The effect of wind on the performance of the grapevine

by

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part, submitted it at any university for a degree.

JW Pienaar

SUMMARY

Wind, as a component of the environment, contributes to the viticultural concept of *terroir* in the South Western Cape region of South Africa. Many other components also contribute to *terroir* (e.g. soil, altitude, direction of slope, etc.) and it is difficult to quantify the contribution of each. A good *terroir* promotes slow and complete ripening of the berries. A vineyard on such a *terroir* produces good quality crops over time and the effects of climatic extremes on the performance of the vine are limited by this *terroir*.

Although grapevines in the South Western Cape are exposed to strong synoptic southerly and southeasterly winds during the growing season and sea breezes add to the effect of wind in coastal areas, little is known about the effect of wind on grapevine performance. This preliminary study was undertaken to obtain more information on the effect of wind on some morphological and reproductive characteristics of Merlot noir. The aim was to obtain preliminary data which can serve as a basis for future studies on the effect of wind on grapevine performance.

Important differences in wind speed were measured spatially in a selected vineyard and exposure to wind was observed to result in essential viticultural differences. The effect of wind on vegetative parameters, canopy density, yield, berry composition and wine quality was investigated. Wind caused leaves on primary shoots of exposed vines to be smaller, but increased lateral growth in their fruiting zones. Sheltered vines had longer shoots but no significant differences were measured concerning cane diameter and pruning mass. Although it was expected that sheltered vines would have denser canopies, similar canopy densities were measured for both treatments. Vines exposed to wind responded with decreased stomatal conductance. As a result, leaf temperature was affected, showing differences between sheltered and exposed vines. Sheltered vines had more bunches per vine but fewer berries per bunch. As a result, bunches of sheltered vines were smaller than those of exposed vines. No significant difference was observed concerning the yield under the two treatments. The effect of wind on stomatal conductance had an essential impact on berry composition, thus directly influencing the quality of wine. Grapes from exposed vines showed a higher colour index. Berries from sheltered vines had significantly lower pH values and potassium concentrations and the malic acid content was lower than in berries from exposed vines.

Wine from sheltered vines had more vegetative undertones in comparison with the stronger fruity character of exposed vines. A better acid balance, together with superior complexity (fullness/mouth feel), contributed to the better overall quality identified during the evaluation of wine produced from sheltered vines.

OPSOMMING

Wind as 'n omgewingsfaktor dra by tot die wingerdkundige konsep van *terroir* in die Suidwes-Kaap streek van Suid-Afrika. Baie ander komponente dra ook by tot *terroir* (bv. grond, hoogte bo seespieël, rigting van helling, ens.) en dit is moeilik om die bydrae van elk te kwantifiseer. 'n Goeie *terroir* bevorder stadige en volledige rypwording van die korrels. 'n Wingerd gevestig op so 'n *terroir* produseer jaarliks hoë kwaliteit oeste met goeie sapsamestellings en die *terroir* beperk die negatiewe invloed van uiterste klimaatsomstandighede op wingerdprestasie.

Alhoewel wingerde in die Suidwes-Kaap gedurende die groeiseisoen aan sterk sinopties suidelike en suid-oostelike winde blootgestel is en seebriese 'n bykomstige effek in kusgebiede het, is daar beperkte kennis oor die effek wat wind op wingerdprestasie het. Hierdie voorlopige studie is onderneem om meer inligting oor die effek van wind op sommige morfologiese en reproduktiewe eienskappe van Merlot noir in te win. Die mikpunt was om verwysingsdata in te samel wat as 'n basis vir toekomstige studies oor die effek van wind op wingerdprestasie kan dien.

Belangrike verskille in windspoed is gemeet in die geselekteerde wingerd en waarnemings het getoon dat blootstelling aan wind tot kenmerkende wingerdkundige verskille gelei het. Die effek van wind op vegetatiewe parameters, lowerdigtheid, oesgrootte, druifsamestelling en wynkwaliteit is ondersoek. Wind het kleiner blare op primêre lote van wind-blootgestelde stokke veroorsaak, maar het laterale groei in hul trossones verhoog. Wind-beskermde stokke het langer lote gehad maar geen noemenswaardige verskille is ten opsigte van lootdeursnee en snoeimassa gemeet nie. Die verwagting was dat beskermde stokke digter lower sal hê, maar soortgelyke lowerdigthede is vir beide beskermde en wind-blootgestelde stokke gemeet. Stokke blootgestel aan wind het met 'n verlaagde huidmondjiegeleiding gereageer. Gevolglik is blaartemperatuur beïnvloed, met verskille tussen beskermde en blootgestelde wingerde. Beskermde stokke het meer trosse per stok maar minder korrels per tros gehad. As gevolg hiervan was die trosse van beskermde stokke kleiner as die van blootgestelde wingerde. Geen noemenswaardige verskille in die oesgroottes is tussen die twee behandelings gemeet nie. Die effek van wind op huidmondjiegeleiding het 'n belangrike impak op druifsamestelling gehad en het daarom 'n direkte invloed op wynkwaliteit gehad. Druiwe van blootgestelde stokke het 'n hoër kleurindeks getoon. Die pH en kaliumkonsentrasie van druiwe van beskermde stokke was merkbaar laer en het minder appelsuur gehad as die van die blootgestelde stokke.

Die wyn van beskermde stokke het meer vegetatiewe geure gehad in vergelyking met die sterker vrugtige karakter van blootgestelde stokke. 'n Beter suurbalans,

tesame met goeie kompleksiteit (volheid/mondgevoel), het egter meegebring dat beskermde stokke 'n beter wyngehalte lewer.

This thesis is dedicated to my parents, Wouter and Rae Pienaar, my sister, Wilmi, and my brother, Anton.

The True Vine:

"I am the true Vine, and my Father is the Gardener.

He cuts off every branch that does not produce fruit, and He prunes the branches that do bear fruit so they will produce even more.

You have already been pruned for greater fruitfulness by the message I have given you.

Remain in Me, and I will remain in you. For a branch cannot produce fruit if it is severed from the Vine, and you cannot be fruitful apart from the Vine.

Yes, I am the Vine; you are the branches. Those who remain in Me, and I in them, will produce much fruit. For apart from Me you can do nothing.

Anyone who parts from Me is thrown away like a useless branch and withers. Such branches are gathered into a pile to be burned.

But if you stay joined to Me and My words remain in you, you may ask any request you like, and it will be granted!

My true disciples produce much fruit. This brings glory to My Father."

Jesus to His disciples – John 15

BIOGRAPHICAL SKETCH

Jacobus Wilhelm Pienaar was born in the Western Cape Region of South Africa in 1979. He grew up in the town of Stellenbosch where he also finished school, matriculating from the Paul Roos Gymnasium at the end of 1996. Before enrolling for university and pursuing a career in Viticulture and Oenology, he travelled and worked in Europe, where his passion for the vine was awoken. He completed his BScAgric (Viticulture and Oenology) degree in 2001, and then furthered his education by enrolling for his MScAgric (in Viticulture) at the beginning of 2002. He also had the opportunity during 2003 to spend some time gaining invaluable experience in Germany during the European harvest season.

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PREFACE

Each chapter of this thesis is introduced separately; the research results are presented in Chapters 3 and 4 and summarised and concluded in Chapter 5, which also presents general conclusions.

Chapter 1 **Introduction and aims of the study**

Chapter 2 **Literature Review**

The effect of wind on the performance of the grapevine

Chapter 3 **Research Results**

The effect of wind on the performance of *Vitis vinifera* L.cv. Merlot noir in the South Western Cape region of South Africa. I. Vegetative growth, canopy density, stomatal conductance

Chapter 4 **Research Results**

The effect of wind on the performance of *Vitis vinifera* L.cv. Merlot noir in the South Western Cape region of South Africa. II. Yield, berry composition and wine quality

Chapter 5 **General Discussion and Conclusions**

CONTENTS

Chapter 1

INTRODUCTION AND AIMS OF THE STUDY

1.1 INTRODUCTION

The effect of wind on the performance of the grapevine under South African conditions is not well documented despite the phenomenon of regular, strong synoptic winds and gentle local breezes, that are common occurrences during the growth period of the grapevine.

There are various opportunities of contribution to knowledge concerning this subject and there is a need to explore the direct effect of wind on grapevines. Currently most information concerning the effect of wind is vague. It is not known whether the effect might be cultivar specific, *terroir* specific or restricted to specific environmental conditions. The effect of wind may be a multidimensional field of study and its interactions, whether morphological, anatomical or physiological, must be investigated. It may be important for the viticultural industry to optimise the positive and minimise the negative effects of wind.

Southeasterly winds in the Western Cape region of South Africa have apparent growth-retarding effects and yield reduction is also frequently ascribed to wind. The cooling effect of the sea breeze however, is well known. Studies conducted by Le Roux (1974), Saayman (1981), Carey & Bonnardot (2000), Carey (2001) and Bonnardot *et al*. (2001, 2002) established a basis of *terroir* studies and viticultural zoning for the Western Cape region of South Africa. Focusing mainly on the effect of sea breezes, Bonnardot *et al*. (2002) used the Regional Atmospheric Modelling System (RAMS) to determine the climatic patterns in the area. Climatic data, soil characteristics, and oenological and viticultural data were combined to investigate the site-cultivar interaction (Carey & Bonnardot, 2000; Carey, 2001). From these studies, it became clear that an understanding of the direct effect of wind on grapevine performance is lacking in the Western Cape. The effect of moderate winds (4 $m.s^{-1}$) on grapevine performance in South Africa has not yet been quantified. In this regard, however, some research has been done in Australia (Dry & Botting, 1993) and America (Bettiga *et al*., 1996). These studies focused on the effect of wind on growth and yield components of Cabernet franc (Dry & Botting, 1993) as well as the effect of wind shelter on the grapevine performance of Chardonnay grapes (Bettiga *et al*., 1996). Both studies were concentrated on the effect of wind on microclimate, vegetative parameters and yield components.

In this thesis it is hypothesised that wind may affect grapevine morphology and physiology, thereby affecting the growth and performance of the vine. As wind may, therefore, be a significant parameter to take into account for viticultural zoning, site selection and vineyard management, a field study was initiated to investigate the effect of wind on grapevines, with specific reference to vegetative growth, canopy density, stomatal conductance, yield parameters, berry composition and ultimately wine quality.

The study was conducted in a commercial vineyard of Merlot in the Somerset West area on the Morgenstêr estate. Persistent moderate winds (3 $m.s^{-1}$- 6 $m.s^{-1}$) characterise the growing season at Morgenstêr, while sporadic gusts and strong winds also occur (6 $m.s^{-1}$ to greater than 10 $m.s^{-1}$). The soil consists of stony and rocky Glenrosa forms with Malmesbury shale. Soil characteristics are considered to be uniform throughout the experimental vineyard. A windbreak on the northeastern side protects the vineyard, while, as a result of slope and aspect, the southern side of the vineyard is better protected against the predominant southeasterly wind. There is a further slope decline from the eastern to the western side of the vineyard, lending more protection to the grapevines at the bottom of the slope (the western side). The close proximity of water, the dam on the western side of the vineyard, may also affect the meso- and microclimate in the vineyard (Addenda A, B and C).

The study was conducted on Merlot grapes for problem identification concerning the effect of wind and to motivate the necessity for further research. Merlot is adaptable to most soils and is relatively easy to cultivate. It can be a vigorous naturally high yielding variety – depending on cultivation practices (Kerridge & Antcliff, 1999). The berries of Merlot grapes are relatively thin-skinned, which makes the variety prone to bunch rot diseases (Orffer, 1979). This will no doubt also affect the colour and tannin structure of the wine, for this cultivar is known for soft tannins and silky textures. Merlot is sensitive to physical wind damage, frost and, being a cultivar that buds and flowers early, can be susceptible to low budding percentages (Orffer, 1979; Kerridge & Antcliff, 1999).

1.2 AIMS OF THE STUDY

- To monitor the growth and performance of *Vitis vinifera* L.cv. Merlot noir grapevines as affected by different wind regimes;
- To measure the effect of wind on grapevine canopy density and vigour as expressed by shoot length, lateral shoot development and leaf surface area of Merlot noir;
- To determine stomatal conductance in sheltered and exposed grapevines;
- To establish the effect of persistent moderate wind on the yield and grape composition of Merlot noir;
- To determine the effect of wind on wine quality and character of Merlot noir.

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Chapter 2

LITERATURE REVIEW

The effect of wind on the performance of the grapevine

2.1 INTRODUCTION

The effect of wind on grapevine performance under South African conditions has not been determined. Previous studies (Le Roux, 1974; Carey & Bonnardot, 2000; Carey, 2001; Bonnardot *et al.*, 2001, 2002) have suggested that sea breezes are a significant climatic phenomenon in the South Western Cape and that this has implications for grapevine performance. A quantification of these implications will contribute to a better understanding of how *terroir* affects the performance of specific vineyards.

The effect of wind on the performance of the grapevine may be direct and indirect as a result of the interrelationship between wind and other climatic factors, such as temperature and relative humidity (Ewart, Iland & Sitters, 1987; Calò, Tomasi, Crespan & Costacurta, 1996; Eloff, personal communication). There is also an interaction between wind and topographic elements such as slope and orientation, which will indirectly affect the vine. All these factors may affect not only the morphology and anatomy of the grapevine, but especially physiology, thus affecting the quantitive and qualitive response of the grapevine.

Other living creatures, unlike plants, have the ability to move and shelter themselves against wind. As part of plant life, the grapevine must be able to adapt to wind, as it cannot escape from it. This review is an attempt to summarise the information on how these adjustments take place, their implication for growth reactions and physiological functioning of the grapevine and, finally, yield, berry composition and wine quality.

2.2 WIND AS A PART OF *TERROIR*

2.2.1 DEFINING *TERROIR*

The term ***terroir*** defines the natural environment in which the grapevine is cultivated and includes the soil, topography and climate of the vineyard. This natural environment determines a district's agricultural suitability and thus affects the characteristics of the final product. This makes the grapes and wine more than just another commodity, but rather a distinct product from an inimitable place (or *terroir*) (Robinson, 1994). *Terroir* is also described as a unit in which the interrelationship between the natural environmental features (soil, parent material, topography and climate) results in a relatively homogenous environment for grapevine cultivation. The producer can not easily modify this interaction of natural environmental elements and this interaction is evident in the final product, assisted by various viticultural practices, resulting in typical wines of identifiable origin (Carey, 2001).

The effects of **soil** on the performance of the grapevine is often disputed (Saayman, 1981). The effects of soil are frequently confused with other cultivation factors such as soil surface management, irrigation, nutrition, etc. These effects are commonly ascribed to the interaction between soil structure and soil water status (Saayman, 1992b). This, in turn, is expected to determine and interact with soil temperature, effective depth and chemical composition. The grapevine will perform well on various types of soil, albeit to a greater or lesser extent, and this adaptability makes it difficult to "define" the perfect soil (Carey, 2001).

Topography is regarded as the link between soil and climate (Bohmrich, 1997). Topography will determine the mesoclimate in the vineyard, but can be affected by structures such as wind filters. It can be defined as the static feature of the terrain that has significant implications for the cultivation of crops such as vines (Robinson, 1994; Bohmrich, 1997; Carey, 2001). These features include altitude, slope and inclination, aspect and the proximity of water bodies.

Climate is the most variable of all the *terroir* elements (Saayman, 1992a). *Temperature* is probably the most essential of all climatic parameters (Le Roux, 1974). Together with relative humidity and wind, it invariably affects all physiological processes in the vine (Bohmrich, 1997; Calò *et al.*, 1996). Most functions and physiological processes are affected by temperature. Temperature is essential when it comes to the control of vine growth and development and the ripening of the grapes. Furthermore, it has an effect on enzymatic activities that directly affect the development of compounds responsible for flavours, aromas and colour in grapes, the accumulation of sugar and the production of carbohydrates, the process of photosynthesis and the metabolism of acids (Calò *et al.*, 1996).

Radiation, commonly referred to as sunlight, is the ultimate source of life on earth. Together with carbon dioxide and water, sunlight takes part in the process of photosynthesis, producing oxygen and carbohydrates (Mather, 1974). Canopy management affects canopy microclimate and thus the sunlight penetration that supports the process of photosynthesis in grapevines. Wind causes leaves to flutter, thereby affecting the leaf surface exposed to direct sunlight. Movement of leaves, on the other hand, can increase the amount of sun flecks and thus diffuse sunlight in the canopy. Wind also transports dust and sand particles that cover the surface area of leaves (Wilson, 1998). These factors will determine the amount of radiation that reaches the leaf surface. Sunlight affects leaf temperatures and will consequently also affect the rate of respiration and photosynthesis (Mather, 1974; Wilson, 1998). The effect of radiation on the berries is demonstrated in their chemical and aromatic composition (Jackson & Lombard, 1993; Calò *et al.*, 1996).

Winds are often symptomatic for *rainfall* (Preston-Whyte & Tyson, 1988). The interaction between wind, temperature and humidity and the effect it has on evaporation form the basis of precipitation formation (Barry & Chorley, 1968; Critchfield, 1974; Preston-Whyte & Tyson, 1988). In the Western Cape of South Africa, northwesterly winds are indicative of approaching rainfall. Rainfall is one of the more conflicting components of climate when it comes to viticulture (Wilson, 1998). It is necessary to encourage sufficient growth and to prevent water stress in essential growth stages, for example ripening. Untimely rainfall at certain phenological stages decreases the quality of the grapes (Robinson, 1994). Early season rainfall can be valuable for quality, depending on the effect it has on the vegetative growth of the vines, as well as the effect on fruit set. Surplus rainfall after fruit set, together with other factors, can promote vegetative growth well into the ripening season, as the result of excessive carbohydrate transport to the shoots instead of to the berries and result in poor berry ripening, eventually reducing grape quality (Robinson, 1994). Rainfall during harvest can result in swelling and splitting of berries. The swelling will result in the dilution of sugars and aromas and sometimes partial ripening, whereas the splitting of berries will increase the chances for micro-organisms to infect the clusters and cause spontaneous fermentation and oxidation of grapes on the vines (Wilson, 1998). Untimely rainfall during the growing season can result in excessive growth and vigorous vines with consequent poor canopy conditions and shading (Wilson, 1998).

The positive effect of *wind* is twofold. It can be accredited to the cooling effect of sea breezes and dry winds that have a reducing effect on the occurrence of disease occurrence (Carey, 2001). In contrast, wind can have a detrimental effect on the physical condition of the vine through the breaking of young shoots, the blowing away of pollen and the effect it has on stomatal closure. The latter will result in the reduction of photosynthesis, which will eventually decrease the amount of soluble solids and carbohydrates in the berries. According to Freeman, Kliewer and Stern (1982) it can also be responsible for high pH values in the juice.

It is not easy to establish the precise contribution of each element of *terroir*. This is because of the unique complexity of the interrelationship between the different components of *terroir*. These interactions contribute to a *terroir* that will affect the ripening of the berries. A good *terroir* will promote slow and complete ripening (Robinson, 1994). It will result in regular good quality crops and juice composition and will limit the effect of climatic extremes (Jackson & Lombard, 1993).

Wind has been defined as one of the most unstable climatic elements (Preston-Whyte & Tyson, 1988). It changes in velocity as a result of short-period accelerations and decelerations. The term gustiness refers to the fluctuation of the direction and the speed of the wind, supporting the notion that wind is a very unpredictable climatic element. Wind gusts are affected by the general atmospheric conditions on a meso- or microclimatic scale. Gustiness can change in a matter of hours or minutes (Preston-Whyte & Tyson, 1988). It is this characteristic of the wind that makes it difficult to quantify the precise wind speeds and directions. Most available wind data therefore record mean values. In field research, it is more exact to work with hourly data when investigating wind on a meso and/or micro scale, although even this represents mean data.

2.2.2 TYPES OF WINDS

2.2.2.1 SYNOPTIC WINDS

Kendrew (1961) described wind on a synoptic scale in the South Western Cape of South Africa. The prevailing synoptic wind in the summer (October – March) is strong southerly to southeasterly, while northerly and northwesterly winds tend to be most prominent during the winter months (May – August) (Kendrew, 1961). Hot "berg" winds with a northerly and/or easterly origin also occur in the mornings before they are neutralised by the effect of the southerly sea breezes. Topographic factors, e.g. the proximity of a large body of water and the openness of the landscape, affect synoptic winds in the South Western Cape. The mountain ranges obstruct the flow of winds inland and therefore cause these winds to blow along the coastline at high speeds (Kendrew, 1961).

2.2.2.2 LAND AND SEA BREEZES

As a result of different heat capacities, the land surface accumulates and loses heat more easily than water does. During daytime, the air over the land heats up faster relative to the air over the water mass of the sea (Bonnardot *et al.*, 2001). The heat capacity of water is five times that of the soil on the earth's surface (Mather, 1974). Therefore it will take five times the energy and time to heat up the sea water to the same degree as the soil on the surface. If equal amounts of energy were applied to the soil and the water, the soil would heat substantially more than the sea (Mather, 1974). Thus, during the day, air over the land will accumulate heat, while the temperature of air over the sea will remain lower. This will create a pressure difference and air will flow from a state of higher pressure (the cooler area – the sea) to a state of lower pressure (the warmer area – the land) (Bonnardot *et al.*, 2001). This results in a typical **sea breeze** later in the day (Fig. 1). The effect of the sea breeze becomes evident during the later parts of the morning (11:00), when the relative humidity on the land declines to 65%. Later in the afternoon (17:00), when winds reach maximum speeds, the humid air will keep on penetrating inland, depending on topographic barriers (Bonnardot *et al.*, 2002).

Sudden changes in wind speed and direction in the afternoon are the prime indicators of the onset of the sea breeze element of the land-sea breeze system. In moderately warm climates, such as the Western Cape area of South Africa, the sea breeze can reach wind speeds of 7 $m.s^{-1}$ to 9 $m.s^{-1}$ (Bonnardot *et al.*, 2002). The sea breeze is strengthened when it merges with the upslope breezes or valley winds. This results in sea breezes with a velocity of more than 9 $m.s^{-1}$.

During the night and early morning, air over the land cools down sooner relative to air over the sea. This creates a low-pressure system over the sea, because of its warmer status compared to the land (Bonnardot *et al.*, 2001). The rapid heat loss over the land creates a high-pressure system over the land, resulting in a **land breeze** (Fig. 1), which is typical of early morning conditions.

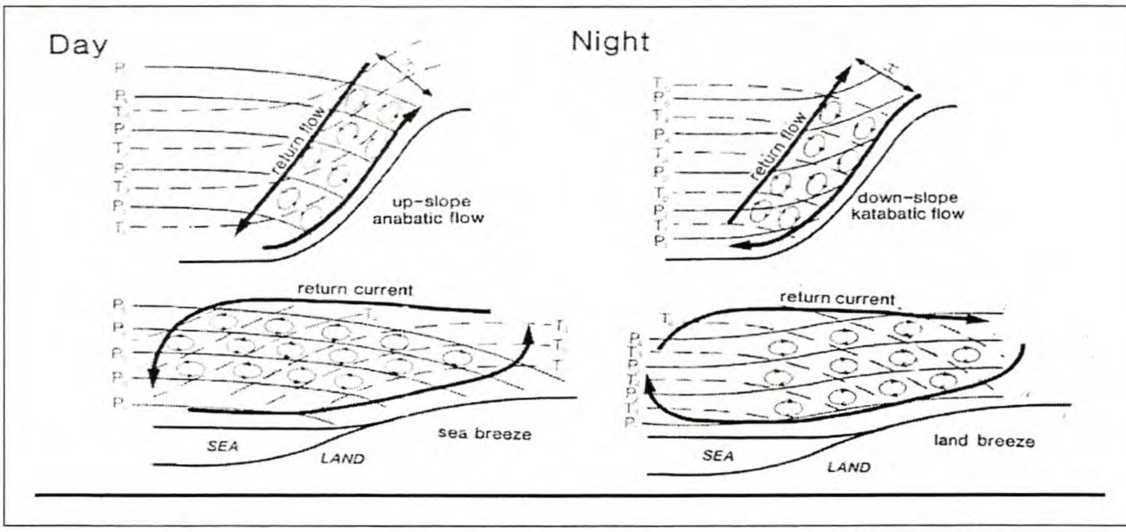

Figure 1. Local circulation producing sea and land breezes (Preston-Whyte & Tyson, 1988)

2.2.2.3 MOUNTAIN AND VALLEY BREEZES

Valley breezes, constricted by the valley walls, tend to blow up the valley axis during warm afternoons as a result of vertically expanding air (Critchfield, 1974) (Figs. 1 & 2). In Fig. 2, white arrows indicate the circulation of heat exchange between the plain and the valley. Valley breezes do not need a large regional pressure gradient and are mostly defined as light breezes. To activate valley breezes, a pressure gradient must exist between the plain and the valley and it must occur during the daytime. Valley breezes are encouraged by the earlier inception of slope breezes that occur as a result of the heat difference between the valley floor and the valley sides and slopes (Barry & Chorley, 1968; Preston-Whyte & Tyson, 1988). Fig. 2d presents an illustration of a simple valley breeze.

The opposite occurs at night, when there is a temperature inversion. During night time, at high altitudes, the land radiates heat and is cooled (Barry & Chorley, 1968). Dense cold air from the higher altitudes moves down into the valley (Fig. 3). Heat loss, the accumulation of cold air at the valley bottom, and the movement of cold air down the valley slopes, result in a down-slope **mountain breeze** (Critchfield, 1974; Yoshino, 1975). Fig. 2h illustrates a simple mountain breeze.

Valley and mountain breezes are affected by the macro- and meso-climate, together with the daily and seasonal changes of the sun's position relative to the

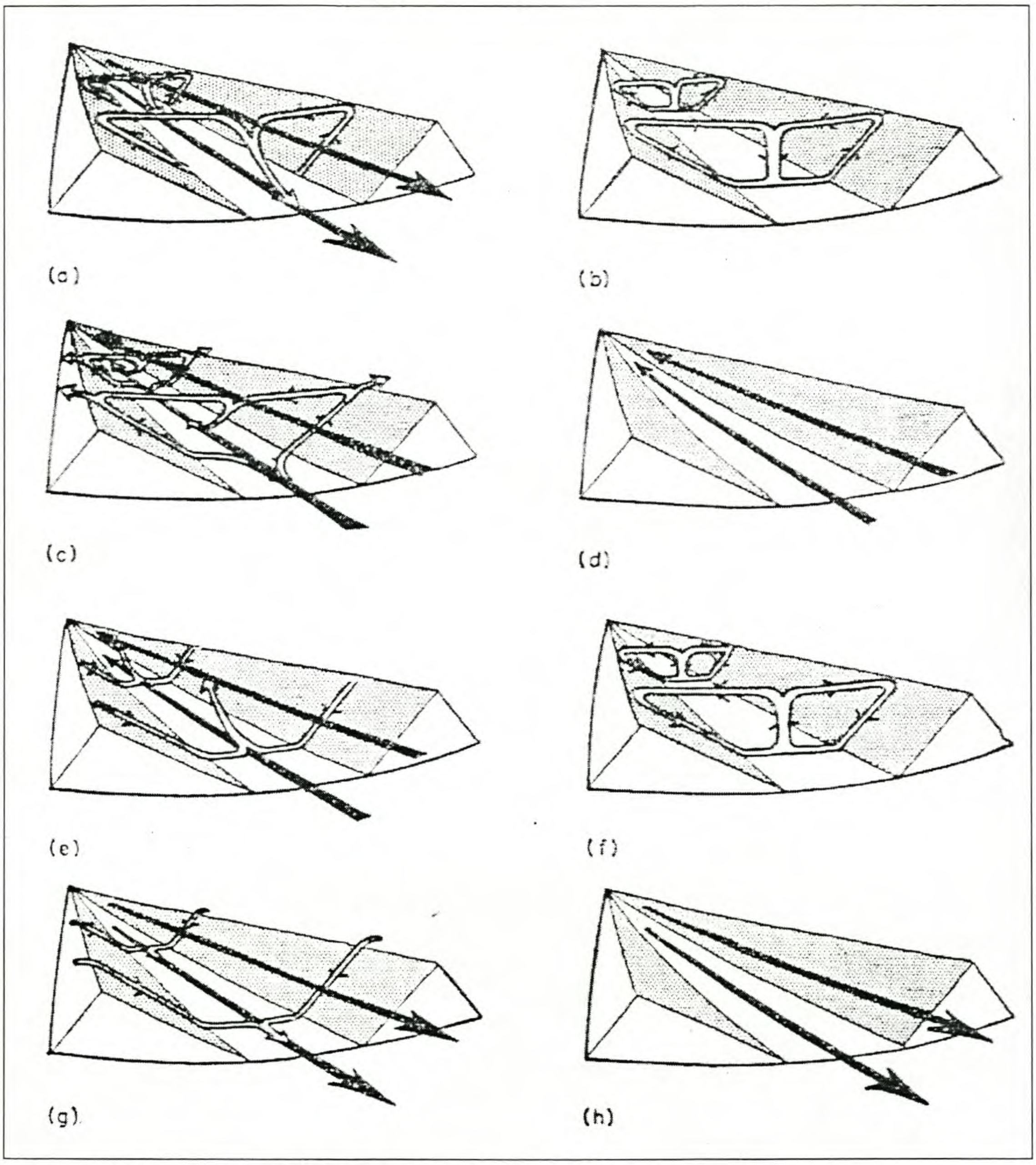

Figure 2. The development of mountain and valley winds during the day.

(a) At sunrise the valleys are cold and the plains are warm; (b) At 9:00 am, the plain and valley temperatures are equal; (c) In the early afternoon valleys become warmer than the plains; (d) In the late afternoon, valleys continue to be warmer; (e) Sunset, with little difference between valley and plain temperature; (f) Early evening; the plain and valley temperatures are equal; (g) At midnight, plains are warmer than valleys; (h) Late night, valleys much colder compared to plains (Barry & Chorley, 1968) earth's surface. The position of the sun determines the amount of sunlight exposure and thus the temperature exchange between the valley floor and the slopes (Yoshino, 1975). This, in turn, impacts on the vegetation in the valley. All of this is affected by topography. Topographic factors include the following: the length and width of the valley, the slope inclinations, the running direction of the valley, the flatness of the valley floor and its contours and hills, the altitude of the adjacent ridges and the space between the valley and the plain (Yoshino, 1975).

Hills and mountains play a very important role and affect the movement of air over them (Barry & Chorley, 1968). When air moves along the local pressure gradient over a barrier (mountain), there is often a loss of humidity via precipitation on the mountain. The cooled air then accumulates heat as it descends on the lee side of the mountain. This will result in strong and gusty winds on the lee side of the mountain. These winds will also be warm and the general humidity and air moisture on the lee side of the mountain will decrease (Barry & Chorley, 1968).

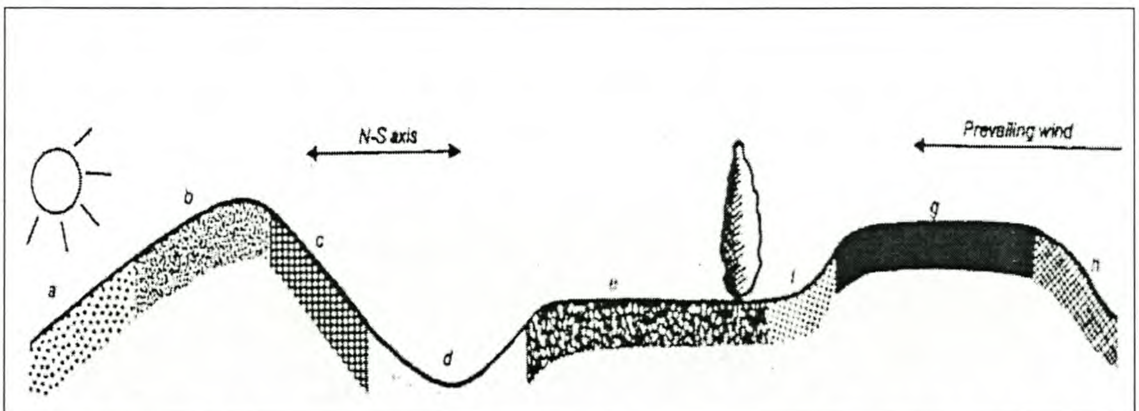

Figure 3. The effect of topographic factors on the mesoclimate (Coombe & Dry, 1992): (a) Slope with northern aspect; warmer as a result of the more direct sunlight; (b) Cooler than a, because of higher altitude; (c) Southern slope; cool as a result of receiving diffuse radiation and the cooling effect of the wind; (d) Valley that will accumulate cold air in the night and during the winter; (e) Warmer compared to (d) with protection against the predominant wind; (f) Slope provides protection against the wind; (g) In the direct line of the prevailing wind; (h) = (c).

2.2.3 TOPOGRAPHIC ELEMENTS AFFECTING THE WIND

The fundamental elements of topography include altitude, aspect, slope shape and inclination, relative isolation of the hills and the proximity of bodies of water

(Carey, 2001). Coombe & Dry (1992) researched the interactions between topography and wind; their work is summarised in Fig. 3. Slopes facing the prevailing wind receive more wind than the protected valley floors. For this reason, hill crests are more exposed and vines planted here frequently need protection against wind damage. Areas exposed to wind generally experience cooler temperatures than protected valley floors and this impacts on grapevine performance and berry composition. Therefore various wine styles are produced from the same cultivar planted in different positions in the landscape. The topographic effect on the mesoclimate is expressed in spatial variability of temperature and wind (Carey, 2001).

Temperature, in general, declines with increasing **altitude**. The lapse rate of temperature varies with area and season, but it is generally accepted to decrease by 0.3°C with every 100 m increase in altitude in the South Western Cape region, while it will decrease by 0.6°C in most other areas (Literature cited in Carey, 2001). Vineyards planted at higher altitudes sometimes demonstrate less vigorous growth, which in many instances can be associated with better quality wine. These higher lying areas could be more exposed to cooling winds and sea breezes, which will further increase the quality of the harvest. The interaction between the cooling effect of the sea breeze and topographic elements, such as altitude and aspect, could affect the character and quality of the grapes. This is because of the positive effect of cool temperatures on aroma development of most cultivars, but mainly of white cultivars (Jackson & Lombard, 1993; Marais, Hunter & Haasbroek, 1999; Bonnardot *et al.*, 2001). During daytime in the summer months, elevated areas will be cooler than lower-lying areas, while the opposite will occur at night-time. At night, the cooler air will gather at the valley bottom due to the fact that cold night air is heavier than the warm day air (Bohmrich, 1997).

The **aspect** of a vineyard refers to the direction in which the slope is facing. Generally, slopes facing the sun for most of the day will be warmer than slopes facing away from the sun (Carey, 2001). Slope affects the perpendicularity of sunlight and, hence, temperature. Both warmer and colder slopes can be affected by other factors, such as wind. Aspect affects the spatial variability of the wind. Windward-facing slopes can cause moist air to rise, which will result in higher quantity and frequency of rainfall (Carey, 2001). In the southern hemisphere, western and northern slopes are regarded as warmer. These slopes have higher direct sunlight interception relative to the eastern and southern slopes, which are considered to be cooler. The eastern slopes heat up faster in the mornings due to the direct sunlight that they receive in the early mornings (Carey, 2001).

Convex terrain in general has less day-night temperature variation in comparison to concave landscapes. Concave landscapes are where most accumulation of direct sunlight takes place (Wilson, 1998), as well as the greatest accumulation of soil moisture (Carey, 2001). In all cases, altitude along with exposure to the prevailing wind has a significant effect on temperature variation (Fig. 3) (Wilson, 1998; Carey, 2001).

Proximity of bodies of water is also integrated with the complexity of topography. Land and water surfaces have different characteristics and energy balances. The land has distinct variations in daily temperatures. It heats and cools quickly because of its low thermal conductivity. But, there are only slight temperature variations in the ocean's water surface. This is because its water is in constant motion and any change in temperature is dispersed to substantial depths (Bonnardot *et al.*, 2002).

Sea breezes have a profound effect on the performance of vineyards planted in close proximity to the sea. Although the complex interaction between local topography and airflow makes it difficult to quantify the sea breeze effect, the research by Bonnardot *et al.* (2002) clearly indicates that vineyards exposed to these breezes may have a qualitative advantage.

2.2.4 THE EFFECT OF CLIMATIC FACTORS ON WIND

It is essential to understand the fundamental laws that govern the different environmental factors. To understand the interaction between these factors, it is important to be familiar with the basic laws of atmospheric physics. Therefore some of these laws will be mentioned and discussed, where relevant.

2.2.4.1 TEMPERATURE, PRESSURE AND AIR DENSITY

On a mesoclimatic scale, **temperature** variations causing a **pressure** gradient can result in wind. The interaction between these elements affects the occurrence of diseases (see 2.3.5) and will have an impact on berry and wine composition (see 2.3.4).

The atmosphere constantly experiences changes in temperature, which are caused by many different factors. As a result, sequential and spatial deviations from the regular reigning temperature will occur (Preston-Whyte & Tyson, 1988). Atmospheric pressure is responsible for winds and thus for heat and moisture transfer between different areas (Critchfield, 1974). Horizontal pressure gradients occur as a result of temperature variation (Critchfield, 1974).

Conduction is the transfer of the heat and kinetic energy of molecules and atoms. Wherever a temperature difference occurs, heat will always be passed on to the colder body (Critchfield, 1974). If there is temperature gradient between the land, warmed by radiation, and the cooler air above the surface, heat will be transferred to the lower levels of the air via conduction. This will result in the cooling of the land. The reverse will occur when the land is cooler than the adjacent air. Then the heat will be transferred to the land and the air will cool down. This event will impact on the development of pressure systems over the land and, consequently, on the occurrence of different types of winds and breezes (Preston-Whyte & Tyson, 1988).

Air density is essential with regard to wind such as land and sea, as well as mountain and valley breezes, because these breezes are partly reliant on the displacement of air (Preston-Whyte & Tyson, 1988). A gas containing water vapour will be denser than one consisting of dry air. When there are clouds in the atmosphere, they will affect air density, and consequently temperature and air pressure and determine the occurrence of wind (Preston-Whyte & Tyson, 1988).

2.2.4.2 WATER VAPOUR, HUMIDITY AND CONDENSATION

Water vapour in the atmosphere affects the diffusion of radiation. Water vapour plays an important role with regard to heat transfer by means of the process of evaporation. Therefore water vapour is not only significant with respect to moisture exchange in the atmosphere, but also with respect to the exchange of heat (Critchfield, 1974). The amount of water vapour in the atmosphere is generally referred to as **humidity**. Humidity is extremely variable and can be affected by air pressure or air temperature (Barry & Chorley, 1968).

Condensation takes place under various circumstances, and is affected by humidity, temperature, pressure, and the movement of air. Conditions for condensation are most favourable when there is a decrease in air temperature, resulting in active cooling of air in the atmosphere due to the mixing of air masses of different temperatures (Preston-Whyte & Tyson, 1988). The condensation process requires some type of cooling to be maintained. Two essential cooling models exist, namely, adiabatic and diabatic cooling.

Diabatic cooling involves:

- Heat loss as a result of irradiation;
- Conduction and the direct contact of the object with colder surfaces;
- Integration with colder air.

Adiabatic processes involve the following:

- A decline in surface pressure, resulting in the formation of fog;
- A rise of air, which is a consequence of:
    - Convection;
    - Orographic lifting;
    - Convergence of wind and air currents.

The adiabatic cooling outlined above is responsible for the rising of air and is of primary importance for condensation. Convection entails the integration of currents of air by specific motions and happens on a vertical plane in the atmosphere. Orographic lifting is the rising of air caused by topographic barriers (Mather, 1974). These barriers can either be the cause or can intensify the process of lifting the air. Convergence occurs when winds of different speeds and from different directions meet. In the tropics, these winds all have comparable temperature characteristics, while further away from the tropics, in the middle latitudes, there is a more distinct temperature gradient between these winds. This results in frontal lifting, where the warmer air overrides the cooler air and the frontal lifting produces frontal precipitation (Critchfield, 1974; Mather, 1974).

2.3 THE EFFECT OF WIND ON GRAPEVINE BEHAVIOUR AND PERFORMANCE

2.3.1 ANATOMY AND MORPHOLOGY

The vine's response to wind depends on the velocity of the wind. Shoots oscillate in response to wind energy and damage occurs when the oscillation exceeds the physical limits that the shoots can endure (Zeeman, 1981). The resultant loss of the tips reduces the shoot length. Shoot breakage stimulates lateral shoot growth and, thus, the production of a second crop. Inflorescences are affected due to rubbing of shoots and leaves under severe conditions. This can result in complete loss of potential bunches. Wind also causes burning of leaves and can lead to defoliation (Hamilton, 1989; Dry, 1993).

Thigmomorphogenesis is described as the adaptation of plants to environmental mechanical influences, whether it is on an anatomical or physiological level (Jaffe & Forbes, 1992). The term thigmomorphogenesis describes any form of mechanical stress or mechanical perturbation that the plant may experience (Jaffe, 1973). It may be caused by rain, turbulent water flow, vibrations or wind, shade caused by other plants or parts of the same plant, or rubbing of plants against one another. This phenomenon occurs under several environmental circumstances, but is most prominent in extreme conditions of water flow or turbulent wind (Jaffe & Forbes, 1992; Salisbury & Ross, 1992).

Thigmomorphogenesis causes plants to have shorter stems and smaller leaves (Jaffe & Forbes, 1992). Shoots are thicker than usual, showing a decrease in stress susceptibility and an increased senescence. Plants such as tomato seedlings, bean plants, cucumbers and celery have responded to this phenomenon, even though not all species respond (Jaffe, 1973; Jaffe & Forbes, 1992). The phenomenon is greatly underestimated and may also affect the chemical composition, transpiration and photosynthesis of leaves (Jaffe & Forbes, 1992). It has yet to be investigated in grapevines.

The plant sends out a signal received during mechanical perturbation and then responds to this signal. Jaffe & Forbes (1992) suggested the following responses:

- The signal may be transmitted by means of a bioelectric response;
- Inhibition of phloem transport;
- Hormonal response.

The permeability of the membranes is affected by thigmomorphogenesis. This allows plant growth regulators and ions such as potassium to pass through from the symplast into the cell wall and can result in stimulation of different growth reactions (Jaffe, 1973).

Alterations in the membrane affect the production of hormones by increasing the accessibility of precursor molecules (Salisbury & Ross, 1992). Abscisic acid

(ABA), contributes to retarded growth. Mechanical perturbation increases the ABA content of plants (Jaffe & Forbes, 1992). Normally, the presence of ABA causes the stomata to close, helping the plant to regain normal turgor (Pharis & Reid, 1984). Mechanical perturbation also causes a decrease in gibberellin content which contributes to retarded growth due to the inhibition of cell division and growth (Jaffe & Forbes, 1992).

The growth regulators, ethylene and auxin, are essential components of mechanical perturbation as they increase when this occurs (Jaffe & Forbes, 1992). Auxins are essential for cell growth in actively growing shoot and root tips. They are also involved in the inhibition of lateral shoot growth (Salisbury & Ross, 1992; Robinson, 1994). Mechanical perturbation induces a rise in levels of auxin in the plant (Jaffe & Forbes, 1992). A correlation has been shown between strong winds (6 $m.s^{-1}$ to 10 $m.s^{-1}$) and the production of the growth regulator ethylene (Brown & Leopold, 1973) in pine trees, where ethylene was found to reduce the elongation of stems, while increasing their thickness. Ethylene also is a growth inhibitor (Robinson, 1994) and promotes senescence and abscission of leaves (Salisbury & Ross, 1992).

The effects of thigmomorphogenesis are evident in the anatomy and morphology of stems and leaves of various plants. At times the whole plant may be deformed. Plants that develop and grow in a windy environment become toughened to resist strong winds. There will be an increased development of cell wall structures, due to an increased amount of lignified xylem, collenchyma and sclerenchyma. In comparison, sheltered plants that have been prevented from swaying by guide wires will break easier when exposed to severe windy conditions (Jaffe & Forbes, 1992).

2.3.2 PHYSIOLOGY

The major effect of wind on grapevine physiology is through stomatal response. Wind causes a decrease in stomatal conductance, which limits the photosynthetic activity and transpiration rate of the plant (Dry, 1993). This has a carry-over effect on the performance of the plant, but it may be that this effect is only observed the following growing season (Dry & Botting, 1993).

The quantitive effect of wind on stomatal conductance of exposed vine leaves depends on the velocity of the wind (Dry & Botting, 1993). Compared to sheltered vines, the **stomatal conductance** of exposed vine leaves decreases rapidly after the wind starts to blow. It will remain lower for the total windy period, but there will be no significant distinction between the stomatal conductance of the sheltered and the exposed vines within 24 to 36 hours after the wind has stopped (Kobriger, Kliewer & Lagier, 1984). These changes in stomatal conductance are not affected by changes in leaf water potential (Freeman *et al.* 1982, Kobriger *et al.*, 1984 and Bettiga, Dokoozlian & Williams, 1996), as wind has no direct effect on leaf water potential.

Wind has an indirect effect on stomatal conductance:

- It lowers the leaf temperature;
- it alters the concentration of CO_2 in the region of the stomatal opening;
- it diminishes the boundary layer around the leaf;
- it brings physical damage to the epidermal cells and the cuticle; and
- long-term exposure to fresh winds (7 $m.s^{-1}$ to 10 $m.s^{-1}$) can affect the development of structures and cells that play an intricate role in stomatal functioning (Weyers & Meidner, 1990).

Leaves are the main location of **photosynthesis** in plants. The resultant carbohydrates are metabolised into sugars before being transported to berries in the form of sucrose. Enzymes such as invertase and sucrose synthetase metabolise the carbohydrates (Hunter, Skrivan & Ruffner, 1994). The distribution of carbon assimilates and carbon translocation in the form of sucrose is thus a very complex system and places high demand on leaves, bearing in mind that the quality of the berries and bunches is directly related to the export status of the leaves (Hunter *et al.*, 1994). Variation in leaf exposure and age induce continual changes in the import and export ratios of the photosynthetic assimilate. An ever-changing microclimate plus the effect of the wind will also affect these ratios (Hunter *et al.*, 1994).

The basal and apical leaves contribute to the photosynthetic pool in different ways and at different times during the season. Early in the season sucrose concentrations in the younger leaves are higher than those of the mature leaves. After veraison, the tendency is reversed. The contributions of the basal leaves are dominant until the berries reach pea size. Thereafter (between pea size and harvest) their input declines (Hunter *et al.*, 1994). Basal leaves are largely responsible for nourishing the clusters and berries for most part of the growing season. Before the onset of veraison, the input of apical leaves is rather consistent, while the greater part of their contribution occurs during the ripening period up till harvest. Daily fluctuations in sugar levels in the leaves are the same for basal and apical leaves (Hunter *et al.*, 1994).

Sucrose is the major carbohydrate that is translocated through the vine and also the primary product of photosynthesis (Hunter *et al.*, 1994). The longevity of the vines, yield and quality of the crop are determined by the following aspects of sucrose transport: (i) the partitioning between different sources and sinks, (ii) the accumulation and storage in different sinks and (iii) the utilisation of sucrose. The availability of sucrose is determined by: (i) the rate of sucrose synthetase and invertase activity, (ii) the rate of photosynthesis, (iii) the loading and unloading of sucrose into and out of the phloem and (iv) the sink size and activity. This together with the existence of a sucrose gradient, controls the import and export of sucrose Defoliation can alter the source:sink relationship in such a way that it will impact on the transportation of sucrose into the berries (Hunter *et al.*, 1994; Hunter, personal communication).

A reduction of **transpiration** will reduce the supply of nutrients that are transported in the water flow (Campbell-Clause, 1998). A decrease in transpiration rate causes an increase in leaf temperature where there is an abundant water supply. This will result in higher rates of respiration (Kobriger *et al.*, 1984; Bettiga *et al.*, 1996; Campbell-Clause, 1998).

Liu *et al.* (1978) conducted a study of vines grown in large and small pots, where they determined the effect of different irrigation cycles on grapes and the effect this had with specific regards to the concentration of abscisic acid in the vines. According to these authors, there is a close relationship between ABA, stomatal conductance and photosynthesis. It has been noted that the stomata closes when the leaf water potential reaches a specific minimum, between -1300 and -1600 kPa (Liu *et al.*, 1978; Freeman *et al.*, 1982). According to Freeman *et al.* (1982), wind does not appear to increase the water stress up to the point that the stomata will close. Stomatal closure is accredited to the relationship between the wind, the concentration of ABA and environmental factors.

The physiological and physical responses of the vines throughout the varying water regimes applied by Liu *et al.* 1978 were the following :

- After two days of drying out the soil (something that in practice can occur as a result of wind), the berries and leaves started to show signs of flaccidness. There was also a decrease in the colour of the berries as they started to soften and became less turgid;

- ABA concentrations increased in the leaves during the drying period; photosynthetic activity decreased during the period of drying and this was related to the decline in the water potential. This can be ascribed to the higher stomatal resistance. The photochemical deterioration of photosynthesis, accompanied by the stomatal closure (high stomatal resistance) had a collective effect on the fixation of CO_2 (Pharis & Reid, 1984).

When the plant experiences water stress, there will be a build-up of ABA in the leaves. This growth regulator functions primarily as an inhibitory growth regulator. The flux of potassium into the guard cells is reduced by the presence of ABA and will lead to stomatal closure. The ABA that accumulates in the leaves therefore causes the stomata to close (Pharis & Reid, 1984). Increased ABA levels will result from prolonged and severe water stress (Liu *et al.,* 1978). This will result in incomplete recovery of the photosynthetic potential despite the fact that the plant has not lost its stomatal functions (Liu *et al.,* 1978).

Leaves might not experience stress but ABA can cause stomatal closure due to the fact that the roots are experiencing stress (Pharis & Reid, 1984). It is because the stress in the roots acts as a signal to the plant and the plant responds by producing ABA in the roots. ABA is then transported from the roots *via* the xylem to the leaves where, in response, the stomata close. Other growth regulators also affect the stomatal mechanism, but, except for cytokinins, their function is described as secondary. Cytokinins affect important processes such as ion uptake, photosynthetic rate and nutrient flow (Pharis & Reid, 1984).

2.3.3 VEGETATIVE AND REPRODUCTIVE GROWTH

Freeman *et al.* (1982), Kobriger *et al.* (1984), Dry and Botting (1993), Bettiga *et al.* (1996) and Campbell-Clause (1998) investigated the response of vines exposed to wind compared to sheltered vines. Some of the results are summarised in Tables 2, 1, 3 & 4.

The difference in response between reproductive and vegetative parameters to wind contributed to a lower fruit yield:pruning mass ratio for sheltered

Chardonnay vines (Table 2) (Bettiga *et al.,* 1996). This can cause imbalance in the vines (Dry & Botting, 1993).

Table 1. Growth response of Cabernet franc to wind (Dry & Botting, 1993)

Parameters	Sheltered vines (Mean wind speed of <4 $m.s^{-1}$)	Exposed vines (Mean wind speed of >4 $m.s^{-1}$)
Vegetative growth		
Shoot number per meter cordon	46	50*
Shoot length (cm)	105	62**
Node number per shoot	15.9	13.4*
Mean internode length (cm)	6.6	4.6*
Mean mass per cane (g)	33.5	17**
Pruning mass per meter cordon (kg/m)	1.63	0.85**
Yield		
Inflorescence number per meter cordon	74	62
Inflorescence/shoot	1.53	1.41
Canopy density in fruit zone		
Leaf layer number	4.7	4.1*
% Shaded leaves	58	55 ^{ns}
% Shaded bunches	96	88 ^{ns}

* significant at $p \leq 0.05$ ** significant at $p \leq 0.01$ ns = non-significant

Sheltered Chardonnay vines had a higher total leaf area compared to exposed vines. Both primary and lateral leaf surface areas were larger than those of exposed vines (Table 2). According to Bettiga *et al.* (1996), the primary leaves of sheltered vines were 40% bigger compared to those of exposed vines, while the lateral leaves were 30% bigger. The increased leaf area in sheltered vines was ascribed to both number and individual leaf size. Sheltered Cabernet franc vines also had a higher canopy density in the fruiting zone (Table 1)(Dry & Botting, 1993). Sheltered Chardonnay vines had a higher pH and lower titratable acid concentration in the berries. This was the effect of increased potassium in berries (Table 4) – the result of shading (Bettiga *et al.*, 1996; Hunter, 2000).

Table 2. The effect of wind on vegetative growth parameters of Chardonnay grapes (Bettiga *et al.*, 1996)

Parameters	Exposed vines (Mean. wind speed of >4 $m.s^{-1}$)	Sheltered vines (Mean. wind speed of <4 $m.s^{-1}$)
Mean. leaf area (per leaf)		
On primary shoots (cm^2)	88	123**
On lateral shoots (cm^2)	31	40**
Total leaf area per vine		
Primary (m^2)	6.6	12.2**
Lateral (m^2)	2.6	3.5**
Total (m^2)	8.9	15.8**
Number of nodes per shoot	19	20 ^{ns}
Internode length (cm)	4.6	5.8**
Pruning mass/vine (kg)	1.7	2.9*
Yield: pruning mass ratio	4.3	3.0**

* significant at $p \leq 0.05$ ** significant at $p \leq 0.01$ ns = non-significant

Table 3. The effect of wind on yield parameters of Chardonnay grapes (Bettiga *et al.*, 1996)

Parameters	Exposed vines (avg. wind speed of >4 $m.s^{-1}$)	Sheltered vines (avg. wind speed of <4 $m.s^{-1}$)
Yield per vine (kg)	7.8	9.0*
Bunches per vine	66	70*
Bunch mass (g)	119	131**
Berries per bunch	83	88**
Berry weight (g)	1.44	1.46 ^{ns}

* significant at $p \leq 0.05$ ** significant at $p \leq 0.01$ ns = non-significant

Table 4. The effect of wind on the fruit composition of Chardonnay grapes (Bettiga *et al.*, 1996)

Parameters	Exposed vines (avg. wind speed of >4 $m.s^{-1}$)	Sheltered vines (avg. wind speed of <4 $m.s^{-1}$)
Soluble solids (°B)	22.2	22.3 ^{ns}
Titratable acidity (g/l)	7.6	7.0**
pH	3.45	3.51**

* significant at $p \leq 0.05$ ** significant at $p \leq 0.01$ ns = non-significant

Sheltered Cabernet franc vines had longer shoots than the exposed vines (Table 1). This could be ascribed to there being more nodes per shoot (Dry & Botting, 1993) and longer internodes (Dry & Botting, 1993; Bettiga *et al.*, 1996). The longer shoots were heavier for Cabernet franc and, together with the increased shoot thickness, ultimately resulted in a higher pruning mass compared to exposed vines. Exposed Cabernet franc vines had more shoots per meter cordon (Table 1), but the ratio of long shoots (longer than 75 cm) to short shoots (shorter than 50 cm) for sheltered vines was higher. Both exposed and sheltered vines were spur pruned. Exposed Chardonnay and Cabernet franc vines had the same percentage of short shoots relative to sheltered vines, but had fewer shoots exceeding 50 cm (Dry & Botting, 1993; Bettiga *et al.*, 1996). Contradictory to these results were the findings of Hamilton (1989), where shoot length, number and weight were unchanged by the provision of shelter.

The yield of exposed Chardonnay vines was considerably lower than that of the sheltered vines (Table 3). Bunches of sheltered vines had more berries per bunch. The bud fertility of sheltered vines was higher, resulting in more bunches per meter cordon (Bettiga *et al.*, 1996). The yield:pruning mass ratio of sheltered Chardonnay and Cabernet franc vines was lower, mainly because of higher vigour (Tables 1 & 2). The higher yield of the sheltered vines could be attributed to better initiation and development of the primordia, better berry set and/or more flowers per bunch. High canopy density could, however, neutralise this positive effect (Dry & Botting, 1993). The sheltered vines and exposed Chardonnay vines reached maturity at more or less the same time, despite the fact that the sheltered vines had a higher yield (Bettiga *et al.*, 1996).

2.3.4 BERRY AND WINE COMPOSITION

There is a specific relationship between the microclimate and the chemical composition of the berries and bunches of Sauvignon blanc (Marais *et al.*, 1999). The effect of wind on berry and wine composition is multidimensional. The indirect effect of the wind impacts on the aroma composition through its effect on temperature, humidity, water relations, solar radiation, etc. (see 2.2.4).

According to Heymann, Noble & Boulton (1986) and Morrison & Noble (1990), the interaction between solar radiation and temperature is a complex phenomenon and, although these are not the only two factors affecting aroma, they are considered the most important (Morrison & Noble, 1990). Other factors such as the nutrient status, irrigation cycles and soil water status have an effect on the growth patterns of the vine and its vigour (Heymann *et al.,* 1986). This determines the canopy dimensions and density, and the microclimate. The latter includes air movements that ultimately affect the exposure to sunlight and temperature of the berries and this, in the end, will have an important impact on the composition of grape aroma (Marais *et al.*, 1999).

According to measurements obtained by Rojas-Lara & Morrison (1989), minimal temperature differences were found between the temperature inside the bunch and the temperature around the bunch. This was ascribed to the movement of air between bunches. This movement had an equalising effect on temperature, thus a positive cooling effect, specifically with regard to Sauvignon blanc grapes and the production of methoxypyrazines (Marais *et al.,* 1999). Decreasing concentrations of monoterpenes were found with increasing canopy density, while levels of methoxypyrazines decreased with increasing exposure to sunlight (Marais *et al.,* 1999).

The effect of solar radiation, in contrast to that of the temperature, was more significant for Sauvignon blanc grapes (Marais *et al.*, 1999). This was also the finding of by Morrison & Noble (1990) for Cabernet Sauvignon grapes. They suggested that the effect of leaf shading on the development of aromas and flavours in the berries was predominantly due to reduced light intensity in the canopy, rather than temperature variation. Interference in the natural growth of the vines by means of canopy management practices altered the microclimate and ultimately the grape composition and wine styles that were the result of these various conditions (Marais *et al.,* 1999). This was due to the effect of these practices on enzyme activity that regulated the metabolism of the aromatic components and compounds (Morrison & Noble, 1990).

Potassium uptake into the berries affects the pH of the grapes (Hamilton, 1989). High potassium levels in the berries are unfavourable as they cause high pH values in the grape juice (Robinson, 1994). These high levels can be the result of dense canopies with poor exposure to light and air flow (Jackson & Lombard, 1993) causing an increase in temperature, a higher respiration rate, and thus lower photosynthetic activity (Hamilton, 1989). In association with the higher temperatures and possible inhibited photosynthesis, there may be an increased rate of potassium transport, causing lower titratable acidity and a higher pH at similar sugar concentrations. This was typically found in the case of sheltered vines (Hamilton, 1989; Bettiga *et al.*, 1996)(Table 4).

2.3.5 DISEASES

The effects of wind on grapevine diseases are interlinked with temperature and relative humidity. This relationship was found to affect the development of aerial mycelium and the number of conidia of *Botrytis cinerea* produced on grape berries (Thomas, Marois & English, 1988). The result of wind was ascribed to its effect on evaporative potential. A strong empirical relationship was discovered between evaporative potential and wind speed in studies performed in a growth chamber (Thomas *et al.*, 1988). The removal of leaves in the bunch zone increased air movement and effectively reduced *Botrytis cinerea* (Thomas *et al.*, 1988).

In the same way, wind speeds of 3 $m.s^{-1}$ to 4 $m.s^{-1}$ increased the dispersal of conidia of *Uncinula necator* (Willocquet *et al.*, 1998). Wind was the indirect cause of conidia dispersal of *Uncinula necator* as a result of leaf movement (shaking). Greater wind speeds resulted in higher frequency of *Uncinula necator* and the dispersal of its conidia. This effect was amplified by gusts of wind. The conidia, however, were not dispersed by the prevailing wind before they had been dislodged from the leaves by some form of mechanical intervention. Leaf movement represented an essential mechanism for dislodging the conidia (Willocquet *et al.*, 1998). Alterations made to the canopy resulted in a better flow of wind through the canopy. This changed the microclimate (especially the humidity) in and around the canopy.

2.4 THE MANAGEMENT OF WIND IN VITICULTURE

2.4.1 LONG-TERM PRACTICES

The decisions concerning normal long-term practices are not as much affected by wind as by other climatic factors such as temperature or radiation. On the other hand, strong winds often cause devastating physical damage to vines. These effects can be limited by good long-term management practices such as establishing windbreaks, correct trellis systems, etc. (Archer, personal communication). The essence of quality grape production lies in cautious **site selection**. Site selection is rarely a free choice and there are always other factors to consider (Davidson, 1992) such as farm infrastructure, adjacent vineyard blocks, etc. The interaction between wind, other climatic factors and topography, however, cannot be ignored (Davidson, 1992). For **cultivar choice,** it is essential to know the cultivar's inherent resistance to wind. Some cultivars are more resistant to wind than others. It is better to plant a cultivar that has some resistance to wind on an exposed site.

Examples of cultivars that are sensitive to wind damage (Orffer, 1979; Kerridge & Antcliff, 1999) are:

- Colombar - susceptible to damage in the early parts of the season;
- Merlot noir – shoots break and tumble;
- Palomino – bunches are often blown off by strong winds;
- Sémillon – highly susceptible during early season;
- Shiraz – moderately susceptible to wind damage;
- Tinta Barocca – sensitive to wind damage;
- Trebbiano - susceptible to damage.

Examples of cultivars that are resistant to wind damage (Orffer, 1979; Kerridge & Antcliff, 1999) are:

- Riesling – tolerant to wind;
- Weisser Riesling – fairly tolerant to wind;
- Cabernet franc - fairly tolerant to wind;
- Cabernet Sauvignon - tolerant to wind;
- Chenin blanc – highly tolerant to wind.

The choice of **row direction** is determined by factors such as topography, prevailing wind direction, irrigation needs and soil types. The amount of direct sunlight and its effect on temperature and canopy growth should also be taken into account (Coombe & Dry, 1992). Under South African conditions, a north-south row direction is perceived to be warmer in comparison to rows that are planted east to west. Wind tends to blow the foliage to one side of the canopy with rows orientated diagonally to the prevailing wind. This causes young berries to be exposed to severe sunburn (Coombe & Dry, 1992). In cool climates, vines planted at a right angle to the prevailing wind will trap more warm air in the canopy. Rows that are planted parallel to the prevailing wind are unlikely to have this problem. Canopies parallel to the prevailing wind dry off faster after rain and the probability of diseases is less. In warm climates, rows planted in the same direction as the prevailing wind will benefit from the cooling effect of the wind. It will also reduce the relative humidity in the vineyard, thus decreasing the chance of problems with disease (Dry, 1993; Dry & Botting, 1993).

In vineyards exposed to wind, a **trellis system** with additional foliage wires renders better protection against wind damage. It reduces the rolling of the foliage on the lee side, as well as shoot breakage (Coombe & Dry, 1992). Where vines are trained on a vertical multi-wired trellis system with movable wires and are exposed to severe winds, the movable wires can be tied together. Instead of shoots experiencing the force of the wind individually, the foliage will oscillate collectively (Archer, personal communication).

2.4.2 WINDBREAKS

Windbreaks are reputed to improve the microclimate in vineyards (Ludvigsen, 1989). An improved microclimate lessens the transpiration rate and evaporation, leading to a quicker recovery of plant water status and, therefore, more favourable conditions for photosynthesis and other physiological processes (Hamlet, 2000).

Research showed that, by reducing the wind speed with tree windbreaks, the productivity of crops increased by 5-25% (Brandle, Johnson & Akeson, 1992). Bettiga *et al.* (1996) conducted a study to investigate the effect of windbreaks on microclimatic parameters. The measured wind speed above the canopy for sheltered and exposed vineyards was 1.7 $m.s^{-1}$ and 3.5 $m.s^{-1}$ respectively. The researchers reported significant air temperature differences, measured inside and outside the canopy. The vineyard sheltered by a windbreak recorded slightly lower temperatures (~1°C) than the control. Slight variations (~2% decrease) in relative humidity were also observed (Bettiga *et al.*, 1996).

The most important factor to consider when planting or constructing a windbreak is its design. This is dependent upon the following factors (Hamilton, 1989):

- The total area that needs protection against the wind;
- The prevailing wind direction for the region and/or vineyard;
- The topographic aspects of the landscape;
- The material or tree specie(s) to be used for the windbreak;
- The maintenance and management of the windbreak.

The advantages of windbreaks are that they (Hamilton, 1989; Ludvigsen, 1989):

- Reduce wind speed and alter the path of direction of the prevailing wind;
- Reduce the burning and wilting effect of the wind;
- Increase availability of moist air as the result of dew formation;
- Reduce the rates of transpiration and evapotranspiration;
- Have the potential to alter soil and air temperatures.

Artificial windbreaks have an advantage over **natural windbreaks** in that they are immediate in their effect (Ludvigsen, 1989). Planting natural windbreaks within existing vineyards does not solve the immediate problem, but is a medium-term or long-term solution. In South Africa this problem is solved by establishing natural windbreaks three years before the vines are planted (Archer, personal communication). Artificial windbreaks, however, limit the wind effectively as soon as they are constructed and they will therefore increase yields of existing vineyards in the following year (Ludvigsen, 1989).

Both natural and artificial windbreaks have their disadvantages (Ludvigsen, 1989):

Artificial windbreaks are disadvantaged by:

- Higher financial implications for they are more expensive to construct;
- Limited durability of materials and/or cloth used for construction;
- Higher frequency of windbreaks are needed for them to be effective.

Natural windbreaks are disadvantaged by:

- Trees taking a longer time to become effective for this is dependent on the growth rate of the trees;
- Trees causing shading that will negatively affect the yield of the vineyard and composition of the berries;
- The possibility of being a fire hazard;
- Trees creating a habitat for pest insects to nest;
- Natural windbreaks being a potential alternative host for crop diseases;
- Trees forming competitive root systems with the crop plants.

It must be realised that it will never be possible to stop the wind and thus windbreaks act more as **"windfilters"**, altering the speed and direction of the wind (Archer, personal communication). Well-constructed windfilters reduce shoot breakage and other physical damage caused by high-velocity winds. They also improve the vegetative performance of vines in windy areas (Dry & Botting, 1993). Wind or air approaching the windfilter, however, will form a high-pressure area in front of the windfilter on the windward side and push the air over the top of the windfilter into the low-pressure area on the leeward side (Plummer, 1990). This effect is more pronounced in the case of solid windbreaks than in the case of permeable windfilters.

When windfilters reduce wind speed, they create a drag force on the wind field. They create a triangular wind-free area on the leeward side. This area is called the "quiet" zone because it experiences less turbulence. Downwind from the "quiet" zone is the turbulent "wake" zone (Hamlet, 2000).

The physical damage caused by wind in vineyards is a result of turbulence caused by the meeting of different air currents that have diverse velocities. The amount of turbulence is directly related to the wind speed: the higher the wind speed, the lower the amount of turbulence behind the windbreak (Plummer, 1990). High-pressure air that flows over the windbreak will be sucked into the low-pressure area behind the windbreak, where there will be a mixing of air, creating turbulence (Plummer, 1990). When the porosity of the windfilter is poor and the original wind speed is high, the amount of turbulence will increase and will be closer to the windfilter (Plummer, 1990). This is the problem with solid windbreaks, for they will significantly reduce the wind speed, but will amplify the turbulence. The object when building or planting a windfilter then is to find the balance between significantly reducing the wind speed and diminishing the chances for turbulence. This balance is obtained with a proper windfilter design, that allows the desired amount of air to pass through it (Plummer, 1990).

The **"quiet" zone** entails a triangular area behind the windfilter and is bound by a line from the top of the windfilter to about 8*h* (Fig. 4) (Brandle, Hintz & Sturrock, 1988), where 8*h* refers to the distance from the windfilter and is equal to 8 times the height of the windfilter. Wind currents in the "quiet" zone are reduced considerably, resulting in less turbulence and wind fluctuation (Brandle *et al.*, 1988).

The **"wake" zone** (Fig. 4) extends from 8*h* and continues further downwind to 16*h*. Here the turbulence increases and currents again join with the upwind velocities (Brandle *et al.*, 1988). Heat and mass transfers are enhanced, resulting in lower daytime temperatures and humidity over the crops (Brandle *et al.*, 1988).

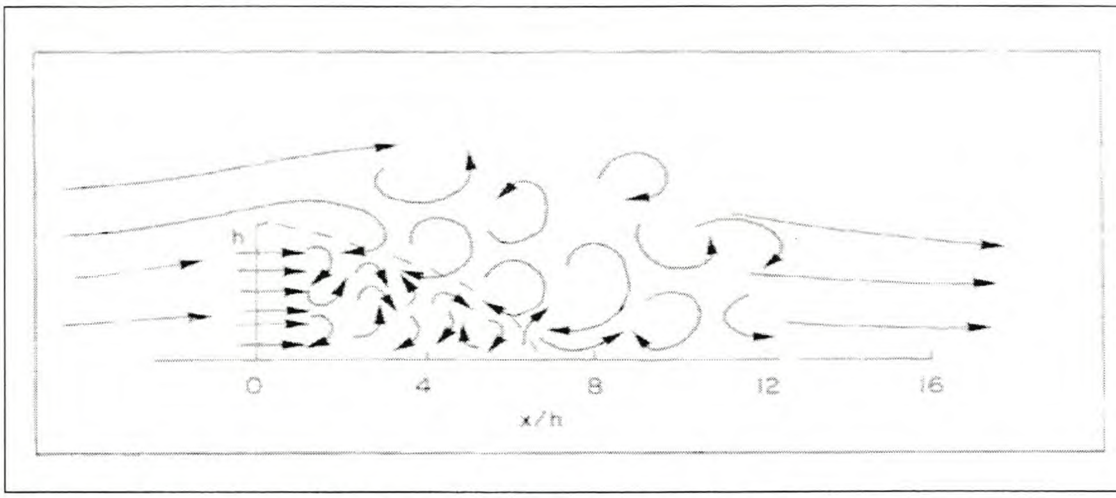

Figure 4. An illustration of the turbulence behind a windbreak (Brandle et al., 1988)

The **distance between windfilters** is determined by economic factors and major topographic features (Plummer, 1990). This includes the cost and benefits of erecting the windfilters and whether this is financially viable; the windiness of the area, in conjunction with the mesoclimate and the value of the crop and its sensitivity to wind (Plummer, 1990). The last mentioned is essential because various cultivars have diverse susceptibility to wind. It is suggested that the distance between consecutive windfilters be a minimum of 10 to 20 times the height of the preceding windfilter for maximum protection (Plummer, 1990). An increase in the height of the windfilter will result in a more effective and greater area of protection. It is recommended that the distance between the windfilters on sloping ground should be 12 to 14 times the height of the windfilters, while in an area with little or no slope the distance between the windfilters can be up to 20 times the height of the windfilters (Plummer, 1990; Bettiga *et al.*, 1996).

The most effective windfilter is one that is perpendicular to the prevailing wind (Hamlet, 2000). With every deviation of 30°, the effectivity of the windfilter decreases by approximately 10% and the area that is protected will diminish considerably (Bettiga *et al.*, 1996). The height:length ratio is essential for optimum protection of crops so it is suggested that the **length of the windfilter** should, at least, be 11 times its height, but at best it should be 15 times the length of the original height of the windfilter (Hamlet, 2000).

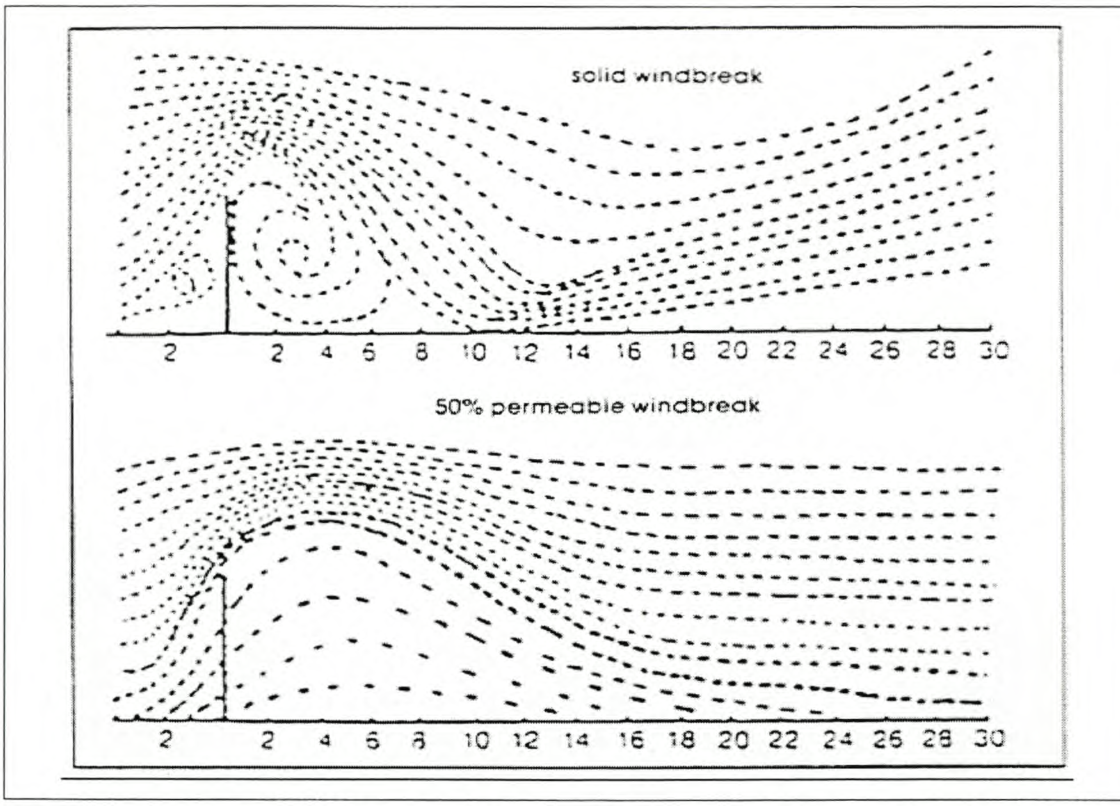

Figure 5. The airflow over a solid windbreak, compared to a windbreak with 50% permeability (Plummer, 1990)

A narrow windfilter will be most effective and its effect will increase with the increase in length of the windfilter (Plummer, 1990). It is important that the windfilter has a **permeability** of 40 – 60%. The dotted lines in the bottom part of Fig. 5 represent airflow through and around the windfilter. The low density of these lines is a clear indication of less turbulence in the "quiet" zone, just as the far scattered dotted lines are an indication of lower wind velocity. However, no holes should occur in the windfilter. A large, single hole will enhance the wind speed through the hole. This hole will act as a funnel and will result in serious damage (Plummer, 1990). The permeability of the windfilter determines to what extent the windfilter will condense the kinetic force of the wind by filtering the airflow. A solid, impermeable obstruction will only deflect the wind and will result in a very small wind free zone on the leeward side, due to the vast differences in pressure creating turbulence (Plummer, 1990). The high density of dotted lines in the upper part of Fig. 5 illustrates this turbulence in the "quiet" zone and high velocity winds on the leeward side.

2.4.3 SHORT-TERM PRACTICES

Wind patterns on a microclimatic scale are complex. A close relationship exists between wind speed inside the canopy and the canopy density. Inside a dense canopy, less airflow occurs as a result of interference by the leaves (Smart & Robinson, 1991). By decreasing the density of the canopy, the positive effects of the wind can be emphasised.

One of the aims of **canopy management** is to manipulate the microclimate by altering canopy density (Smart & Robinson, 1991). Canopy management refers to a variety of viticultural techniques applied to alter the amount of leaves and shoots and their positioning, and to achieve the desired arrangement of shoots and bunches (Coombe & Dry, 1992). Changing the density of vineyard canopies impacts on the flow of air through the vegetation, thereby altering the temperatures around the bunches and leaves.

Pruning has significant implications for the functioning of the vine. It firstly determines the potential shoot positioning and density (Smart & Robinson, 1991). Pruning also affects the quality and quantity of fruit production, the balance between the reproductive and vegetative growth of the vine, and the size and form of the vine (Coombe & Dry, 1992). Although it is not the determining factor, wind will affect the decision of whether the pruned vines will be left with short spurs or long canes (Jackson & Lombard, 1993); spur-pruned vines are more resistant to wind damage than cane-pruned vines.

2.5 SUMMARY AND CONCLUSIONS

Wind is regarded as a part of *terroir* because it interacts with other environmental elements. It has direct and/or indirect effects on the vegetative and reproductive performance of the grapevine. Canopy characteristics and thus microclimate and, therefore, also all the physiological processes in the vine are affected by wind.

Sheltered vines have longer shoots, more leaves and a reduced yield:pruning mass ratio. The chemical composition of the berries changes due to increased canopy density and shading of sheltered vines. This causes an increase in the concentration of juice potassium and therefore an increase in pH and decrease in acidity. Hence, canopy management practices will need to be adjusted for sheltered vines to optimise the yield response, by ensuring reduced canopy density so as to emphasize the positive temperature effects of wind I the canopy.

Wind affects grapevine physiology through altering stomatal conductance. A close relationship exists between stomatal conductance, photosynthesis and transpiration. Stomatal conductance is reduced by wind, reducing the photosynthetic activity and transpiration rate. The translocation processes and hormone distribution in the vine are therefore altered.

Further studies need to be conducted on grapevines to establish the precise effect of wind on the interaction between stomatal conductance, its mechanism of closure and growth regulators. In this regard, the role of growth regulators such as ABA should not be underestimated. Furthermore, the possible impact of thigmomorphogenesis on vines also needs to be examined. Even though it is only specific to certain plant species, the literature gives a strong indication of its potential effect on grapevines.

By quantifying the effect of wind on grapevine performance, a contribution can be made to proper evaluation of *terroir*. This quantification will supply a sounder basis for choosing sites, implementing windfilters, adjusting long- and short-term practices and managing airflow for better viticultural results.

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Chapter 3

RESEARCH RESULTS

The effect of wind on the performance of *Vitis vinifera* L. cv. Merlot noir in the South Western Cape region of South Africa. I. Vegetative growth, canopy density, stomatal conductance

CHAPTER 3

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3.2 ABSTRACT

The effect of wind on vegetative parameters of *Vitis vinifera* L. cv. Merlot was investigated over a period of two years in a windy area in the South Western Cape region of South Africa. Significant variations in wind speed were measured spatially in the vineyard and different growth responses were observed between exposed and sheltered vines. Vines receiving less wind characteristically had higher pruning mass, larger primary leaves and longer shoots. Vines exposed to winds of up to 10 $m.s^{-1}$ responded with decreased stomatal conductance and decreased growth. The effect of lower stomatal conductance of exposed leaves has potential implications for other physiological processes as it may reduce photosynthetic activity and transpiration. Although sheltered vines were expected to have higher canopy density, no significant differences were evident. This was explained by increased lateral growth in the fruiting zone of exposed vines.

Key words: Wind-protected vines, wind-exposed vines, wind speed, canopy density, stomatal conductance

3.3 INTRODUCTION

Studies conducted by Le Roux (1974), Saayman (1981), Carey & Bonnardot (2000), Carey (2001) and Bonnardot *et al.* (2001, 2002) laid the foundation for *terroir* studies and viticultural zoning in the South Western Cape region of South Africa. Despite the generally accepted importance of the sea breeze effect for viticulture in this region (Bonnardot *et al.*, 2002), knowledge concerning the effect of wind on the physiology and vegetative performance of the grapevine is not conclusive for South African viticultural conditions. Both positive and negative effects of wind have been experienced. In spring and summer, vineyards are exposed to persistent strong southeasterly winds (Kendrew, 1961) and moderate sea-breezes in the coastal regions (Bonnardot *et al.*, 2002). The effect of wind therefore can not be ignored.

According to Bettiga *et al.* (1996), sheltered vines of Chardonnay grapes have higher leaf area surface than exposed vines for both primary and secondary leaves. Sheltered vines of Cabernet franc grapes have also been found to have higher canopy density in their fruiting zone (Dry & Botting, 1993). This could be associated with higher berry pH and lower titratable acid concentrations as a result of shading and concomitant increased levels of potassium (Bettiga *et al.*, 1996; Hunter, 2000). Sheltered vines had longer shoots due to having more nodes and longer internodes (Dry & Botting, 1993). Exposed vines had a lower pruning mass even though they had more shoots per meter cordon (Dry & Botting, 1993). This was due to the longer and heavier shoots of sheltered vines (Dry & Botting, 1993).But Hamilton (1989) obtained contradictory results, having found no differences in shoot length, number or weight of sheltered and exposed vines.

Exposed Chardonnay (Freeman *et al.*, 1982) and Cabernet franc (Dry & Botting, 1993) grapevines, were found to have lower stomatal conductance than sheltered vines.

Persistent moderate winds (3-6 $m.s^{-1}$) and occasional strong to gale-force winds (>6 $m.s^{-1}$) in the South Western Cape grape-growing region of South Africa may possibly retard vegetative growth but the effect of moderate winds (3-6 $m.s^{-1}$) on grapevine performance has not yet been quantified in this region. This paper focuses on the effect of wind on the vegetative response of the grapevine, namely growth changes that are morphologically measurable.

This paper furthermore investigates the effect of wind on stomatal conductance to quantify the effect of wind on vegetative characteristics and physiological performance of Merlot.

3.4 MATERIALS AND METHODS

3.4.1 VINEYARD CHARACTERISTICS

The study was conducted on *Vitis vinifera* L. cv. Merlot, clone 36A, grafted onto 110 Richter (*Vitis Berlandieri* var. Rességuier nr.2 X *Vitis rupestris* var. Martin). The 1,9 ha commercial vineyard in which the experiment was conducted was established in 1995. The vineyard received supplementary drip irrigation twice a week for three hours at a time. This continued up to a fortnight prior to the projected harvest. Vines were split-cordon trained and vertically trellised. The cordon was 0,70 m above ground level and the trellis height was at 1,80 m. The vines were spaced 3,0 m x 1,20 m. The rows in this vineyard were planted in an east-west direction. The soil consisted of stony and rocky Glenrosa with Malmesbury shale as parent material. The soil characteristics were uniform throughout the experimental vineyard (Saayman, personal communication, 2005). Observed differences in exposure to wind in the vineyard occurred as a result of topographical variation and a windbreak. On the eastern side, the windbreak protected the vineyard from southeasterly winds, while the northwestern side of the vineyard was better protected against the predominant southeasterly wind as a result of slope and aspect. A further slope decline from the southeastern to the northwestern side of the vineyard allowed more protection for the vines at the bottom of the slope (the northern side) (Addenda A & B). The vines were pruned to 12 to 14 buds per meter of cordon (6 to 7 two-bud spurs) and suckered to 12 to 14 shoots per meter. Shoots were positioned with the aid of movable foliage wires and random leaf removal according to the method proposed by Hunter (2000) was performed in January, at the beginning of ripening. Rather than topping a specific number of times, this was only done to maintain shoot lengths at 30 cm above the top foliage wire.

3.4.2 EXPERIMENTAL LAYOUT

Thirty experimental sites of 14 grapevines were identified in the Merlot vineyard in January 2002. Weekly readings with the hand-held anemometer were performed during the period middle January to end February 2002 and were analysed to identify a pattern of wind exposure in this vineyard. Based on these measurements, 14 of the 30 sites were identified as relatively wind-sheltered and 16 as relatively wind-exposed sites. There were ca. 30 buffer vines between the adjacent experimental sites.

3.4.3 MEASUREMENT OF WIND SPEED

Four stationary anemometers (represented as stations) (Mike Cotton design, MC Systems) were strategically positioned among the 30 sites based on the final classification (Fig. 1):

1. Station 1 – 5 rows from the southern boundary of the vineyard, between sites 4 and 5
2. Station 2 – 10 rows from the southern boundary of the vineyard, between sites 11 and 12
3. Station 3 – middle row of the vineyard, between sites 17 and 18
4. Station 4 – 10 rows from the northern boundary of the vineyard, between sites 21 and 22

Between the different stations were four to five buffer rows. The anemometers were mounted at a height of 2 m above the ground. The hourly data were recorded on a MC Systems 486T data logger, and downloaded on a weekly basis. Wind-speed data were measured from before veraison till the end of harvest (25/11/2002 – 15/04/2003).

3.4.4 VINEYARD MEASUREMENTS

3.4.4.1 CANOPY MEASUREMENTS

Canopy density was determined by means of the point quadrat method (Smart & Robinson, 1991). The measurements were performed in the bunch zone, ca. 100 cm above ground level. These measurements were performed during the last week of January in 2002 and 2003 and repeated in the first week of February in 2002 and 2003. One insertion per reference vine was made, resulting in 196 and 224 insertions respectively for the sheltered and the exposed treatments, per measurement day.

Canopy density was also determined by measuring light intensity inside the canopy, using a Decagon Sunfleck ceptometer. Measurements were performed at 100 cm above ground level between 10:00 and 14:00 on clear, sunny days.

One reading per reference vine was taken, resulting in 196 and 224 readings respectively for the sheltered and the exposed treatments, per measurement period. These readings were repeated twice per season for 2002 and 2003 – during the last week of January and the first week of February.

3.4.4.2 PHYSIOLOGICAL MEASUREMENTS

Stomatal conductance and temperature of intact leaves were measured in the field, with a PP Systems porometer. Shoots were selected at random on the reference vines and measurements were performed on leaves situated on node numbers 6 to 8 (120 cm above ground level). One leaf per shoot per vine was measured, resulting in 196 and 224 readings respectively for the sheltered and the exposed treatments, per measurement day. This was done between 09:00 and 11:00 on clear, sunny days. These readings were repeated twice per season for 2002 and 2003 – during the last week of January and the first week of February.

3.4.4.3 LEAF MEASUREMENTS

Leaf sampling involved the removal of whole shoots from the vines, using seven shoots per experimental plot. Shoots were selected at random and were put in plastic bags to ensure that no loss of leaves occurred while being transported to the storage facilities. The leaves were stored overnight at 4°C after sampling. The leaf area measurements were conducted in a laboratory, using a LI-COR Li-3000 leaf area meter. Leaf area of primary and lateral shoots was determined separately.

3.4.4.4 CANE MEASUREMENTS

Cane sampling was performed at the end of June in 2002 and 2003 and involved the removal of 14 canes from each experimental site. These canes were selected at random. Cane mass was measured in the vineyard, using a 100N pull scale. After sampling the canes were stored at 12°C for less than 4 days.

Both the diameter and the mass of individual canes were measured in the laboratory. Using the same material, cane length and internode length were measured and node number per cane was counted.

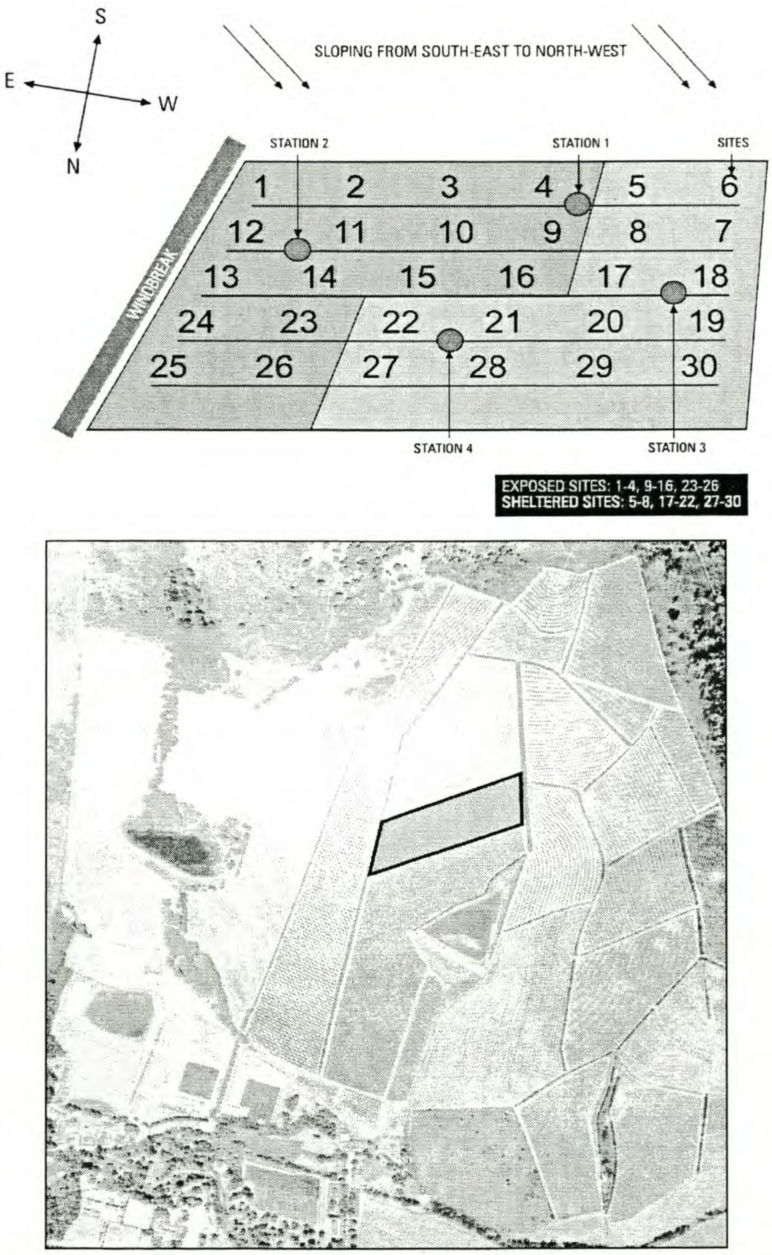


Figure 1. Layout of the experimental sites situated in the vineyard at Somerset West, in the South Western Cape. There were 4 to 5 buffer rows between the different stations and approximately 25 to 30 buffer vines between the adjacent sites.

Figure 1. Layout of the experimental sites situated in the vineyard at Somerset West, in the South Western Cape. There were 4 to 5 buffer rows between the different stations and approximately 25 to 30 buffer vines between the adjacent sites.

3.4.5 STATISTICAL ANALYSES

The data were analysed by using the t-test of equal variance. The Folded F-test was implemented to investigate the homogeneity of variance, together with the Shapiro-Wilk test, which verifies the normality of the statistics. No transformations or non-parametric tests were carried out on the data.

3.5 RESULTS AND DISCUSSION

3.5.1 WIND VELOCITY

Wind direction was noted from official weather forecasts. Typical wind conditions were recorded for the 2002/2003 season, with respect to the measurement of the prevailing southerly and southeasterly winds.

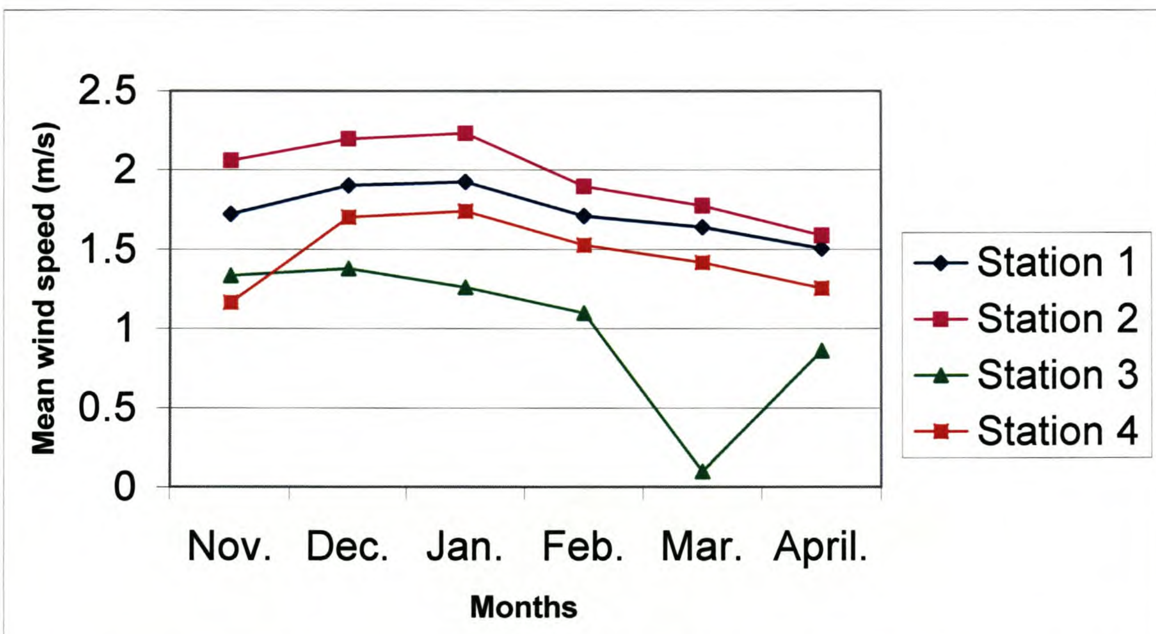
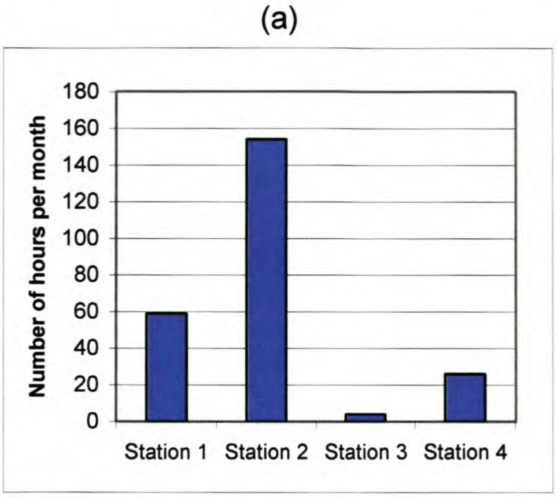


Figure 2. Mean monthly wind speed for period 2002/11/02 to 2003/04/15 recorded at four anemometers situated in a Merlot vineyard in Somerset West in the South Western Cape. Stations 1 and 2 represent exposed sites and stations 3 and 4 represent sheltered sites.

Mean monthly wind speed differed at the positions of each of the four stations. This presented a broad picture of wind variations and included days with little or no wind.



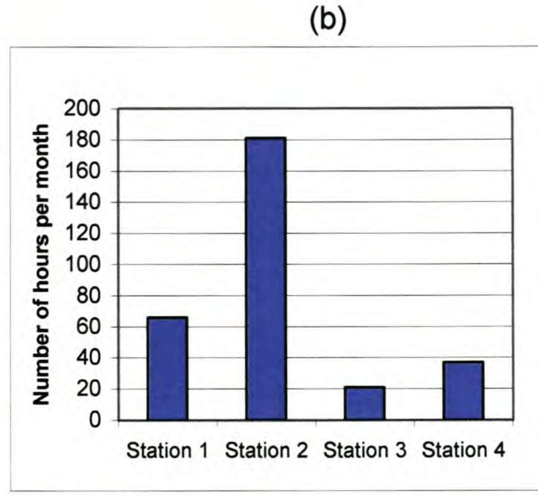


Figure 3. Total number of hours per month at wind speed > 3 m.s^{-1} for period (a) 2002/11/25 – 2002/12/31 and (b) 2003/01/01 – 2003/02/28 recorded at the four anemometer stations situated in the vineyard at Somerset West in the South Western Cape.

Station 2 recorded the highest mean wind speed (1.96 m.s^{-1}), while station 3 recorded the lowest mean wind speed (1.01 m.s^{-1}) throughout the measurement period (2002/11/02 – 2002/04/15) (Fig. 2).

Station 2 recorded the greater number of hours with wind speeds greater than 3 m.s^{-1}, while station 3 recorded the least (Fig. 3). Considering these results, it is evident that stations 1 and 2 represent exposed positions of the vineyard, while stations 3 and 4 signify the sheltered positions of the vineyard. These results confirmed the experimental layout based on measurements made with the handheld anemometer.

3.5.2 GRAPEVINE VEGETATIVE GROWTH

3.5.2.1 CANOPY CHARACTERISTICS

Merlot is a moderately vigorous grower (Orffer, 1979; Kerridge & Antcliff, 1999) and a canopy with long shoots and numerous leaves was therefore expected. The number and total area of the primary leaves of sheltered vines were found to be significantly higher than those of the exposed vines (Table 1). This corresponded to the results obtained by Bettiga *et al.* (1996) for *Vitis vinifera* L. cv. Chardonnay.

Based on literature (Dry, 1993; Dry & Botting, 1993; Bettiga *et al.*, 1996), denser canopies were expected for sheltered vines. In this study however, no significant differences in canopy density were measured using the point quadrat method (Table 2). The practice of leaf removal in early January, prior to the measurements, may have contributed to these inconclusive results. On the NDVI (Normalised Difference Vegetation Index) image for 2002 (Addendum C), no clear distinction could be found with regard to vigour. None-the-less, light-intensity measurements (Table 3) suggested that sheltered vines had less dense canopies, which can be attributed to the fact that exposed vines had a higher number of lateral leaves compared to sheltered vines (Table 1). This could be the result of a natural tipping action the wind causes, stimulating lateral shoot growth. Increased lateral leaves contribute to the production of carbohydrates during the ripening phase (Hunter *et al.* 1994).

Sheltered vines had significantly longer shoots and longer internodes, while the number of nodes per shoot was similar to those of exposed vines (Table 1). Although no physical damage was caused by light, persistent winds, some shoots were damaged by the periodical strong gusts of southeasterly winds (personal observation). Thus, shorter shoots may have resulted from damage and breakages due to wind damage and the sensitivity of Merlot. The shorter shoots of exposed vines were also the result of shorter internodes. No significant difference in shoot diameter was found (Table 1), and shoot length differences appeared to be largely responsible for the higher cane mass of sheltered vines.

Dry & Botting (1993) showed that sheltered Cabernet franc vines had longer shoots and longer internode lengths and reported that sheltered vines had longer shoots due to higher number of nodes per shoot and longer internodes. They further reported that the greater pruning mass of sheltered vines was primarily the result of longer shoots. Bettiga *et al.* (1996) found internode lengths of sheltered Chardonnay vines to be longer, but found no significant difference in number of nodes per shoot. In contrast, Hamilton (1989) had reported no difference in shoot length.

Although it was expected that exposed vines would have thicker shoots, no significant differences in either mean or individual cane mass or shoot diameter were observed (Table 1). Hamilton (1988) similarly reported no differences in cane mass between sheltered and exposed vines.

Table 1. The effect of wind on the vegetative parameters of *Vitis vinifera* L. cv Merlot noir 2002 and 2003, Somerset West, South Western Cape

Parameters	2002 and 2003	
	Exposed	**Sheltered**
Leaf area		
Primary shoots		
Total (cm^2)	1723.9	2324.7*
Mean area per leaf (cm^2)	89.6	111.2*
Number of leaves/shoot	19.3	21.3*
Lateral shoots		
Total (cm^2)	1310.0	1092.6**
Mean area per leaf (cm^2)	31.6	32.9^{ns}
Number of leaves/main shoot	42.0	33.1*
Primary shoot characteristics		
Nodes/cane	23.8	25.3^{ns}
Internode length (cm)	5.19	5.91*
Cane length (cm)	121.3	144.5*
Cane diameter (mm)	8.50	8.48^{ns}
Total cane mass/experimental site (kg)	8.91	9.40^{ns}
Mean cane mass (g)	79.76	77.67^{ns}

* Significant at $p \leq 0.05$, ** significant at $p \leq 0.01$, ns = non-significant

Table 2. The effect of wind on the canopy density of *Vitis vinifera* L. cv Merlot, Somerset West, South Western Cape, 2002 and 2003 season.

Parameters	2002 and 2003	
	Exposed	**Sheltered**
% Gaps	7.35	8.52^{ns}
Leaf layer number	2.21	2.01^{ns}
% Shaded leaves	23.98	20.5^{ns}
% Shaded bunches	63.40	59.99^{ns}

ns = non-significant

3.5.2.2 STOMATAL CONDUCTANCE

Table 3. The effect of exposure to wind on specific physiological parameters in the leaves of *Vitis vinifera* L. cv Merlot 2002 and 2003, Somerset West, South Western Cape

Parameters	2002 and 2003	
	Exposed	**Sheltered**
Leaf temperature (°C)	28.41	30.10*
Light intensity inside the canopy ($\mu E.m^{-2}.s^{-1}$)	92	115*
Stomatal conductance ($\mu mol.m^{-2}.s^{-1}$)	44.04	54.69**

* Significant at $p \leq 0.05$, ** significant at $p \leq 0.01$

The leaf temperature of sheltered vines was significantly higher than that of the leaves of exposed vines (Table 3), with a difference of almost 2°C being recorded (Table 3). This may have been due to increased airflow through exposed canopies resulting in heat dissipation, although a lower transpiration rate as a result of lower stomatal conductance would be expected to increase leaf temperature. Moderate winds will affect transpiration rates of grapevines in a similar pattern compared to stomatal conductance. Transpiration rates of exposed vines are generally considered to be lower than sheltered vines (Kobriger *et al.* 1984). On the other hand, sheltered vines received more direct sunlight in the cluster zone, which is indicative of a more "open" canopy, due to having fewer lateral leaves (Table 1). This may have had implications for leaf temperatures. Increase stomatal conductance of sheltered vines would result in higher assimilation rates further explaining the higher leaf temperature (Freeman *et al.*, 1982).

Exposed vines had significantly lower stomatal conductance than sheltered vines (Table 3). This corresponds with the findings of Kobriger *et al.* (1984); Dry & Botting (1993) and Bettiga *et al.* (1996). The stomata of vines exposed to stronger winds have been found to close faster than those of vines exposed to light winds, with differences of several hours being recorded (Dry, 1993).

It is to be expected that reduced stomatal conductance will lead to reduced levels of photosynthesis. Freeman *et al.* (1982), Kobriger *et al.* (1984) and Dry (1993) had found that moderate winds (3-6 $m.s^{-1}$) reduced photosynthesis through the effect on stomatal conductance. Studies conducted by Takahashi *et al.* (1976), also indicated that wind caused reductions in photosynthesis. This reduction may not, however be linear and deserves further study. The positive cooling effect of wind (Table 3) may have a greater impact on photosynthetic activity than the reduced stomatal conductance.

3.6 CONCLUSIONS

Shelter can be expected to have a significant effect on grapevine performance in windy areas, as the wind reducing factor of shelter on vegetative growth would appear to produce a more effective canopy for photosynthesis due to a greater effective leaf area. Protection from wind also increases stomatal conductance, resulting in a hyperbolic improvement of photosynthetic activity. Adjustment to general canopy management practices, such as trellising and shoot positioning will be necessary to ensure that sheltered vines do not compromise their capacity as net exporters of assimilates. Their larger capacity would be expected to enable sheltered vines to produce and ripen bigger yields in relation to exposed vines.

The wind data suggest that decreasing vegetative parameters, such as shoot length and mean leaf area of primary shoots, as well as stomatal conductance of vines, are not limited to exposure to fresh and/or strong winds only, but also to persistent moderate winds. Information regarding number of hours exposure to wind was more valuable than mean wind speed data.

Based on these results, wind should be regarded as a factor in viticultural zoning, site selection and general management practices. Proper site selection and vineyard layout will enhance the positive contribution of wind towards modern viticulture. Exposure to wind should therefore be regulated to restrict the negative effects and enhance its positive contribution (e.g. reduced temperature).

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Chapter 4

RESEARCH RESULTS

The effect of wind on the performance of *Vitis vinifera* L. cv. Merlot in the South Western Cape region of South Africa. II. Yield, berry composition and wine quality

CHAPTER 4

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4.2 ABSTRACT

The effect of wind on yield, berry composition and wine quality of *Vitis vinifera* L. cv. Merlot was monitored over two years in a coastal vineyard in the South Western Cape region of South Africa. Significant variations in wind speed were measured in the vineyard and differences in yield and berry composition were observed between exposed and sheltered grapevines, with implications for wine quality. The number of bunches per vine was significantly higher for sheltered vines. Although sheltered vines had more bunches, there were fewer berries per bunch and bunches were smaller than those of exposed vines. The potassium concentration and pH of grapes of exposed vines were significantly higher than those of sheltered vines. Grapes from sheltered vines showed less colour and less malic acid than those from exposed vines.

Key words: Wind-exposed vines, Wind-protected vines, wind speed, berry composition and wine quality

4.3 INTRODUCTION

Persistent strong southeasterly winds (Kendrew, 1961) and moderate sea-breezes in the coastal regions (Bonnardot *et al.*, 2002) are characteristic of the coastal vineyards in the South Western Cape. Despite their acknowledged importance in zoning studies (Carey & Bonnardot, 2000), (Carey, 2001) and (Bonnardot *et al.*, 2001 & 2002), the implications of wind exposure for the yield, berry composition and wine quality have not yet been investigated.

The response of the grapevine to wind needs to be quantified in terms of reproductive reactions. This project focuses on the reactions that are morphologically measurable.

Studies in Australia with Cabernet franc grapevines exposed to persistent winds have found that their yield was lower than that of sheltered vines (Dry & Botting, 1993). This was the result of better initiation and development of primordia and higher bud fertility of sheltered vines (Dry & Botting, 1993). These factors contributed to more berries per bunch, as well as more bunches per meter cordon (Dry & Botting, 1993). Bettiga *et al.* (1996) performed a comparable study on Chardonnay grapes, and obtained similar results.

Sheltered vines have been found to have higher berry pH and lower titratable acidity as a result of increased levels of potassium (Hamilton, 1989; Bettiga *et al.*, 1996). High potassium can result from dense canopies (Jackson & Lombard, 1993) and these high levels are unfavourable for wine pH and colour (Robinson, 1994). Higher potassium levels also indicate higher growth rates and denser canopies that in turn will lead to less fertility. A denser canopy also has a greater exposed leaf surface area for transpiration (water loss) that will cause an increase in potassium.

Reduced photosynthetic activity results in lower sucrose concentrations. Potassium will be loaded into the phloem if a sucrose deficiency occurs, increasing concentration levels of potassium in the berries (Freeman *et al.*, 1982).

It is important to bear in mind that the effect of wind might be cultivar specific and that this study focuses on Merlot.

4.4 MATERIALS AND METHODS

4.4.1 VINEYARD CHARACTERISTICS AND EXPERIMENTAL LAYOUT

The study was conducted on *Vitis vinifera* L. cv. Merlot, clone 36A, grafted onto 110 Richter (*Vitis Berlandieri* var. Rességuier nr.2 X *Vitis rupestris* var. Martin). Details of the vineyard characteristics and experimental layout of sites and stationary anemometers have been described in a companion paper (Chapter 3, paragraph 3.4.1 – 3.4.3 & Fig. 1).

4.4.2 VINEYARD MEASUREMENTS

Details of the canopy and physiological measurements have been described in a companion paper (Chapter 3, paragraph 3.4.4.1 – 3.4.4.2).

4.4.2.1 BERRY AND BUNCH MEASUREMENTS

The number of bunches per shoot, berry number per bunch, as well as the berry and bunch mass, were determined. Fourteen bunches per site were harvested at random, sampling one bunch per vine. Grapes were sampled in the early morning (06:00 – 09:00), in mid-February 2002 and 2003, at ca. 22°B. The grapes were stored overnight at -4°C for further measurement and analyses. Grapes were put in plastic bags to ensure that no berry loss occurred while they were being transported to the storage facilities.

The number of bunches per shoot were determined in the vineyard by counting the remains of peduncles after leaf fall. The number of bunches removed for the measurement of other parameters was also taken into account.

4.4.2.2 FRUIT COMPOSITION

Juice samples were prepared by crushing 7 to 8 randomly selected bunches from each site by hand in a glass beaker, separating the juice from the skins through a sieve filter and then filtering the juice for a second time, using Cameo 25 AS acetate filters.

Each juice sample was split to obtain a duplicate sample. The duplicate samples were used to calculate a mean and the standard correction was done on this figure.

Samples were analysed with the Fosscan 2000, using Fourier transform infrared spectrometry. Parameters that were analysed included sugar (°B), individual acid concentration (malic and tartaric), pH, colour (at 420 nm, 520 nm and 620 nm), and potassium concentration. After every sample, the Fosscan 2000 was standardised according to the procedure manual to ensure accurate readings. The titratable acid concentration was also determined manually by the titration method, because of abnormally low Fosscan readings.

4.4.2.3 WINEMAKING

Wine was made by standard small-scale winemaking procedures of the University of Stellenbosch. The grapes were harvested at 22°B between 06:00 and 09:00. They were crushed and pressed, using a basket press. No cold maceration or extended skin contact was allowed. The juice fermented on the skins at 20°C in 20 litre plastic bins and the punch-down method was used twice daily to extract colour. The wine underwent inoculated malolactic fermentation, cold tartrate stabilisation and protein stabilisation by bentonite additions before being filtered and bottled. No wood contact was allowed. Duplicate wines were produced for treatments. They were sensorially evaluated by a trained panel of seven judges and an unstructured line scale (Addendum D) was used to score the wines according to colour intensity, cultivar aroma characteristics, acid balance, body, astringency and global quality.

4.4.3 STATISTICAL ANALYSES

The data were analysed by using the t-test of equal variance. The p-value of this test is an indication of whether there are significant differences concerning the various treatments. The Folded F-test was implemented to investigate the homogeneity of variance, together with the Shapiro-Wilk test that verifies the normality of the statistics. No transformations or non-parametric tests were carried out on the data.

4.5 RESULTS AND DISCUSSION

4.5.1 WIND

Wind speed data were gathered from before veraison till the end of harvest (25/11/2002 – 15/04/2003) (Table 1). Stations 1 and 2 were the most exposed to winds with speeds greater than 3 $m.s^{-1}$, both at pre-veraison stage and between veraison and harvest. These stations recorded more hours per month of moderate winds (3-6 $m.s^{-1}$). Grapevines in the vicinity of stations 1 and 2 were classified as exposed and vines in the vicinity of stations 3 and 4 as sheltered.

Table 1. Summary of wind speed data in a vineyard of *Vitis vinifera* L. cv. Merlot 2002 and 2003 at Somerset West in the South Western Cape region

		Pre-veraison		**Veraison - harvest**	
	Mean wind speed ($m.s^{-1}$)	Hours/month < 3 $m.s^{-1}$	Hours/month > 3 $m.s^{-1}$	Hours/month < 3 $m.s^{-1}$	Hours/month > 3 $m.s^{-1}$
Station 1	1.74	367	59	642	66
Station 2	1.96	348	154	527	181
Station 3	1.01	498	4	687	21
Station 4	1.47	475	26	671	37

4.5.2 GRAPEVINE MEASUREMENTS

4.5.2.1 PHYSIOLOGY

The leaf temperature of sheltered vines was significantly higher than that of exposed vines (Table 2). Such leaf temperature differences may indicate that transpiration, photosynthesis and respiration rates were changed. According to Freeman *et al.* (1982) and Kobriger *et al.* (1984), decreased stomatal conductance may result in reduced photosynthetic activity. Therefore the lower stomatal conductance that was determined reflects the hyperbolic relationship between stomatal conductance and photosynthetic activity.

Table 2. The effect of wind on leaf temperature and stomatal conductance of *Vitis vinifera* L. cv. Merlot, Somerset West in the South Western Cape region 2002 and 2003

Parameters	**2002 and 2003**	
	Exposed	**Sheltered**
Leaf temperature (°C)	28.41	30.10*
Stomatal conductance ($\mu mol.m^{-2}.s^{-1}$)	44.04	54.69**

* Significant at $p \leq 0.05$, ** significant at $p \leq 0.01$

4.5.2.2 YIELD COMPONENTS

Sheltered vines had significantly more bunches than exposed vines, but did not yield a significantly higher crop (Table 3). Despite expected greater yields of sheltered vines, no significant difference was found. This can be ascribed to a higher bunch mass in the case of exposed vines and this, in turn, was due to a higher number of berries per bunch than in the case of sheltered vines. This may be due to a better canopy microclimatic environment during the formation of flower cluster primordia resulting in the formation of better developed primordia. The light intensity readings (Chapter 3, Table 3) corroborate this. Although it was expected that berry set of exposed vines would be hampered by more wind, this apparently did not happen.

Table 3. The effect of the wind on reproductive performance of *Vitis vinifera* L. cv. Merlot, Somerset West in the South Western Cape region 2002 and 2003

Parameters	**2002 and 2003**	
	Exposed	**Sheltered**
Bunch mass (g)	157.97	135.16*
Berry mass (g)	1.21	1.17^{ns}
Berry no. per bunch	112.3	121.5**
Budding %	87.66	89.38^{ns}
Bunches/vine	19.14	21.47*
Yield/vine (kg)	3.02	2.90^{ns}

* Significant at $p \leq 0.05$, ** significant at $p \leq 0.01$, ns = non-significant

For practical reasons, grapes from both treatments were harvested on the same day. This appears to be valid as there was no significant difference in sugar concentration, suggesting that the time of ripening was unaffected by shelter (Table 4). Also no significant difference was found in sugar concentration, corroborating findings obtained by Ewart *et al.* (1987), Hamilton (1989) and Bettiga *et al.* (1996). Exposed vines had more lateral leaves (Chapter 3, paragraph 3.5.2.1), which are mainly responsible for the production of carbohydrates during the ripening phase (Hunter *et al.*, 1994). This resulted in more leaves contributing to photosynthesis and the production of sugars and acids. The canopy quality (Chapter 3, paragraph 3.5.2.1) of exposed vines and sheltered vines eliminated interior shade as a possible cause for altered grape composition.

4.5.2.3 FRUIT COMPOSITION

Potassium concentrations in berries of exposed vines were significantly higher compared to those of sheltered vines (Table 4). This is contrary to the findings by Ewart *et al.* (1987), who found no significant variation between sheltered and exposed vines. Archer & Strauss (1989) concluded that shading in the canopy would cause the potassium concentration and the pH in the berries to rise. The higher number of lateral leaves in the fruiting zone of exposed vines may have caused a shading effect resulting in a higher potassium concentration. This was substantiated by the fact that the exposed vines in this study also had higher pH values compared to sheltered vines (Table 4). However, shading did not cause a problem as is shown by canopy density data (Chapter 3, Table 2). The reduction of photosynthate transport, specifically sucrose, is linked to the levels of potassium in grapes (Freeman *et al.*, 1982). As a result of reduced sucrose concentration, potassium is loaded into the phloem to help sustain turgor pressure in the phloem. This potassium is then translocated to the berries. But no significant difference is noted in sugar concentration (Table 4). The increase of potassium could possibly be ascribed to an increased water loss as the result of an increased transpiration, resulting from the exposure of a greater leaf area of lateral leaves to wind. This aspect deserves further study.

Table 4. The effect of the wind on berry composition of *Vitis vinifera* L. cv. Merlot , Somerset West in the South Western Cape region 2002 and 2003 determined by Fosscan 2000

Parameters	**2002 and 2003**	
	Exposed	**Sheltered**
Sugar (100g/ml)	225.88	220.36^{ns}
pH	3.31	3.27*
Total titratable acidity (g/l)	4.10	3.85^{ns}
Malic acid (g/l)	0.96	0.79**
Tartaric acid (g/l)	6.56	6.21^{ns}
Potassium (mg/l)	1165.6	1061.1*
Colour index	4.16	3.54*

* Significant at $p \leq 0.05$, ** significant at $p \leq 0.01$, ns = non-significant

The hyperbolic effect that exists between photosynthetic activity and stomatal conductance (Freeman *et al.*, 1982; Kobriger *et al.*, 1984) provides evidence that the photosynthetic activity of exposed vines will be inhibited as a result of lower stomatal conductance (Table 2). The inhibition of photosynthesis can reduce sucrose synthesis and therefore favour the transport of potassium into the berries (Ewart *et al.*, 1987; Ludvigsen, 1989). According to Jackson & Lombard (1993), in California, high pH values in the berries were the result of high-speed wind (speed not mentioned) reducing stomatal conductance.

No significant difference was found regarding tartaric acid concentrations (TA). In contrast, malic acid concentrations (MA) of sheltered vines were significantly lower than those of exposed vines (Table 4). Malic acid is more sensitive to metabolic reduction than TA (Due *et al.*, 1993; Calò *et al.*, 1996). The higher leaf temperature of sheltered vines may suggest a higher respiration rate of MA (Table 2). In contrast, TA is more stable under higher temperature conditions (Calò *et al.*, 1996). Although total titratable acidity can increase as a result of higher concentrations of MA, no significant difference was found (Table 4). The values of titratable acidity obtained by the Fosscan FT-IR and titration method differ, but a correlation was found (Figure 1).

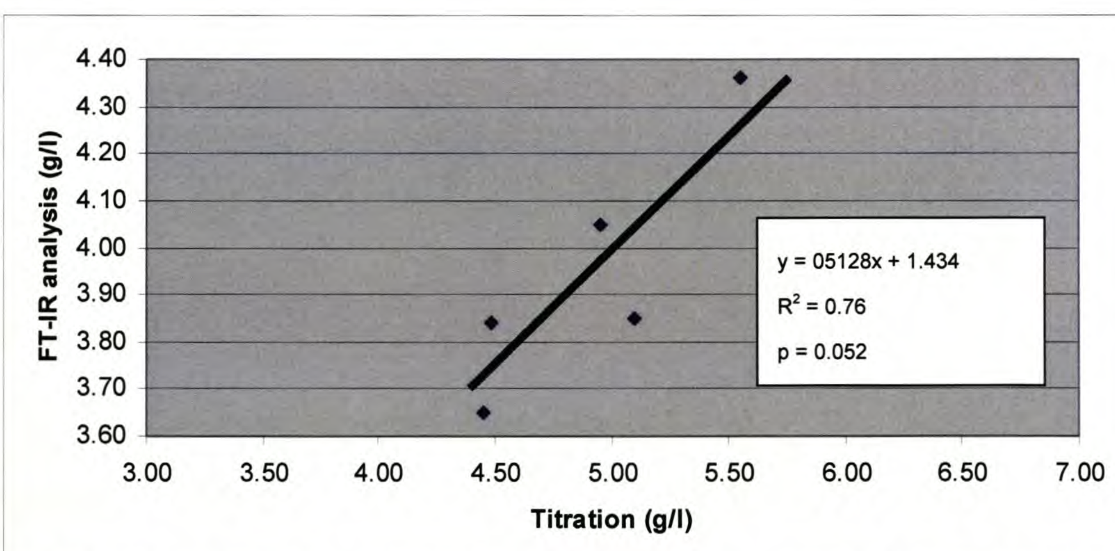

Figure 1. The correlation between total titratable acid of the Fosscan titration vs. Manual titration.

The grape skin colour index of sheltered vines was found to be lower than in exposed vines (Table 4). Two essential enzymes, PAL (phenylalanine ammonia lyase) and flavanone synthase, contribute to the regulation of the biosynthesis of anthocyanins. These enzymes show a positive response to UV light and mechanical damage (Seymour *et al.*, 1993). As exposed vines experienced more shoot breakage and defoliation (personal observation), it was expected that these enzymes would be in higher concentration and thus lead to a higher anthocyanin expression in exposed vines. The sensorial evaluation (Fig. 2) of wines did not confirm the grape skin colour measurements, with no significant difference in wine colour being noted.

Berry juice pH also affects the structural changes of anthocyanins (Timberlake, 1982). Depending on the pH and acid concentration of the berry medium, the anthocyanins can vary between red, bluish or purplish colours. It has been reported that the red colour might diminish in low acid mediums (Timberlake, 1982), thus diminishing the red colour of the grapes of sheltered vines.

4.5.2.4 WINE CHARACTERISTICS

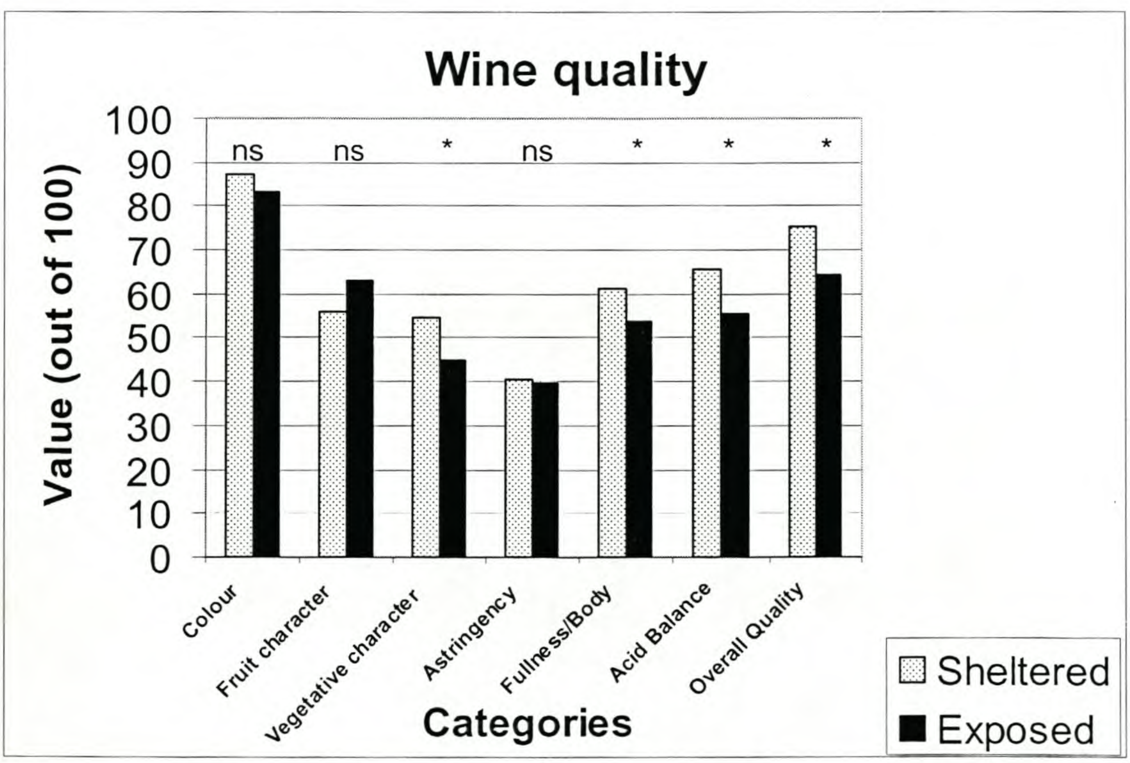

Figure 2. The differences in quality of wines from sheltered and exposed vines as by sensorial evaluation * Significant at $p \leq 0.05$, ns = non-significant

Figure 2 shows the differences between the wine quality of sheltered and exposed vines. The wine of sheltered vines was sensorially evaluated as having no significant difference in colour intensity compared to exposed vines. No difference was found in astringency and wine from neither of the two treatments was found to be astringent. Wine from sheltered vines had a better acid balance. Wines from sheltered vines had more complexity (fullness/body). They had strong vegetative undertones in comparison to the exposed vines. Wine produced from sheltered vines was evaluated as having better overall quality.

4.6 CONCLUSION

The data suggest that provision of shelter from wind impacts on grapevine yield, grape composition and wine quality.

The positive results obtained with sheltered vines may be the consequence of improved photosynthesis due to increased stomatal conductance.

The effect of wind on berry composition and wine quality may occur *via* the effect on grapevine physiology. Although only stomatal conductance was investigated in this study, the interrelationship between stomatal conductance and photosynthesis, and their significance for berry composition, has been well documented in available literature.

Even though sheltered vines can produce higher yields, this would have no significance unless accompanied by quality. The relationship between the different berry components contributes to quality. As the change in the relationship of must pH, acid, potassium and soluble solids may reflect the degree to which wind impacts on the physiological performance of vines, management of wind speed by shelter will have a positive effect on the grapevine physiology due to increased photosynthetic capacity and stomatal conductance and thereby impact on the relationship in which the different berry components occur.

The importance of wind as a part of viticultural zoning, site selection and general management practices was underlined by the results of this study. Proper site selection and vineyard layout will form the foundation for enhancing the positive contribution of wind, such as the cooling effect, to grapevine performance. Regulating this contribution will require precise canopy management and it is recommended that windfilters be employed to regulate the wind flow and restrict the negative effects, such as reduced stomatal conductance.

Additional research is needed to explore wind with regard to other *Vitis vinifera* cultivars.
Findings concerning the effect of wind on *Vitis vinifera* L. cv. Merlot have provided some information which could be used in future wind-related studies in South Africa.

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Chapter 5

GENERAL DISCUSSION AND CONCLUSIONS

CHAPTER 5

5.1 INTRODUCTION

The aim of this study was to gain improved understanding of the effect of wind on grapevine performance under South African conditions. It is only when clarity is obtained on the role of wind in grapevine functioning that it can be considered in viticultural zoning.

5.2 GENERAL DISCUSSION

It became apparent that wind had a significant effect on grapevines. Not only did it reduce growth, but it also caused changes in wine styles. Measured differences with regards to leaf temperature and stomatal conductance in sheltered and exposed grapevines may indicate that other physiological processes, e.g. photosynthesis and transpiration, are also negatively affected by exposure to wind.

Grapevine response to wind can be divided into two categories. The first category (from the literature) concerns physical responses such as mechanical damage, e.g. shoot breakage, defoliation and pollen being blown away. The second category (from this study) concerns physiological responses such as reduced stomatal conductance, which may impact on photosynthetic activity. The above-mentioned responses may occur in response to persistent moderate winds, or even with occasional gusts and stronger prevailing winds. This investigative study has also raised important questions about the effect of wind on the grapevine, e.g. the effect of wind on hormonal concentrations and distributions.

5.3 PERSPECTIVES AND DIRECTIONS FOR FUTURE RESEARCH

Unlike most natural beings, plants do not have the ability to move away from negative external stimuli. Consequently, plants should exhibit some form of adaptation to these circumstances. Thigmomorphogenesis describes mechanical stress or perturbation regarding the adaptation of plants to environmental mechanical influences, such as water flow or persistent wind. Not all species respond to this phenomenon and it is unclear whether thigmomorphogenesis plays a role in the grapevine. The phenomenon should be researched with regard to *Vitis vinifera*.

This phenomenon has a strong relationship with growth regulators which raises further questions. The detailed mechanisms of hormonal changes, ion fluxes and nutrient transport in vines with regard to wind need to be investigated. These mechanisms cause primary and secondary responses in plants, whether on a physiological or morphological level. It is suggested that the physiological reactions in vines exposed to persistent moderate windy conditions are the result of hormonal alterations, e.g. the mechanism of stomatal closure and the consequences of this on photosynthetic activity.

A further question that was raised concerns the role of potassium. Potassium may affect numerous processes and parameters in the vine, e.g. the mechanisms of stomatal closure and its interrelationship with the concentrations of sucrose in the phloem, resulting in different concentrations of both above-mentioned parameters in berries, consequently altering the composition of the berries and wine quality as a result of its relationship with berry pH.

Wind-impact studies should be associated with a specific cultivar. Due to their diverse genetic composition, cultivars display different responses. The diversity, for instance, with regard to vigour and susceptibility to diseases, is apparent. It would be important not to generalise and use the response of a specific cultivar to instigate change in general cultivation practices, but rather to use the information as a guideline. Further studies on different cultivars should be performed.

5.4 CONCLUSIONS

The effect of wind cannot be negated, as it impacts on grapevine functioning, vegetative and reproductive response and wine composition and quality. It may be possible to harness the benefit of wind (reduced leaf temperature) without experiencing its disadvantages (increased potassium and wine pH) by means of windfilters and adjustment of row direction. Exposure to wind, especially in coastal areas, must be taken into account during zoning and site selection, but further studies are needed to understand the mechanism by which wind affects the grapevine response.

ADDENDUM A

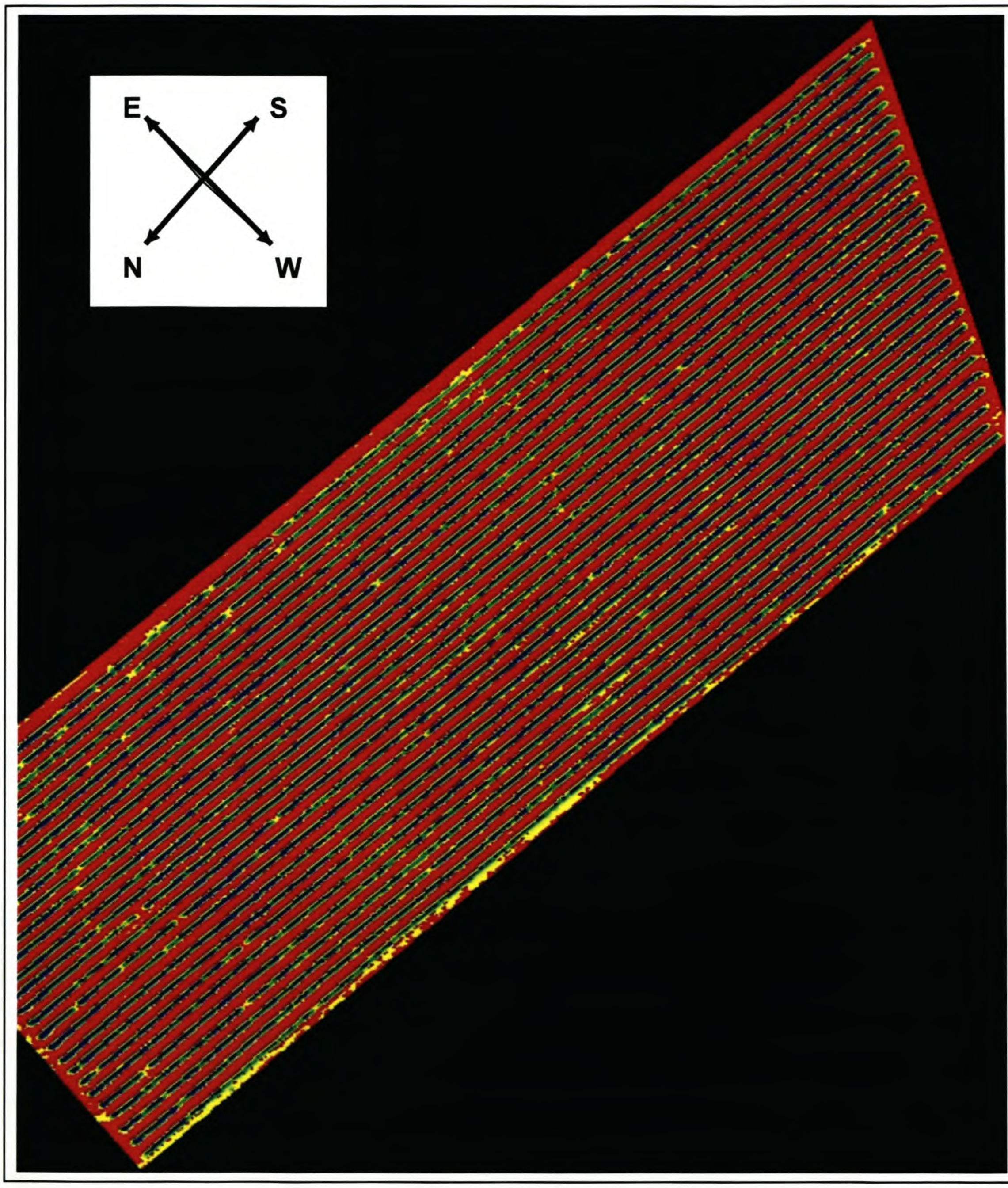
Aerial photo:

The position of the experimental vineyard (green block); the proximity of nearby water (blue block); the windbreak (red boundary) and surrounding vegetation.

ADDENDUM B

The photo was taken from the bottom of the slope (western side of the vineyard). It illustrates the effect of the slope in this particular vineyard. The pre-dominant southeasterly wind blows from the top of the slope, down into the hollow at the bottom.

ADDENDUM C



NDVI:

Indicating the differences in canopy density. Red indicates the ground, yellow low canopy density and blue high canopy density.

ADDENDUM D

Block		Judge		Sample	

Sensory analysis of Merlot: Stellenbosch 2003

Colour intensity

Not good — Intense

Cultivar characteristic

Poor — Excellent

Acid balance

Faint — Intense

Body

Poor — Full body

Astringency

Faint — Intense

Quality

Poor — Excellent

General comments

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Wine evaluation score sheet