategies. With current developments in environmental monitoring, Geographic Information Systems (GIS) and precision viticulture using remote sensing, the term 'terroir study' is getting a new meaning. The large amount of environmental data that can be collected using modern monitoring equipment available to viticulturists will enable a new approach to be adopted in the study of yield and ripeness modelling. In the past mostly regression-based modelling was used. New remote sensing and data acquisition technologies enable the application of neural networks, and these give an unprecedented precision to yield estimates (Drummond and Sudduth, 1999).

A recent development in precision agriculture and viticulture has allowed the possibility of estimating soil spatial characteristics using soil electrical conductivity (EC) or passive microwave measurements. Sudduth *et al.* (1999) found that EC was strongly correlated with topsoil depth above a claypan. Oldak and Jackson (1999) performed soil moisture mapping using passive microwave measurements and GIS. Precision viticulture, a novel technological approach to viticultural practices based on remote sensing (Lamb, 1999) enables improved irrigation management, sequential harvest of different blocks within vineyards according to aerial maps of grape ripeness, or differential planting of new vineyards according to aerial soil maps. According to the present results, soil moisture content and topsoil depth are highly correlated with fruit and wine characteristics. Work by Vaudour *et al*. (1998) in France in defining 'terroirs' showed how these new technologies could be successfully utilised to characterise and define different grape growing environments.

Potential benefits of adopting similar methodology to define 'terroirs' and viticultural zones to the New Zealand wine industry are substantial, particularly for Cabernet Sauvignon, a cultivar difficult to manage because

of its strong vegetative vigour and late fruit maturation. Defining 'terroirs' and utilising them in site selection will reduce the proportion of 'poor' seasons, add value to the work of grape growers and wine makers, and will also facilitate the application of adequate vineyard management techniques in order to amplify wine typicity to 'terroir'.

The New Zealand wine industry is a relative newcomer in the world's market of premium wine. New Zealand stands to gain significant benefits from undertaking similar studies in various regions, with a variety of cultivars, rootstocks and management practices. In effect, such studies of potential 'terroirs' will help New Zealand not only make up for its lack of viticultural tradition, but will also give an advantage over traditional wine producing countries. Unrestrained by traditionalism and rigid regulations, New Zealand grape and wine industry can utilise the knowledge of its future 'terroirs' along with the cutting edge viticultural and oenological techniques to ensure its premium wines have little competition in designated market niches.

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APPENDICES

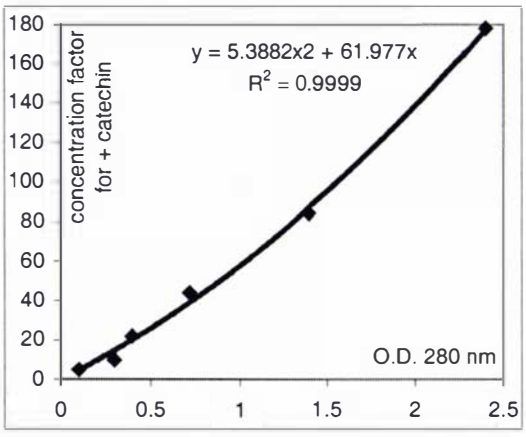
Appendix 1. Canopy Density Scorecard

		Vineyard and Date					
Canopy gaps	**Points**						
about 40%	**10**						
about 50% or more	**8**						
about 30%	**6**						
about 20%	**4**						
about 10% or less	**0**						
Leaf size							
slightly small	**10**						
average	**8**						
slightly large	**6**						
very large	**2**						
very small	**2**						
Leaf colour							
leaves green, healthy, slightly dull and pale	**10**						
leaves dark, shiny healthy	**6**						
leaves yellowish green, healthy	**6**						
leaves with mild nutrient deficiency symptoms	**6**						
unhealthy leaves, with marked necrosis or chlorosis	**2**						
Canopy density (mean leaf layer number)							
about 1 or less	**10**						
about 1.5	**8**						
about 2	**4**						
more than 2	**2**						
Fruit exposure							
about 60% or more exposed	**10**						
about 50%	**8**						
about 40%	**6**						
about 30%	**4**						
about 20% or less	**2**						
Shoot length							
about 10-20 nodes	**10**						
about 8-10 nodes	**6**						
about 20-25 nodes	**6**						
less than about 8 nodes	**2**						
more than about 30 nodes	**2**						
Lateral growth							
limited or zero lateral growth	**10**						
moderate vigour lateral growth	**6**						
very vigorous growth	**2**						
Growing tips							
about 5% or less	**10**						
about 10%	**8**						
about 20%	**6**						
about 30%	**4**						
about 40%	**2**						
about 50% or more	**0**						
Total score (ex 80)							

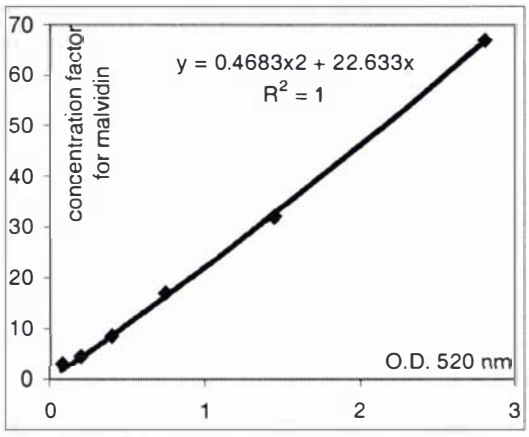
From: Smart, R.E.; Robinson, M.D. (1991): *Sunlight into Wine. A Handbook for Winegrape Canopy Management.* Winetitles, Adelaide

Appendix 2. Calculation of the Content of Polyphenols and Anthocyanins

The following empirical equations (D.J. Martin, pers. comm.) were used to calculate the content of polyphenols and anthocyanins based on the UV spectrophotometer readings of diluted berry skin extracts. Six different concentrations of +catechin (concentration factors 5, 10, 20, 40, 80 and 180) and malvidin (concentration factors 3, 5, 8, 18, 30, 68) were read on a UV spectrophotometer at 280 nm and 520 nm respectively and the readings were plotted against the respective concentration factors (these represent 1 mg of substance / 50 ml solution). Quadratic regressions obtained (see figures below) were used to predict concentrations of polyphenols and anthocyanins, respectively, in the experimental samples.



Relation between Optical Density (O.D.) 280 nm and concentration / dilution factor of +catechin



Relation between O.D. 520 nm and concentration / dilution factor of malvidin

Extractable polyphenols [*EP*] in g per kg of fresh berries:

$$EP = \frac{d \times (5.3882 \times OD280s^2 + 61.977 \times OD280s) \times 100}{BW_{50}}$$

Where the symbols are: *d* – dilution ratio (20), *OD*280*s* – optical density of synthetic wine solution at 280nm, and BW_{50} the weight of 50 berries in g

Extractable anthocyanins [*EA*] in g per kg of fresh berries:

$$EA = \frac{d \times (0.4683 \times OD520s^2 + 22.633 \times OD520s) \times 100}{BW_{50}}$$

Where the symbols are: *d* – dilution ratio (20), *OD*520*s* – optical density of synthetic wine solution at 520nm, and BW_{50} as above.

Total polyphenols [*TP*] in g per kg of fresh berries:

$$TP = \frac{d \times (5.3882 \times p^2 + 61.977 \times p) \times 100}{BW_{50}}$$

Where the symbols are: *d* – dilution ratio (20), *p* – the result of the equation shown below, and BW_{50} the weight of 50 berries in g.

Total anthocyanins [*TAC*] in g per kg of fresh berries:

$$TAC = \frac{d \times (0.4683 \times q^2 + 22.633 \times q) \times 100}{BW_{50}}$$

Where the symbols are: *d* – dilution ratio (20), *q* – the result of the equation shown below, and BW_{50} the weight of 50 berries in g.

The value of p *is calculated as:*

$$p = \frac{(OD280s + OD280h) \times 100}{11.644 \times \left(\frac{OD280h}{OD280s}\right)^2 - 37.933 \times \left(\frac{OD280h}{PD280s}\right) + 101.4}$$

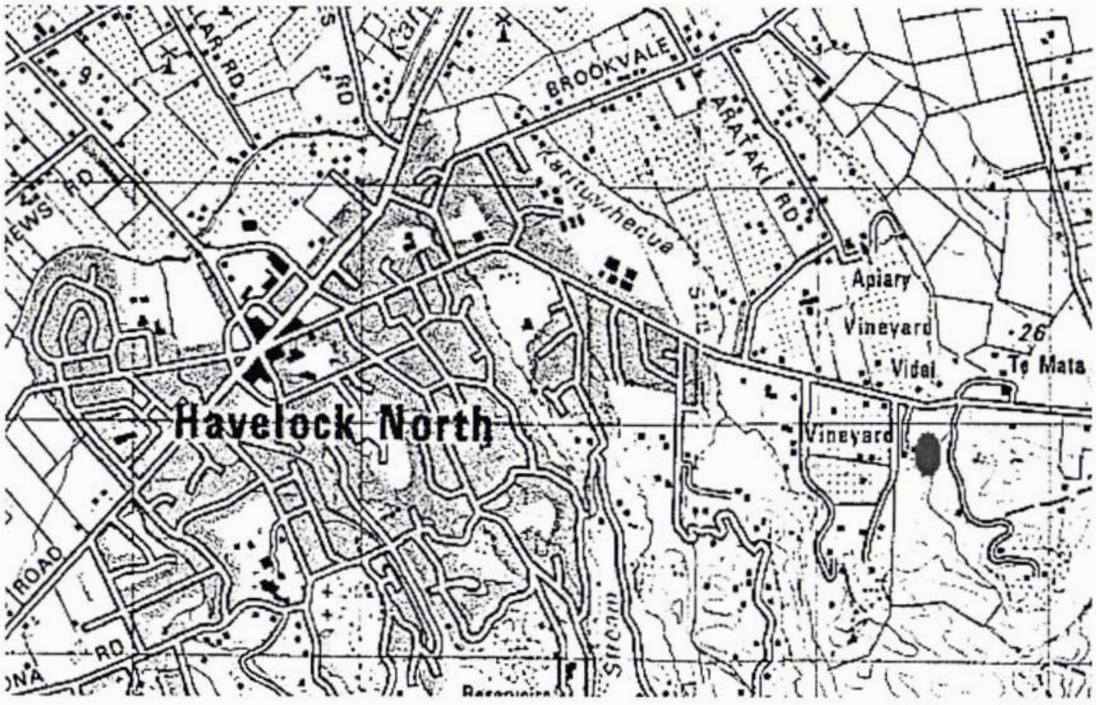
The symbols are: OD280s - optical density of synthetic wine solution at 280nm, OD280h – optical density of 2% HCl solution at 280 nm.

The value of q *is calculated as:*

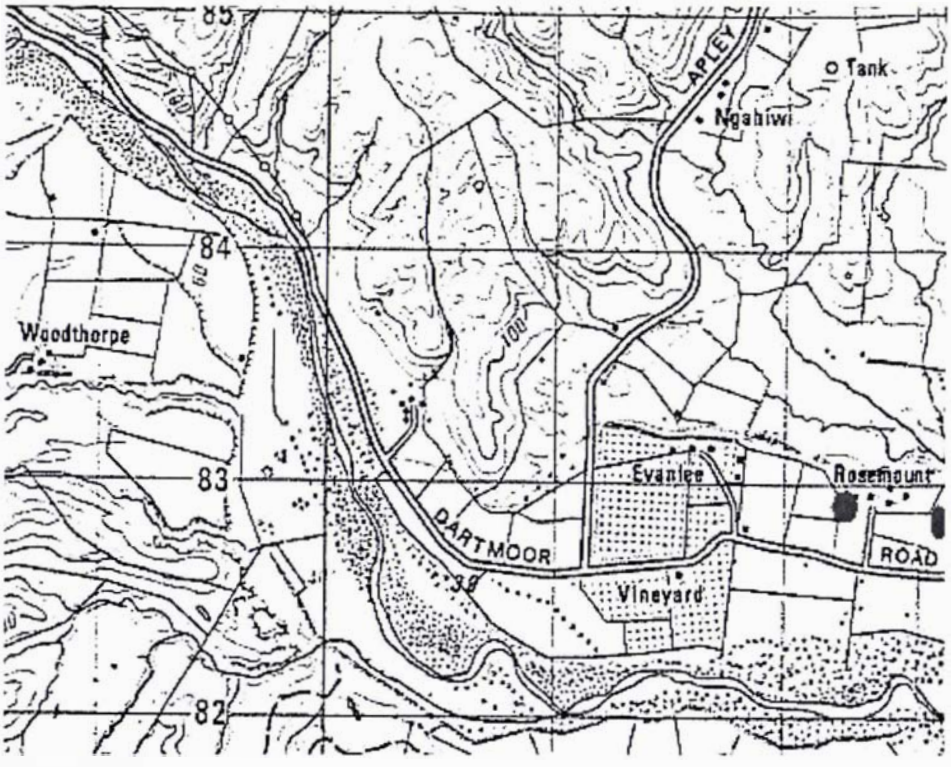
$$q = \frac{(OD520s + OD520h) \times 100}{11.644 \times \left(\frac{OD520h}{OD520s}\right)^2 - 37.933 \times \left(\frac{OD520h}{PD520s}\right) + 101.4}$$

The symbols are: OD520s - optical density of synthetic wine solution at 520nm, OD520h – optical density of 2% HCl solution at 520nm.

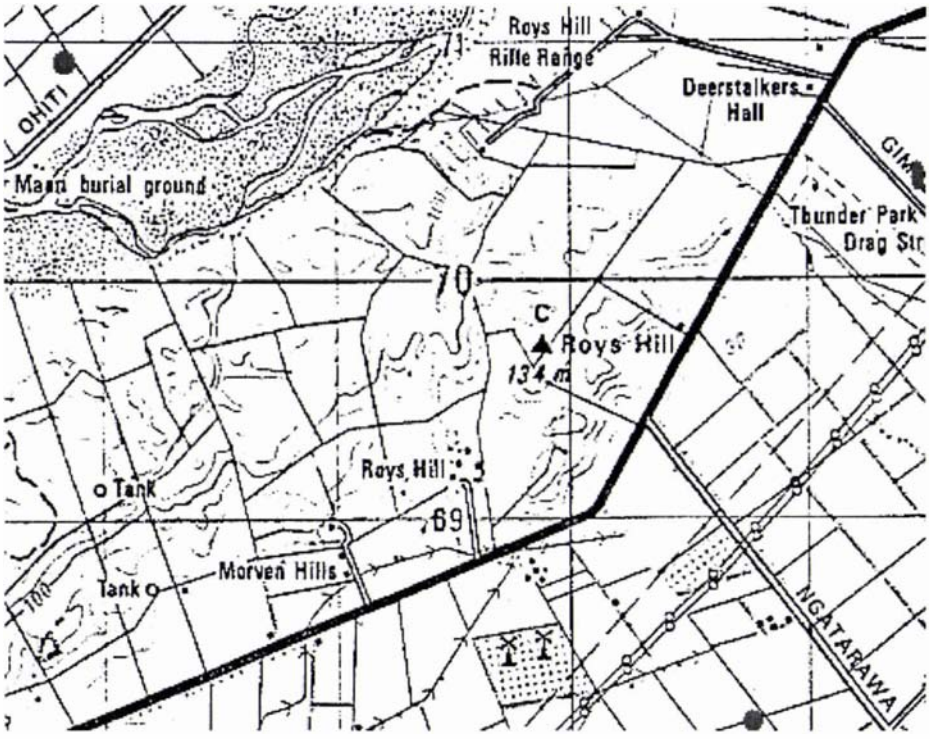
Appendix 3. Topographical locations of some of the studied vineyard sites



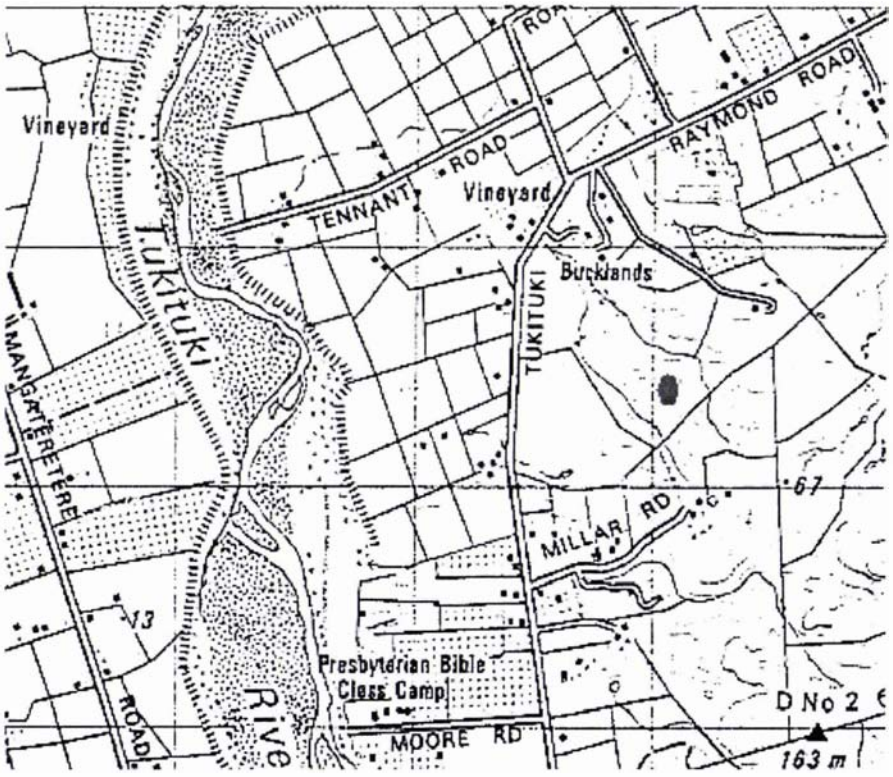
Topographical location of the AIT site (red mark) studied in 1996/97, located at the foothills of Te Mata Peak



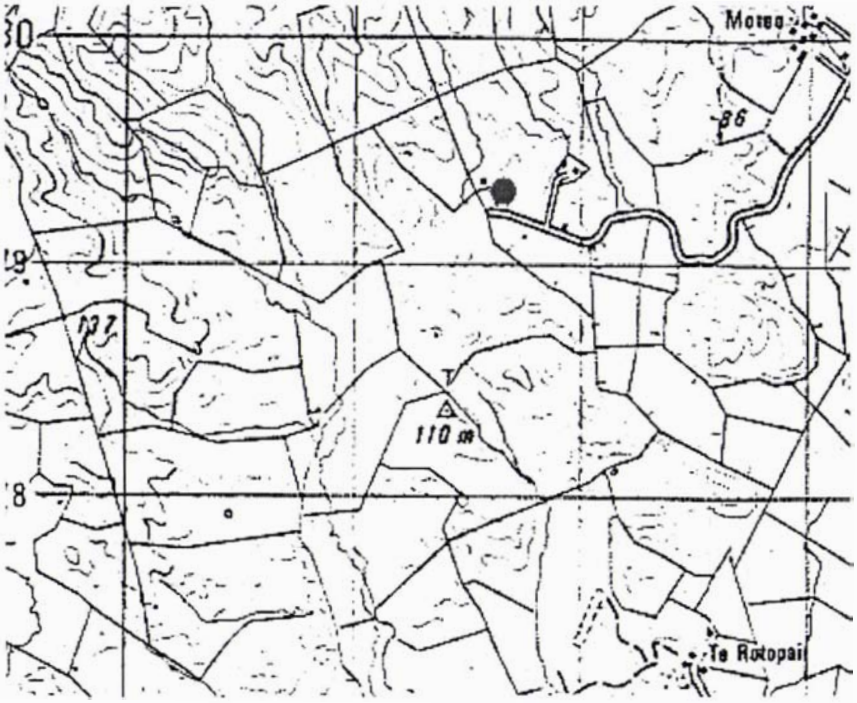
Topographical locations of the BPN (red, studied in all three seasons) and RSW (green, studied in 1996/97) sites on the north bank of the Tutaekuri River in the Dartmoor / Puketapu sub-region



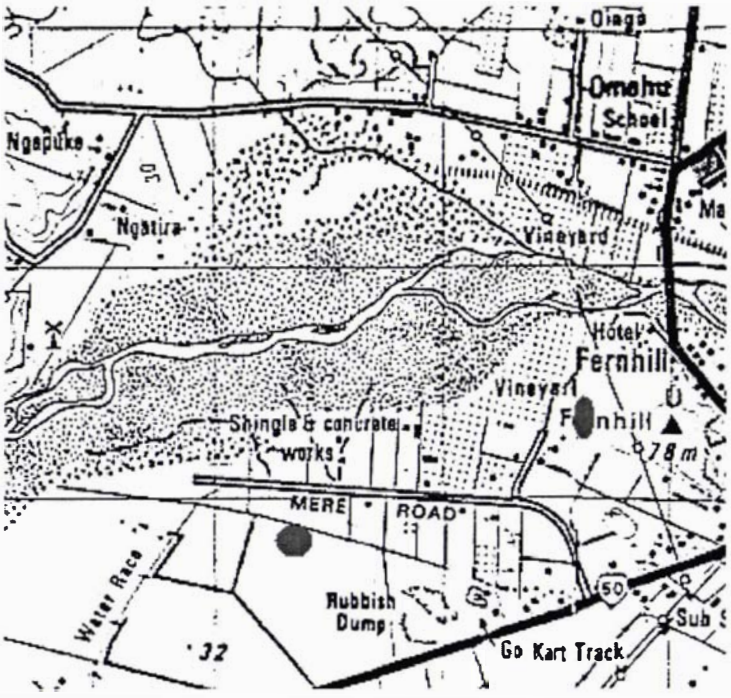
Topographical locations of the NGW and BEL sites (green marks, studied in 1996/97) and the approximate position of the Gimblett road area vineyards (red mark, sites BOB and KNG studied in 1996/97 and JRS in all three seasons)



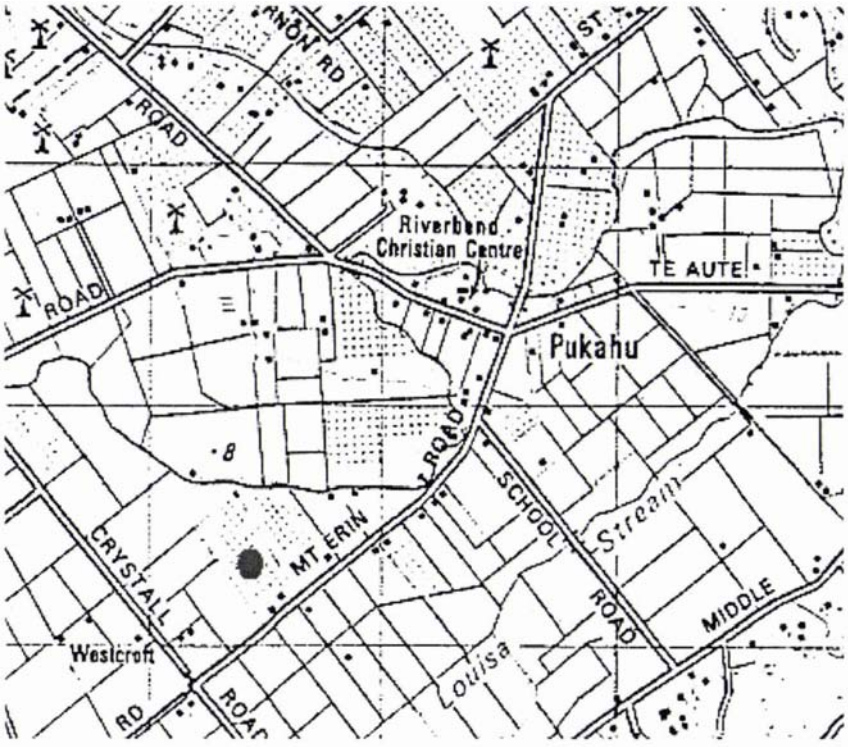
Topographical location of the MMR site (red mark) studied in all three seasons, located on the eastern bank of the Tukituki River and 3 km from the Pacific Ocean



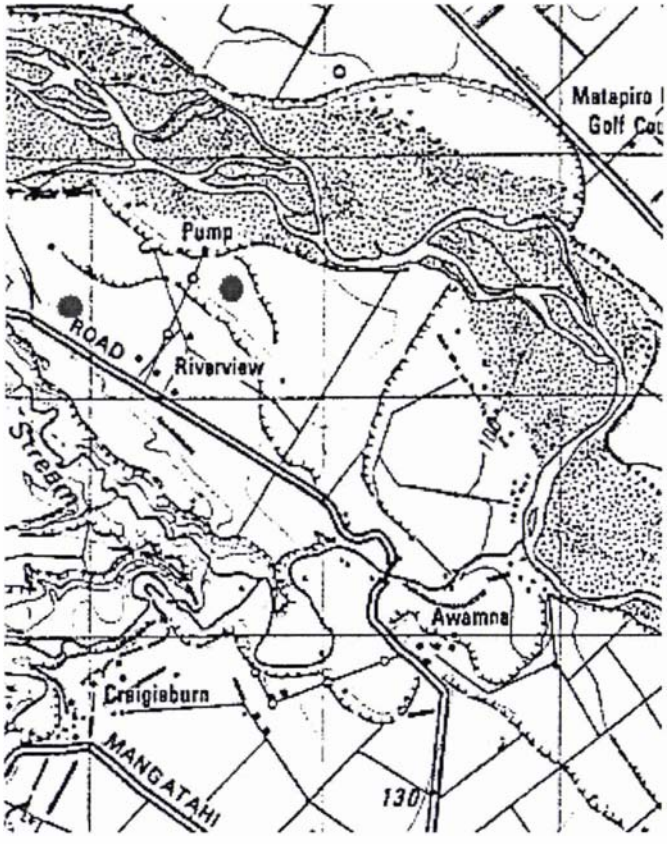
Topographical location of the RCT site, located near Moteo, in the Dartmoor / Puketapu sub-region



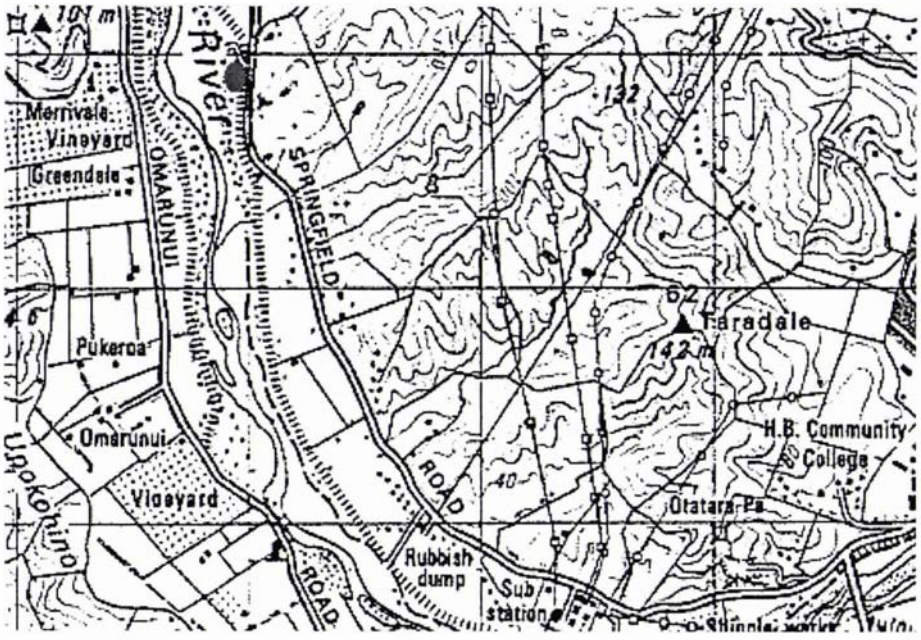
Topographical locations of the ROB (red mark) and SCR (green mark) sites studied in 1996/97, located in the Fernhill area



Topographical location of the RSG site (red mark) studied in 1996/97, located in the Longlands area of the Havelock North / Te Mata sub-region



Topographical locations of the RVV (red mark) and the RV2 (green mark) sites located on the terraces of the Ngaruroro River in the Mangatahi / Maraekakaho sub-region



Topographical location of the SFV site located on the eastern bank of the Tutaekuri River in the Taradale / Meeanee / Brookfields sub-region

Appendix 4. The Set-up of Li-Cor LI1000 Data Loggers

Out of eight channels available on LI1000 data loggers, Li-Cor radiation sensor was connected to channel three, two soil temperature sensors were attached to channels four and five, while the sixth channel was used for the air temperature sensors.

Channel 3 setup (Li-Cor radiation sensor)

RANGE	A
MULT	*
LABEL	LT
PER	1440
INTERVAL	60
RESET	0:00
THR	0.01
STORE	INT
MIN/MAX	NO

* - Site RVV=23.6; JRS=24.9; BPN=10.7; SFV=10.6; LND=24.0; MMR=23.3

Channels 4 and 5 setup (soil temperature sensors)

RANGE	A
a0	0
a1	1
a2	0
a3	0
a4	0
a5	0

MATH	OFF
LABEL	ST
PER	1440
INTERVAL	60
RESET	0:00
THR	-1.00E+09
STORE	MEAN
MIN/MAX	NO
TIME STAMP	NO

Channel 6 setup (air temperature sensor)

RANGE	A
a0	0
a1	1
a2	0
a3	0
a4	0
a5	0
MATH	OFF
LABEL	AT
PER	60
INTERVAL	60
RESET	0:00
THR	-1.00E+09
STORE	MEAN
MIN/MAX	YES
TIME STAMP	NO

Coefficients a 0 through 5 for the temperature sensors were set to zero so that the reading from the sensors was the actual voltage (V). Calculation of temperatures was done based on the following equation:

$$t = \frac{c1}{\ln\left(\left(\frac{5000}{V}\right) - 33.2\right) - \ln c2 + \frac{c1}{298.3} - 273.3}$$

Values of c1 and c2 were previously determined for each of the sensors, thus calibrating the sensors to give the readings within +/- 0.1°C.

Temperature sensors calculation coefficients

Probe #	Coefficient c1	Coefficient c2	Site/use*
1	3867.26	10.0649	BPN/at
2	3864.75	10.0325	LND/at
4	3852.40	10.0723	JRS/at
5	3861.22	10.0604	RVV/at
6	3855.17	10.0669	SFV/at
8	3866.35	10.1018	MMR/at
9	3854.95	10.1616	RVV/st30

10	3858.35	10.1127	RVV/st15
11	3844.93	10.1914	MMR/st15
12	3852.33	10.1949	JRS/st30
13	3858.25	10.1868	LND/st30
14	3859.57	10.1760	JRS/st15
15	3855.67	10.1353	MMR/st30
16	3844.35	10.1716	SFV/st15
17	3851.59	10.1441	SFV/st30
18	3858.41	10.2198	BPN/st15
19	3864.71	10.2240	LND/st15
20	3852.33	10.2273	BPN/st30

* - at: air temperature; st15 and st30 soil temperatures at 15 cm and 30 cm respectively

Appendix 5. Soil Descriptions and Classifications

Site: RVV

- Situated on alluvial fan originating in small gully
- Well drained soil (hydromorphic class 5)

Classifications:

Local soil name: Ngatarawa sandy loam

New Zealand Soil Classification: Argillic Fragic Pallic Soils

USDA Soil Classification: Oxyaquic Haplustalf, loamy-skeletal, mixed, mesic.

Horizon	Depth (m)	Horizon Description
A1	0 - 0.10	Black (10YR 2/1) sandy loam; moderately weak soil strength; firm penetration resistance; moderately pedal; many fine polyhedral peds; many thick horizontal roots (from vines); moderately rapid estimated permeability; non-reactive to reactive aluminium test.
A2	0.10 - 0.19	Black (10YR 2/1) and dark yellowish brown (10YR 4/4) sandy loam; moderately weak soil strength; firm penetration resistance; weakly pedal; many coarse blocky peds; many thick horizontal roots (from vines); moderately rapid estimated permeability.
A/B	0.19 - 0.30	Dark yellowish brown (10YR 4/4) and very dark brown (10YR 2/2) sandy loam; slightly sticky; moderately weak soil strength; stiff penetration resistance; weakly pedal; many coarse blocky peds; common 2mm thick roots; moderately rapid estimated permeability.
Bw	0.30 - 0.45	Dark yellowish brown (10YR 4/4) sandy loam; sticky; moderately firm soil strength; stiff penetration resistance; weakly pedal; many coarse blocky peds; common 2mm thick roots; moderate estimated permeability; non-reactive to reactive aluminium test.

2B	0.45 - 0.70	Brown to dark brown (10YR 4/3) heavy sandy loam with estimated 40% medium and fine gravel; sticky; moderately weak soil strength; weakly pedal; many fine polyhedral peds and single grains; common very fine roots; moderately rapid estimated permeability.
2Bt	0.70 - 0.92	Dark yellowish brown (10YR 4/4) sandy clay loam with estimated 40% coarse and very coarse gravel; sticky; few clay coatings; moderately weak soil strength; moderately pedal; many medium blocky peds breaking to fine polyhedral peds; common very fine roots; moderately slow estimated permeability; non-reactive to reactive aluminium test.
2BCgp	0.92 - 1.08	Wet light brownish grey (2.5Y 6/2) heavy sandy loam with estimated 40% coarse and very coarse gravel; common fine distinct strong brown (7.5YR 5/6) mottles; sticky; dilatant non-cohesive soil consistence; apedal; common very fine roots; moderate estimated permeability.
2BCx	1.08 - 1.15+	Slightly moist yellowish brown (10YR 5/4) gravelly sandy loam with estimated 40% medium and fine gravel; nonsticky; slow estimated permeability.

Site: JRS

- Situated on alluvial plain of Ngaruroro River
- Excessively drained

Classifications:

Local soil name:	Omahu stony gravels
New Zealand Soil Classification:	Typic Fluvial Recent Soils
USDA Soil Classification:	Typic Ustifluvent, sandy-skeletal, mixed, mesic.

Horizon	Depth (m)	Horizon Description
A	0 - 0.07	Dark brown (10YR 3/3) loamy fine sand with estimated 50% coarse and very coarse gravel; loose particle-packing; many thick roots; rapid estimated permeability.
C1	0.07 - 0.73	Very dark greyish brown (2.5Y 3/2) gravels with sand (estimated 70% coarse and very coarse gravels with sand packing interstices); compact particle-packing; many roots (diameters 2 to 8 millimetres); very rapid estimated permeability.
C2	0.73 - 0.85	Open coarse and very coarse gravels (estimated 70% by volume); loose particle-packing; many roots (diameters 1 to 2 millimetres); extremely rapid estimated permeability.

C3	0.85 - 1.2+	Very dark greyish brown (2.5Y 3/2) gravels with sand (estimated 70% coarse and very coarse gravels with sand packing interstices); compact particle-packing; common roots (1 millimetre diameter).

Site: BPN

- Situated on recent alluvial floodplain (protected by stopbanks)
- Well drained soil (hydromorphic class 5)

Classifications:

Local soil name: Omarunui silt loam on sand
New Zealand Soil Classification: Typic Fluvial Recent Soils
USDA Soil Classification: Mollic Ustifluvent, fine-loamy over sandy, mixed, mesic.

Horizon	Depth (m)	Horizon Description
A	0 - 0.19	Dark brown (10YR 3/3) silt loam; non-sticky; moderately weak soil strength; stiff penetration resistance; weakly pedal; medium blocky peds breaking to fine polyhedral peds; many fine grass roots; moderate estimated permeability.
A/B	0.19 - 0.35	Dark brown (10YR 3/3) and brown to dark brown (10YR 4/3) silt loam (fine-loamy particle size class) with few gravels; non-sticky; moderately firm soil strength; stiff penetration resistance; weakly pedal; medium blocky peds; many fine grass roots; moderate estimated permeability.
bA	0.35 - 0.43	Very dark greyish brown (10YR 3/2) sandy loam; non-sticky; moderately weak soil strength; firm penetration resistance; earthy apedal; many fine grass roots; moderate estimated permeability.
C	0.43 - 0.96	Light olive brown (2.5Y 5/4) loamy fine sand; non-sticky; very weak soil strength; soft penetration resistance; massive apedal; common 3mm thick roots; moderately rapid estimated permeability.
bA1	0.96 - 1.11	Greyish brown (2.5Y 5/2) and very dark grey (10YR 3/1) silt loam (fine-silty particle size class); no mottling other than a few dusky-coloured, decomposed fine roots; non-sticky; moderately weak soil strength; stiff penetration resistance; weakly pedal; medium blocky peds breaking to fine polyhedral peds; common 3mm thick roots; moderate estimated permeability.
bA2	1.11 - 1.35	Very dark grey (10YR 3/1) silty clay; no mottling other than a few dusky-coloured, decomposed fine roots; sticky; moderately weak soil strength; stiff penetration resistance; moderately pedal; fine

		polyhedral peds; common 3mm thick roots; moderate estimated permeability.

Continuation below base of pit, by hand auger:

Cu(f)1	1.35 - 1.70	Light olive brown (2.5Y 5/4) silt loam (coarse-loamy particle size class); many medium distinct grey (10YR 5/1) and many medium distinct strong brown (7.5YR 4/6) mottles; moderate estimated permeability.
Cu(f)2	1.70 - 1.90	Light olive brown (2.5Y 5/4) loamy fine sand; many medium distinct grey (10YR 5/1) and many medium distinct strong brown (7.5YR 4/6) mottles; moderately rapid estimated permeability.
Cu(f)3	1.90 - 2.40+	Light olive brown (2.5Y 5/4) heavy silt loam; many medium distinct grey (10YR 5/1) and many medium distinct strong brown (7.5YR 4/6) mottles; moderate estimated permeability.

Site: SFV

- Imperfectly drained soil (hydromorphic class 3)

Classifications:

Local soil name:	Pakowhai silt loam
New Zealand Soil Classification:	Mottled Fluvial Recent Soils
USDA Soil Classification:	Oxyaquic Ustifluvent, fine-silty over clayey, mixed, mesic.

Horizon	Depth (m)	Horizon Description
A1	0 - 0.15	Dark brown (10YR 3/3) silt loam (fine-loamy particle size class); moderately weak soil strength; soft penetration resistance; moderately pedal; medium blocky peds and fine polyhedral peds; many 3mm to 10mm roots; moderate estimated permeability.
A2	0.15 - 0.26	Dark brown (10YR 3/3) heavy silt loam; moderately firm soil strength; stiff penetration resistance; moderately pedal; medium blocky peds; many 3mm to 10mm roots; moderately slow estimated permeability.
C	0.26 - 0.32	Olive brown (2.5Y 4/4) loamy fine sand; very weak soil strength; stiff penetration resistance; massive apedal; many 3mm to 10mm roots; moderate estimated permeability; discontinuous lens.
bA	0.32 - 0.45	Very dark greyish brown (10YR 3/2) heavy silt loam; moderately weak soil strength; stiff penetration resistance; moderately pedal; medium blocky peds breaking to fine polyhedral peds; many 3mm to 10mm roots; moderate estimated permeability.
bA/B	0.45 - 0.51	Brown to dark brown (10YR 4/3) and some very dark greyish brown (3/2) silty clay; moderately firm

		soil strength; stiff penetration resistance; moderately pedal; medium blocky peds breaking to fine polyhedral peds; common 2mm thick roots; moderate estimated permeability.
Bgg	0.51 - 0.71	Greyish brown (2.5Y 5/2) silty clay; common fine distinct brown to dark brown (7.5YR 4/4) mottles; moderately weak soil strength; stiff penetration resistance; weakly pedal; blocky peds breaking to extremely fine spheroidal peds; common 2mm thick roots; moderate estimated permeability.
Cu(f)1	0.71 - 1.15	Yellowish brown (10YR 5/4) fine sandy loam; many medium distinct light brownish grey (2.5Y 6/2) and common fine distinct dark yellowish brown (10YR 4/6) mottles; moderately weak soil strength; stiff penetration resistance; massive apedal; common 2mm thick roots; moderate estimated permeability.

Continuation below base of pit, by hand auger:

Cg	1.15 - 1.90	Light brownish grey (2.5Y 6/2) silt loam; common medium distinct yellowish brown (10YR 5/6) mottles; moderately firm soil strength; stiff penetration resistance; massive apedal; common 2mm thick roots; moderately slow estimated permeability.
Cu(f)2	1.90 - 2.10+	Light olive brown (2.5Y 5/4) loamy fine sand; very weak soil strength; stiff penetration resistance; single grain apedal; moderate estimated permeability.

Site: LND

- Moderately well drained soil (hydromorphic class 4)

Classifications:

Local soil name:	Esk sand
New Zealand Soil Classification:	Typic Sandy Recent Soils
USDA Soil Classification:	Aquic Ustipsamment, mixed, mesic.

Horizon	Depth (m)	Horizon Description
A	0 - 0.10	Brown to dark brown (10YR 4/3) loamy sand; moderately weak soil strength; soft penetration resistance; weakly pedal; medium blocky peds; many very fine roots; moderately rapid estimated permeability.
Ap	0.10 - 0.27	Olive brown (2.5Y 4/4) loamy sand; very weak soil strength; soft penetration resistance; massive apedal; common very fine roots; moderately rapid estimated permeability.
C	0.27 - 0.78	Greyish brown (2.5Y 5/2) sand; very weak soil strength; stiff penetration resistance; single grain apedal; common very fine roots; rapid estimated permeability.

Cg	0.78 - 1.30	Greyish brown (2.5Y 5/2) loamy sand; many common faint light olive brown (2.5Y 5/4) and few fine distinct yellowish brown (10YR 5/6) mottles; very weak soil strength; stiff penetration resistance; massive apedal; common very fine roots; rapid estimated permeability.

Site: MMR

- Situated on ancient, dissected alluvial fan, with loess.
- Poorly drained soil (hydromorphic class 2)

Classifications:

Local soil name:	Waipukurau sandy loam
New Zealand Soil Classification:	Duric Perch-gley Pallic Soils
USDA Soil Classification:	Aeric Epiaquept, fine-loamy, mixed, mesic.

Horizon	Depth (m)	Horizon Description
Ap	0 - 0.18	Moist; very dark brown (10YR 2/2) sandy loam; moderately weak soil strength; stiff penetration resistance; moderately pedal; many fine polyhedral peds; few 5 millimetre thick roots; moderate estimated permeability; moist.
Bgp	0.18 - 0.34	Wet; light brownish grey (10YR 6/2) clay loam with common medium faint light olive brown (2.5Y 5/4) mottles; moderately firm soil strength; soft penetration resistance; weakly pedal; common medium blocky peds; few 5 millimetre thick roots; moderate estimated permeability.
Bw(gp)	0.34 - 0.60	Very moist; light olive brown (2.5Y 5/4) sandy clay loam with many medium distinct light brownish grey (10YR 6/2) mottles; moderately weak soil strength; soft penetration resistance; weakly pedal breaking to moderately pedal; common medium blocky peds breaking to many fine polyhedral peds; few 5 millimetre thick roots; moderate estimated permeability.
Bx	0.60 - 0.65+	Dry; light olive brown (2.5Y 5/4) very hard duripan; slow estimated permeability.

Appendix 6: Visual Basic for Excel Custom Functions for Data Processing

Function GDD

```
'Calculates Growing Degree Days or Hours
'For a given base temperature, 10 °C by default
Function GDD(a, Optional tbase) As Double
Dim Difference As Double
If IsMissing(tbase) Then tbase = 10
```

```
For Each c In a
    Difference = c.Value - tbase
    If Difference < 0 Then Difference = 0
    GDD = GDD + Difference
Next
End Function
```

Function ESA

```
'Calculates ESA based on:
'Canopy height, width, and row spacing in cm
'Divided canopy: FALSE or TRUE - Enter 0 or -1 (Optional)
'Formula based on Smart and Robinson, "Sunlight Into Wine", 1991.
Function ESA(Height, Width, RowSpacing, Optional Divided) As Variant
    If IsMissing(Divided) Then Divided = 0
    L = 10000 / RowSpacing
    S = 2 * Height + Width
    If Divided <> 0 Then S = S * 2
    ESA = S * L
End Function
```

Function TUNKNOWN

```
'Calculates unknown temperature or other meteorological data
'for site n based on known data for x and y
'tx - temperature at site x
'ty - temperature at site y
'dxy - distance x-y in km
'dxn - distance x-n in km
Function tunknown(tx, ty, dxy, dxn) As Variant
    tunknown = (((2 * (dxy - dxn) / dxy) * tx) + ((2 * dxn / dxy) * ty)) / 2
End Function
```

Function INTERPOLATE

```
'Requires ValueStart: the starting value
'ValueEnd: the final value
'DateStart: the starting date
'DateEnd: the final date
'DateX: the date for which the interpolation is needed
'NB: The function also extrapolates (DateX can be earlier than DateStart or later
than DateEnd)
Function Interpolate(ValueStart, ValueEnd, DateStart, DateEnd, DateX) As Variant
    Dim NumDays As Integer: 'Number of days from start to end
    Dim Rate As Variant: 'Rate of change
    Dim DaysToX As Integer: 'Number of days from start to date x
    NumDays = DateEnd - DateStart
    Rate = ValueEnd - ValueStart
    DaysToX = DateX - DateStart
    Interpolate = ValueStart + (Rate / NumDays) * DaysToX
End Function
```

Appendix 7: Meteorological Conditions in 1996/97

Some meteorological data available for 1996/97 from the Pakowhai (temperatures), Havelock North (wind and radiation) and Lawn Road (rainfall) weather stations (The Horticulture and Food Institute of New Zealand, Havelock North) are layed out in the following table:

	Mean temperature	Minimum temperature	Maximum temperature	Absolute Minimum temperature	Absolute maximum temperature
October	12.9	6.4	19.0	–0.1	24.8
November	14.0	7.4	20.0	0.8	27.9
December	16.5	11.4	21.6	3.9	28.4
January	16.5	11.9	22.6	5.9	29.5
February	18.1	13.0	25.4	7.6	32.8
March	15.7	11.3	22.4	5.3	31.1
April	12.0	6.2	20.3	–1.4	29.9
	Rainfall	WindDir	Windrun	Radiation	Sol Engy
October	14.8	103.6	-	-	-
November	21.1	206.2	-	-	-
December	112.4	166.8	184.8	258.2	22.3
January	56.8	161.6	191.0	262.2	22.6
February	64.0	151.7	130.7	215.7	18.6
March	99.4	173.6	158.5	150.9	13.0
April	33.4	197.6	137.8	129.7	11.2

Legend: WindDir – wind direction; Windrun – average daily summation of wind speed (m s^{-1}); Radiation – Average solar radiation in µmol m^{-2} s^{-1}; Sol Engy – Total Daily Solar Radiation in mol m^{-2}

Appendix 8: Notes Accompanying Microvinification Procedure

1) Preparation
   a Grapes harvested by hand.
   b Rotten or damaged fruit removed when appropriate.
   c Individually numbered card assigned to each wine for identification.
   d Details of fruit conditions and varietal characteristics are recorded.
   e Fruit weighted.
2) Refrigerate
   Grapes are chilled overnight (or a minimum of 8 hours) in the cool room at 2°C.
3) De-stem/crush
   An "Amos" de-stemmer/crusher is used to de-stem and crush the grapes.
4) +SO_2
   SO_2 is added at a rate of 30 mg kg^{-1} of crushed fruit (before crushing).
5) Pre-fermentation adjustments
   a Must analysis is performed on free-run juice. When calculating the quantities required for must adjustments an estimate of the yield of wine is used (70% of the weight of fruit before crushing).

b If the pH of must is above 3.60 sufficient tartaric acid is added to bring it down to this level.
c For musts of bulk red wine varieties the minimum acceptable total soluble solids (TSS) is 20°Brix. For premium quality red varieties it is desirable to have even higher TSS levels (ie 22-24°Brix). In this study sucrose was added to the must to raise the TSS to 22 °Brix where it was below that value.
d Must is inoculated with the rehydrated yeast culture after attaining a minimum temperature of 15°C. This usually takes at least 8 hours.

6) Inoculation
Active Dried Wine Yeast "Lalvin" strain L 2056 is rehydrated according to the manufacturer's instruction and inoculated at a rate of 0.25 g kg^{-1} of crushed grapes (before crushing).

7) Inoculation with ML bacteria
a After the must has been fermenting for two days it is inoculated with a culture of the bacteria *Oenococcus oeni* which will initiate the malolactic fermentation (MLF).
b A commercially available starter culture, "Viniflora", is added directly to fermenting must at the rate of 12 mg L^{-1} of wine (ie 8 mg for each kg of fruit before crushing).
c This is actually double the inoculation rate recommended by the manufacturer. The freeze-dried culture is a mixture of cells with a nutrients medium. By dividing up this inoculum we run the risk of selecting a smaller quantity of cells than is recommended. Using a larger quantity compensates for this possibility.

8) Fermentation
a Red wine is fermented in a room which is maintained at a temperature of 25°C.
b The cap is plunged twice daily for the first 5 or 6 days of active fermentation and once daily thereafter.
c If H_2S is detected early during fermentation (ie the first two days) 200 mg L^{-1} of DAP is added. This was not necessary in the present study.
d The wine is fermented and kept in contact with the skins for a total period of 10 days. Experience has shown that red wines are usually dry (ie below 2.5 g L^{-1} residual sugar), within six days of being inoculated with the yeast culture.

9) Pressing
a A "Willmes" air bag press (60 kg capacity) is used to press the wines.
b First press – 2 bar pressure for 5 minutes. Second press – 4 bar for 5 minutes.
c The average yield of wine in L is 70% of the numerical value of the weight in kg of grapes before crushing.
d After pressing the wine is aerated.

10) MLF (Malolactic Fermentation)
a The current protocol for inducing MLF has been so successful that the process is often complete by the time the wine is pressed off-skins.
b After pressing the unclarified wine is kept at a temperature of 20°C in glass bottles sealed with a silicon rubber bung. A blanket of inert gas (30% CO_2, 70% N_2) is maintained in the headspace over the wine

and it is left to settle for at least one week. If at any time during this period active gassing (ie tiny bubbles) has been noted then this is a good indication that the MLF is still progressing. If after a week there is still no sin of any activity then the pH and TA of the wine will be determined (see note 11).

c To confirm the fact that the MLF is complete the level of malic acid in the wine is determined using an enzymatic method. This is only done after activity has ceased off or the pH and TA levels indicate the process is likely to have already finished. The MLF is deemed to be complete when the malic acid concentration in the wine has dropped below 50 mg L^{-1}.

11) Check pH/TA
   a If no gas formation has been noted in the week after pressing the pH and TA of the wine is checked to ascertain whether the MLF was already complete at pressing.
   b It is important to avoid picking up precipitated crystals of tartrate when withdrawing wine samples for this pH measurements.
12) Clarification
   a The wine is racked off the gross lees when it has been established that the MLF is complete. This will be at least a week after pressing but may be considerably longer.
   b The wine is aerated following this first racking.
   c The headspace above the wine is purged with CO_2 following aeration.
13) H_2S?
   a If a strong odour of volatile sulphur compounds is detected in the wine after racking then it will be fined with copper sulphate ($CuSO_4$).
   b Copper is usually added at a rate of 0.25-0.5 mg Cu^{2+} L^{-1} of wine.
14) +SO_2
   a After racking, 45 mg L^{-1} SO_2 is added to the wine.
   b The free SO_2 level in the wine is checked a couple of days later (see note 17).
15) Check pH/TA
   a The pH of the wine is checked and adjusted with tartaric acid if it is found to be above 3.75. The TA of the sample is also checked.
   b Care should be taken to avoid picking up crystals of precipitated tartrate when withdrawing samples for analysis. Wine samples are de-gassed before these analyses are performed.
16) +Clarifying Enzyme
   a A commercial enzyme preparation to aid the clarification of the wine Ultrazyme 100G is used at a rate of 0.02 g L^{-1}.
   b Following enzyme addition the wine is left a further week at 20°C before being put into cold storage.
17) Check SO_2
   a The free SO_2 level in the wine is checked using the aspiration method and adjusted if it has fallen below 15 mg L^{-1}.
   b In order to get the appropriate increase in free SO_2 it is actually necessary to calculate the difference between the measured SO_2 and target SO_2 levels and to make an addition of 2-3 times this amount.

c After cold stabilisation the SO_2 levels of red wines are monitored about once a month.

18) +Oak chips?

Oak chips are added to the wine only when it is necessary to imitate commercial red wine practices. The addition of oak chips to wines vinted from viticultural trials complicates the sensory evaluation of these wines and is therefore not recommended.

19) Cold stabilisation

a After its first racking red wine is kept in the cool room (at 2°C) for 6-8 weeks.

b The wine then receives a second racking off the tartrate deposit. This is also done with aeration. The headspace above the wine is purged with CO_2 following racking.

c 'Cold stability' is a natural consequence of the wines being kept at this low temperature for this period of time.

d Following cold stabilisation the red wines are stored at a temperature of 15°C.

20) Fining

a Fining is necessary to increase the clarity of the wine before bottling but it also helps to reduce astringency.

b The temperature of the wine at fining should be around 15°C.

c Red wines are fined with fresh egg whites that have been dissolved in distilled water in the recommended manner. Around 1-2 egg whites are used per 100 L of wine.

d When the wine is racked after fining (around seven days later), it should be optically clear. If this is not the case, further treatment may be necessary before proceeding with filtration and/or bottling.

21) Correction of faults

Before the wine is filtered and bottled a final tasting is made to determine whether there are any winemaking faults that should be rectified. Probably the most common type of fault would be a sulphur off-character in the bouquet of the wine.

22) Filtration

a Sterile filtration is not usually necessary for dry red wines if they have undergone a complete MLF. However coarse filtration is justified as it removes any larger particles and is likely to increase clarity of the wine. The fact that these wines are processed in a relatively short time frame also means filtration is even more desirable step. The following procedure is employed for the coarse filtration of red wines.

b The wine is racked for one final time into a stainless steel pressure container in preparation for filtration.

c Nitrogen gas under pressure is used to push the wine out of the pressure can and through a 10 inch cartridge depth filter in a stainless steel holder.

d The "UltiPleat" cartridge filter is used for this purpose and this is produced by Pall. The product number of the cartridge used is AB1UY1007J. This particular grade of filter has an absolute retention rating of 10 µm.

e Sterile filtration of red wines may be necessary in special circumstances. If this is the case then the procedure that would be

followed would be similar to that used for white wines. However a 10 inch membrane cartridge would probably have to be employed in order to achieve an acceptable flow rate when filtering young red wine.

23) Bottling

a Bottles are rinsed with "sterile" filtered tap water before use.

b Just prior to filling the bottles are purged with CO_2 gas.

Appendix 9: Correlation of selected variables observed in 1996/97 at 28 sites

STATISTICA: Basic Statistics and Tables

STAT. BASIC STATS — Correlations (season1.sta)
Marked correlations are significant at p < .05000
N=28 (Casewise deletion of missing data)

Variable	FD_F	F_V	FD_V	FD_20	F_20	V_20	FD_H	NUMCLUST	CLUSTWGT	YLD	BERRYWGT	TSS	TA
FD_F	1.00	.15	.81*	.50*	-.02	-.11	.52*	-.15	.12	-.04	-.06	-.21	.59*
F_V	.15	1.00	.71*	.45*	.43*	-.08	.32	.12	.26	.25	-.13	-.22	.49*
FD_V	.81*	.71*	1.00	.63*	.24	-.12	.56*	-.03	.24	.12	-.12	-.28	.71*
FD_20	.50*	.45*	.63*	1.00	.86*	.70*	.78*	.04	.19	.18	.10	-.42*	.64*
F_20	-.02	.43*	.24	.86*	1.00	.87*	.59*	.14	.15	.22	.15	-.36	.38*
V_20	-.11	-.08	-.12	.70*	.87*	1.00	.47*	.09	.02	.11	.24	-.27	.15
FD_H	.52*	.32	.56*	.78*	.59*	.47*	1.00	-.06	.24	.10	-.17	.20	.41*
NUMCLUST	-.15	.12	-.03	.04	.14	.09	-.06	1.00	-.26	.80*	-.16	-.16	-.21
CLUSTWGT	.12	.26	.24	.19	.15	.02	.24	-.26	1.00	.36	.26	.07	.26
YLD	-.04	.25	.12	.18	.22	.11	.10	.80*	.36	1.00	.00	-.13	-.05
BERRYWGT	-.06	-.13	-.12	.10	.15	.24	-.17	-.16	.26	.00	1.00	-.40*	.19
TSS	-.21	-.22	-.28	-.42*	-.36	-.27	.20	-.16	.07	-.13	-.40*	1.00	-.43*
TA	.59*	.49*	.71*	.64*	.38*	.15	.41*	-.21	.26	-.05	.19	-.43*	1.00
IR	-.56*	-.51*	-.70*	-.67*	-.44*	-.21	-.35	.19	-.21	.06	-.22	.56*	-.97*
PH	-.46*	.03	-.32	-.35	-.12	-.15	-.03	-.00	.26	.14	-.05	.55*	-.54*
PHENOLS	-.23	-.05	-.19	-.27	-.17	-.16	-.24	-.05	-.19	-.19	-.33	.03	-.36
ANTHOC	-.27	-.19	-.31	-.33	-.21	-.13	-.21	.00	-.21	-.14	-.33	.14	-.45*
IRA	-.53*	-.48*	-.66*	-.63*	-.41*	-.19	-.35	.19	-.23	.04	-.28	.47*	-.93*
TPHENOLS	-.24	-.06	-.21	-.12	.01	.04	.10	-.23	.01	-.19	-.49*	.35	-.27
TANTHOC	-.14	-.23	-.24	-.15	-.09	.02	.11	-.06	-.01	-.03	-.40*	.36	-.29
ANTHEXTR	-.14	.04	-.08	-.24	-.19	-.23	-.35	.04	-.23	-.16	-.02	-.18	-.20
MAL_AC	.39*	.21	.40*	.12	-.09	-.22	-.05	-.13	-.02	-.15	-.01	-.32	.64*
TAR_AC	.29	.50*	.50*	.51*	.42*	.18	.45*	-.04	.19	.05	-.18	-.06	.66*
K_MUST	.04	.12	.10	.14	.14	.08	.23	-.17	.52*	.14	-.04	.11	.30
N	.07	.49*	.34	.08	.05	-.22	.16	-.15	.34	.02	.06	.02	.24
P	.49*	.02	.36	.35	.11	.11	.24	-.01	.14	.11	-.16	-.16	.29
K	.42*	-.02	.29	.24	.02	.04	.14	-.09	.16	-.01	.07	-.23	.50*
CA	.17	.34	.33	.22	.15	-.03	.11	-.14	.45*	.10	.21	-.21	.27
MG	-.15	-.06	-.14	.04	.14	.19	-.08	-.31	.48*	-.03	.28	-.17	.13
CANDENS	.55*	.42*	.64*	.25	-.04	-.27	.32	-.09	.39*	.16	.15	-.07	.46*
ESA_000	.17	.12	.20	.20	.13	.08	-.16	.49*	.19	.62*	.45*	-.53*	.22
PRUNING	.31	.42*	.48*	.31	.17	-.05	.08	-.03	.44*	.25	.53*	-.38*	.45*
YP_RATIO	-.43*	-.21	-.44*	-.40*	-.21	-.11	-.21	.38*	-.25	.20	-.49*	.32	-.61*
DRYPROD	.22	.44*	.43*	.32	.24	.02	.11	.35	.51*	.67*	.41*	-.35	.32
AVETOCT	-.38*	-.30	-.45*	-.45*	-.29	-.15	-.24	.18	-.15	.04	.26	.25	-.44*
AVETNOV	-.39*	-.30	-.45*	-.48*	-.32	-.19	-.28	.16	-.18	.01	.25	.26	-.45*
AVETDEC	-.33	-.32	-.42*	-.44*	-.32	-.17	-.26	.27	-.27	.06	.22	.22	-.41*
AVETJAN	-.29	-.27	-.37	-.41*	-.30	-.18	-.22	.25	-.21	.08	.26	.21	-.36
AVETFEB	-.31	-.30	-.40*	-.46*	-.34	-.21	-.27	.26	-.27	.04	.23	.22	-.40*
AVETMAR	-.24	-.29	-.35	-.31	-.21	-.07	-.15	.28	-.23	.10	.26	.17	-.31
AVETAPR	-.40*	-.26	-.44*	-.46*	-.29	-.18	-.25	.12	-.10	.02	.27	.28	-.44*
AVETSSN	-.34	-.30	-.42*	-.44*	-.31	-.17	-.25	.22	-.21	.05	.25	.23	-.41*
RAINOCT	.28	-.16	.10	-.21	-.41*	-.36	-.39*	-.08	-.13	-.15	.31	-.30	.16
RAINNOV	-.14	-.17	-.20	-.43*	-.41*	-.36	-.22	.23	-.45*	-.07	-.41*	.24	-.41*
RAINDEC	.19	-.26	-.02	-.18	-.32	-.21	-.41*	-.01	-.16	-.11	.23	-.31	.13
RAINJAN	.45*	.04	.34	.32	.10	.09	.00	-.08	.08	.01	.08	-.43*	.44*
RAINFEB	-.16	.35	.09	.23	.36	.20	.26	-.21	.53*	.12	.19	.09	.15
RAINMAR	.33	.26	.39*	.35	.21	.09	.13	-.29	.44*	.02	.41*	-.33	.51*
RAINAPR	.28	.15	.29	.31	.19	.12	.16	.05	.01	.10	-.33	-.19	.24
RAINSSN	.26	.17	.29	.21	.09	.00	-.01	-.19	.29	.02	.25	-.29	.39*

STAT. BASIC STATS — Correlations (season1.sta)
Marked correlations are significant at p < .05000
N=28 (Casewise deletion of missing data)

Variable	IR	PH	PHENOLS	ANTHOC	IRA	TPHENO LS	TANTHO C	ANTHEX TR	MAL_AC	TAR_AC	K_MUST	N	P
FD_F	-.56*	-.46*	-.23	-.27	-.53*	-.24	-.14	-.14	.39*	.29	.04	.07	.49*
F_V	-.51*	.03	-.05	-.19	-.48*	-.06	-.23	.04	.21	.50*	.12	.49*	.02
FD_V	-.70*	-.32	-.19	-.31	-.66*	-.21	-.24	-.08	.40*	.50*	.10	.34	.36
FD_20	-.67*	-.35	-.27	-.33	-.63*	-.12	-.15	-.24	.12	.51*	.14	.08	.35
F_20	-.44*	-.12	-.17	-.21	-.41*	.01	-.09	-.19	-.09	.42*	.14	.05	.11
V_20	-.21	-.15	-.16	-.13	-.19	.04	.02	-.23	-.22	.18	.08	-.22	.11
FD_H	-.35	-.03	-.24	-.21	-.35	.10	.11	-.35	-.05	.45*	.23	.16	.24
NUMCLUST	.19	-.00	-.05	.00	.19	-.23	-.06	.04	-.13	-.04	-.17	-.15	-.01
CLUSTWGT	-.21	.26	-.19	-.21	-.23	.01	-.01	-.23	-.02	.19	.52*	.34	.14
YLD	.06	.14	-.19	-.14	.04	-.19	-.03	-.16	-.15	.05	.14	.02	.11
BERRYWGT	-.22	-.05	-.33	-.33	-.28	-.49*	-.40*	-.02	-.01	-.18	-.04	.06	-.16
TSS	.56*	.55*	.03	.14	.47*	.35	.36	-.18	-.32	-.06	.11	.02	-.16
TA	-.97*	-.54*	-.36	-.45*	-.93*	-.27	-.29	-.20	.64*	.66*	.30	.24	.29
IR	1.00	.55*	.31	.42*	.95*	.23	.30	.17	-.56*	-.66*	-.26	-.21	-.27
PH	.55*	1.00	.14	.11	.47*	.24	.09	.06	-.52*	-.17	.18	.25	-.26
PHENOLS	.31	.14	1.00	.92*	.55*	.48*	.25	.73*	.08	-.16	.10	.26	-.18
ANTHOC	.42*	.11	.92*	1.00	.68*	.58*	.53*	.53*	.05	-.27	.09	.25	-.15

IRA	.95*	.47*	.55*	.68*	1.00	.39*	.44*	.29	-.42*	-.64*	-.18	-.08	-.26

STATISTICA: Basic Statistics and Tables
STAT.
BASIC
STATS

Correlations (season1.sta)
Marked correlations are significant at p < .05000
N=28 (Casewise deletion of missing data)

Variable	IR	PH	PHENOLS	ANTHOC	IRA	TPHENOLS	TANTHOC	ANTHEXTR	MAL_AC	TAR_AC	K_MUST	N	P
TPHENOLS	.23	.24	.48*	.58*	.39*	1.00	.84*	-.21	-.21	-.04	.14	.17	-.03
TANTHOC	.30	.09	.25	.53*	.44*	.84*	1.00	-.43*	-.16	-.23	.05	.04	.05
ANTHEXTR	.17	.06	.73*	.53*	.29	-.21	-.43*	1.00	.21	-.09	.05	.21	-.21
MAL_AC	-.56*	-.52*	.08	.05	-.42*	-.21	-.16	.21	1.00	.33	.29	.25	.35
TAR_AC	-.66*	-.17	-.16	-.27	-.64*	-.04	-.23	-.09	.33	1.00	.47*	.25	.21
K_MUST	-.26	.18	.10	.09	-.18	.14	.05	.05	.29	.47*	1.00	.37	.15
N	-.21	.25	.26	.25	-.08	.17	.04	.21	.25	.25	.37	1.00	-.04
P	-.27	-.26	-.18	-.15	-.26	-.03	.05	-.21	.35	.21	.15	-.04	1.00
K	-.47*	-.32	-.26	-.22	-.45*	-.27	-.16	-.09	.46*	.43*	.52*	.07	.33
CA	-.27	.12	.04	.08	-.18	.06	.04	.02	.17	.16	.35	.78*	.34
MG	-.14	.11	-.05	-.05	-.13	.04	-.02	-.04	-.11	-.06	.34	.20	-.10
CDI	-.41*	-.15	-.26	-.23	-.40*	-.31	-.20	-.08	.28	.34	.25	.43*	.05
ESA_000	-.29	-.18	-.26	-.35	-.33	-.49*	-.40*	.00	.09	.03	-.00	-.08	.21
PRUNING	-.48*	.04	-.17	-.23	-.45*	-.24	-.28	-.03	.25	.22	.19	.48*	.14
YP_RATIO	.62*	.16	.17	.21	.58*	.14	.20	.10	-.37	-.39*	-.18	-.32	-.30
DRYPROD	-.34	.09	-.22	-.25	-.33	-.28	-.23	-.10	.12	.19	.21	.37*	.16
AVETOCT	.46*	.46*	-.03	.07	.39*	-.21	-.05	.15	-.29	-.40*	.05	.01	-.50*
AVETNOV	.47*	.45*	.02	.12	.40*	-.19	-.04	.20	-.27	-.39*	.06	.03	-.50*
AVETDEC	.44*	.30	-.08	.05	.36	-.29	-.06	.14	-.25	-.41*	-.04	-.06	-.53*
AVETJAN	.39*	.31	-.10	.02	.32	-.30	-.07	.12	-.23	-.38*	-.00	-.01	-.53*
AVETFEB	.42*	.30	-.05	.08	.36	-.28	-.06	.17	-.22	-.40*	-.02	-.03	-.53*
AVETMAR	.34	.25	-.17	-.02	.26	-.35	-.09	.09	-.20	-.35	.03	-.10	-.42*
AVETAPR	.46*	.51*	.02	.11	.39*	-.16	-.03	.17	-.29	-.37	.09	.08	-.51*
AVETSSN	.44*	.37	-.06	.06	.36	-.26	-.06	.15	-.25	-.39*	.02	-.01	-.52*
RAINOCT	-.18	-.29	.16	.09	-.12	-.29	-.20	.30	.42*	-.16	-.02	-.12	-.01
RAINNOV	.40*	.09	.26	.27	.41*	.30	.27	.05	-.25	-.20	-.32	.02	-.31
RAINDEC	-.14	-.35	-.03	-.03	-.12	-.39*	-.22	.19	.47*	-.13	-.01	-.34	.22
RAINJAN	-.46*	-.45*	-.20	-.22	-.43*	-.27	-.16	-.08	.53*	.15	.09	-.27	.67*
RAINFEB	-.14	.48*	-.18	-.16	-.16	.03	-.03	-.16	-.02	.22	.44*	.38*	.17
RAINMAR	-.52*	-.07	-.11	-.18	-.47*	-.24	-.24	.02	.41*	.20	.35	.15	.37
RAINAPR	-.25	-.20	-.22	-.20	-.26	.06	.11	-.31	.25	.23	.03	-.15	.74*
RAINSSN	-.40*	-.05	-.15	-.17	-.37	-.22	-.16	-.03	.45*	.16	.31	.04	.49*

STAT.
BASIC
STATS

Correlations (season1.sta)
Marked correlations are significant at p < .05000
N=28 (Casewise deletion of missing data)

Variable	K	CA	MG	CDI	ESA_000	PRUNING	YP_RATIO	DRYPROD	AVETOCT	AVETNOV	AVETDEC	AVETJAN	AVETFEB
FD_F	.42*	.17	-.15	.55*	.17	.31	-.43*	.22	-.38*	-.39*	-.33	-.29	-.31
F_V	-.02	.34	-.06	.42*	.12	.42*	-.21	.44*	-.30	-.30	-.32	-.27	-.30
FD_V	.29	.33	-.14	.64*	.20	.48*	-.44*	.43*	-.45*	-.45*	-.42*	-.37	-.40*
FD_20	.24	.22	.04	.25	.20	.31	-.40*	.32	-.45*	-.48*	-.44*	-.41*	-.46*
F_20	.02	.15	.14	-.04	.13	.17	-.21	.24	-.29	-.32	-.32	-.30	-.34
V_20	.04	-.03	.19	-.27	.08	-.05	-.11	.02	-.15	-.19	-.17	-.18	-.21
FD_H	.14	.11	-.08	.32	-.16	.08	-.21	.11	-.24	-.28	-.26	-.22	-.27
NUMCLUST	-.09	-.14	-.31	-.09	.49*	-.03	.38*	.35	.18	.16	.27	.25	.26
CLUSTWGT	.16	.45*	.48*	.39*	.19	.44*	-.25	.51*	-.15	-.18	-.27	-.21	-.27
YLD	-.01	.10	-.03	.16	.62*	.25	.20	.67*	.04	.01	.06	.08	.04
BERRYWGT	.07	.21	.28	.15	.45*	.53*	-.49*	.41*	.26	.25	.22	.26	.23
TSS	-.23	-.21	-.17	-.07	.53*	-.38*	.32	-.35	.25	.26	.22	.21	.22
TA	.50*	.27	.13	.46*	.22	.45*	-.61*	.32	-.44*	-.45*	-.41*	-.36	-.40*
IR	-.47*	-.27	-.14	-.41*	-.29	-.48*	.62*	-.34	.46*	.47*	.44*	.39*	.42*
PH	-.32	.12	.11	-.15	-.18	.04	.16	.09	.46*	.45*	.30	.31	.30
PHENOLS	-.26	.04	-.05	-.26	-.26	-.17	.17	-.22	-.03	.02	-.08	-.10	-.05
ANTHOC	-.22	.08	-.05	-.23	-.35	-.23	.21	-.25	.07	.12	.05	.02	.08
IRA	-.45*	-.18	-.13	-.40*	-.33	-.45*	.58*	-.33	.39*	.40*	.36	.32	.36
TPHENOLS	-.27	.06	.04	-.31	-.49*	-.24	.14	-.28	-.21	-.19	-.29	-.30	-.28
TANTHOC	-.16	.04	-.02	-.20	-.40*	-.28	.20	-.23	-.05	-.04	-.06	-.07	-.06
ANTHEXTR	-.09	.02	-.04	-.08	.00	-.03	.10	-.10	.15	.20	.14	.12	.17
MAL_AC	.46*	.17	-.11	.28	.09	.25	-.37	.12	-.29	-.27	-.25	-.23	-.22
TAR_AC	.43*	.16	-.06	.34	.03	.22	-.39*	.19	-.40*	-.39*	-.41*	-.38*	-.40*
K_MUST	.52*	.35	.34	.25	-.00	.19	-.18	.21	.05	.06	-.04	-.00	-.02
N	.07	.78*	.20	.43*	-.08	.48*	-.32	.37*	.01	.03	-.06	-.01	-.03
P	.33	.34	-.10	.05	.21	.14	-.30	.16	-.50*	-.50*	-.53*	-.53*	-.53*
K	1.00	.31	.39*	.38*	.11	.31	-.45*	.23	-.09	-.10	.02	.05	.03
CA	.31	1.00	.41*	.32	.18	.57*	-.43*	.48*	-.16	-.15	-.19	-.15	-.17
MG	.39*	.41*	1.00	-.08	.01	.20	-.20	.14	-.03	-.06	-.02	.00	-.04
CDI	.38*	.32	-.08	1.00	.09	.55*	-.42*	.50*	.03	.02	.03	.10	.05
ESA_000	.11	.18	.01	.09	1.00	.57*	-.25	.73*	-.11	-.12	-.07	-.05	-.06
PRUNING	.31	.57*	.20	.55*	.57*	1.00	-.77*	.89*	-.10	-.11	-.13	-.07	-.11
YP_RATIO	-.45*	-.43*	-.20	-.42*	-.25	-.77*	1.00	-.50*	.26	.25	.30	.25	.28
DRYPROD	.23	.48*	.14	.50*	.73*	.89*	-.50*	1.00	-.06	-.08	-.08	-.01	-.07
AVETOCT	-.09	-.16	-.03	.03	-.11	-.10	.26	-.06	1.00	1.00*	.96*	.96*	.96*
AVETNOV	-.10	-.15	-.06	.02	-.12	-.11	.25	-.08	1.00*	1.00	.95*	.94*	.95*

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Correlations (season1.sta)
Marked correlations are significant at p < .05000
N=28 (Casewise deletion of missing data)

Variable	K	CA	MG	CDI	ESA_000	PRUNING	YP_RATIO	DRYPROD	AVETOCT	AVETNOV	AVETDEC	AVETJAN	AVETFEB
AVETDEC	.02	-.19	-.02	.03	-.07	-.13	.30	-.08	.96*	.95*	1.00	.99*	1.00*
AVETJAN	.05	-.15	.00	.10	-.05	-.07	.25	-.01	.96*	.94*	.99*	1.00	.99*
AVETFEB	.03	-.17	-.04	.05	-.06	-.11	.28	-.07	.96*	.95*	1.00*	.99*	1.00
AVETMAR	.11	-.18	-.01	.08	.01	-.05	.20	.01	.93*	.91*	.97*	.97*	.97*
AVETAPR	-.14	-.13	-.04	.04	-.14	-.09	.23	-.06	.99*	.99*	.91*	.92*	.92*
AVETSSN	-.02	-.17	-.03	.05	-.08	-.10	.26	-.05	.99*	.98*	.99*	.99*	.99*
RAINOCT	.18	-.08	-.12	.17	.29	.23	-.22	.10	.10	.15	.13	.15	.18
RAINNOV	-.30	-.16	-.28	-.34	-.26	-.50*	.52*	-.42*	.11	.15	.19	.14	.20
RAINDEC	.26	-.13	-.18	.05	.30	.10	-.13	.03	.08	.12	.11	.11	.14
RAINJAN	.34	.09	-.09	.14	.40*	.28	-.40*	.22	-.44*	-.43*	-.45*	-.44*	-.43*
RAINFEB	-.01	.36	.15	.30	-.08	.33	-.30	.31	.19	.17	-.03	.02	-.03
RAINMAR	.27	.29	.14	.45*	.32	.62*	-.65*	.49*	-.14	-.14	-.27	-.20	-.24
RAINAPR	.12	.17	-.21	-.08	.13	-.03	-.11	.02	-.51*	-.51*	-.55*	-.57*	-.56*
RAINSSN	.24	.25	-.05	.31	.27	.42*	-.47*	.33	-.09	-.07	-.22	-.18	-.19

STAT. Correlations (season1.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=28 (Casewise deletion of missing data)

Variable	AVETMA R	AVETAP R	AVETSS N	RAINOC T	RAINNO V	RAINDE C	RAINJA N	RAINFE B	RAINMA R	RAINAP R	RAINSS N
FD_F	-.24	-.40*	-.34	.28	-.14	.19	.45*	-.16	.33	.28	.26
F_V	-.29	-.26	-.30	-.16	-.17	-.26	.04	.35	.26	.15	.17
FD_V	-.35	-.44*	-.42*	.10	-.20	-.02	.34	.09	.39*	.29	.29
FD_20	-.31	-.46*	-.44*	-.21	-.43*	-.18	.32	.23	.35	.31	.21
F_20	-.21	-.29	-.31	-.41*	-.41*	-.32	.10	.36	.21	.19	.09
V_20	-.07	-.18	-.17	-.36	-.36	-.21	.09	.20	.09	.12	.00
FD_H	-.15	-.25	-.25	-.39*	-.22	-.41*	.00	.26	.13	.16	-.01
NUMCLUST	.28	.12	.22	-.08	.23	-.01	-.08	-.21	-.29	.05	-.19
CLUSTWGT	-.23	-.10	-.21	-.13	-.45*	-.16	.08	.53*	.44*	.01	.29
YLD	.10	.02	.05	-.15	-.07	-.11	.01	.12	.02	.10	.02
BERRYWGT	.26	.27	.25	.31	-.41*	.23	.08	.19	.41*	-.33	.25
TSS	.17	.28	.23	-.30	.24	-.31	-.43*	.09	-.33	-.19	-.29
TA	-.31	-.44*	-.41*	.16	-.41*	.13	.44*	.15	.51*	.24	.39*
IR	.34	.46*	.44*	-.18	.40*	-.14	-.46*	-.14	-.52*	-.25	-.40*
PH	.25	.51*	.37	-.29	.09	-.35	-.45*	.48*	-.07	-.20	-.05
PHENOLS	-.17	.02	-.06	.16	.26	-.03	-.20	-.18	-.11	-.22	-.15
ANTHOC	-.02	.11	.06	.09	.27	-.03	-.22	-.16	-.18	-.20	-.17
IRA	.26	.39*	.36	-.12	.41*	-.12	-.43*	-.16	-.47*	-.26	-.37
TPHENOLS	-.35	-.16	-.26	-.29	.30	-.39*	-.27	.03	-.24	.06	-.22
TANTHOC	-.09	-.03	-.06	-.20	.27	-.22	-.16	-.03	-.24	.11	-.16
ANTHEXTR	.09	.17	.15	.30	.05	.19	-.08	-.16	.02	-.31	-.03
MAL_AC	-.20	-.29	-.25	.42*	-.25	.47*	.53*	-.02	.41*	.25	.45*
TAR_AC	-.35	-.37	-.39*	-.16	-.20	-.13	.15	.22	.20	.23	.16
K_MUST	.03	.09	.02	-.02	-.32	-.01	.09	.44*	.35	.03	.31
N	-.10	.08	-.01	-.12	.02	-.34	-.27	.38*	.15	-.15	.04
P	-.42*	-.51*	-.52*	-.01	-.31	.22	.67*	.17	.37	.74*	.49*
K	.11	-.14	-.02	.18	-.30	.26	.34	-.01	.27	.12	.24
CA	-.18	-.13	-.17	-.08	-.16	-.13	.09	.36	.29	.17	.25
MG	-.01	-.04	-.03	-.12	-.28	-.18	-.09	.15	.14	-.21	-.05
CDI	.08	.04	.05	.17	-.34	.05	.14	.30	.45*	-.08	.31
ESA_000	.01	-.14	-.08	.29	-.26	.30	.40*	-.08	.32	.13	.27
PRUNING	-.05	-.09	-.10	.23	-.50*	.10	.28	.33	.62*	-.03	.42*
YP_RATIO	.20	.23	.26	-.22	.52*	-.13	-.40*	-.30	-.65*	-.11	-.47*
DRYPROD	.01	-.06	-.05	.10	-.42*	.03	.22	.31	.49*	.02	.33
AVETOCT	.93*	.99*	.99*	.10	.11	.08	-.44*	.19	-.14	-.51*	-.09
AVETNOV	.91*	.99*	.98*	.15	.15	.12	-.43*	.17	-.14	-.51*	-.07
AVETDEC	.97*	.91*	.99*	.13	.19	.11	-.45*	-.03	-.27	-.55*	-.22
AVETJAN	.97*	.92*	.99*	.15	.14	.11	-.44*	.02	-.20	-.57*	-.18
AVETFEB	.97*	.92*	.99*	.18	.20	.14	-.43*	-.03	-.24	-.56*	-.19
AVETMAR	1.00	.87*	.96*	.10	.00	.14	-.31	.07	-.13	-.46*	-.11
AVETAPR	.87*	1.00	.96*	.12	.12	.07	-.45*	.26	-.09	-.52*	-.04
AVETSSN	.96*	.96*	1.00	.14	.14	.11	-.43*	.09	-.18	-.54*	-.14
RAINOCT	.10	.12	.14	1.00	-.03	.84*	.44*	-.30	.45*	-.14	.46*
RAINNOV	.00	.12	.14	-.03	1.00	-.22	-.55*	-.59*	-.80*	-.15	-.62*
RAINDEC	.14	.07	.11	.84*	-.22	1.00	.71*	-.16	.46*	.22	.65*
RAINJAN	-.31	-.45*	-.43*	.44*	-.55*	.71*	1.00	.12	.68*	.70*	.81*
RAINFEB	.07	.26	.09	-.30	-.59*	-.16	.12	1.00	.56*	.22	.56*
RAINMAR	-.13	-.09	-.18	.45*	-.80*	.46*	.68*	.56*	1.00	.22	.88*
RAINAPR	-.46*	-.52*	-.54*	-.14	-.15	.22	.70*	.22	.22	1.00	.53*
RAINSSN	-.11	-.04	-.14	.46*	-.62*	.65*	.81*	.56*	.88*	.53*	1.00

Variables:

Var 6: FD_F - Days from 1 October to flowering
Var 7: F_V - Days from flowering to véraison
Var 8: FD_V - Days from 1 October to véraison
Var 9: FD_20 - Days from 1 October to TSS=20°Brix
Var 10: F_20 - Days from flowering to TSS 20°Brix
Var 11: V_20 - Days from véraison to TSS=20°Brix
Var 12: FD_H - Days from 1 October to harvest
Var 17: NUMCLUST - Number of clusters m^{-2}
Var 18: CLUSTWGT - Estimated cluster weight at harvest [g]
Var 20: YLD - Estimated yield of grapes [kg m^{-2}]
Var 21: BERRYWGT - Berry weight [g]
Var 22: TSS - TSS [°Brix] at harvest
Var 23: TA - TA [g/L^{-1}] at harvest
Var 24: IR - Index of ripeness at harvest
Var 25: PH - pH at harvest
Var 26: PHENOLS - Extractable polyphenols [mg kg^{-1}]
Var 27: ANTHOC - Extractable anthocyanins [mg kg^{-1}]
Var 28: IRA - Index of ripeness adjusted for anthocyanins
Var 29: TPHENOLS - Total polyphenols [mg kg^{-1}]
Var 30: TANTHOC - Total anthocyanins [mg kg^{-1}]
Var 31: ANTHEXTR - Extractability of anthocyanins [%]
Var 32: MAL_AC - Malic acid (g L^{-1}) at harvest
Var 33: TAR_AC - Tartaric acid (g L^{-1}) at harvest
Var 34: K_MUST - Potassium in must (g L^{-1}) at harvest
Var 35: N - Nitrogen (%) in leaf petioles at véraison
Var 36: P - Phosphorus (%) in leaf petioles at véraison
Var 37: K - Potassium (%) in leaf petioles at véraison
Var 38: CA - Calcium (%) in leaf petioles at véraison
Var 39: MG - Magnesium (%) in leaf petioles at véraison
Var 41: CDI - Canopy density index
Var 42: ESA_000 - Estimated exposed leaf surface area [thousands of m^2 ha^{-1}]
Var 43: PRUNING - Pruning weights [kg m^{-2}]
Var 44: YP_RATIO - Crop load
Var 45: DRYPROD - Dry production
Var 46: AVETOCT - Average air temperature for October (°C)
Var 47: AVETNOV - Average air temperature for November (°C)
Var 48: AVETDEC - Average air temperature for December (°C)
Var 49: AVETJAN - Average air temperature for January (°C)
Var 50: AVETFEB - Average air temperature for February (°C)
Var 51: AVETMAR - Average air temperature for March (°C)
Var 52: AVETAPR - Average air temperature for April (°C)
Var 53: AVETSSN - Average air temperature for October-April (°C)
Var 68: RAINOCT - Total rainfall for October [mm]
Var 69: RAINNOV - Total rainfall for November [mm]
Var 70: RAINDEC - Total rainfall for December [mm]
Var 71: RAINJAN - Total rainfall for January [mm]
Var 72: RAINFEB - Total rainfall for February [mm]
Var 73: RAINMAR - Total rainfall for March [mm]
Var 74: RAINAPR - Total rainfall for April [mm]
Var 75: RAINSSN - Total rainfall for October-April [mm]

Appendix 10: Correlation of selected variables observed in the 1996/97, 1997/98 and 1998/99 seasons

STAT. Correlations (3ssnful2.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=18 (Casewise deletion of missing data)

Variable	N	P	K	CA	MG	BWGTH	ESA100 0	CDI	PRUNWG T	YPRATI O	CLUSTW GT	NUMCLU ST	YLD
N	1.00	-.05	-.22	.37	-.57*	.33	-.06	.36	.40	-.35	.46	-.49*	-.06
P	-.05	1.00	-.07	-.16	-.26	-.46	-.12	-.43	-.33	.04	-.35	-.21	-.39

STATISTICA: Basic Statistics and Tables

STAT. Correlations (3ssnful2.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=18 (Casewise deletion of missing data)

Variable	N	P	K	CA	MG	BWGTH	ESA100 0	CDI	PRUNWG T	YPRATI O	CLUSTW GT	NUMCLU ST	YLD
K	-.22	-.07	1.00	-.22	-.06	-.47*	.43	.07	.39	-.09	-.30	.56*	.39
CA	.37	-.16	-.22	1.00	-.03	.27	-.13	.53*	.30	-.39	.05	-.18	-.19
MG	-.57*	-.26	-.06	-.03	1.00	.09	-.12	-.26	-.30	.30	.09	.13	.12
BWGTH	.33	-.46	-.47*	.27	.09	1.00	.04	.36	.16	-.34	.41	-.46	-.21
ESA1000	-.06	-.12	.43	-.13	-.12	.04	1.00	.30	.24	-.01	-.09	.44	.41
CDI	.36	-.43	.07	.53*	-.26	.36	.30	1.00	.66*	-.46	.24	-.04	.09
PRUNWGT	.40	-.33	.39	.30	-.30	.16	.24	.66*	1.00	-.80*	.06	-.02	.03
YPRATIO	-.35	.04	-.09	-.39	.30	-.34	-.01	-.46	-.80*	1.00	.12	.38	.51*
CLUSTWGT	.46	-.35	-.30	.05	.09	.41	-.09	.24	.06	.12	1.00	-.42	.38
NUMCLUST	-.49*	-.21	.56*	-.18	.13	-.46	.44	-.04	-.02	.38	-.42	1.00	.65*
YLD	-.06	-.39	.39	-.19	.12	-.21	.41	.09	.03	.51*	.38	.65*	1.00
DRYPROD	.26	-.50*	.54*	.09	-.14	-.02	.45	.54*	.75*	-.25	.30	.41	.68*
TSS	-.03	.20	-.14	-.39	.16	-.40	-.48*	-.53*	-.27	.36	.33	-.21	.10
TA	.46	.04	-.34	.39	-.22	.47	.16	.61*	.11	-.20	.44	-.43	-.11
IR	-.36	.02	-.03	-.40	.27	-.31	.07	-.46	-.77*	.97*	.15	.45	.60*
PH	-.07	-.16	.56*	-.47*	-.15	-.31	.00	-.15	.37	-.13	-.28	.32	.13
TARTAR	.27	.18	-.63*	.54*	.08	.06	-.45	.15	-.24	.14	.26	-.30	-.13
MALIC	.52*	-.01	.04	.13	-.53*	.39	.34	.51*	.39	-.44	.08	-.29	-.20
TMRATIO	-.38	.21	-.22	.01	.52*	-.46	-.46	-.43	-.46	.49*	.07	.05	.10
TANTHOC	.14	.35	-.53*	-.12	-.03	-.07	-.21	-.38	-.56*	.39	.30	-.40	-.17
TPHENOLS	.20	.27	-.61*	-.07	-.02	-.03	-.31	-.32	-.49*	.32	.29	-.47*	-.27
ANTHOC	.31	.04	-.35	.09	-.10	.05	-.13	-.18	-.09	-.07	.27	-.47*	-.29
PHENOLS	.32	-.00	-.32	.08	-.12	.06	-.14	-.13	-.02	-.14	.21	-.46	-.34
ANTHEXTR	.19	-.41	.37	.30	-.11	.11	.10	.29	.69*	-.67*	-.11	-.04	-.16
FD_F	.42	.22	-.25	.19	-.25	.16	.29	.39	.11	-.09	.49*	-.44	-.02
FD_V	.61*	.07	-.20	.32	-.40	.20	.19	.65*	.39	-.29	.54*	-.44	.01
F_V	.58*	-.26	.04	.37	-.45	.16	-.12	.73*	.70*	-.49*	.29	-.15	.08
FD_IR20	.54*	-.05	-.35	.42	-.27	.58*	.15	.65*	.23	-.31	.54*	-.50*	-.11
FD_TSS20	.48*	-.22	-.11	.53*	-.21	.61*	.31	.81*	.42	-.44	.40	-.34	-.06
FD_H	.53*	-.06	-.18	.28	-.16	.40	.20	.57*	.35	-.26	.69*	-.40	.14
F_IR20	.52*	-.17	-.35	.47	-.24	.69*	.07	.67*	.25	-.37	.48*	-.45	-.14
V_IR20	.41	-.12	-.38	.41	-.15	.70*	.10	.53*	.09	-.27	.44	-.45	-.17
AVEOCT	-.28	-.03	.29	-.03	-.13	-.08	-.05	-.03	.05	-.14	-.65*	.39	-.14
AVENOV	-.29	-.01	.16	-.51*	.33	-.46	-.11	-.43	-.23	.56*	.19	.19	.44
AVEDEC	-.56*	.08	.39	-.56*	.25	-.62*	-.10	-.57*	-.32	.55*	-.35	.54*	.35
AVEJAN	-.59*	.00	.51*	-.46	.24	-.60*	.04	-.39	-.10	.35	-.52*	.69*	.33
AVEFEB	-.19	.10	.02	-.40	.36	-.39	-.05	-.43	-.27	.53*	.33	.04	.39
AVEMAR	-.56*	.02	.45	-.52*	.37	-.61*	.03	-.45	-.12	.44	-.27	.59*	.45
AVEAPR	-.40	.03	.38	-.52*	.37	-.56*	.04	-.46	-.09	.44	-.06	.43	.48*
AVESSN	-.52*	.03	.40	-.55*	.34	-.61*	-.03	-.50*	-.19	.49*	-.23	.52*	.43
RAINOCT	-.33	-.05	.54*	-.42	.27	-.41	.27	-.17	.19	.12	-.08	.24	.29
RAINNOV	.00	-.27	.28	.19	-.24	.05	.20	.17	.11	-.03	-.33	.40	.14
RAINDEC	.46	-.02	-.39	.48*	-.25	.67*	-.01	.38	.06	-.41	.23	-.57*	-.46
RAINJAN	-.15	-.01	.32	.10	-.21	.04	.05	.14	.17	-.28	-.59*	.29	-.19
RAINFEB	.56*	-.09	-.57*	.39	-.08	.55*	-.22	.35	.01	-.19	.60*	-.67*	-.27
RAINMAR	.27	-.11	-.11	.34	-.32	.43	.05	.33	.13	-.38	-.14	-.13	-.33
RAINAPR	-.29	-.04	.25	.13	-.11	.06	.11	.21	.19	-.31	-.68*	.41	-.19
RAINSSN	.17	-.10	.01	.36	-.29	.42	.06	.38	.19	-.43	-.29	-.06	-.35

STAT. Correlations (3ssnful2.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=18 (Casewise deletion of missing data)

Variable	DRYPRO D	TSS	TA	IR	PH	TARTAR	MALIC	TMRATI O	TANTHO C	TPHENO LS	ANTHOC	PHENOL S	ANTHEX TR
N	.26	-.03	.46	-.36	-.07	.27	.52*	-.38	.14	.20	.31	.32	.19
P	-.50*	.20	.04	.02	-.16	.18	-.01	.21	.35	.27	.04	-.00	-.41
K	.54*	-.14	-.34	-.03	.56*	-.63*	.04	-.22	-.53*	-.61*	-.35	-.32	.37
CA	.09	-.39	.39	-.40	-.47*	.54*	.13	.01	-.12	-.07	.09	.08	.30
MG	-.14	.16	-.22	.27	-.15	.08	-.53*	.52*	-.03	-.02	-.10	-.12	-.11
BWGTH	-.02	-.40	.47	-.31	-.31	.06	.39	-.46	-.07	-.03	.05	.06	.11
ESA1000	.45	-.48*	.16	.07	.00	-.45	.34	-.46	-.21	-.31	-.13	-.14	.10
CDI	.54*	-.53*	.61*	-.46	-.15	.15	.51*	-.43	-.38	-.32	-.18	-.13	.29
PRUNWGT	.75*	-.27	.11	-.77*	.37	-.24	.39	-.46	-.56*	-.49*	-.09	-.02	.69*
YPRATIO	-.25	.36	-.20	.97*	-.13	.14	-.44	.49*	.39	.32	-.07	-.14	-.67*
CLUSTWGT	.30	.33	.44	.15	-.28	.26	.08	.07	.30	.29	.27	.21	-.11
NUMCLUST	.41	-.21	-.43	.45	.32	-.30	-.29	.05	-.40	-.47*	-.47*	-.46	-.04
YLD	.68*	.10	-.11	.60*	.13	-.13	-.20	.10	-.17	-.27	-.29	-.34	-.16
DRYPROD	1.00	-.13	.01	-.16	.36	-.26	.15	-.27	-.53*	-.54*	-.26	-.24	.39
TSS	-.13	1.00	-.39	.33	.25	.12	-.52*	.66*	.56*	.56*	.43	.35	-.20
TA	.01	-.39	1.00	-.20	-.71*	.46	.68*	-.38	.22	.20	.10	.08	-.22
IR	-.16	.33	-.20	1.00	-.13	.08	-.45	.44	.36	.25	-.08	-.17	-.64*
PH	.36	.25	-.71*	-.13	1.00	-.58*	-.20	-.08	-.42	-.38	-.24	-.18	.32
TARTAR	-.26	.12	.46	.08	-.58*	1.00	-.01	.38	.39	.42	.09	.02	-.47
MALIC	.15	-.52*	.68*	-.45	-.20	-.01	1.00	-.86*	-.07	-.07	.04	.10	.15

STATISTICA: Basic Statistics and Tables

STAT. Correlations (3ssnful2.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=18 (Casewise deletion of missing data)

	DRYPRO							TMRATI	TANTHO	TPHENO		PHENOL	ANTHEX

Variable	D	TSS	TA	IR	PH	TARTAR	MALIC	O	C	LS	ANTHOC	S	TR
TMRATIO	-.27	.66*	-.38	.44	-.08	.38	-.86*	1.00	.37	.38	.16	.07	-.33
TANTHOC	-.53*	.56*	.22	.36	-.42	.39	-.07	.37	1.00	.96*	.76*	.64*	-.42
TPHENOLS	-.54*	.56*	.20	.25	-.38	.42	-.07	.38	.96*	1.00	.82*	.75*	-.30
ANTHOC	-.26	.43	.10	-.08	-.24	.09	.04	.16	.76*	.82*	1.00	.97*	.27
PHENOLS	-.24	.35	.08	-.17	-.18	.02	.10	.07	.64*	.75*	.97*	1.00	.39
ANTHEXTR	.39	-.20	-.22	-.64*	.32	-.47	.15	-.33	-.42	-.30	.27	.39	1.00
FD_F	.06	.10	.72*	-.09	-.49*	.33	.45	-.08	.56*	.52*	.49*	.41	-.16
FD_V	.30	.02	.73*	-.29	-.33	.35	.51*	-.20	.28	.30	.33	.30	.01
F_V	.57*	-.16	.29	-.49*	.20	.15	.31	-.29	-.44	-.33	-.22	-.12	.34
FD_IR20	.09	-.29	.94*	-.28	-.58*	.40	.63*	-.39	.25	.22	.21	.15	-.11
FD_TSS20	.27	-.54*	.84*	-.41	-.43	.23	.62*	-.50*	-.09	-.11	-.02	-.04	.08
FD_H	.35	.04	.69*	-.20	-.30	.31	.35	-.14	.24	.19	.20	.11	-.09
F_IR20	.09	-.44	.90*	-.33	-.53*	.37	.63*	-.47*	.07	.05	.04	.01	-.07
V_IR20	-.05	-.43	.89*	-.23	-.63*	.36	.60*	-.44	.19	.14	.10	.04	-.16
AVEOCT	-.06	-.56*	-.33	-.14	.33	-.24	.00	-.29	-.70*	-.68*	-.69*	-.59*	.09
AVENOV	.12	.75*	-.55*	.50*	.36	-.21	-.57*	.57*	.16	.16	.06	.02	-.16
AVEDEC	-.00	.37	-.79*	.51*	.52*	-.37	-.62*	.44	-.21	-.22	-.36	-.35	-.18
AVEJAN	.14	.12	-.80*	.32	.61*	-.42	-.53*	.28	-.48*	-.47*	-.54*	-.49*	-.04
AVEFEB	.06	.81*	-.34	.49*	.11	-.06	-.52*	.63*	.45	.42	.33	.25	-.21
AVEMAR	.21	.42	-.78*	.42	.56*	-.37	-.63*	.47*	-.26	-.26	-.33	-.32	-.08
AVEAPR	.25	.58*	-.71*	.41	.53*	-.34	-.63*	.52*	-.11	-.11	-.16	-.17	-.07
AVESSN	.15	.47*	-.78*	.46	.55*	-.36	-.64*	.49*	-.20	-.21	-.30	-.29	-.11
RAINOCT	.33	.30	-.51*	.06	.47*	-.49*	-.22	.19	-.26	-.24	-.09	-.04	.25
RAINNOV	.17	-.52*	-.17	-.01	.23	-.07	.18	-.34	-.48*	-.49*	-.40	-.35	.14
RAINDEC	-.26	-.49*	.78*	-.39	-.62*	.28	.67*	-.52*	.21	.21	.29	.30	.09
RAINJAN	-.00	-.71*	-.10	-.28	.21	-.20	.23	-.44	-.70*	-.69*	-.66*	-.56*	.13
RAINFEB	-.17	.03	.72*	-.20	-.51*	.52*	.29	-.05	.52*	.54*	.48*	.40	-.12
RAINMAR	-.13	-.70*	.43	-.35	-.23	.15	.54*	-.56*	-.17	-.15	-.10	-.04	.10
RAINAPR	.01	-.76*	-.07	-.28	.15	-.18	.18	-.42	-.71*	-.70*	-.69*	-.59*	.10
RAINSSN	-.09	-.82*	.36	-.42	-.15	.05	.53*	-.61*	-.41	-.39	-.32	-.25	.14

STAT. Correlations (3ssnful2.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=18 (Casewise deletion of missing data)

Variable	FD_F	FD_V	F_V	FD_IR2 0	FD_TSS 20	FD_H	F_IR20	V_IR20	AVEOCT	AVENOV	AVEDEC	AVEJAN	AVEFEB
N	.42	.61*	.58*	.54*	.48*	.53*	.52*	.41	-.28	-.29	-.56*	-.59*	-.19
P	.22	.07	-.26	-.05	-.22	-.06	-.17	-.12	-.03	-.01	.08	.00	.10
K	-.25	-.20	.04	-.35	-.11	-.18	-.35	-.38	.29	.16	.39	.51*	.02
CA	.19	.32	.37	.42	.53*	.28	.47	.41	-.03	-.51*	-.56*	-.46	-.40
MG	-.25	-.40	-.45	-.27	-.21	-.16	-.24	-.15	-.13	.33	.25	.24	.36
BWGTH	.16	.20	.16	.58*	.61*	.40	.69*	.70*	-.08	-.46	-.62*	-.60*	-.39
ESA1000	.29	.19	-.12	.15	.31	.20	.07	.10	-.05	-.11	-.10	.04	-.05
CDI	.39	.65*	.73*	.65*	.81*	.57*	.67*	.53*	-.03	-.43	-.57*	-.39	-.43
PRUNWGT	.11	.39	.70*	.23	.42	.35	.25	.09	.05	-.23	-.32	-.10	-.27
YPRATIO	-.09	-.29	-.49*	-.31	-.44	-.26	-.37	-.27	-.14	.56*	.55*	.35	.53*
CLUSTWGT	.49*	.54*	.29	.54*	.40	.69*	.48*	.44	-.65*	.19	-.35	-.52*	.33
NUMCLUST	-.44	-.44	-.15	-.50*	-.34	-.40	-.45	-.45	.39	.19	.54*	.69*	.04
YLD	-.02	.01	.08	-.11	-.06	.14	-.14	-.17	-.14	.44	.35	.33	.39
DRYPROD	.06	.30	.57*	.09	.27	.35	.09	-.05	-.06	.12	-.00	.14	.06
TSS	.10	.02	-.16	-.29	-.54*	.04	-.44	-.43	-.56*	.75*	.37	.12	.81*
TA	.72*	.73*	.29	.94*	.84*	.69*	.90*	.89*	-.33	-.55*	-.79*	-.80*	-.34
IR	-.09	-.29	-.49*	-.28	-.41	-.20	-.33	-.23	-.14	.50*	.51*	.32	.49*
PH	-.49*	-.33	.20	-.58*	-.43	-.30	-.53*	-.63*	.33	.36	.52*	.61*	.11
TARTAR	.33	.35	.15	.40	.23	.31	.37	.36	-.24	-.21	-.37	-.42	-.06
MALIC	.45	.51*	.31	.63*	.62*	.35	.63*	.60*	.00	-.57*	-.62*	-.53*	-.52*
TMRATIO	-.08	-.20	-.29	-.39	-.50*	-.14	-.47*	-.44	-.29	.57*	.44	.28	.63*
TANTHOC	.56*	.28	-.44	.25	-.09	.24	.07	.19	-.70*	.16	-.21	-.48*	.45
TPHENOLS	.52*	.30	-.33	.22	-.11	.19	.05	.14	-.68*	.16	-.22	-.47*	.42
ANTHOC	.49*	.33	-.22	.21	-.02	.20	.04	.10	-.69*	.06	-.36	-.54*	.33
PHENOLS	.41	.30	-.12	.15	-.04	.11	.01	.04	-.59*	.02	-.35	-.49*	.25
ANTHEXTR	-.16	.01	.34	-.11	.08	-.09	-.07	-.16	.09	-.16	-.18	-.04	-.21
FD_F	1.00	.90*	.12	.78*	.60*	.81*	.55*	.57*	-.78*	-.11	-.63*	-.74*	.20
FD_V	.90*	1.00	.54*	.81*	.71*	.86*	.65*	.56*	-.63*	-.17	-.67*	-.70*	.04
F_V	.12	.54*	1.00	.35	.45	.42	.41	.18	.08	-.18	-.30	-.18	-.30
FD_IR20	.78*	.81*	.35	1.00	.92*	.85*	.96*	.94*	-.44	-.54*	-.88*	-.90*	-.30
FD_TSS20	.60*	.71*	.45	.92*	1.00	.79*	.93*	.88*	-.22	-.62*	-.83*	-.75*	-.47
FD_H	.81*	.86*	.42	.85*	.79*	1.00	.74*	.69*	-.65*	-.20	-.70*	-.73*	.05
F_IR20	.55*	.65*	.41	.96*	.93*	.74*	1.00	.97*	-.22	-.66*	-.87*	-.84*	-.49*
V_IR20	.57*	.56*	.18	.94*	.88*	.69*	.97*	1.00	-.26	-.67*	-.86*	-.85*	-.46
AVEOCT	-.78*	-.63*	.08	-.44	-.22	-.65*	-.22	-.26	1.00	-.34	.33	.54*	-.66*
AVENOV	-.11	-.17	-.18	-.54*	-.62*	-.20	-.66*	-.67*	-.34	1.00	.74*	.55*	.91*
AVEDEC	-.63*	-.67*	-.30	-.88*	-.83*	-.70*	-.87*	-.86*	.33	.74*	1.00	.93*	.49*
AVEJAN	-.74*	-.70*	-.18	-.90*	-.75*	-.73*	-.84*	-.85*	.54*	.55*	.93*	1.00	.25

STATISTICA: Basic Statistics and Tables

STAT. Correlations (3ssnful2.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=18 (Casewise deletion of missing data)

Variable	FD_F	FD_V	F_V	FD_IR2 0	FD_TSS 20	FD_H	F_IR20	V_IR20	AVEOCT	AVENOV	AVEDEC	AVEJAN	AVEFEB
AVEFEB	.20	.04	-.30	-.30	-.47	.05	-.49*	-.46	-.66*	.91*	.49*	.25	1.00
AVEMAR	-.50*	-.52*	-.22	-.83*	-.76*	-.52*	-.86*	-.87*	.15	.81*	.93*	.91*	.61*
AVEAPR	-.32	-.35	-.20	-.72*	-.70*	-.33	-.81*	-.82*	-.10	.91*	.84*	.77*	.78*
AVESSN	-.51*	-.53*	-.24	-.84*	-.79*	-.54*	-.87*	-.88*	.14	.85*	.96*	.90*	.64*
RAINOCT	-.12	-.15	-.11	-.54*	-.43	-.26	-.66*	-.68*	-.07	.70*	.60*	.59*	.57*
RAINNOV	-.40	-.29	.11	-.19	.02	-.32	-.06	-.10	.67*	-.38	.05	.23	-.59*
RAINDEC	.44	.42	.11	.79*	.73*	.42	.83*	.87*	-.11	-.80*	-.87*	-.87*	-.61*
RAINJAN	-.60*	-.45	.14	-.22	.03	-.48*	-.01	-.04	.95*	-.53*	.11	.34	-.79*
RAINFEB	.62*	.61*	.20	.82*	.67*	.72*	.79*	.80*	-.54*	-.42	-.79*	-.89*	-.14
RAINMAR	-.05	.02	.14	.38	.47*	.03	.53*	.53*	.47*	-.90*	-.56*	-.40	-.90*
RAINAPR	-.57*	-.43	.13	-.18	.06	-.44	.04	.00	.89*	-.54*	.07	.34	-.77*
RAINSSN	-.20	-.08	.20	.29	.46	-.08	.48*	.46	.65*	-.88*	-.44	-.24	-.96*

STAT. Correlations (3ssnful2.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=18 (Casewise deletion of missing data)

Variable	AVEMAR	AVEAPR	AVESSN	RAINOC T	RAINNO V	RAINDE C	RAINJA N	RAINFE B	RAINMA R	RAINAP R	RAINSS N
N	-.56*	-.40	-.52*	-.33	.00	.46	-.15	.56*	.27	-.29	.17
P	.02	.03	.03	-.05	-.27	-.02	-.01	-.09	-.11	-.04	-.10
K	.45	.38	.40	.54*	.28	-.39	.32	-.57*	-.11	.25	.01

CA	-.52*	-.52*	-.55*	-.42	.19	.48*	.10	.39	.34	.13	.36
MG	.37	.37	.34	.27	-.24	-.25	-.21	-.08	-.32	-.11	-.29
BWGTH	-.61*	-.56*	-.61*	-.41	.05	.67*	.04	.55*	.43	.06	.42
ESA1000	.03	.04	-.03	.27	.20	-.01	.05	-.22	.05	.11	.06
CDI	-.45	-.46	-.50*	-.17	.17	.38	.14	.35	.33	.21	.38
PRUNWGT	-.12	-.09	-.19	.19	.11	.06	.17	.01	.13	.19	.19
YPRATIO	.44	.44	.49*	.12	-.03	-.41	-.28	-.19	-.38	-.31	-.43
CLUSTWGT	-.27	-.06	-.23	-.08	-.33	.23	-.59*	.60*	-.14	-.68*	-.29
NUMCLUST	.59*	.43	.52*	.24	.40	-.57*	.29	-.67*	-.13	.41	-.06
YLD	.45	.48*	.43	.29	.14	-.46	-.19	-.27	-.33	-.19	-.35
DRYPROD	.21	.25	.15	.33	.17	-.26	-.00	-.17	-.13	.01	-.09
TSS	.42	.58*	.47*	.30	-.52*	-.49*	-.71*	.03	-.70*	-.76*	-.82*
TA	-.78*	-.71*	-.78*	-.51*	-.17	.78*	-.10	.72*	.43	-.07	.36
IR	.42	.41	.46	.06	-.01	-.39	-.28	-.20	-.35	-.28	-.42
PH	.56*	.53*	.55*	.47*	.23	-.62*	.21	-.51*	-.23	.15	-.15
TARTAR	-.37	-.34	-.36	-.49*	-.07	.28	-.20	.52*	.15	-.18	.05
MALIC	-.63*	-.63*	-.64*	-.22	.18	.67*	.23	.29	.54*	.18	.53*
TMRATIO	.47*	.52*	.49*	.19	-.34	-.52*	-.44	-.05	-.56*	-.42	-.61*
TANTHOC	-.26	-.11	-.20	-.26	-.48*	.21	-.70*	.52*	-.17	-.71*	-.41
TPHENOLS	-.26	-.11	-.21	-.24	-.49*	.21	-.69*	.54*	-.15	-.70*	-.39
ANTHOC	-.33	-.16	-.30	-.09	-.40	.29	-.66*	.48*	-.10	-.69*	-.32
PHENOLS	-.32	-.17	-.29	-.04	-.35	.30	-.56*	.40	-.04	-.59*	-.25
ANTHEXTR	-.08	-.07	-.11	.25	.14	.09	.13	-.12	.10	.10	.14
FD_F	-.50*	-.32	-.51*	-.12	-.40	.44	-.60*	.62*	-.05	-.57*	-.20
FD_V	-.52*	-.35	-.53*	-.15	-.29	.42	-.45	.61*	.02	-.43	-.08
F_V	-.22	-.20	-.24	-.11	.11	.11	.14	.20	.14	.13	.20
FD_IR20	-.83*	-.72*	-.84*	-.54*	-.19	.79*	-.22	.82*	.38	-.18	.29
FD_TSS20	-.76*	-.70*	-.79*	-.43	.02	.73*	.03	.67*	.47*	.06	.46
FD_H	-.52*	-.33	-.54*	-.26	-.32	.42	-.48*	.72*	.03	-.44	-.08
F_IR20	-.86*	-.81*	-.87*	-.66*	-.06	.83*	-.01	.79*	.53*	.04	.48*
V_IR20	-.87*	-.82*	-.88*	-.68*	-.10	.87*	-.04	.80*	.53*	.00	.46
AVEOCT	.15	-.10	.14	-.07	.67*	-.11	.95*	-.54*	.47*	.89*	.65*
AVENOV	.81*	.91*	.85*	.70*	-.38	-.80*	-.53*	-.42	-.90*	-.54*	-.88*
AVEDEC	.93*	.84*	.96*	.60*	.05	-.87*	.11	-.79*	-.56*	.07	-.44
AVEJAN	.91*	.77*	.90*	.59*	.23	-.87*	.34	-.89*	-.40	.34	-.24
AVEFEB	.61*	.78*	.64*	.57*	-.59*	-.61*	-.79*	-.14	-.90*	-.77*	-.96*
AVEMAR	1.00	.96*	.99*	.74*	-.04	-.96*	-.05	-.79*	-.70*	-.02	-.58*
AVEAPR	.96*	1.00	.96*	.78*	-.21	-.94*	-.29	-.65*	-.82*	-.28	-.76*
AVESSN	.99*	.96*	1.00	.73*	-.07	-.95*	-.07	-.77*	-.72*	-.08	-.61*
RAINOCT	.74*	.78*	.73*	1.00	-.02	-.67*	-.13	-.65*	-.59*	-.22	-.49*
RAINNOV	-.04	-.21	-.07	-.02	1.00	.05	.72*	-.36	.59*	.55*	.64*
RAINDEC	-.96*	-.94*	-.95*	-.67*	.05	1.00	.12	.72*	.71*	.08	.64*
RAINJAN	-.05	-.29	-.07	-.13	.72*	.12	1.00	-.40	.65*	.91*	.82*
RAINFEB	-.79*	-.65*	-.77*	-.65*	-.36	.72*	-.40	1.00	.31	-.39	.14
RAINMAR	-.70*	-.82*	-.72*	-.59*	.59*	.71*	.65*	.31	1.00	.54*	.95*
RAINAPR	-.02	-.28	-.08	-.22	.55*	.08	.91*	-.39	.54*	1.00	.73*
RAINSSN	-.58*	-.76*	-.61*	-.49*	.64*	.64*	.82*	.14	.95*	.73*	1.00

Variables:

Var 4: N - Nitrogen in leaf petioles at véraison [% d.w.]
Var 5: P - Phosphorus in leaf petioles at véraison [% d.w.]
Var 6: K - Potassium in leaf petioles at véraison [% d.w.]
Var 7: CA - Calcium in leaf petioles at véraison [% d.w.]
Var 8: MG - Magnesium in leaf petioles at véraison [% d.w.]
Var 9: BWGTH - Berry weight at harvest [g]
Var 10: ESA1000 - Estimated exposed leaf surface area [thousands of m^2 ha^{-1}]
Var 12: CDI - Canopy density index
Var 13: PRUNWGT - Pruning weights [kg m^{-2}]
Var 14: YPRATIO - Crop load
Var 15: CLUSTWGT - Cluster weight [g]
Var 16: NUMCLUST - Number of clusters m^{-2}
Var 17: YLD - Yield of grapes [kg m^{-2}]
Var 18: DRYPROD - Dry production [kg m^{-2}]
Var 19: TSS - Total soluble solids [°Brix] at harvest
Var 20: TA - Titratable acidity [g L^{-1}] at harvest
Var 21: IR - Index of ripeness at harvest
Var 22: PH - pH of must at harvest
Var 23: TARTAR - Tartaric acid [g L^{-1}] at harvest
Var 24: MALIC - Malic acid [g L^{-1}] at harvest
Var 25: TMRATIO - Tartaric : Malic ratio
Var 26: TANTHOC - Total anthocyanins [mg kg^{-1}]
Var 27: TPHENOLS - Total polyphenols [mg kg^{-1}]
Var 28: ANTHOC - Extractable Anthocyanins [mg kg^{-1}]
Var 29: PHENOLS - Extractable Polyphenols [mg kg^{-1}]
Var 30: ANTHEXTR - Extractability of Anthocyanins [%]
Var 32: FD_F - Days from 1 Oct to flowering
Var 33: FD_V - Days from 1 Oct to véraison
Var 34: F_V - Days from flowering to véraison
Var 35: FD_IR20 - Days from 1 Oct to IR=20
Var 36: FD_TSS20 - Days from 1 Oct to TSS=20°Brix
Var 37: FD_H - Days from 1 Oct to harvest
Var 38: F_IR20 - Days from flowering to IR=20
Var 39: V_IR20 - Days from véraison to IR=20
Var 40: AVEOCT - Average air temperature for October [°C]
Var 41: AVENOV - Average air temperature for November [°C]
Var 42: AVEDEC - Average air temperature for December [°C]
Var 43: AVEJAN - Average air temperature for January [°C]
Var 44: AVEFEB - Average air temperature for February [°C]
Var 45: AVEMAR - Average air temperature for March [°C]
Var 46: AVEAPR - Average air temperature for April [°C]
Var 47: AVESSN - Average air temperature from October to April [°C]
Var 54: RAINOCT - Total rainfall for October [mm]
Var 55: RAINNOV - Total rainfall for November [mm]
Var 56: RAINDEC - Total rainfall for December [mm]
Var 57: RAINJAN - Total rainfall for January [mm]
Var 58: RAINFEB - Total rainfall for February [mm]
Var 59: RAINMAR - Total rainfall for March [mm]
Var 60: RAINAPR - Total rainfall for April [mm]
Var 61: RAINSSN - Total rainfall from October to April [mm]

Correlations for variables observed in the 1997/98 and 1998/99 seasons only:

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Correlations (ssn23pca.sta)
Marked correlations are significant at p < .05000
N=12 (Casewise deletion of missing data)

Variable	IR20	CLWG	NOCL	YLD	IPF	IPV	IPCY	BWG	SHL	PRWG	YPRAT	CDI	NF
IR20	1.00	.24	.05	.26	-.60*	-.85*	-.82*	.65*	.63*	.79*	-.49	.87*	.53
CLWG	.24	1.00	-.15	.73*	.19	-.16	-.07	.10	.19	.12	.29	.01	-.10
NOCL	.05	-.15	1.00	.54	.01	.19	.15	.02	.07	.02	.22	.24	-.50
YLD	.26	.73*	.54	1.00	.13	-.02	.01	.07	.16	.13	.40	.16	-.43
IPF	-.60*	.19	.01	.13	1.00	.77*	.86*	-.12	-.32	-.48	.34	-.54	-.53
IPV	-.85*	-.16	.19	-.02	.77*	1.00	.99*	-.41	-.54	-.81*	.57	-.77*	-.70*
IPCY	-.82*	-.07	.15	.01	.86*	.99*	1.00	-.35	-.51	-.76*	.53	-.75*	-.69*
BWG	.65*	.10	.02	.07	-.12	-.41	-.35	1.00	.47	.46	-.40	.56	.08
SHL	.63*	.19	.07	.16	-.32	-.54	-.51	.47	1.00	.64*	-.54	.71*	.38
PRWG	.79*	.12	.02	.13	-.48	-.81*	-.76*	.46	.64*	1.00	-.82*	.73*	.55
YPRAT	-.49	.29	.22	.40	.34	.57	.53	-.40	-.54	-.82*	1.00	-.48	-.64*
CDI	.87*	.01	.24	.16	-.54	-.77*	-.75*	.56	.71*	.73*	-.48	1.00	.44
NF	.53	-.10	-.50	-.43	-.53	-.70*	-.69*	.08	.38	.55	-.64*	.44	1.00
PF	-.27	-.02	-.60*	-.46	-.12	-.05	-.07	-.34	-.25	-.02	-.22	-.50	.45
KF	.35	.25	-.01	.29	-.32	-.54	-.51	-.14	-.21	.44	-.10	.25	.26
CAF	.07	.68*	-.30	.39	.12	-.04	.00	-.24	-.11	.05	.21	-.12	-.05
MGF	-.16	.23	-.27	-.01	.13	.27	.25	.04	-.07	-.18	.11	-.44	-.12
PHE	-.79*	-.30	-.10	-.29	.21	.55	.48	-.81*	-.86*	-.69*	.51	-.74*	-.26
AC	-.75*	-.15	-.15	-.21	.19	.51	.45	-.80*	-.85*	-.67*	.55	-.77*	-.23
TAR	-.11	.43	.17	.50	.08	.18	.17	-.60*	-.13	-.10	.31	-.28	-.02
MAL	.66*	-.32	.12	-.14	-.57	-.74*	-.73*	.42	.30	.69*	-.61*	.74*	.46
TMR	-.41	.30	-.11	.19	.12	.45	.39	-.55	-.29	-.45	.47	-.65*	-.21
KJCE	-.18	-.30	.13	-.11	.07	.02	.03	-.12	-.48	-.05	.00	-.13	-.07
TSS	-.85*	.08	-.28	-.16	.46	.66*	.63*	-.60*	-.61*	-.75*	.56	-.85*	-.39
TA	.93*	.42	.17	.49	-.49	-.73*	-.70*	.55	.50	.69*	-.30	.72*	.42
PH	-.40	-.31	-.28	-.44	-.03	-.03	-.04	-.26	-.51	-.12	-.04	-.31	.02
IR	-.96*	-.29	-.21	-.41	.47	.74*	.70*	-.65*	-.66*	-.77*	.45	-.82*	-.41
MI	-.57	.10	-.27	-.11	.21	.53	.47	-.35	-.40	-.59*	.45	-.74*	-.31
WSC	-.59*	.07	-.17	-.08	.39	.65*	.61*	-.27	-.28	-.56	.39	-.66*	-.47
SFO	-.64*	-.40	.26	-.14	.40	.69*	.64*	-.22	-.76*	-.71*	.53	-.55	-.64*
SFN	-.70*	-.33	.24	-.11	.38	.73*	.67*	-.35	-.82*	-.84*	.69*	-.64*	-.61*

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Correlations (ssn23pca.sta)
Marked correlations are significant at p < .05000
N=12 (Casewise deletion of missing data)

Variable	IR20	CLWG	NOCL	YLD	IPF	IPV	IPCY	BWG	SHL	PRWG	YPRAT	CDI	NF
SFD	-.62*	-.08	.05	-.02	.24	.61*	.54	-.48	-.79*	-.82*	.80*	-.66*	-.46
SFJ	-.60*	.03	.01	.04	.21	.59*	.52	-.47	-.71*	-.83*	.83*	-.69*	-.48
SFF	-.63*	.06	.03	.08	.26	.64*	.57	-.42	-.70*	-.86*	.84*	-.75*	-.53
SFM	-.62*	.02	.06	.06	.25	.64*	.56	-.38	-.67*	-.87*	.85*	-.70*	-.54
TO	-.01	-.62*	.10	-.43	.09	.03	.05	.30	.10	.07	-.36	.22	-.01
TN	-.12	.69*	-.30	.36	.15	.10	.11	-.33	-.33	-.32	.57	-.35	-.04
TD	-.55	.24	-.19	.10	.46	.56	.56	-.53	-.79*	-.77*	.79*	-.65*	-.35
TJ	-.60*	-.36	.26	-.09	.40	.65*	.61*	-.42	-.66*	-.78*	.64*	-.47	-.41
TF	-.16	.61*	-.21	.37	.07	.15	.14	-.41	-.31	-.31	.54	-.42	-.08
TM	-.22	.56	-.13	.36	.16	.28	.26	-.34	-.39	-.41	.61*	-.47	-.20
TAL	-.11	.67*	-.24	.40	.07	.09	.09	-.30	-.26	-.21	.45	-.41	-.07
WIO	-.16	.49	-.35	.19	-.20	-.07	-.11	-.44	-.35	-.24	.46	-.36	-.01
WIN	-.00	-.36	.29	-.08	-.03	-.02	-.02	.31	.10	.03	-.08	.28	-.38
WID	-.05	-.67*	.16	-.42	.14	.13	.14	.33	-.06	.02	-.32	.14	-.14
WIJ	.06	-.62*	.13	-.38	-.03	-.02	-.02	.29	.08	.13	-.39	.24	-.03
WIF	-.10	.11	.18	.26	-.12	.21	.14	-.58*	-.17	-.17	.26	-.29	.02
WIM	-.03	-.59*	.35	-.21	-.10	.05	.01	.21	.10	.10	-.29	.18	-.25
WIA	-.03	-.77*	.33	-.43	-.01	.07	.05	.26	.09	.07	-.37	.24	-.01
WIS	-.01	-.66*	.26	-.33	-.06	.05	.02	.23	.04	.07	-.31	.20	-.15
STO	-.49	-.65*	-.00	-.53	.36	.44	.44	-.03	-.42	-.40	.01	-.30	-.25
STN	-.61*	-.17	-.30	-.36	.45	.53	.53	-.39	-.76*	-.76*	.56	-.52	-.20
STD	-.71*	.08	-.37	-.20	.50	.58*	.58*	-.49	-.82*	-.79*	.65*	-.74*	-.29
STJ	-.77*	-.32	-.24	-.44	.56	.71*	.69*	-.39	-.78*	-.84*	.51	-.68*	-.32
STF	-.67*	.19	-.36	-.10	.45	.60*	.58*	-.51	-.75*	-.77*	.66*	-.79*	-.28
STM	-.76*	-.02	-.27	-.22	.46	.71*	.68*	-.53	-.78*	-.89*	.70*	-.80*	-.35
SMO	.73*	.45	-.02	.36	-.27	-.57	-.51	.54	.81*	.70*	-.47	.56	.40
SMN	.57	.34	-.21	.09	-.42	-.53	-.52	.32	.80*	.54	-.45	.44	.53
SMD	.17	-.44	.07	-.31	-.23	-.23	-.24	.34	.39	.29	-.48	.40	.02
SMJ	.32	-.57	.08	-.44	-.21	-.29	-.29	.45	.49	.43	-.66*	.58*	.25
SMF	.38	-.62*	.03	-.51	-.35	-.39	-.40	.42	.48	.46	-.68*	.63*	.36
SMM	.34	-.58*	.03	-.45	-.23	-.30	-.30	.43	.42	.43	-.67*	.56	.27

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Correlations (ssn23pca.sta)
Marked correlations are significant at p < .05000
N=12 (Casewise deletion of missing data)

Variable	PF	KF	CAF	MGF	PHE	AC	TAR	MAL	TMR	KJCE	TSS	TA	PH
IR20	-.27	.35	.07	-.16	-.79*	-.75*	-.11	.66*	-.41	-.18	-.85*	.93*	-.40
CLWG	-.02	.25	.68*	.23	-.30	-.15	.43	-.32	.30	-.30	.08	.42	-.31
NOCL	-.60*	-.01	-.30	-.27	-.10	-.15	.17	.12	-.11	.13	-.28	.17	-.28
YLD	-.46	.29	.39	-.01	-.29	-.21	.50	-.14	.19	-.11	-.16	.49	-.44
IPF	-.12	-.32	.12	.13	.21	.19	.08	-.57	.12	.07	.46	-.49	-.03
IPV	-.05	-.54	-.04	.27	.55	.51	.18	-.74*	.45	.02	.66*	-.73*	-.03
IPCY	-.07	-.51	.00	.25	.48	.45	.17	-.73*	.39	.03	.63*	-.70*	-.04
BWG	-.34	-.14	-.24	.04	-.81*	-.80*	-.60*	.42	-.55	-.12	-.60*	.55	-.26
SHL	-.25	-.21	-.11	-.07	-.86*	-.85*	-.13	.30	-.29	-.48	-.61*	.50	-.51
PRWG	-.02	.44	.05	-.18	-.69*	-.67*	-.10	.69*	-.45	-.05	-.75*	.69*	-.12
YPRAT	-.22	-.10	.21	.11	.51	.55	.31	-.61*	.47	.00	.56	-.30	-.04
CDI	-.50	.25	-.12	-.44	-.74*	-.77*	-.28	.74*	-.65*	-.13	-.85*	.72*	-.31
NF	.45	.26	-.05	-.12	-.26	-.23	-.02	.46	-.21	-.07	-.39	.42	.02
PF	1.00	.05	.08	.40	.40	.49	.17	-.24	.40	.01	.50	-.22	.44
KF	.05	1.00	.29	-.41	.09	.12	.19	.52	-.24	.48	-.28	.41	.39
CAF	.08	.29	1.00	.37	.09	.20	.49	-.37	.51	-.42	.24	.15	-.23
MGF	.40	-.41	.37	1.00	.04	.14	.10	-.68*	.72*	-.69*	.40	-.10	-.26
PHE	.40	.09	.09	.04	1.00	.98*	.24	-.40	.42	.33	.76*	-.71*	.56

AC	.49	.12	.20	.14	.98*	1.00	.33	-.48	.53	.25	.81*	-.63*	.52
TAR	.17	.19	.49	.10	.24	.33	1.00	-.39	.67*	-.07	.17	.15	-.39
MAL	-.24	.52	-.37	-.68*	-.40	-.48	-.39	1.00	-.82*	.47	-.78*	.50	.21
TMR	.40	-.24	.51	.72*	.42	.53	.67*	-.82*	1.00	-.46	.59*	-.22	-.28
KJCE	.01	.48	-.42	-.69*	.33	.25	-.07	.47	-.46	1.00	-.07	-.12	.60*
TSS	.50	-.28	.24	.40	.76*	.81*	.17	-.78*	.59*	-.07	1.00	-.75*	.39
TA	-.22	.41	.15	-.10	-.71*	-.63*	.15	.50	-.22	-.12	-.75*	1.00	-.47
PH	.44	.39	-.23	-.26	.56	.52	-.39	.21	-.28	.60*	.39	-.47	1.00
IR	.35	-.31	.01	.20	.85*	.81*	-.02	-.61*	.38	.10	.89*	-.95*	.51
MI	.48	-.41	.30	.85*	.49	.57	.15	-.85*	.81*	-.48	.78*	-.49	.05
WSC	.21	-.56	.35	.82*	.37	.41	.07	-.86*	.72*	-.59*	.70*	-.57	-.11
SFO	-.14	-.17	-.33	-.21	.61*	.53	-.10	-.17	-.01	.59*	.42	-.57	.35
SFN	-.03	-.20	-.26	-.05	.72*	.68*	.01	-.35	.20	.45	.56	-.57	.32
SFD	.16	-.11	.12	.36	.78*	.81*	.15	-.61*	.56	.00	.72*	-.48	.23
SFJ	.18	-.17	.18	.46	.72*	.76*	.20	-.69*	.66*	-.10	.73*	-.46	.15
SFF	.20	-.22	.09	.44	.67*	.72*	.23	-.71*	.66*	-.02	.73*	-.45	.13
SFM	.14	-.27	.03	.42	.65*	.69*	.15	-.69*	.61*	-.05	.71*	-.45	.13
TO	-.37	-.15	-.69*	-.62*	-.18	-.34	-.54	.55	-.73*	.55	-.40	-.20	.19
TN	.32	.19	.73*	.47	.32	.47	.47	-.60*	.64*	-.35	.54	.07	-.06

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Correlations (ssn23pca.sta)
Marked correlations are significant at p < .05000
N=12 (Casewise deletion of missing data)

Variable	PF	KF	CAF	MGF	PHE	AC	TAR	MAL	TMR	KJCE	TSS	TA	PH
TD	.11	.07	.41	.12	.70*	.75*	.41	-.57	.50	.17	.65*	-.37	.12
TJ	-.19	-.11	-.36	-.29	.62*	.54	.10	-.22	.06	.52	.33	-.49	.19
TF	.38	.11	.71*	.61*	.35	.50	.58*	-.68*	.81*	-.44	.55	.05	-.14
TM	.33	.01	.65*	.65*	.37	.52	.51	-.73*	.80*	-.43	.60*	.00	-.16
TAL	.42	.15	.70*	.67*	.25	.42	.53	-.65*	.78*	-.44	.50	.10	-.12
WIO	.48	.31	.63*	.39	.45	.59*	.36	-.43	.61*	-.23	.58*	-.05	.25
WIN	-.59*	-.05	-.43	-.60*	-.16	-.30	-.55	.49	-.67*	.43	-.28	-.18	.23
WID	-.40	-.15	-.61*	-.49	-.10	-.26	-.55	.51	-.66*	.54	-.36	-.23	.18
WIJ	-.40	-.08	-.58*	-.57	-.18	-.33	-.45	.59*	-.65*	.53	-.47	-.13	.11
WIF	.17	.04	.36	.28	.29	.36	.88*	-.38	.77*	-.20	.11	.09	-.45
WIM	-.42	-.13	-.60*	-.54	-.14	-.28	-.37	.52	-.54	.50	-.38	-.18	.13
WIA	-.32	-.23	-.84*	-.57	-.12	-.28	-.51	.54	-.69*	.51	-.39	-.18	.17
WIS	-.42	-.11	-.62*	-.58*	-.11	-.27	-.43	.56	-.61*	.55	-.41	-.19	.15
STO	-.11	-.19	-.62*	-.42	.34	.19	-.43	.17	-.42	.67*	.11	-.59*	.45
STN	.13	-.10	.10	-.03	.73*	.70*	-.08	-.37	.13	.23	.65*	-.58*	.39
STD	.33	-.04	.25	.15	.79*	.82*	.11	-.56	.36	.21	.83*	-.59*	.43
STJ	.16	-.25	-.12	-.02	.74*	.69*	-.12	-.41	.13	.35	.67*	-.74*	.42
STF	.44	-.13	.40	.44	.75*	.82*	.26	-.75*	.63*	-.06	.89*	-.52	.25
STM	.32	-.27	.22	.34	.80*	.83*	.18	-.72*	.57	.00	.87*	-.64*	.23
SMO	-.08	.03	.12	.27	-.85*	-.77*	.04	.17	-.05	-.52	-.60*	.72*	-.56
SMN	.20	-.21	.20	.40	-.65*	-.55	.09	-.01	.17	-.74*	-.31	.52	-.52
SMD	-.35	-.15	-.45	-.55	-.35	-.47	-.48	.60*	-.64*	.29	-.44	-.07	.09
SMJ	-.37	-.20	-.50	-.49	-.46	-.60*	-.57	.67*	-.74*	.13	-.60*	.05	-.05
SMF	-.31	-.13	-.49	-.48	-.42	-.55	-.59*	.72*	-.74*	.10	-.61*	.08	.01
SMM	-.37	-.13	-.43	-.48	-.43	-.56	-.53	.69*	-.72*	.17	-.63*	.07	-.05

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Correlations (ssn23pca.sta)
Marked correlations are significant at p < .05000
N=12 (Casewise deletion of missing data)

Variable	IR	MI	WSC	SFO	SFN	SFD	SFJ	SFF	SFM	TO	TN	TD	TJ
IR20	-.96*	-.57	-.59*	-.64*	-.70*	-.62*	-.60*	-.63*	-.62*	-.01	-.12	-.55	-.60*
CLWG	-.29	.10	.07	-.40	-.33	-.08	.03	.06	.02	-.62*	.69*	.24	-.36
NOCL	-.21	-.27	-.17	.26	.24	.05	.01	.03	.06	.10	-.30	-.19	.26
YLD	-.41	-.11	-.08	-.14	-.11	-.02	.04	.08	.06	-.43	.36	.10	-.09
IPF	.47	.21	.39	.40	.38	.24	.21	.26	.25	.09	.15	.46	.40
IPV	.74*	.53	.65*	.69*	.73*	.61*	.59*	.64*	.64*	.03	.10	.56	.65*
IPCY	.70*	.47	.61*	.64*	.67*	.54	.52	.57	.56	.05	.11	.56	.61*
BWG	-.65*	-.35	-.27	-.22	-.35	-.48	-.47	-.42	-.38	.30	-.33	-.53	-.42
SHL	-.66*	-.40	-.28	-.76*	-.82*	-.79*	-.71*	-.70*	-.67*	.10	-.33	-.79*	-.66*
PRWG	-.77*	-.59*	-.56	-.71*	-.84*	-.82*	-.83*	-.86*	-.87*	.07	-.32	-.77*	-.78*
YPRAT	.45	.45	.39	.53	.69*	.80*	.83*	.84*	.85*	-.36	.57	.79*	.64*
CDI	-.82*	-.74*	-.66*	-.55	-.64*	-.66*	-.69*	-.75*	-.70*	.22	-.35	-.65*	-.47
NF	-.41	-.31	-.47	-.64*	-.61*	-.46	-.48	-.53	-.54	-.01	-.04	-.35	-.41
PF	.35	.48	.21	-.14	-.03	.16	.18	.20	.14	-.37	.32	.11	-.19
KF	-.31	-.41	-.56	-.17	-.20	-.11	-.17	-.22	-.27	-.15	.19	.07	-.11
CAF	.01	.30	.35	-.33	-.26	.12	.18	.09	.03	-.69*	.73*	.41	-.36
MGF	.20	.85*	.82*	-.21	-.05	.36	.46	.44	.42	-.62*	.47	.12	-.29
PHE	.85*	.49	.37	.61*	.72*	.78*	.72*	.67*	.65*	-.18	.32	.70*	.62*
AC	.81*	.57	.41	.53	.68*	.81*	.76*	.72*	.69*	-.34	.47	.75*	.54
TAR	-.02	.15	.07	-.10	.01	.15	.20	.23	.15	-.54	.47	.41	.10
MAL	-.61*	-.85*	-.86*	-.17	-.35	-.61*	-.69*	-.71*	-.69*	.55	-.60*	-.57	-.22
TMR	.38	.81*	.72*	-.01	.20	.56	.66*	.66*	.61*	-.73*	.64*	.50	.06
KJCE	.10	-.48	-.59*	.59*	.45	.00	-.10	-.02	-.05	.55	-.35	.17	.52
TSS	.89*	.78*	.70*	.42	.56	.72*	.73*	.73*	.71*	-.40	.54	.65*	.33
TA	-.95*	-.49	-.57	-.57	-.57	-.48	-.46	-.45	-.45	-.20	.07	-.37	-.49
PH	.51	.05	-.11	.35	.32	.23	.15	.13	.13	.19	-.06	.12	.19
IR	1.00	.63*	.63*	.58	.65*	.67*	.64*	.62*	.61*	-.04	.20	.56	.51
MI	.63*	1.00	.91*	.14	.34	.70*	.79*	.77*	.75*	-.60*	.57	.44	.07
WSC	.63*	.91*	1.00	.14	.28	.57	.65*	.61*	.61*	-.45	.40	.35	.03
SFO	.58	.14	.14	1.00	.95*	.58*	.51	.57	.58*	.38	-.15	.54	.82*
SFN	.65*	.34	.28	.95*	1.00	.79*	.73*	.77*	.78*	.14	.08	.67*	.87*
SFD	.67*	.70*	.57	.58*	.79*	1.00	.98*	.94*	.95*	-.41	.55	.77*	.63*
SFJ	.64*	.79*	.65*	.51	.73*	.98*	1.00	.97*	.98*	-.48	.60*	.76*	.55
SFF	.62*	.77*	.61*	.57	.77*	.94*	.97*	1.00	.99*	-.41	.54	.75*	.60*
SFM	.61*	.75*	.61*	.58*	.78*	.95*	.98*	.99*	1.00	-.39	.51	.71*	.61*
TO	-.04	-.60*	-.45	.38	.14	-.41	-.48	-.41	-.39	1.00	-.88*	-.33	.30
TN	.20	.57	.40	-.15	.08	.55	.60*	.54	.51	-.88*	1.00	.66*	-.03
TD	.56	.44	.35	.54	.67*	.77*	.76*	.75*	.71*	-.33	.66*	1.00	.64*
TJ	.51	.07	.03	.82*	.87*	.63*	.55	.60*	.61*	.30	-.03	.64*	1.00
TF	.21	.68*	.52	-.17	.07	.57	.64*	.59*	.55	-.95*	.96*	.59*	-.07
TM	.26	.73*	.59*	-.04	.21	.67*	.73*	.68*	.66*	-.91*	.94*	.64*	.02
TAL	.14	.69*	.52	-.24	-.01	.50	.58*	.55	.50	-.95*	.93*	.50	-.17
WIO	.29	.60*	.37	-.13	.07	.52	.59*	.52	.49	-.82*	.84*	.50	-.14

STATISTICA: Basic Statistics and Tables

STAT. Correlations (ssn23pca.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=12 (Casewise deletion of missing data)

Variable	IR	MI	WSC	SFO	SFN	SFD	SFJ	SFF	SFM	TO	TN	TD	TJ
WIN	-.03	-.50	-.31	.41	.17	-.29	-.32	-.28	-.25	.77*	-.70*	-.29	.15
WID	.01	-.50	-.32	.49	.25	-.27	-.37	-.32	-.29	.96*	-.85*	-.25	.33
WIJ	-.11	-.59*	-.43	.37	.11	-.42	-.48	-.42	-.41	.96*	-.89*	-.33	.24
WIF	.02	.31	.23	-.06	.09	.29	.33	.34	.27	-.49	.34	.34	.15
WIM	-.06	-.50	-.34	.42	.17	-.37	-.40	-.32	-.31	.86*	-.90*	-.41	.19
WIA	-.04	-.55	-.43	.41	.21	-.31	-.41	-.35	-.31	.92*	-.92*	-.42	.33
WIS	-.05	-.55	-.39	.45	.20	-.35	-.41	-.34	-.33	.94*	-.90*	-.34	.28
STO	.44	-.20	-.13	.75*	.59*	.11	.01	.08	.10	.83*	-.59*	.14	.66*
STN	.71*	.33	.28	.62*	.70*	.71*	.62*	.57	.58*	.00	.38	.81*	.66*
STD	.77*	.53	.42	.58*	.70*	.77*	.73*	.72*	.70*	-.23	.58*	.90*	.58*
STJ	.80*	.36	.33	.78*	.82*	.67*	.60*	.60*	.61*	.20	.15	.74*	.77*
STF	.73*	.75*	.62*	.42	.60*	.83*	.83*	.80*	.78*	-.50	.74*	.87*	.42
STM	.81*	.71*	.62*	.59*	.75*	.87*	.86*	.84*	.83*	-.31	.56	.87*	.60*
SMO	-.77*	-.19	-.17	-.85*	-.84*	-.62*	-.52	-.50	-.50	-.24	-.00	-.62*	-.72*
SMN	-.53	.06	.04	-.88*	-.81*	-.49	-.39	-.41	-.40	-.40	.12	-.56	-.80*
SMD	-.18	-.58*	-.40	.11	-.16	-.62*	-.62*	-.58*	-.56	.82*	-.84*	-.56	-.13
SMJ	-.30	-.65*	-.44	-.07	-.30	-.67*	-.73*	-.74*	-.69*	.82*	-.87*	-.67*	-.18
SMF	-.31	-.63*	-.45	-.13	-.33	-.63*	-.69*	-.73*	-.68*	.75*	-.83*	-.68*	-.22
SMM	-.31	-.66*	-.44	-.05	-.29	-.65*	-.72*	-.73*	-.70*	.82*	-.86*	-.61*	-.17

STAT. Correlations (ssn23pca.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=12 (Casewise deletion of missing data)

Variable	TF	TM	TAL	WIO	WIN	WID	WIJ	WIF	WIM	WIA	WIS	STO	STN
IR20	-.16	-.22	-.11	-.16	-.00	-.05	.06	-.10	-.03	-.03	-.01	-.49	-.61*
CLWG	.61*	.56	.67*	.49	-.36	-.67*	-.62*	.11	-.59*	-.77*	-.66*	-.65*	-.17
NOCL	-.21	-.13	-.24	-.35	.29	.16	.13	.18	.35	.33	.26	-.00	-.30
YLD	.37	.36	.40	.19	-.08	-.42	-.38	.26	-.21	-.43	-.33	-.53	-.36
IPF	.07	.16	.07	-.20	-.03	.14	-.03	-.12	-.10	-.01	-.06	.36	.45
IPV	.15	.28	.09	-.07	-.02	.13	-.02	.21	.05	.07	.05	.44	.53
IPCY	.14	.26	.09	-.11	-.02	.14	-.02	.14	.01	.05	.02	.44	.53
BWG	-.41	-.34	-.30	-.44	.31	.33	.29	-.58*	.21	.26	.23	-.03	-.39
SHL	-.31	-.39	-.26	-.35	.10	-.06	.08	-.17	.10	.09	.04	-.42	-.76*
PRWG	-.31	-.41	-.21	-.24	.03	.02	.13	-.17	.10	.07	.07	-.40	-.76*
YPRAT	.54	.61*	.45	.46	-.08	-.32	-.39	.26	-.29	-.37	-.31	.01	.56
CDI	-.42	-.47	-.41	-.36	.28	.14	.24	-.29	.18	.24	.20	-.30	-.52
NF	-.08	-.20	-.07	-.01	-.38	-.14	-.03	.02	-.25	-.01	-.15	-.25	-.20
PF	.38	.33	.42	.48	-.59*	-.40	-.40	.17	-.42	-.32	-.42	-.11	.13
KF	.11	.01	.15	.31	-.05	-.15	-.08	.04	-.13	-.23	-.11	-.19	-.10
CAF	.71*	.65*	.70*	.63*	-.43	-.61*	-.58*	.36	-.60*	-.84*	-.62*	-.62*	.10
MGF	.61*	.65*	.67*	.39	-.60*	-.49	-.57	.28	-.54	-.57	-.58*	-.42	-.03
PHE	.35	.37	.25	.45	-.16	-.10	-.18	.29	-.14	-.12	-.11	.34	.73*
AC	.50	.52	.42	.59*	-.30	-.26	-.33	.36	-.28	-.28	-.27	.19	.70*
TAR	.58*	.51	.53	.36	-.55	-.55	-.45	.88*	-.37	-.51	-.43	-.43	-.08
MAL	-.68*	-.73*	-.65*	-.43	.49	.51	.59*	-.38	.52	.54	.56	.17	-.37
TMR	.81*	.80*	.78*	.61*	-.67*	-.66*	-.65*	.77*	-.54	-.69*	-.61*	-.42	.13
KJCE	-.44	-.43	-.44	-.23	.43	.54	.53	-.20	.50	.51	.55	.67*	.23
TSS	.55	.60*	.50	.58*	-.28	-.36	-.47	.11	-.38	-.39	-.41	.11	.65*
TA	.05	.00	.10	-.05	-.18	-.23	-.13	.09	-.18	-.18	-.19	-.59*	-.58*
PH	-.14	-.16	-.12	.25	.23	.18	.11	-.45	.13	.17	.15	.45	.39
IR	.21	.26	.14	.29	-.03	.01	-.11	.02	-.06	-.04	-.05	.44	.71*
MI	.68*	.73*	.69*	.60*	-.50	-.50	-.59*	.31	-.50	-.55	-.55	-.20	.33
WSC	.52	.59*	.52	.37	-.31	-.32	-.43	.23	-.34	-.43	-.39	-.13	.28
SFO	-.17	-.04	-.24	-.13	.41	.49	.37	-.06	.42	.41	.45	.75*	.62*
SFN	.07	.21	-.01	.07	.17	.25	.11	.09	.17	.21	.20	.59*	.70*
SFD	.57	.67*	.50	.52	-.29	-.27	-.42	.29	-.37	-.31	-.35	.11	.71*
SFJ	.64*	.73*	.58*	.59*	-.32	-.37	-.48	.33	-.40	-.41	-.41	.01	.62*
SFF	.59*	.68*	.55	.52	-.28	-.32	-.42	.34	-.32	-.35	-.34	.08	.57
SFM	.55	.66*	.50	.49	-.25	-.29	-.41	.27	-.31	-.31	-.33	.10	.58*
TO	-.95*	-.91*	-.95*	-.82*	.77*	.96*	.96*	-.49	.86*	.92*	.94*	.83*	.00
TN	.96*	.94*	.93*	.84*	-.70*	-.85*	-.89*	.34	-.90*	-.92*	-.90*	-.59*	.38
TD	.59*	.64*	.50	.50	-.29	-.25	-.33	.34	-.41	-.42	-.34	.14	.81*
TJ	-.07	.02	-.17	-.14	.15	.33	.24	.15	.19	.33	.28	.66*	.66*
TF	1.00	.98*	.98*	.85*	-.77*	-.90*	-.92*	.53	-.87*	-.93*	-.91*	-.66*	.24
TM	.98*	1.00	.95*	.79*	-.73*	-.83*	-.89*	.49	-.84*	-.87*	-.87*	-.58*	.32
TAL	.98*	.95*	1.00	.84*	-.77*	-.90*	-.92*	.47	-.86*	-.95*	-.92*	-.68*	.13
WIO	.85*	.79*	.84*	1.00	-.49	-.80*	-.77*	.30	-.67*	-.85*	-.74*	-.54	.26
WIN	-.77*	-.73*	-.77*	-.49	1.00	.76*	.78*	-.57	.87*	.68*	.84*	.59*	-.07
WID	-.90*	-.83*	-.90*	-.80*	.76*	1.00	.96*	-.45	.86*	.90*	.94*	.85*	.06
WIJ	-.92*	-.89*	-.92*	-.77*	.78*	.96*	1.00	-.35	.92*	.87*	.98*	.76*	-.09
WIF	.53	.49	.47	.30	-.57	-.45	-.35	1.00	-.29	-.40	-.32	-.37	-.08
WIM	-.87*	-.84*	-.86*	-.67*	.87*	.86*	.92*	-.29	1.00	.84*	.97*	.68*	-.23
WIA	-.93*	-.87*	-.95*	-.85*	.68*	.90*	.87*	-.40	.84*	1.00	.90*	.77*	-.06

STATISTICA: Basic Statistics and Tables

STAT. Correlations (ssn23pca.sta)
BASIC Marked correlations are significant at p < .05000
STATS N=12 (Casewise deletion of missing data)

Variable	TF	TM	TAL	WIO	WIN	WID	WIJ	WIF	WIM	WIA	WIS	STO	STN
WIS	-.91*	-.87*	-.92*	-.74*	.84*	.94*	.98*	-.32	.97*	.90*	1.00	.77*	-.10
STO	-.66*	-.58*	-.68*	-.54	.59*	.85*	.76*	-.37	.68*	.77*	.77*	1.00	.44
STN	.24	.32	.13	.26	-.07	.06	-.09	-.08	-.23	-.06	-.10	.44	1.00
STD	.48	.54	.40	.49	-.23	-.17	-.30	.03	-.38	-.31	-.30	.30	.92*
STJ	.06	.16	-.03	.06	.06	.27	.11	-.09	.00	.15	.12	.67*	.93*
STF	.71*	.76*	.64*	.63*	-.47	-.42	-.54	.23	-.57	-.52	-.53	.03	.79*
STM	.54	.62*	.45	.47	-.31	-.22	-.35	.23	-.38	-.31	-.33	.23	.87*
SMO	.04	-.03	.16	-.13	-.29	-.31	-.22	.01	-.25	-.25	-.30	-.65*	-.79*
SMN	.20	.11	.25	.10	-.42	-.50	-.38	.12	-.37	-.35	-.43	-.74*	-.63*
SMD	-.86*	-.88*	-.86*	-.60*	.85*	.75*	.85*	-.45	.89*	.73*	.87*	.49	-.30
SMJ	-.90*	-.91*	-.91*	-.78*	.67*	.76*	.82*	-.47	.74*	.79*	.79*	.43	-.28
SMF	-.86*	-.87*	-.87*	-.69*	.60*	.70*	.76*	-.45	.67*	.75*	.73*	.36	-.26

SMM	-.89*	-.89*	-.89*	-.76*	.65*	.79*	.85*	-.41	.74*	.77*	.81*	.44	-.25

STAT. BASIC STATS — Correlations (ssn23pca.sta)
Marked correlations are significant at p < .05000
N=12 (Casewise deletion of missing data)

Variable	STD	STJ	STF	STM	SMO	SMN	SMD	SMJ	SMF	SMM
IR20	-.71*	-.77*	-.67*	-.76*	.73*	.57	.17	.32	.38	.34
CLWG	.08	-.32	.19	-.02	.45	.34	-.44	-.57	-.62*	-.58*
NOCL	-.37	-.24	-.36	-.27	-.02	-.21	.07	.08	.03	.03
YLD	-.20	-.44	-.10	-.22	.36	.09	-.31	-.44	-.51	-.45
IPF	.50	.56	.45	.46	-.27	-.42	-.23	-.21	-.35	-.23
IPV	.58*	.71*	.60*	.71*	-.57	-.53	-.23	-.29	-.39	-.30
IPCY	.58*	.69*	.58*	.68*	-.51	-.52	-.24	-.29	-.40	-.30
BWG	-.49	-.39	-.51	-.53	.54	.32	.34	.45	.42	.43
SHL	-.82*	-.78*	-.75*	-.78*	.81*	.80*	.39	.49	.48	.42
PRWG	-.79*	-.84*	-.77*	-.89*	.70*	.54	.29	.43	.46	.43
YPRAT	.65*	.51	.66*	.70*	-.47	-.45	-.48	-.66*	-.68*	-.67*
CDI	-.74*	-.68*	-.79*	-.80*	.56	.44	.40	.58*	.63*	.56
NF	-.29	-.32	-.28	-.35	.40	.53	.02	.25	.36	.27
PF	.33	.16	.44	.32	-.08	.20	-.35	-.37	-.31	-.37
KF	-.04	-.25	-.13	-.27	.03	-.21	-.15	-.20	-.13	-.13
CAF	.25	-.12	.40	.22	.12	.20	-.45	-.50	-.49	-.43
MGF	.15	-.02	.44	.34	.27	.40	-.55	-.49	-.48	-.48
PHE	.79*	.74*	.75*	.80*	-.85*	-.65*	-.35	-.46	-.42	-.43
AC	.82*	.69*	.82*	.83*	-.77*	-.55	-.47	-.60*	-.55	-.56
TAR	.11	-.12	.26	.18	.04	.09	-.48	-.57	-.59*	-.53
MAL	-.56	-.41	-.75*	-.72*	.17	-.01	.60*	.67*	.72*	.69*
TMR	.36	.13	.63*	.57	-.05	.17	-.64*	-.74*	-.74*	-.72*
KJCE	.21	.35	-.06	.00	-.52	-.74*	.29	.13	.10	.17
TSS	.83*	.67*	.89*	.87*	-.60*	-.31	-.44	-.60*	-.61*	-.63*
TA	-.59*	-.74*	-.52	-.64*	.72*	.52	-.07	.05	.08	.07
PH	.43	.42	.25	.23	-.56	-.52	.09	-.05	.01	-.05
IR	.77*	.80*	.73*	.81*	-.77*	-.53	-.18	-.30	-.31	-.31
MI	.53	.36	.75*	.71*	-.19	.06	-.58*	-.65*	-.63*	-.66*
WSC	.42	.33	.62*	.62*	-.17	.04	-.40	-.44	-.45	-.44
SFO	.58*	.78*	.42	.59*	-.85*	-.88*	.11	-.07	-.13	-.05
SFN	.70*	.82*	.60*	.75*	-.84*	-.81*	-.16	-.30	-.33	-.29
SFD	.77*	.67*	.83*	.87*	-.62*	-.49	-.62*	-.67*	-.63*	-.65*
SFJ	.73*	.60*	.83*	.86*	-.52	-.39	-.62*	-.73*	-.69*	-.72*
SFF	.72*	.60*	.80*	.84*	-.50	-.41	-.58*	-.74*	-.73*	-.73*
SFM	.70*	.61*	.78*	.83*	-.50	-.40	-.56	-.69*	-.68*	-.70*
TO	-.23	.20	-.50	-.31	-.24	-.40	.82*	.82*	.75*	.82*
TN	.58*	.15	.74*	.56	-.00	.12	-.84*	-.87*	-.83*	-.86*
TD	.90*	.74*	.87*	.87*	-.62*	-.56	-.56	-.67*	-.68*	-.61*
TJ	.58*	.77*	.42	.60*	-.72*	-.80*	-.13	-.18	-.22	-.17
TF	.48	.06	.71*	.54	.04	.20	-.86*	-.90*	-.86*	-.89*
TM	.54	.16	.76*	.62*	-.03	.11	-.88*	-.91*	-.87*	-.89*
TAL	.40	-.03	.64*	.45	.16	.25	-.86*	-.91*	-.87*	-.89*
WIO	.49	.06	.63*	.47	-.13	.10	-.60*	-.78*	-.69*	-.76*
WIN	-.23	.06	-.47	-.31	-.29	-.42	.85*	.67*	.60*	.65*
WID	-.17	.27	-.42	-.22	-.31	-.50	.75*	.76*	.70*	.79*
WIJ	-.30	.11	-.54	-.35	-.22	-.38	.85*	.82*	.76*	.85*
WIF	.03	-.09	.23	.23	.01	.12	-.45	-.47	-.45	-.41
WIM	-.38	.00	-.57	-.38	-.25	-.37	.89*	.74*	.67*	.74*
WIA	-.31	.15	-.52	-.31	-.25	-.35	.73*	.79*	.75*	.77*
WIS	-.30	.12	-.53	-.33	-.30	-.43	.87*	.79*	.73*	.81*
STO	.30	.67*	.03	.23	-.65*	-.74*	.49	.43	.36	.44
STN	.92*	.93*	.79*	.87*	-.79*	-.63*	-.30	-.28	-.26	-.25
STD	1.00	.88*	.94*	.94*	-.73*	-.58*	-.47	-.57	-.57	-.54
STJ	.88*	1.00	.74*	.86*	-.84*	-.73*	-.15	-.19	-.22	-.17
STF	.94*	.74*	1.00	.96*	-.56	-.35	-.66*	-.73*	-.72*	-.71*

STATISTICA: Basic Statistics and Tables

STAT. BASIC STATS — Correlations (ssn23pca.sta)
Marked correlations are significant at p < .05000
N=12 (Casewise deletion of missing data)

Variable	STD	STJ	STF	STM	SMO	SMN	SMD	SMJ	SMF	SMM
STM	.94*	.86*	.96*	1.00	-.70*	-.47	-.52	-.59*	-.58*	-.56
SMO	-.73*	-.84*	-.56	-.70*	1.00	.83*	-.06	.09	.09	.06
SMN	-.58*	-.73*	-.35	-.47	.83*	1.00	-.06	.07	.12	.02
SMD	-.47	-.15	-.66*	-.52	-.06	-.06	1.00	.89*	.83*	.87*
SMJ	-.57	-.19	-.73*	-.59*	.09	.07	.89*	1.00	.98*	.99*
SMF	-.57	-.22	-.72*	-.58*	.09	.12	.83*	.98*	1.00	.97*
SMM	-.54	-.17	-.71*	-.56	.06	.02	.87*	.99*	.97*	1.00

Variables:

Var 15: IR20 - Number of days from 1 Oct to IR=20
Var 19: CLWG - Cluster weight at harvest in g
Var 20: NOCL - Number of clusters per sq. m
Var 22: YLD - Yield of grapes kg per sq. m
Var 23: IPF - Index of Precocity for flowering
Var 24: IPV - Index of Precocity for véraison
Var 25: IPCY - Index of Precocity for the cycle
Var 26: BWG - Berry weight (g) at harvest
Var 27: SHL - Shoot length 12-14 January
Var 28: PRWG - Pruning weight in kg per sq. m
Var 29: YPRAT - Yield:Pruning ratio
Var 30: CDI - Canopy density index (inverse canopy density score)
Var 31: NF - Nitrogen (%) in leaf petioles at flowering
Var 33: PF - Phosphorus (%) in leaf petioles at flowering
Var 35: KF - Potassium (%) in leaf petioles at flowering
Var 37: CAF - Calcium (%) in leaf petioles at flowering
Var 39: MGF - Magnesium (%) in leaf petioles at flowering
Var 41: PHE - Total phenolics in g/kg fw at 22 to 25 March
Var 42: AC - Total anthocyanins in g/kg fw at 22 - 25 Mar
Var 43: TAR - Tartaric acid in g/L on 22-25 March
Var 44: MAL - Malic acid in g/L on 22-25 March
Var 45: TMR - TAR/MAL ratio

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Var 46: KJCE - Potassium in the must in g/L on 22-25 March
Var 47: TSS - TSS 22-24 Mar
Var 48: TA - TA on 22-25 Mar
Var 49: PH - pH on 22-25 March
Var 50: IR - IR as on 24-25 March
Var 52: MI - =(TSS/MAL)*PH ; al measured on 23-25 March ; MI = Maturity Index
Var 53: WSC - Wine Score
Var 54: SFO - Soil Factor for October
Var 55: SFN - Soil Factor for November
Var 56: SFD - Soil Factor for December
Var 57: SFJ - Soil Factor for January
Var 58: SFF - Soil Factor for February
Var 59: SFM - Soil Factor for March
Var 60: TO - Mean t October
Var 61: TN - Mean t November
Var 62: TD - Mean t December
Var 63: TJ - Mean t January
Var 64: TF - Mean t February
Var 65: TM - Mean t March
Var 66: TAL - Mean t April
Var 73: WIO - Rain+Irrig. October
Var 74: WIN - Rain+Irrig. November
Var 75: WID - Rain+Irrig. December
Var 76: WIJ - Rain+Irrig. January
Var 77: WIF - Rain+Irrig. February
Var 78: WIM - Rain+Irrig. March
Var 79: WIA - Rain+Irrig. April
Var 80: WIS - Rain+Irrig. October-April
Var 81: STO - Soil temperature at 30 cm for October
Var 82: STN - Soil temperature at 30 cm for November
Var 83: STD - Soil temperature at 30 cm for December
Var 84: STJ - Soil temperature at 30 cm for January
Var 85: STF - Soil temperature at 30 cm for February
Var 86: STM - Soil temperature at 30 cm for March
Var 87: SMO - Soil moisture content in the 0-30 cm profile relative to estimated FWC for October
Var 88: SMN - Soil moisture content in the 0-30 cm profile relative to estimated FWC for November
Var 89: SMD - Soil moisture content in the 0-30 cm profile relative to estimated FWC for December
Var 90: SMJ - Soil moisture content in the 0-30 cm profile relative to estimated FWC for January
Var 91: SMF - Soil moisture content in the 0-30 cm profile relative to estimated FWC for February
Var 92: SMM - Soil moisture content in the 0-30 cm profile relative to estimated FWC for March
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Appendix 11: Characteristics of soils in the geographical sub-regions of Hawke's Bay

Fernhill/Ohiti/Ngatarawa

Soils within this sub-region are quite variable. **Fernhill** has a deep *Flaxmere* silt loam on gravel, with imperfect drainage and watertable at 30-60 cm (after wet periods). **Gimblett Road** area south-west of **Fernhill**, and part of the viticultural area around **State Highway 50** have only 10-15 cm or 15-30 cm very light soil and/or sand mixed with or overlying stony gravels. These soils have good natural drainage, and a water table at 120 cm or deeper (*Omahu* type). **Ohiti** is located on the left bank of the Ngaruroro River and has soils similar to those described above. It also has some areas of *Flaxmere* silt loam on gravel or sand, and a strip of *Tukituki* stony gravels on the bank of the Ngaruroro that is imperfectly drained, with watertable at 0-60 cm. **Ngatarawa** represents an area of highly sought after viticultural land north-west of Hastings. It is a relatively small area that has several soil types. They include: *Pakowhai* consisting of 30-45 cm deep sandy loam or silt loam on old topsoil, imperfectly drained with a watertable at 30-60 cm; *Te Awa* with more than 60 cm deep clay loam on *Taupo* pumice sand, imperfectly drained, with a watertable at 30-60 cm after wet periods; *Ngatarawa* with 45 cm of deep sandy loam on gravel, good drainage and a very deep watertable at 10 m; and, *Poporangi* with 30-45 cm of ashy sandy loam on sandy loam (loess) on pan at 60 cm, over gravel. The latter is poorly drained so that water is often perched on the pan.

Dartmoor/Puketapu

The left bank of the **Tutaekuri River** consists mainly of *Twyford* sandy loam (or silt loam), while a narrow strip of land on the right bank of this river is mostly of the *Esk* sand type. Further north from the Tutaekuri, the soils become *Matapiro* type with over 30 cm ash on sandy loam (loess) overlying a

pan at 40-50 cm on rolling land. These soils are poorly drained with water perched on the pan. Also present in this sub-region is some *Hastings* silt loam with over 30 cm of clay loam on silt loam; it is imperfectly drained, with a watertable at 30-60 cm. On flat terraces towards **Dartmoor** and also north of **Rosemount**, there is some *Waipukurau* sandy loam with over 30 cm ash on sandy loam (loess) on pan at 40-50 cm; this is also poorly drained with water perched on the pan. Vineyards are planted on a patch of stony gravels above **Rosemount** that are imperfectly drained, with a watertable at 60 cm.

Taradale/Meeanee/Brookfields

The urban area of **Taradale** is surrounded from south and south-east by a *Farndon* soil type with mre than 30 cm silt loam on sandy loam (slightly saline) and with a watertable at 30-60 cm resulting in an imperfectly drained soil. On valley floors to the east, there are patches of very poorly drained *Okawa* soil that is 30-45 cm deep silt loam on clay loam from loess alluvium. **North of Taradale** there is some *Hastings* silt loam and a patch of *Omarunui* sandy loam

Mangatahi/Maraekakaho

Flat river terraces are covered with *Ngatarawa* soil type with over 45 cm deep sandy loam on gravel with a good drainage and a watertable at 10 m. Flats on the banks of **Ngaruroro River** also have some *Hastings* sandy loam. Also present in the sub-region are *Mangatahi* sandy loam and *Poporangi* ashy sandy loam.

Eskdale/Bayview

Esk River area is uniformly covered with *Esk* sands. These soils have more than 45 cm of sand of good drainage, and a watertable deeper than 60 cm. **South of Eskdale** the predominant soil is the *Pakowhai* type having 30-60 cm sand on sandy loam or silt loam; imperfectly drained with a watertable at 30-60 cm after wet periods. **Bayview** viticultural areas are on *Flaxmere* type sands/sandy loams on gravel which are quite deep (over 100 cm). **Bayview** soils are imperfectly drained with a watertable at 30-60 cm.

Haumoana/Te Awanga

Waipukurau soil type with over 30 cm deep ash on sandy loam (loess) with a pan at 40-50 cm covers most of the sub-region, although there is a 200 m wide strip of stony beach gravels along the coast. **South-east of Te Awanga** *Omahu* stony gravels are the most prominent soil type. *Waipukurau* sandy loam is poorly drained and can be waterlogged after excessively rainy winters.

Te Mata/Havelock North

Most of the area **south-east of Havelock North** has a rolling topography and the predominant soil type is *Matapiro* sandy loam. It has over 30 cm of ash on sandy loam (loess) overlying a pan at 40-50 cm. It is poorly drained and water perches on the pan. *Otane* silt loam (poor drainage) and *Havelock* sandy and clay loams (good drainage) are the predominant soils **northeast of Havelock North**. Of importance for viticulture are two to three strips of *Ngatarawa* sandy loam further north-east. Other soil types present in this area, on the left bank of the **Tukituki River** include *Mangateretere* silt loam on clay (imperfectly drained), *Omarunui* sandy loam (good drainage) and some *Esk* sand along the **Tukituki**. **South-west of Havelock North** there is a considerable area of *Poporangi* ashy sandy loam (imperfectly drained), and also *Te Awa* clay loam (poorly drained).

Source: Griffiths, E. (1997): The soil map of the Heretaunga Plains, Hawke's Bay (DSIR,1938) with additional soil surveys by E. Griffiths, G. Smith, B. Purdie and B. McLaughlin of New Zealand Soil Bureau, DSIR, 1971 to 1991, and by E. Griffiths, 1991 to 1997

Appendix 12: Correlations of selected variables in 1997/98 and 1998/99

Coefficients of correlation for selected variables in 1997/98 and 1998/99

STAT.
BASIC
STATS

Correlations (csphenl.sta)
Marked correlations are significant at p < .05000
N=12 (Casewise deletion of missing data)

Variable	NUMDAYS	DURF	GDDOCT	GDDNOV	GDDDEC	GDHNOV	GDHDEC	SR_OCT	SR_NOV	T_S15O CT	T_S15N OV	T_S30O CT	T_S30N OV	SMT30O CT	SMT30N OV	SMT60O CT	SMT60N OV	BSET	BWGT5J AN	BWCV5J AN	SHLENF
NUMDAYS	1.00	-.68*	-.81*	.65*	.07	.68*	.31	.11	.61*	-.84*	-.15	-.75*	-.19	.63*	.40	.38	.23	.24	-.17	.30	.33
DURF	-.68*	1.00	.95*	-.97*	-.50	-.97*	-.70*	-.30	-.83*	.77*	-.27	.72*	-.21	-.50	-.12	-.33	-.17	-.59*	-.07	-.38	-.14
GDDOCT	-.81*	.95*	1.00	-.88*	-.33	-.89*	-.55	-.25	-.81*	.87*	-.04	.79*	-.01	-.65*	-.29	-.45	-.29	-.61*	.14	-.48	-.26
GDDNOV	.65*	-.97*	-.88*	1.00	.66*	1.00*	.84*	.33	.83*	-.65*	.42	-.58*	.38	.36	-.03	.20	.07	.57	.10	.41	-.04
GDDDEC	.07	-.50	-.33	.66*	1.00	.64*	.95*	.56	.65*	.10	.81*	.16	.81*	-.36	-.64*	-.44	-.46	.31	-.07	.50	-.47
GDHNOV	.68*	-.97*	-.89*	1.00*	.64*	1.00	.83*	.32	.84*	-.67*	.41	-.60*	.36	.37	-.01	.20	.07	.56	.10	.39	-.02
GDHDEC	.31	-.70*	-.55	.84*	.95*	.83*	1.00	.46	.74*	-.18	.72*	-.11	.70*	-.11	-.47	-.25	-.33	.43	-.00	.49	-.37
SR_OCT	.11	-.30	-.25	.33	.56	.32	.46	1.00	.75*	.07	.27	.17	.34	-.35	-.63*	-.49	-.53	.10	-.17	.46	-.20
SR_NOV	.61*	-.83*	-.81*	.83*	.65*	.84*	.74*	.75*	1.00	-.53	.27	-.41	.27	.19	-.24	-.06	-.20	.46	-.12	.58*	-.02
T_S15OCT	-.84*	.77*	.87*	-.65*	.10	-.67*	-.18	.07	-.53	1.00	.33	.97*	.40	-.86*	-.62*	-.66*	-.48	-.50	-.08	-.14	-.44
T_S15NOV	-.15	-.27	-.04	.42	.81*	.41	.72*	.27	.27	.33	1.00	.32	.96*	-.55	-.60*	-.47	-.41	-.06	.02	.14	-.45
T_S30OCT	-.75*	.72*	.79*	-.58*	.16	-.60*	-.11	.17	-.41	.97*	.32	1.00	.44	-.87*	-.69*	-.70*	-.51	-.46	-.18	-.00	-.50
T_S30NOV	-.19	-.21	-.01	.38	.81*	.36	.70*	.34	.27	.40	.96*	.44	1.00	-.62*	-.68*	-.54	-.42	-.07	-.07	.21	-.57
SMT30OCT	.63*	-.50	-.65*	.36	-.36	.37	-.11	-.35	.19	-.86*	-.55	-.87*	-.62*	1.00	.85*	.92*	.75*	.53	.03	.16	.68*
SMT30NOV	.40	-.12	-.29	-.03	-.64*	-.01	-.47	-.63*	-.24	-.62*	-.60*	-.69*	-.68*	.85*	1.00	.91*	.87*	.28	.06	-.18	.71*
SMT60OCT	.38	-.33	-.45	.20	-.44	.20	-.25	-.49	-.06	-.66*	-.47	-.70*	-.54	.92*	.91*	1.00	.93*	.54	.09	.03	.66*
SMT60NOV	.23	-.17	-.29	.07	-.46	.07	-.33	-.53	-.20	-.48	-.41	-.51	-.42	.75*	.87*	.93*	1.00	.49	.12	-.09	.51
BSET	.24	-.59*	-.61*	.57	.31	.56	.43	.10	.46	-.50	-.06	-.46	-.07	.53	.28	.54	.49	1.00	.11	.36	.08
BWGT5JAN	-.17	-.07	.14	.10	-.07	.10	-.00	-.17	-.12	-.08	.02	-.18	-.07	.03	.06	.09	.12	.11	1.00	-.70*	-.16
BWCV5JAN	.30	-.38	-.48	.41	.50	.39	.49	.46	.58*	-.14	.14	-.00	.21	.16	-.18	.03	-.09	.36	-.70*	1.00	.17
SHLENF	.33	-.14	-.26	-.04	-.47	-.02	-.37	-.20	-.02	-.44	-.45	-.50	-.57	.68*	.71*	.66*	.51	.08	-.16	.17	1.00

LEGEND NUMDAYS - Number of days from 1 Oct to mid-flowering, DURF – Duration of flowering (5-95%) in days; GDDOCT, GDDNOV, GDDDEC - Growing Degree Days for October, November and December, respectively; GDHNOV, GDHDEC - Growing Degree Hours for November and December, respectively; SR_OCT, SR_NOV – Solar Radiation for October and November, respectively (mol/m²), T_S15OCT, T_S15NOV – Soil temperature at 15 cm for October and November, respectively; T_S30OCT, T_S30NOV – Soil temperature at 30 cm for October and Novamber, respectively; SMT30OCT, SMT30NOV = Soil Moisture Content 0-30 cm for October and November, respectively; SMT60OCT, SMT60NOV – Soil Moisture Content 0-60 cm for October and November, respectively; BSET– Berry Set Percentage, BWGTSJAN – Berry Weight on 5 January; BWCV5JAN – Coefficient of Variation of Berry Weight on 5 January; SHLENF – Shoot Length at Flowering

Appendix 13: Berry composition in 1997/98 and 1998/99

TSS, TA, malic and tartaric acid, potassium, total polyphenols and anthocyanins during the development and ripening in 1997/98 season on a per berry basis

TSS mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
20/01/98	10.9	20/01/98	13.3	20/01/98	9.8	21/01/98	14.0	21/01/98	17.7	21/01/98	10.9
27/01/98	11.7	27/01/98	15.8	27/01/98	11.6	28/01/98	15.6	28/01/98	24.7	28/01/98	14.6
3/02/98	12.6	3/02/98	28.2	3/02/98	12.6	4/02/98	19.5	4/02/98	49.0	4/02/98	15.6
10/02/98	28.4	10/02/98	64.1	10/02/98	19.0	11/02/98	29.7	11/02/98	62.4	11/02/98	29.1
17/02/98	47.0	17/02/98	82.7	17/02/98	38.6	18/02/98	51.7	18/02/98	100.3	18/02/98	82.8
24/02/98	68.5	24/02/98	121.9	24/02/98	59.0	25/02/98	84.7	25/02/98	106.6	25/02/98	130.3
3/03/98	81.2	3/03/98	133.5	3/03/98	81.4	4/03/98	127.4	4/03/98	146.8	4/03/98	154.7
10/03/98	114.1	10/03/98	148.0	10/03/98	115.8	11/03/98	175.8	11/03/98	185.5	11/03/98	197.6
17/03/98	145.3	17/03/98	165.6	17/03/98	143.1	18/03/98	192.8	18/03/98	213.8	18/03/98	205.4
24/03/98	134.6	24/03/98	154.6	24/03/98	172.4	25/03/98	191.8	25/03/98	229.7	25/03/98	218.6
31/03/98	147.3			30/03/98	182.3	30/03/98	216.3	30/03/98	224.4	30/03/98	209.1
7/04/98	148.8			8/04/98	183.2	6/04/98	208.5	7/04/98	209.7	6/04/98	206.6
				14/04/98	188.8	15/04/98	231.6			14/04/98	232.0
				20/04/98	185.3						

TA mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
20/01/98		20/01/98		20/01/98		21/01/98		21/01/98		21/01/98	
27/01/98	10.4	27/01/98	12.3	27/01/98	11.8	28/01/98	14.9	28/01/98	19.4	28/01/98	13.3
3/02/98	10.5	3/02/98	10.8	3/02/98	11.6	4/02/98	13.9	4/02/98	19.1	4/02/98	11.5
10/02/98	13.6	10/02/98	9.3	10/02/98	12.4	11/02/98	14.6	11/02/98	18.3	11/02/98	13.9
17/02/98	11.9	17/02/98	7.6	17/02/98	15.3	18/02/98	14.3	18/02/98	16.3	18/02/98	13.0
24/02/98	8.6	24/02/98	6.2	24/02/98	12.5	25/02/98	13.2	25/02/98	13.9	25/02/98	12.9
3/03/98	8.1	3/03/98	6.0	3/03/98	13.1	4/03/98	10.7	4/03/98	13.1	4/03/98	9.6
10/03/98	7.5	10/03/98	4.6	10/03/98	10.2	11/03/98	9.9	11/03/98	11.9	11/03/98	9.1
17/03/98	7.3	17/03/98	4.8	17/03/98	9.9	18/03/98	9.1	18/03/98	10.2	18/03/98	8.0

24/03/98	6.3	24/03/98	3.9	24/03/98	8.6	25/03/98	7.3	25/03/98	9.3	25/03/98	7.5
31/03/98	5.6			30/03/98	7.1	30/03/98	7.1	30/03/98	8.9	30/03/98	6.3
7/04/98	5.3			8/04/98	6.0	6/04/98	7.0	7/04/98	7.6	6/04/98	5.3
				14/04/98	6.2	15/04/98	6.0			14/04/98	6.4
				20/04/98	5.8						

tartaric acid mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
20/01/98	3.3	20/01/98	3.1	20/01/98	2.7	21/01/98	4.7	21/01/98	5.1	21/01/98	3.0
27/01/98	2.7	27/01/98	2.4	27/01/98	3.7	28/01/98	6.1	28/01/98	4.5	28/01/98	4.0
3/02/98	2.7	3/02/98	2.6	3/02/98	3.3	4/02/98	6.0	4/02/98	5.6	4/02/98	2.6
10/02/98	3.6	10/02/98	2.9	10/02/98	3.3	11/02/98	5.1	11/02/98	4.9	11/02/98	3.5
17/02/98	4.1	17/02/98	2.9	17/02/98	3.1	18/02/98	5.6	18/02/98	4.3	18/02/98	4.0
24/02/98	2.1	24/02/98	3.8	24/02/98	3.2	25/02/98	2.9	25/02/98	3.9	25/02/98	3.3
3/03/98	3.5	3/03/98	2.6	3/03/98	2.6	4/03/98	4.9	4/03/98	5.3	4/03/98	4.7
10/03/98	3.8	10/03/98	2.3	10/03/98	4.6	11/03/98	3.2	11/03/98	4.4	11/03/98	3.2
17/03/98	5.2	17/03/98	2.0	17/03/98	4.0	18/03/98	5.1	18/03/98	4.7	18/03/98	3.6
24/03/98	5.0	24/03/98	2.4	24/03/98	3.5	25/03/98	3.6	25/03/98	3.2	25/03/98	3.3
31/03/98	4.0			30/03/98	3.2	30/03/98	4.1	30/03/98	5.0	30/03/98	5.1
7/04/98	2.6			8/04/98	1.5	6/04/98	2.5	7/04/98	5.1	6/04/98	2.4
				14/04/98	1.8	15/04/98	3.5			14/04/98	3.8
				20/04/98	1.1						

malic acid mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
20/01/98	5.5	20/01/98	4.2	20/01/98	3.6	21/01/98	8.1	21/01/98	5.2	21/01/98	4.6
27/01/98	4.7	27/01/98	5.6	27/01/98	9.4	28/01/98	11.0	28/01/98	13.3	28/01/98	8.9
3/02/98	7.5	3/02/98	6.1	3/02/98	7.8	4/02/98	7.0	4/02/98	10.3	4/02/98	6.1
10/02/98	5.5	10/02/98	2.9	10/02/98	5.5	11/02/98	6.8	11/02/98	10.1	11/02/98	7.7
17/02/98	2.6	17/02/98	3.6	17/02/98	10.5	18/02/98	8.1	18/02/98	10.9	18/02/98	4.4
24/02/98	4.8	24/02/98	3.3	24/02/98	10.1	25/02/98	9.3	25/02/98	8.5	25/02/98	4.2
3/03/98	3.7	3/03/98	2.4	3/03/98	10.9	4/03/98	4.1	4/03/98	6.3	4/03/98	3.8
10/03/98	3.5	10/03/98	2.5	10/03/98	6.2	11/03/98	6.0	11/03/98	5.3	11/03/98	2.2
17/03/98	2.0	17/03/98	1.3	17/03/98	4.7	18/03/98	2.7	18/03/98	6.2	18/03/98	1.9
24/03/98	2.0	24/03/98	1.2	24/03/98	5.4	25/03/98	2.9	25/03/98	2.4	25/03/98	1.4
31/03/98	2.1			30/03/98	6.1	30/03/98	3.0	30/03/98	3.0	30/03/98	2.0
7/04/98	1.5			8/04/98	3.8	6/04/98	3.3	7/04/98	3.4	6/04/98	2.1
				14/04/98	3.3	15/04/98	2.1			14/04/98	2.4
				20/04/98	4.9						

K mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
20/01/98	0.3	20/01/98	0.3	20/01/98	0.4	21/01/98	0.3	21/01/98	0.3	21/01/98	0.3
27/01/98	0.1	27/01/98	0.2	27/01/98	0.5	28/01/98	0.5	28/01/98	0.5	28/01/98	0.3
3/02/98	0.3	3/02/98	0.3	3/02/98	0.5	4/02/98	0.4	4/02/98	0.7	4/02/98	0.3
10/02/98	0.5	10/02/98	0.3	10/02/98	0.5	11/02/98	0.5	11/02/98	0.7	11/02/98	0.5
17/02/98	0.3	17/02/98	0.7	17/02/98	1.0	18/02/98	0.4	18/02/98	1.2	18/02/98	0.5
24/02/98	0.8	24/02/98	1.0	24/02/98	1.1	25/02/98	1.0	25/02/98	1.1	25/02/98	0.8
3/03/98	0.9	3/03/98	1.1	3/03/98	1.4	4/03/98	0.9	4/03/98	1.2	4/03/98	1.2
10/03/98	0.9	10/03/98	1.4	10/03/98	1.6	11/03/98	1.8	11/03/98	1.6	11/03/98	1.3
17/03/98	0.9	17/03/98	1.1	17/03/98	1.6	18/03/98	1.1	18/03/98	1.7	18/03/98	1.0
24/03/98	1.0	24/03/98	1.1	24/03/98	1.9	25/03/98	1.2	25/03/98	1.3	25/03/98	1.0
31/03/98	1.2			30/03/98	2.1	30/03/98	1.6	30/03/98	1.7	30/03/98	1.6
7/04/98	1.2			8/04/98	1.8	6/04/98	1.8	7/04/98	1.5	6/04/98	1.6
				14/04/98	1.9	15/04/98	1.8			14/04/98	1.8
				20/04/98	2.3						

total anthocyanins mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
17/02/98	0.1	17/02/98	0.5	17/02/98	0.0	18/02/98	0.1	18/02/98	0.4	18/02/98	0.4
24/02/98	0.2	24/02/98	0.9	24/02/98	0.2	25/02/98	0.2	25/02/98	0.3	25/02/98	0.6
3/03/98	0.4	3/03/98	1.0	3/03/98	0.3	4/03/98	0.5	4/03/98	0.6	4/03/98	0.8
10/03/98	0.7	10/03/98	1.3	10/03/98	0.6	11/03/98	0.8	11/03/98	0.7	11/03/98	1.2
17/03/98	0.9	17/03/98	1.4	17/03/98	1.1	18/03/98	1.1	18/03/98	0.8	18/03/98	1.1
24/03/98	1.0	24/03/98	1.6	24/03/98	1.1	25/03/98	1.1	25/03/98	1.1	25/03/98	1.3
31/03/98	0.9			30/03/98	0.9	30/03/98	1.0	30/03/98	1.1	30/03/98	1.2
7/04/98	1.2			8/04/98	1.2	6/04/98	1.0	7/04/98	1.5	6/04/98	1.3
				14/04/98	1.3	15/04/98	1.5			14/04/98	1.7
				20/04/98	1.1						

total phenolics mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
17/02/98	1.1	17/02/98	2.5	17/02/98	1.0	18/02/98	1.2	18/02/98	2.3	18/02/98	1.9
24/02/98	0.9	24/02/98	3.0	24/02/98	1.1	25/02/98	1.1	25/02/98	1.4	25/02/98	2.4
3/03/98	1.5	3/03/98	3.3	3/03/98	1.3	4/03/98	1.9	4/03/98	2.2	4/03/98	2.7
10/03/98	2.3	10/03/98	4.4	10/03/98	2.3	11/03/98	2.7	11/03/98	2.6	11/03/98	3.8
17/03/98	3.0	17/03/98	4.4	17/03/98	3.7	18/03/98	3.8	18/03/98	2.7	18/03/98	3.4
24/03/98	3.1	24/03/98	5.2	24/03/98	3.6	25/03/98	3.4	25/03/98	3.4	25/03/98	4.0
31/03/98	3.1			30/03/98	3.1	30/03/98	3.5	30/03/98	3.8	30/03/98	4.9
7/04/98	3.8			8/04/98	3.9	6/04/98	3.1	7/04/98	5.4	6/04/98	4.1
				14/04/98	4.1	15/04/98	5.1			14/04/98	5.7
				20/04/98	4.0						

TSS, TA, malic and tartaric acid, potassium, total polyphenols and anthocyanins during the development and ripening in 1998/99 season on a per berry basis

TSS mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
21/01/99	12.5	21/01/99	14.2	21/01/99	14.2	21/01/99	16.6	21/01/99	20.7	21/01/99	13.9
26/01/99	15.6	26/01/99	23.7	26/01/99	15.2	26/01/99	17.7	26/01/99	25.1	26/01/99	19.5
2/02/99	27.0	2/02/99	51.8	2/02/99	19.2	2/02/99	40.2	2/02/99	45.6	2/02/99	33.3
9/02/99	59.0	9/02/99	85.8	9/02/99	25.7	9/02/99	69.1	9/02/99	72.2	9/02/99	46.7
15/02/99	77.4	15/02/99	93.7	15/02/99	41.9	15/02/99	89.7	15/02/99	108.4	15/02/99	79.3
23/02/99	109.8	23/02/99	122.6	23/02/99	74.0	23/02/99	133.5	24/02/99	146.4	24/02/99	122.7
2/03/99	122.7	2/03/99	143.7	2/03/99	96.6	2/03/99	138.8	2/03/99	177.5	2/03/99	142.6
8/03/99	128.4	8/03/99	159.3	8/03/99	121.5	8/03/99	156.9	8/03/99	167.1	8/03/99	150.2
16/03/99	163.9	16/03/99	161.4	16/03/99	162.4	16/03/99	178.9	16/03/99	187.4	16/03/99	170.3
23/03/99	147.0	22/03/99	169.1	23/03/99	159.7	23/03/99	179.3	23/03/99	207.1	23/03/99	192.9
30/03/99	179.2			30/03/99	163.2	30/03/99	180.9	30/03/99	221.0	30/03/99	205.7
6/04/99	170.3			8/04/99	184.8						
				12/04/99	195.7						

TA mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
21/01/99	9.6	21/01/99	9.5	21/01/99	11.0	21/01/99	11.6	21/01/99	15.4	21/01/99	11.0
26/01/99	11.3	26/01/99	12.2	26/01/99	11.6	26/01/99	12.0	26/01/99	18.1	26/01/99	14.3
2/02/99	16.8	2/02/99	14.5	2/02/99	14.4	2/02/99	16.4	2/02/99	20.5	2/02/99	17.7
9/02/99	18.1	9/02/99	21.1	9/02/99	16.8	9/02/99	13.6	9/02/99	18.3	9/02/99	17.5
15/02/99	15.0	15/02/99	11.4	15/02/99	16.2	15/02/99	12.3	15/02/99	16.3	15/02/99	16.3
23/02/99	10.5	23/02/99	7.2	23/02/99	14.8	23/02/99	10.2	24/02/99	13.6	24/02/99	15.1
2/03/99	8.5	2/03/99	6.2	2/03/99	13.8	2/03/99	7.4	2/03/99	12.4	2/03/99	12.7
8/03/99	7.0	8/03/99	5.7	8/03/99	11.0	8/03/99	8.1	8/03/99	10.7	8/03/99	10.9
16/03/99	6.6	16/03/99	5.0	16/03/99	9.9	16/03/99	7.0	16/03/99	9.6	16/03/99	8.4
23/03/99	5.3	22/03/99	5.1	23/03/99	8.2	23/03/99	6.0	23/03/99	8.9	23/03/99	9.8
30/03/99	5.8			30/03/99	8.2	30/03/99	6.0	30/03/99	8.4	30/03/99	8.7

6/04/99	5.2			8/04/99	7.6						
				12/04/99	8.3						

tartaric acid mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
21/01/99	4.1	21/01/99	4.0	21/01/99	7.7	21/01/99	4.7	21/01/99	6.0	21/01/99	4.4
26/01/99	4.8	26/01/99	3.8	26/01/99	5.3	26/01/99	5.3	26/01/99	5.6	26/01/99	4.6
2/02/99	5.3	2/02/99	3.8	2/02/99	5.6	2/02/99	7.5	2/02/99	6.4	2/02/99	5.7
9/02/99	4.9	9/02/99	3.4	9/02/99	5.6	9/02/99	3.9	9/02/99	4.1	9/02/99	4.4
15/02/99	3.3	15/02/99	4.2	15/02/99	4.4	15/02/99	4.3	15/02/99	4.2	15/02/99	4.5
23/02/99	4.7	23/02/99	3.8	23/02/99	3.3	23/02/99	4.1	24/02/99	4.2	24/02/99	4.7
2/03/99	2.8	2/03/99	2.1	2/03/99	3.4	2/03/99	3.1	2/03/99	4.5	2/03/99	4.2
8/03/99	2.7	8/03/99	2.7	8/03/99	2.5	8/03/99	1.9	8/03/99	4.2	8/03/99	3.5
16/03/99	3.5	16/03/99	2.6	16/03/99	2.9	16/03/99	3.6	16/03/99	3.7	16/03/99	2.4
23/03/99	2.1	22/03/99	3.0	23/03/99	1.8	23/03/99	2.5	23/03/99	2.5	23/03/99	3.2
30/03/99	2.7			30/03/99	2.6	30/03/99	3.3	30/03/99	3.9	30/03/99	3.3
6/04/99	3.1			8/04/99	3.0						
				12/04/99	2.8						

malic acid mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
21/01/99	5.7	21/01/99	4.6	21/01/99	2.2	21/01/99	4.1	21/01/99	6.2	21/01/99	3.5
26/01/99	6.2	26/01/99	4.4	26/01/99	6.9	26/01/99	8.2	26/01/99	12.9	26/01/99	10.7
2/02/99	10.7	2/02/99	7.3	2/02/99	13.7	2/02/99	10.0	2/02/99	12.4	2/02/99	14.4
9/02/99	13.7	9/02/99	9.8	9/02/99	13.9	9/02/99	10.1	9/02/99	11.0	9/02/99	10.9
15/02/99	9.5	15/02/99	9.3	15/02/99	10.9	15/02/99	7.5	15/02/99	10.5	15/02/99	10.0
23/02/99	9.2	23/02/99	4.6	23/02/99	11.5	23/02/99	8.6	24/02/99	12.9	24/02/99	9.3
2/03/99	5.0	2/03/99	4.9	2/03/99	10.6	2/03/99	4.1	2/03/99	7.9	2/03/99	9.1
8/03/99	5.1	8/03/99	3.1	8/03/99	8.4	8/03/99	4.4	8/03/99	6.3	8/03/99	6.5
16/03/99	4.1	16/03/99	2.7	16/03/99	7.3	16/03/99	4.1	16/03/99	6.9	16/03/99	5.5
23/03/99	3.7	22/03/99	3.0	23/03/99	7.7	23/03/99	3.2	23/03/99	5.3	23/03/99	5.7
30/03/99	3.2			30/03/99	5.9	30/03/99	2.9	30/03/99	5.3	30/03/99	4.4
6/04/99	3.0			8/04/99	5.3						
				12/04/99	6.3						

K mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
21/01/99	0.2	21/01/99	0.1	21/01/99	0.3	21/01/99	0.1	21/01/99	0.3	21/01/99	0.1
26/01/99	0.3	26/01/99	0.2	26/01/99	0.3	26/01/99	0.1	26/01/99	0.2	26/01/99	0.2
2/02/99	0.3	2/02/99	0.4	2/02/99	0.2	2/02/99	0.6	2/02/99	0.4	2/02/99	0.3
9/02/99	0.6	9/02/99	1.0	9/02/99	0.4	9/02/99	0.6	9/02/99	0.8	9/02/99	0.5
15/02/99	0.7	15/02/99	1.0	15/02/99	0.8	15/02/99	0.9	15/02/99	1.1	15/02/99	0.8
23/02/99	0.8	23/02/99	1.2	23/02/99	1.0	23/02/99	1.3	24/02/99	1.4	24/02/99	1.1
2/03/99	0.9	2/03/99	1.4	2/03/99	1.0	2/03/99	1.2	2/03/99	1.5	2/03/99	1.1
8/03/99	0.8	8/03/99	1.6	8/03/99	0.9	8/03/99	1.3	8/03/99	1.5	8/03/99	1.1
16/03/99	0.9	16/03/99	1.6	16/03/99	1.3	16/03/99	1.2	16/03/99	1.9	16/03/99	1.5
23/03/99	1.2	22/03/99	2.2	23/03/99	1.8	23/03/99	1.4	23/03/99	2.1	23/03/99	1.7
30/03/99	1.5			30/03/99	1.9	30/03/99	1.8	30/03/99	2.1	30/03/99	1.7
6/04/99	1.7			8/04/99	2.1						
				12/04/99	2.5						

total anthocyanins mg/berry

Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
15/02/99	0.3	15/02/99	0.4	15/02/99	0.0	15/02/99	0.2	15/02/99	0.3	15/02/99	0.1
23/02/99	0.5	23/02/99	0.7	23/02/99	0.2	23/02/99	0.6	24/02/99	0.5	24/02/99	0.4
2/03/99	0.6	2/03/99	0.9	2/03/99	0.3	2/03/99	0.6	2/03/99	0.8	2/03/99	0.5
8/03/99	0.9	8/03/99	1.0	8/03/99	0.5	8/03/99	0.9	8/03/99	0.9	8/03/99	0.7
16/03/99	0.9	16/03/99	1.1	16/03/99	1.0	16/03/99	0.9	16/03/99	0.9	16/03/99	0.8

23/03/99	0.9	22/03/99	1.4	23/03/99	0.9	23/03/99	0.9	23/03/99	0.9	23/03/99	0.9
30/03/99	0.9			30/03/99	0.8	30/03/99	0.7	30/03/99	1.0	30/03/99	1.0
6/04/99	1.0			8/04/99	0.9						
				12/04/99	0.9						

total phenolics mg/berry

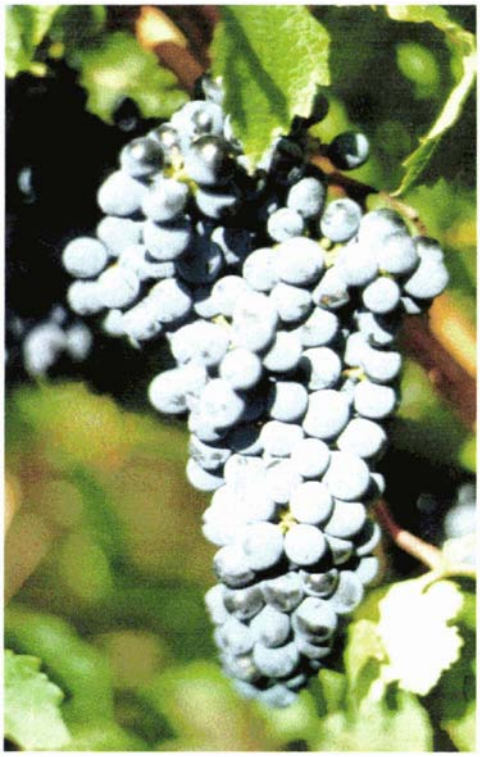
Date	RVV	Date	JRS	Date	BPN	Date	SFV	Date	LND	Date	MMR
15/02/99	1.6	15/02/99	1.5	15/02/99	0.6	15/02/99	0.9	15/02/99	1.4	15/02/99	0.7
23/02/99	1.8	23/02/99	2.5	23/02/99	1.1	23/02/99	2.2	24/02/99	1.8	24/02/99	1.5
2/03/99	2.2	2/03/99	3.1	2/03/99	1.3	2/03/99	2.2	2/03/99	2.6	2/03/99	1.7
8/03/99	3.2	8/03/99	3.6	8/03/99	2.0	8/03/99	3.0	8/03/99	3.2	8/03/99	2.5
16/03/99	3.3	16/03/99	3.9	16/03/99	3.6	16/03/99	3.3	16/03/99	3.1	16/03/99	2.9
23/03/99	3.2	22/03/99	4.8	23/03/99	3.2	23/03/99	3.4	23/03/99	3.4	23/03/99	3.2
30/03/99	3.4			30/03/99	3.1	30/03/99	2.8	30/03/99	3.8	30/03/99	3.9
6/04/99	3.5			8/04/99	3.3						
				12/04/99	3.5						

Appendix 14: Photographs

RVV – Riverview Vineyard, Mangatahi/Maraekakaho

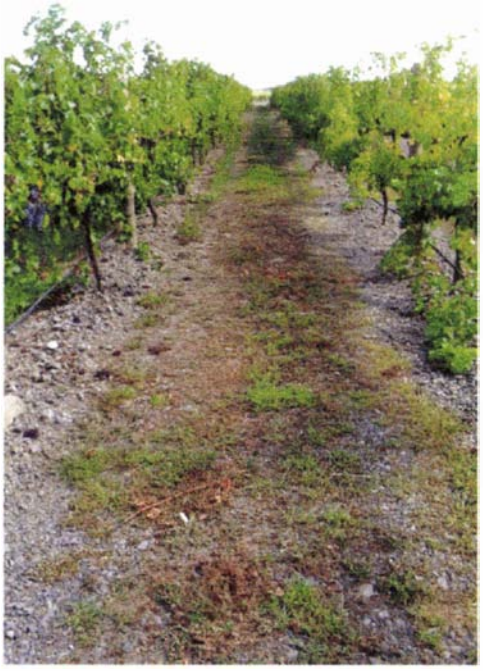
RVV – Growth stopping before harvest (1997/98)

RVV – Well managed Scott-Henry canopy



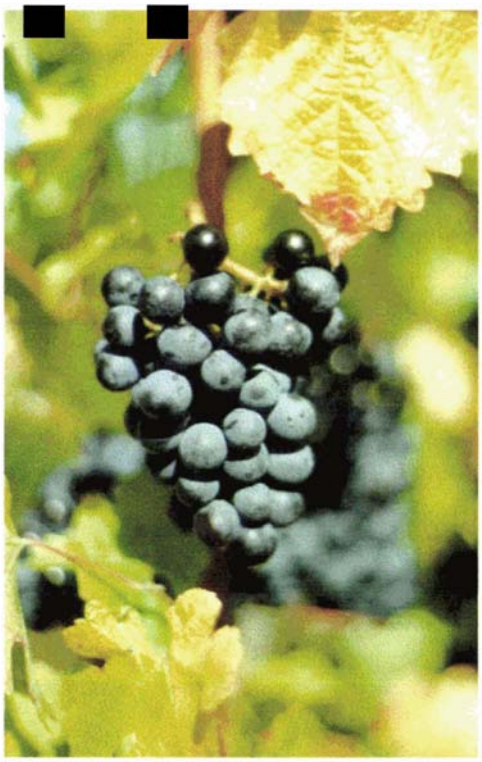
RVV – A tight cluster of rather small berries (1997/98)

JRS – A vineyard on *Omahu* stony gravels. Canopy gaps are obvious on canopy shadow in mid-row



JRS – Despite gravelly soil and restricted irrigation, a slight grass growth is still present (late summer 1997/98)

JRS – Close to harvest (1997/98). Leaves showing water stress symptoms.



JRS – A typical cluster at this site: small number of smallish berries

BPN –No irrigation and very low rainfall (1997/98) but the grass cover does not retreat. Note slashed shoots on the vineyard floor

BPN – The same view by the end of autumn (1997/98). Grass is growing vigorously, and leaves are still on vines

BPN – Near-harvest photo (1997/98). Some berries are still going through véraison.

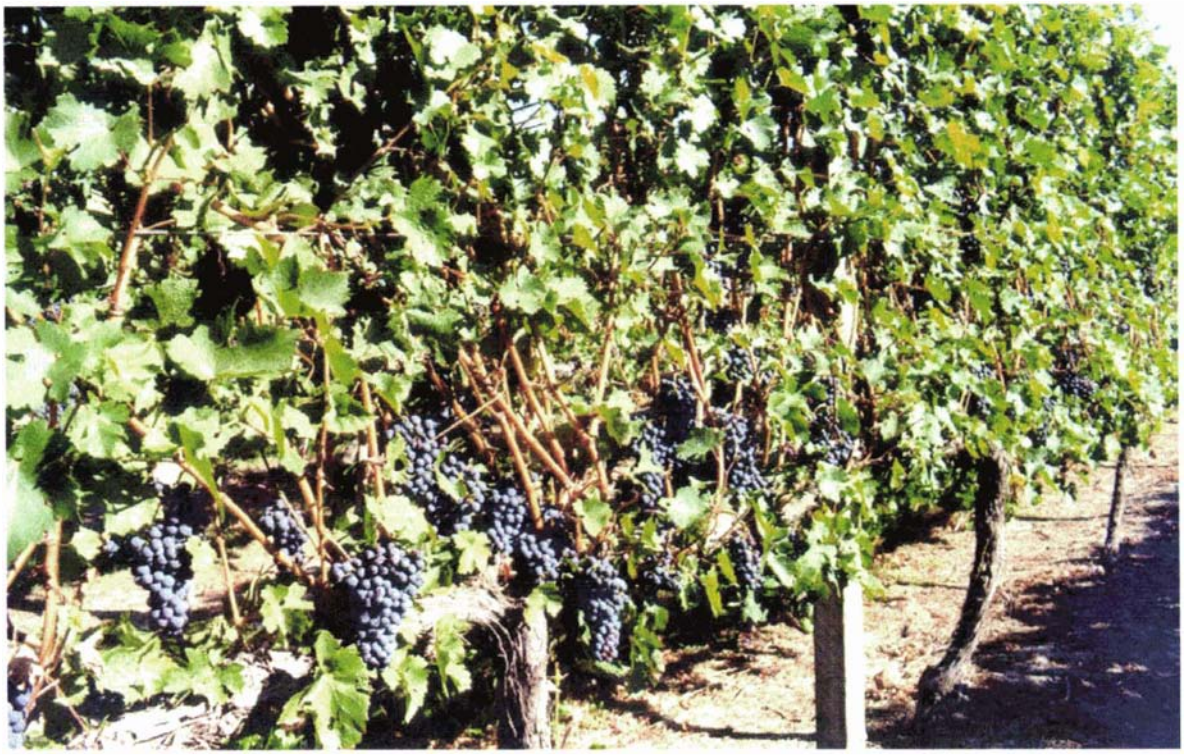
BPN – An example of shade created by excessive shoot growth (after véraison, 1997/98)

BPN – A shaded cluster amidst dark green leaves (1997/98)

SFV – Springfield Vineyard near Taradale

SFV – Recently trimmed shoots.

SFV – Chicory in mid-row survived a very dry summer of 1998 without any irrigation



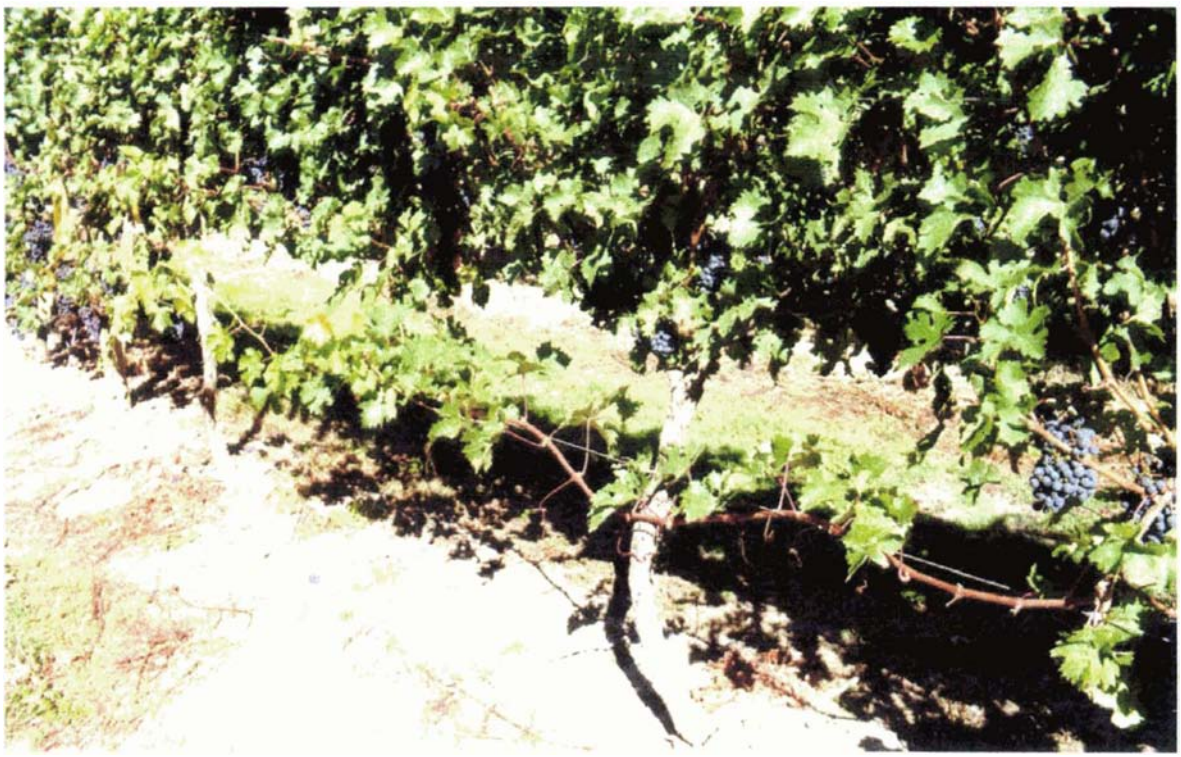
SFV – Horizontal cordon with well-exposed fruit thanks to rigorous defoliation

SFV – A tight cluster resulting from high set percentage and large berries

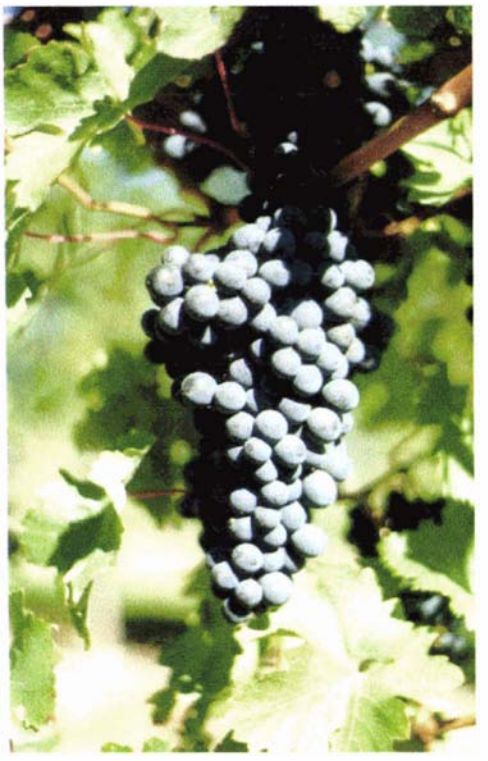
LND – Linden Estate Winery vineyard on Napier-Taupo Highway

LND –Grass cover still growing in mid-row despite dry summer (1997/98), sandy soil and no irrigation

LND – Sylvoz vines bear a lot of heavy clusters (170-180 g)

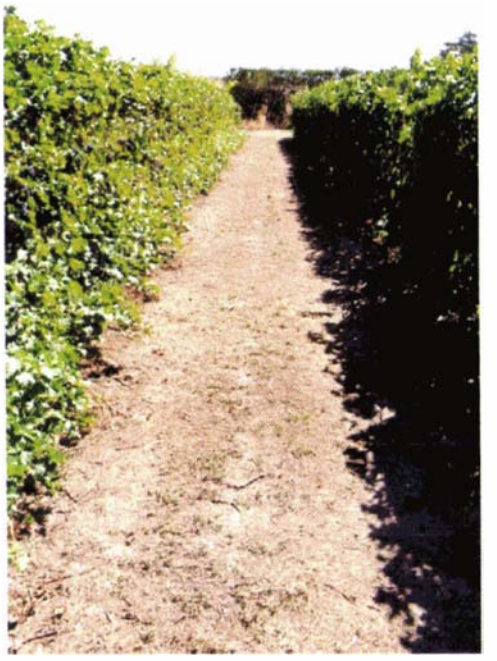


LND – Regardless of drought shoots are growing up to 4 m (bottom tier)



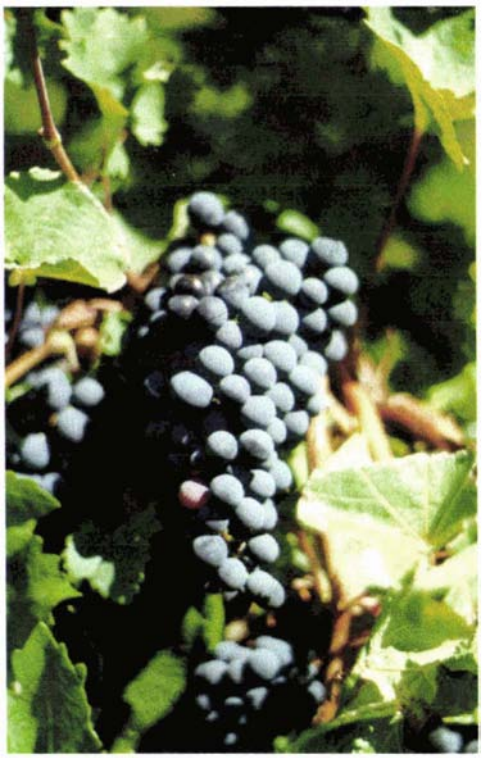
LND – The site with consistently largest berries throughout the trial

MMR – A vineyard between the Tukituki River and the Pacific Ocean

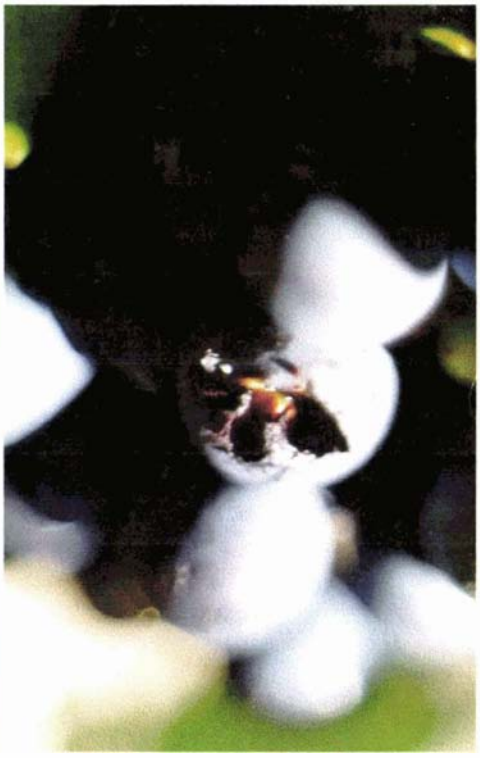


MMR – Grass cover dried out in mid-row. The view shown looks at the Pacific Ocean.

MMR – Yellowish leaves and results of defoliation in the fruiting zone.



MMR – A cluster ripening.



MMR – Bird damages to clusters (left) and berries (right)