

EXPERIMENTS TO MODIFY  
GRAPE JUICE POTASSIUM  
CONTENT AND WINE QUALITY  
ON GRANITE DERIVED SOILS  
NEAR PAARDEBERG

by

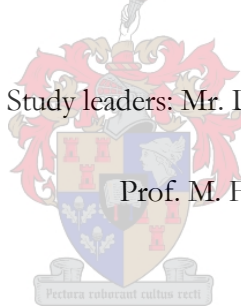
G. Agenbach

A thesis submitted in partial  
fulfillment of the requirements for the  
degree of

Master of Science in Agriculture

Study leaders: Mr. D. Saayman

Prof. M. Fey



University of Stellenbosch

December 2006

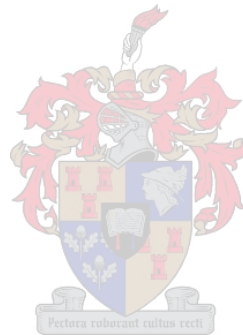
2005

## DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is entirely of my own original research and has not, in whole or in part, been submitted to any other University for the purpose of obtaining a further degree.

Signed:.....

Date:.....



University of Stellenbosch

Abstract

EXPERIMENTS TO MODIFY GRAPE JUICE  
POTASSIUM CONTENT AND WINE  
QUALITY ON GRANITE DERIVED SOILS  
NEAR PAARDEBERG

By G. Agenbach

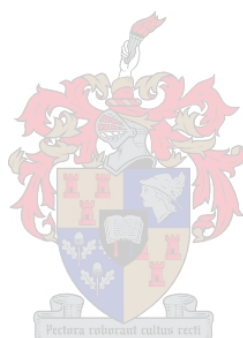
High potassium content in grape juice and wine are associated with low quality red wine in warm wine producing countries. In an attempt to reduce the potassium content of juice, must and wine, a field experiment was laid out on the farms Meerlus and Kersfontein in the Paardeberg area near Wellington in 1998 on granite derived soils to investigate the effect of canopy management and fertiliser applications on berry K accumulation and wine quality.

Four fertiliser applications, three canopy treatments and a  $\text{MgSO}_4$  foliar spray were studied. The three fertiliser treatments being: none (control),  $\text{CaSO}_4$ ,  $\text{Ca(OH)}_2$ , and  $\text{MgSO}_4$  applications. The canopy treatments were: thin to two shoots per bearer, tip, vertical shoot positioning (VSP) and the removal of yellow leaves and lateral shoots (canopy 1), thin to three shoots per bearer, top after véraison and VSP (canopy 2) and VSP with top after véraison (canopy 3/control). Magnesium sulfate sprays were applied at véraison for two seasons (1999/00 and 2000/01).

Seasonal effects produced the most significant differences in this experiment. Canopy treatments did not affect juice K concentration at harvest. Canopy 1 and 2 produced significantly lower wine pH values at Kersfontein. Fertiliser treatments had no effect on juice K concentration nor did it affect wine quality. Magnesium sulphate foliar sprays did not affect juice K concentration

at harvest but significantly lowered juice and wine pH, improved wine colour density and total phenolic content.

It appears for this experiment that soil K content before véraison, shoot growth at and after véraison and water stress after véraison were the main factors determining juice K concentration at harvest.



Universiteit van Stellenbosch

Opsomming

VELDEKSPERIMENTE IN DIE  
PAARDEBERG OMGEWING OM DIE  
KALIUM KONSENTRASIE VAN  
DRUIWESAP TE VERLAAG EN OM WYN  
KWALITEIT TE VERBETER

deur G. Agenbach

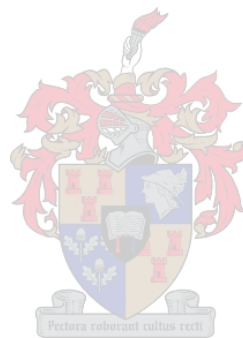
Hoë kalium konsentrasies in druiwesap en wyn kan kwaliteitsprobleme in rooi wyn in terme van te lae suurheid veroorsaak. Veldproewe by Meerlus en Kersfontein is naby Paardeberg in die Wellington omgewing aangelê met die doel om die kalium inhoud van sap en wyn te probeer verlaag deur van wingerdkundige en grondkundige metodes gebruik te maak.

Vier bemestingsbehandelings is toegepas: geen (kontrole),  $\text{CaSO}_4$ ,  $\text{Ca(OH)}_2$ , en  $\text{MgSO}_4$  grondtoedienings. Drie lower behandelings is op die stokke uitgevoer: suier tot twee lote per draer, tip, vertikale loot posisionering (VLP) en die verwydering van sylote en geel blare in die trossone (lower 1); suier tot drie lote per draer, top na deurslaan en VLP (lower 2); en VLP en top voor deurslaan met geen suier nie (lower 3). In die 1999/00 en 2000/01 seisoene is  $\text{MgSO}_4$  blaarspuitte teen deurslaan op blare en trosse in die trossone toegedien in 'n verdere poging om kalium akkumulاسie in korrels te verminder.

Die seisoene het die grootste invloed gedurende hierdie eksperiment gehad. Lowerbestuur behandelings het geen betekenisvolle effek op sap K inhoud gehad nie. Lower 1 en 2 het wel betekenisvol laer wyn pH waardes by Kersfontein veroorsaak. Bemestingsbehandelings het geen invloed op die sap K inhoud teen oes gehad nie en het ook nie wynkwaliteit noemenswaardig beïnvloed nie. Die  $\text{MgSO}_4$  blaarspuitte het nie sap K inhoud beïnvloed nie,

maar het wel sap en wyn pH betekenisvol verlaag, wyn kleur intensiteit en wyn se fenoliese inhoud verhoog.

Dit wil voorkom dat grond kalium inhoud voor deurslaan, lootgroei teen en na deurslaan en waterstremming na deurslaan die hoof faktore in hierdie eksperiment was wat kalium aansameling in die korrels bepaal het.



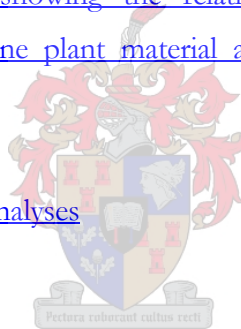
## TABLE OF CONTENTS

<u>1. Introduction</u> .....	1
<u>2. Literature review</u> .....	3
<u>2.1 Introduction</u> .....	3
<u>2.2 Functions of potassium in the vine</u> .....	4
<u>2.3 The general relationship between potassium and wine acidity</u> .....	5
<u>2.4 Absorption of potassium by vine roots</u> .....	8
<u>2.5 Translocation of potassium from the root to the shoot</u> .....	11
<u>2.6 Berry potassium accumulation</u> .....	13
<u>2.6.1 Berry development</u> .....	13
<u>2.6.2 The function of potassium in the berry</u> .....	13
<u>2.6.3 Water supply to the berry</u> .....	16
<u>2.6.4 Solute accumulation in the berry</u> .....	16
<u>2.6.5 Re-translocation of potassium</u> .....	19
<u>2.7 Factors affecting berry potassium accumulation</u> .....	19
<u>2.7.1 Soil factors</u> .....	20
<u>2.7.1.1 Soil factors affecting potassium availability to plants</u> .....	20
<u>2.7.1.2 Potassium availability and plant root absorption</u> .....	22
<u>2.7.2 Variety, rootstock and rootstock/scion combination</u> .....	25
<u>2.7.3 Canopy microclimate</u> .....	27
<u>2.7.4 Cultural practices</u> .....	28
<u>2.7.4.1 Crop load</u> .....	28
<u>2.7.4.2 Canopy management</u> .....	30
<u>2.7.4.3 Fertilisation</u> .....	32
<u>2.7.4.4 Magnesium foliar nutrition</u> .....	34
<u>2.7.4.5 Irrigation</u> .....	35
<u>2.7.5 Environmental effects</u> .....	39
<u>2.8 Conclusions</u> .....	40
<u>3. Materials and Methods</u> .....	43

<a href="#">3.1 Layout of field experiment</a> .....	43
<a href="#">3.2 Experiment treatments</a> .....	44
<a href="#">3.2.1 Fertiliser treatments</a> .....	44
<a href="#">3.2.2 Canopy and foliar spray treatments</a> .....	44
<a href="#">3.3 Analyses</a> .....	45
<a href="#">3.3.1 Determination of growth, yield and yield components</a> .....	45
<a href="#">3.3.2 Soil analyses</a> .....	45
<a href="#">3.3.3 Plant tissue analyses</a> .....	46
<a href="#">3.3.4 Statistical analyses</a> .....	46
<a href="#">4. Results and Discussion</a> .....	48
<a href="#">4.1 The effect of specific fertilisers on soil cation composition</a> .....	48
<a href="#">4.1.1 Soil mineral and particle composition</a> .....	48
<a href="#">4.1.2 Soil Chemical composition</a> .....	49
<a href="#">4.1.2.1 Kersfontein</a> .....	49
<a href="#">4.1.2.2 Meerlus</a> .....	53
<a href="#">4.1.3 Discussion</a> .....	55
<a href="#">4.2 The effect of season, canopy treatment and fertilisers on vine growth and yield components</a> .....	56
<a href="#">4.2.1 Seasonal effects</a> .....	57
<a href="#">4.2.2 The effect of canopy treatments</a> .....	61
<a href="#">4.2.3 The effect of fertiliser applications</a> .....	65
<a href="#">4.2.4 The effect of MgSO<sub>4</sub> foliar applications</a> .....	68
<a href="#">4.2.5 Discussion</a> .....	68
<a href="#">4.3 The effect of season, canopy treatments and fertilisers on vine tissue cation composition</a> .....	70
<a href="#">4.3.1 Seasonal effects</a> .....	70
<a href="#">4.3.2 The effect of canopy treatments</a> .....	74
<a href="#">4.3.3 The effect of fertiliser applications</a> .....	78
<a href="#">4.3.4 The effect of MgSO<sub>4</sub> foliar applications</a> .....	85
<a href="#">4.3.5 Discussion</a> .....	85



<a href="#"><u>4.4 The effect of season, canopy treatments and fertilizers on grape juice and wine components</u></a> .....	88
<a href="#"><u>4.4.1 Seasonal effects</u></a> .....	88
<a href="#"><u>4.4.2 The effect of canopy treatments</u></a> .....	92
<a href="#"><u>4.4.3 The effect of fertilisers</u></a> .....	93
<a href="#"><u>4.4.4 The effect of MgSO<sub>4</sub> foliar applications</u></a> .....	94
<a href="#"><u>4.4.4 Discussion</u></a> .....	94
<a href="#"><u>Conclusions</u></a> .....	97
<a href="#"><u>Literature cited</u></a> .....	99
<a href="#"><u>Appendix A</u></a>	
<a href="#"><u>Table A1. Climatic variables recorded Boland Agricultural School</u></a>	
<a href="#"><u>Fig. A1 &amp; A2. Base saturation of soils at Kersfontein and Meerlus</u></a>	
<a href="#"><u>Fig. A3a&amp;b. Graphs showing the relationship between exchangeable divalent cations and vine plant material at pea-size for Cabernet franc, Meerlus, Paardeberg</u></a>	
<a href="#"><u>Appendix B</u></a>	
<a href="#"><u>ANOVA tables for all analyses</u></a>	



## ACKNOWLEDGMENTS

The author wishes to thank the following persons or institutions:

Winetech for funding the experiment

David Saayman for willingly sharing his expertise, for his guidance and for his patience

Professor Martin Fey for his enthusiasm and for his support

Tienie du Preez, for giving me time off from work to finish this thesis

Gerhard Engelbrecht for the advice, information and for teaching me to thin

Matt Gordon for the spectrometric analyses and his general laboratory assistance

Frikkie Callitz for his invaluable biometric assistance

Paul and Edmund for the cellar assistance and the bottling of the wine samples

Camilla and Kenneth junior for the hard work and assistance with sample preparations

Johan, Pierre and Dorrie for helping me with the canopy measurements

Hendrik, Theunis and Lammie for helping me with the soil sampling

## 1. INTRODUCTION

The lack of acidity in red wine is a problem worldwide in warm wine producing countries. These areas includes vineyards in South Western France (Garcia *et al.*, 2001a), Southern Australia (Somers, 1977) and near Paardeberg in the Wellington area, Cape Province, South Africa (Engelbrecht, 2002).

Acidity is one of the essential factors determining wine quality, allowing good microbial stability and consequently better keeping quality (Boulton *et al.*, 1998a). The interaction between potassium nutrition of vines and the lack of acidity in musts and wines was first confirmed by Somers (1977) and by many workers in the following decades. Wine quality is significantly influenced by pH, which is dependent on the balance of cations and anions in grape juice, must and wine. Potassium is the major cation, while the ionic forms of the organic acids, malic acid and tartaric acid, are the major anions (Somers, 1977, Boulton, 1980b).

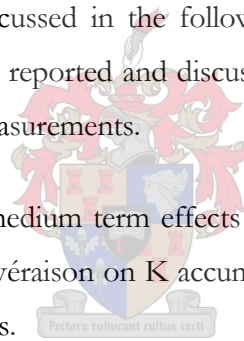
The Paardeberg forms part of the Malmesbury Batolith, which consists of six different granite types and a quartz-porphry dyke (Siegfried 1993). The two farms, Meerlus and Kersfontein, were selected for the high K content of the granite-derived soils on the slopes and foot slopes of the mountain and the relatively warm mesoclimate of the Wellington area (Mean February Temperature (MFT) = 23.6 °C; 30 yr. average A-pan evaporation of 10 mm/day for January, 9.5 mm/day for February).

On Meerlus a five-year-old *Vitis vinifera* L. var. Cabernet franc grafted on 99 Richter (*Vitis Berlandieri* var. Las Sorres x *Vitis rupestris* var. du Lot) was used. The vineyard had a plant spacing of 1.2 x 2.7 m with a three-wire Perold trellising-system. A five-year-old vineyard, Cabernet Sauvignon grafted onto 101-14 Mgt. (*Vitis Riparia* X *Vitis rupestris*) was used at Kersfontein. Here the spacing was 1.2 x 3 m, and the vines were trellised on a three-wire Perold-trellising-system. This trellis was previously extended to support an extra set of canopy wires 30cm above the original set.

Field trials were established to investigate the various techniques available to reduce juice K concentration of Cabernet grapes and so doing possibly increase acidity and reduce juice and wine pH values. Fertilisers were applied to the soil in an attempt to alter the cation ratios in the soil solution under field conditions and so prevent undesirable high K absorption by vine roots. Canopy management techniques known to promote optimum vine performance and to reduce berry K accumulation were performed on the same vines. An  $\text{MgSO}_4$  foliar application at véraison to bunches and leaves in the bunch zone were employed in a further attempt to force lower K accumulation in the berries during the ripening phase.

The project is divided into two separate theses. Engelbrecht (2002) covered field results for the 1998 – 1999 season, while the results obtained during the 1999/00 and 2000/01 seasons will be reported and discussed in the following chapters. In some cases, the means of three season' results are reported and discussed in an attempt to minimise the seasonal effect on some of the measurements.

This thesis concentrates on the medium term effects of fertilisers, canopy management and  $\text{MgSO}_4$  foliar applications at véraison on K accumulation in grape vine tissues, wine pH and wine quality measurements.



## 2. LITERATURE REVIEW

### 2.1 Introduction

The acid content of must and wine is determined by the tartaric acid content and the K concentration of juice and must and the extent of malo-lactic fermentation (Champagnol, 1994). The potential negative relationship between K and wine acidity is well known. Potassium is readily absorbed by vine roots, is readily translocated in the xylem and loaded into the phloem and readily and rapidly transported throughout the entire growing season. The accumulation of K in leaves, shoots and particularly in the berries is considerable. The rate of its uptake is greatly increased during the phase of intense vegetative growth before véraison and the rate and extent of its translocation increases dramatically during fruit ripening after véraison (Hepner & Bravdo, 1985). The berries become the main sink for K after véraison (Ollat & Gaudillère, 1996). At harvest the bunches may account for 60% or more of the total K<sup>+</sup> content for above ground organs (Conradie, 1981b).

Conradie & Saayman (1989) were of the opinion that high soil levels of K cannot be solely held responsible for must with too high K content. Hepner & Bravdo (1985) concluded that the relationship between colour, pH, K and acidity vary with the degree of water availability and crop load (grape yield to pruning mass ratio) and possibly with absolute soil K<sup>+</sup> levels and with the cultivar. Shade in the canopy is one of the most important factors affecting berry K accumulation and adequate canopy management is critical for wine quality (Smart *et al.*, 1985a). Iland (1989) proposed that any factor limiting photosynthesis will lead to a higher K concentration in the juice.

Potassium content of berries are dependent on the growing conditions of the season, the rootstock and competition for transport into the developing shoots and leaves (Boulton *et al.*, 1998b). The growing conditions include potassium availability in the soil, soil water content, the influences of climate on the rate of ripening and the time available to the berry for solute accumulation.

Among the aspects affecting K absorption by vine roots are: the availability of K in the soil solution; the soil water content; the size, age and health of the root system; and the

rootstock and/or rootstock/scion combination. Some workers are of the opinion that grape juice compositional responses to soil K supply is very much specific site related (Ruhl, Fuda & Treeby, 1992).

Over the past few decades research had focused on various aspects of vine cultivation in the search for practical solutions to seemingly genetic predisposal of the vine to accumulate high levels of K in its fruit. Practices investigated include manipulation of soil solution K activity through cation antagonisms, specific rootstocks (and rootstock/scion combinations) with different root K absorption rates, canopy management strategies and, to a lesser extent, irrigation management strategies. These management practices are continuously refined as the physiology of the vine is better understood. To understand these management practices, it is necessary to discuss the roles K ions play in the physiology of the vine.

## **2.2 Functions of potassium in the vine**

Growth of plants is based on cell division, cell enlargement and on the subsequent cell differentiation into tissues with special functions. These steps are regulated by biophysical and biochemical reactions, in which  $K^+$  take part to a variable extent (Beringer, 1980). Potassium ions play various roles in the translocation of assimilates, meristematic growth, maintenance of the water regime of the plant, photosynthesis and the translocation of photosynthates (Mengel & Kirkby, 1987d). These roles can generally be categorised into one or more of the following: the neutralisation of charge; the activation of enzymes; and the regulation of osmotic potential (Lindhauer, 1986).

In the processes of photo-phosphorylation and oxidative phosphorylation,  $K^+$  neutralises the negative charge in the stroma when light activates proton pumping out of the stroma. Although  $Mg^{2+}$  may act as the main counterions to light induced proton pumping within the chloroplast, K concentrations of 100mM seem to be necessary for a high efficiency of photo-phosphorylation. It has been proven that plants with higher leaf K contents have higher rates of ATP synthesis (Mengel & Kirkby, 1987d).

Sucrose loading into the phloem is thought to occur via a cotransport system. Protons are pumped out into the apoplast through the plasmalemma using the energy released

from adenosine triphosphate (ATP) and an adenosine triphosphatase (ATPase) carrier enzyme. This decreases the pH in the apoplast. Protons now diffuse back into the simplast (cystoplasma) along a free chemical concentration gradient, but their movement across the membrane is thought to be coupled to a carrier protein that transports sucrose. Sucrose is therefore supposed to be transported along with the hydrogen ion (Salisbury & Ross, 1985b). When protons move out into the apoplast, the resultant negative charge in the cytosol is neutralised by mainly K ions (Beringer, 1980). According to this phloem loading model, K content of the phloem will rise in step with increasing sucrose content. Etourneaud (1996) is of the opinion that the high K concentration in *Vitis vinifera* berries is the unavoidable result of high sugar accumulation in the berry.

Potassium ions accumulate in cell vacuoles and contribute to osmotic pressure, water uptake and turgor potential. In this osmoregulatory function, K plays a vital role in cell elongation, in the opening and closing of stomata and in plant water regulation (Beringer, 1980).

Potassium ions are involved in the activation of more than 60 enzymes, and are important for cell division and for sugar, starch and protein synthesis (Lindhauer, 1986). Potassium is the dominant counter-ion for the negative charge on proteins and nucleic acids. The reason for this is the low charge to mass ratio of the ion, which results in a relatively small hydration shell and a low tendency to order water. This means that this ion can accumulate in large quantities in the cytosol without affecting the conformational integrity of the proteins present (Maathuis & Sanders, 1996).

It is clear that the vine requires a high  $K^+$  content for the normal functioning of certain biophysical and biochemical processes. Too high levels of  $K^+$  in the berry can unfortunately reduce the quality of wine, the commercial product of the vine.

### **2.3 The general relationship between potassium and wine acidity**

The acidity of wine and must are important since the acidity of the medium dictates to a large degree: the amount of bacteria growth, the solubility of tartaric salts; the effectiveness of sulfur dioxide, ascorbic and enzyme additions; the solubility of proteins; the effectiveness of bentonite; the polymerisation of the colour pigments; and oxidative and browning reactions (Boulton *et al.*, 1998b).

The type of acid, the extent of their dissociation, the resultant titratable acidity and the pH value characterise acidity in wine and must. The pH and titratable acidity are the parameters most commonly measured to determine wine or must acidity. These measurements are resultant and there are various combinations of the different acids and neutralisation reactions that can produce the same pH and titratable acidity values (Boulton *et al.*, 1998b). Total acidity is defined as the proton equivalence of the organic acid anions (Boulton 1980b). In other words: it is the number of protons that the organic acids would contain if they were undisassociated. He calculated total acidity by measuring the acid anion concentrations (by spectrophotometric or chromatographic procedures), expressing these as molar quantities and multiplying it by the number of protons that would result from complete acid dissociation. He defined titratable acidity as the number of protons recovered during a titration with a strong base to a specified endpoint and expressed as a molar quantity. However, not all of the hydrogen ions expected from the acids of grape juice or wine are measured during the determination of titratable acidity. What happens to the missing protons will be discussed next.

The most important organic acids in wine and must are tartaric, malic and citric acid. The production of acids depends on, but is rarely limited by, photosynthesis (Jackson & Lombard, 1993). Malic and citric acids are produced in leaves of all ages but tartaric acid production is limited to areas with rapidly dividing cells such as young berries during the first stage of the set to véraison period and young leaves (Kriedemann, Kliever & Harris, 1970, Champagnol, 1994).

These acids are measured by titration and expressed as total titratable acids (TA). In South Africa, as in France, the titration end point is  $\text{pH} = 7$  with sulfuric acid as reference acid. Organic acid concentrations decrease from véraison to harvest firstly due to berry enlargement and consequent dilution (Boulton *et al.*, 1998c); berry respiration, which is a function of temperature (Jackson & Lombard, 1993) and which mainly influence the malic acid concentration; and the exchange of protons for  $\text{K}^+$  and  $\text{Na}^+$  (Boulton *et al.*, 1998a).

The TA of must is therefore always less than expected from the organic acid concentrations (Boulton, 1980a). Predominately  $\text{K}^+$  is transported across berry



membranes with  $\text{Na}^+$  to a lesser extent, far less so  $\text{Rb}^+$  and  $\text{Li}^+$  and possibly ammonium (Boulton *et al.*, 1998a). The process is thought to be mediated by membrane bound ATPase in the plasmalemma of root, leaf and berry cells. This enzyme exchanges monovalent metal cations for protons while hydrolysing ATP to adenosine diphosphate (ADP). Calcium and magnesium are apparently not transported through this mechanism. This relationship can be described by:

$[\text{K}^+] + [\text{Na}^+] + [\text{H}^+] = [\text{H}^+] \text{ equivalent of the organic anions or total acidity}$  (Boulton, 1980b)

The fraction of the hydrogen ions from the acid pool that are lost in this way can be expressed as the extent of exchange:

Extent of exchange =  $\frac{[\text{K}^+] + [\text{Na}^+]}{[\text{H}^+] \text{ equivalent of organic acid anions}}$  (Boulton *et al.*, 1998a)

With no exchange, the pH would be that of the acid mixture, about 2.2 for wines, while complete exchange would lead to complete neutralization and a pH of approximately 7.5. The pH range of 3 to 4 represents a partially neutralised acid mixture in which the extent of exchange is between 20 percent and 40 percent. The K and Na ions in themselves, therefore, have a negligible effect on pH. Rather, the protons that are exchanged for them are lost from the acid pool, providing a more neutralised solution, a lower titratable acidity and a higher pH than would be expected from the organic acid composition (Boulton *et al.*, 1998b). During vinification the malic acid content may drop and the pH increase further (Ruhl *et al.*, 1992, Jackson & Lombard, 1993). In contrast, the tartaric acid component is not metabolised to any large extent (Champagnol, 1994). This author describes pH of must and wine as a function of the tartrate index, or the ratio of tartaric acid to potassium.

The pH is therefore a function of the extent of exchange and the ratio of the major acids in the buffer solution:

$\text{pH} = f([\text{extent of exchange}] \text{ and } [\text{tartaric/malic}])$  (Boulton *et al.*, 1998a)

Tartaric acid is stronger than malic acid ( $\text{pK}_{a1} = 2.98$  vs.  $\text{pK}_{a1} = 3.40$ ), (Kliewer, 1971) and this will affect the pH at a given extent of exchange. It has been conclusively proven that must composition and acidity in particular is not directly related to the K content of mature berries (Boulton, 1980b). However, grape juice with high K content tend to produce must with low free tartaric acid content, higher malic acid content and higher pH values. Must with high K content tend to produce wines with low total acidity and high pH values.

Various methods have been proposed to limit berry K accumulation and hence reduce juice and must K levels. To understand these methods, or to design new ones, one must look at the routes by which this particular ion arrives in the berry.

#### **2.4 Absorption of potassium by vine roots**

Epstein famously proposed a dual mechanism for the absorption of  $\text{K}^+$  by barley roots in the 1950s and 1960s (In Salisbury & Ross, 1985a). The first system, named System I, operates at an external (soil solution) K concentration of 0 - 0.5  $\text{mmol}^{-1} \text{K}^+$  and follows Michaelis-Menten kinetics with a steep increase in absorption initially, and then a marginal increase in K absorption from 0.1 - 0.5  $\text{mmol}^{-1} \text{K}^+$  supply. At a  $\text{K}^+$  supply of approximately 1  $\text{mmol}^{-1}$  a second mechanism, named System II, becomes operative, resulting in a strong increase in K absorption (Epstein, 1965). At low external K concentrations (in the micromolar regions) a K/H symport has been identified in wheat and *Arabidopsis* (Maathuis & Sanders, 1996). This K/H symport is a carrier protein that couple  $\text{K}^+$  transport to the transport of a proton which has a more favorable energy gradient across the cell membrane. A low affinity  $\text{K}^+$  uptake system operates at high external  $\text{K}^+$  concentrations and is currently partly ascribed to a  $\text{K}^+$  selective channel. A selective channel is a protein that spans the lipid bilayer and forms a selective pore when open (Salisbury & Ross, 1985a). There is evidence that the cortical cells are more important with respect to  $\text{K}^+$  absorption at low external  $\text{K}^+$  concentrations than for example, the epidermal cells (Maathuis & Sanders, 1996).

The absorption of cations and anions by the roots follows three known pathways. For the symplastic pathway, cations and anions are absorbed at the epidermis cell membrane (or cortical cells at low external K concentrations) and transported actively through cell

wall components or perhaps passively via plasmodesmata to the xylem's dead conducting cells. Ions traveling along the apoplastic pathway diffuse and/or move with bulk flow of water from cell to cell through spaces between cell wall polysaccharides until the waterproof Casparian strips in endoplastic cells force the solutes into the cytoplasm of the same endoplastic cells (Salisbury & Ross, 1985a). The third pathway is a modification of the apoplastic pathway. Ions that are not readily transported across cell membranes, or actively pumped out, for example  $\text{Ca}^{2+}$ , presumably gain access to the xylem at unsubsized root tips where Casparian strips have yet to develop (Mengel & Kirkby, 1987b). Potassium is absorbed by roots through both symplastic and apoplastic pathways and is therefore absorbed across the entire active root. The active root surface, capable of water and nutrient absorption, is more or less restricted to the root tips (Jungk, 2001). Calcium is absorbed at unsubsized root tips only with Mg and Na somewhere between K and calcium. This implies that active root growth is required for the absorption of Ca, and to some extent magnesium. Any factor impeding root growth should therefore restrict Ca and Mg absorption before restricting K absorption. Beyond a certain point of root growth impediment, the absorption of water and all nutrients will be restricted.

The factors important in determining root absorbing efficiency and/or the amount of K absorbed by the roots are: the size of the root system (Mengel, 1985); morphological root properties (Jungk, 2001); root metabolism (energy production); photosynthetic rate of above ground plant parts; crop load (Keller *et al.*, 1995); and shoot demand (Drew & Saker, 1984).

There is evidence that plants with larger root systems might be adequately supplied with K on K poor soils while plants with a natural smaller root system will become K deficient (Mengel, 1985). Any factor that restricts root volume, e.g. wetness or limited soil depth, will therefore also restrict K uptake.

One of the most important morphological root properties that affect nutrient absorption is the root radius. The ratio between the surface area of a root system and its mass may be markedly affected by the radius of the roots. The specific soil volume,  $V_s$ , out of which a nutrient diffuses to a sink, is negatively related to the root radius as seen from the following equation:

$$V_s = \Delta r + \frac{\Delta r^2}{2r_0}$$

where  $\Delta r$  = the distance of diffusion,  $r_0$  = root radius (Jungk, 2001)

When the sink has a smaller radius, the concentration gradient necessary to drive a certain diffusive flux is attained at a lower concentration of the nutrient in the bulk soil. Feeding roots have radii of between 50  $\mu\text{m}$  and 150  $\mu\text{m}$ , whereas the radius of root hairs is  $\sim 5 \mu\text{m}$  and that of mycorrhizal hyphae is only  $\sim 1.5 \mu\text{m}$ . Thus, because of their morphological properties, root hairs and mycorrhizal hyphae are potentially more efficient than roots as a sink for diffusing nutrients. This is particularly important for nutrients of low mobility such as P (Jungk, 2001).

Shading that reduces photosynthesis and also causes reduced root to shoot ratios of vines, reduces the potential of roots to absorb K, Ca and especially magnesium (Keller *et al.*, 1995). Hunter & Le Roux (1992) reported that partially defoliated Cabernet Sauvignon (grafted on 99 Richter) had higher root densities and larger numbers of fine roots in all soil layers. It follows that a vine with a favorable canopy microclimate would have a more efficient nutrient absorption capacity. Potassium uptake is also closely related to root metabolism. With sufficient root respiration K uptake can be maintained and the absorbed K retained in the root cells. Insufficient  $\text{O}_2$  supply to roots may result in reduced K absorption and even K leakage from the roots (Mengel, 1985). Insufficient Ca in cell membranes is also known to cause K leakage from cells (Salisbury & Ross, 1985a).

The amount of crop per vine influences the areas where carbohydrates accumulate. Heavily cropped vines accumulate a large part of its total dry mass increase over a season in the fruit. This high percentage of dry mass accumulates at the expense of vegetative tissue, particularly the roots. Between 60 - 80 percent of the vine roots produced each season die, an ongoing process of turnover of the fibrous white roots (Howell, 2001). A reduced replacement of dead roots causes the root system quality to decline. Over-cropping (unfavorable fruit mass to leave area ratio) could in time lead to less efficient root absorption of nutrients.

Increases in root/shoot dry mass ratio, root branching, root elongation and fine root production have been related to modifications of sink strength associated with enhanced shoot-to-root partitioning of photosynthates and N compounds. Some workers have suggested that hormonal balances, especially auxins, cytokinins, abscisic acid and ethylene, are in control of root growth stimulation (Neumann & Römheld, 2001).

Tromp (1980) found that there is a linear relationship between K uptake and growth demand of young apple trees. His observation is consistent with the concept that the long-term uptake of nutrients by fruit trees is determined mainly by metabolic demand. The amount of K taken up by the root system must therefore be related to the K requirement of the above ground parts of the plant. If this requirement is low, then the K uptake by the roots will be low and *vice versa*. This mechanism is supposedly controlled by phloem recycling (Drew & Saker, 1984).

Root absorption of K is not simply a function of the activity of K in the soil solution. Rather root absorption of K is determined by soil K content, root system size and morphology, shoot demand and the energy status of the entire vine. As the vine has clear stages of active shoot growth and stages of reduced shoot growth, the K absorption rate of vine roots will change over the growing season. This complex picture essentially explains the conclusion reached by Boulton (1980a) that absorption of K by the vine will be independent of the soil K content as long as a deficiency does not exist.

## **2.5 Translocation of potassium from the root to the shoot**

Once absorbed in the cortical cells, ions must get into the dead conducting cells of the xylem, mainly vessel elements and tracheas, to be transported upwards to the shoots. This involves transfer from either living pericycle cells or from still living xylem cells. The transport of ions across membranes is a much studied subject. The process is thought to be diffusion along an electrochemical gradient across the plasma membrane (or tonoplast) with ions being selectively helped along by transport, carrier or channel proteins imbedded in or spanning the lipid bilayer. The electrochemical gradient across a membrane is determined by the voltage difference (electrical potential), caused by ATPase pumping  $H^+$  into the cell wall area; and the difference in activities of particular solutes (the chemical potential). The ATPase enzyme functions optimally at a pH of 6

and requires  $K^+$  in the cytosol for its activity (Mengel & Kirkby, 1987c). Metabolic energy or ATP is therefore required for the movement of nutrients in the roots cells (Salisbury & Ross, 1985a). It follows that the amount of K reaching the xylem is a highly regulated process involving the activity of ATPases, channels and carrier proteins and the availability of ATP.

Xylem loading of K is regulated separately from K absorption from the nutrient solution (Engels & Marschner, 1992). According to these authors, root K translocation in the xylem is regulated by shoot demand. Drew & Saker (1984) suggested that K uptake and translocation is regulated by K retranslocation from shoot to root via the phloem. Should nutrient delivery overtake shoot requirements, the excess nutrient is loaded in the phloem of above ground organs and translocated back to the roots. According to Drew & Saker's hypothesis, less K will be recycled via the phloem during periods of rapid shoot growth, which will lead to additional K absorption from the soil. Most of the total K absorption by roots from the soil takes place during the vegetative growth phase (Mengel & Kirkby, 1987d). Swanton & Kliever (1989) found that per-unit-root uptake of nutrients for vines were lower at high root:shoot ratios than at low root:shoot ratios. Potassium is furthermore proven to be the main cation in xylem sap of grape vines (Peuke, 2000).

Rühl (1992) found that relative humidity (transpiration rate) did not influence K uptake at high soil solution K concentration. Potassium translocation from root to shoot in the xylem is therefore probably regulated by the xylem loading capacity of the root and not by transpiration. Root xylem loading capacity, on the other hand, seems to be controlled by shoot demand through phloem recycling. Relative humidity and transpiration rates are less important for Mg transport as well, but more important for Ca transport (Rühl, 1992). A high transpiration rate, therefore, favors Ca transport but does not necessarily influence K transport in the xylem to above ground plant parts.

Once in the shoot and leaves, K is translocated in the phloem to various plant parts and growing leaves and fruit in particular. Potassium is usually the main constituent of phloem sap and can be translocated at a high rate (Mengel & Kirkby, 1987a). Should xylem sap K content outstrip shoot demand, or when the root cells are deficient in K, the

cation can be translocated back to the roots via the phloem where it may be utilised or reloaded into the xylem (Drew & Saker, 1984).

## **2.6 Berry potassium accumulation**

This section describes the current knowledge on how K arrives in the berry and what the function of this nutrient is in the berry. The natural development of the grape berry is discussed first.

### **2.6.1 Berry development**

Berry growth is divided into three growth phases by Winkler (1962): during Period I the berries enlarge rapidly through mainly cell division (Boulton *et al.*, 1998c) while the embryo (or seeds) remain undeveloped; during Period II, the seeds develop and berry growth lags; during Period III, berry growth resumes through mainly cell enlargement. The onset of Period III, *véraison*, marks the stage of rapid sugar accumulation, the loss of chlorophyll and the production of anthocyanins in red varieties. Berry growth during Period III can be further divided into three sub-stages: IIIa, IIIb and IIIc (Wang *et al.*, 2003). Stage IIIa is a period of rapid growth, Stage IIIb is a period of slow growth, while the berries shrink during Stage IIIc.

The berries are weak consumers of photosynthates before Period III (Boulton *et al.*, 1998c), but during Period III, the ripening phase, the vegetative sinks goes dormant and the berries become the major sugar accumulators (Hunter & Ruffner, 2001). Before *véraison*, the grape berry is a utilising sink and berry growth is likely determined by cell metabolism. After *véraison* the berry becomes a storage sink and growth is most probably linked to sugar accumulation mechanisms (Ollat *et al.*, 2002). In a defoliating experiment conducted by Howell in the 1970s on vines trellised in a bilateral cordon, fruit on completely defoliated shoots and cordons was able to mobilise carbohydrates from neighboring shoots and cordons to achieve higher sugar concentrations than the foliated control treatments. This illustrates the sink power of the post-*véraison* berries for carbohydrates (Howell, 2001).

### **2.6.2 The function of potassium in the berry**

The roles of K in the berries are not fully understood. We do know for sure that relatively little K is accumulated in the berry during Period I, none or very little during



Period II and large amounts during Period III. During the cell division period (Period I) K may be required for cell wall loosening and cell enlargement since cell enlargement does take place during Period I (Ollat *et al.*, 2002). During Period II, little or no K<sup>+</sup> is required. After véraison the main function of K is probably to drive cell enlargement through its role in cell wall loosening and by regulating osmotic potential.

Cell wall loosening takes place before, or initiates cell expansion after the onset of ripening (or before any plant cell can enlarge by absorbing water). Potassium is necessary for the process of cell loosening and maintaining sufficiently negative cell water potential thereafter. The apoplast needs to be acidified during cell wall loosening and K is required to balance the extruded protons to steady the plasma membrane potential (Mpelasoka *et al.*, 2003).

In fruit species, water and solutes are transported from the leaves (the source) to the berries (the sink) via sieve tubes of the phloem system. The phloem transport model currently favored by most plant physiologists for source-sink transport, is the pressure flow model of Münch, first proposed by him in 1926 (Salisbury & Ross, 1985b). This model, in its modified form, states that photosynthetic assimilates produced in mesophyll cells of leaves are actively loaded into nearby sieve tubes of minor leaf veins. The water potential gradient between the apoplast (cell wall area) and symplast (sieve tubes) are the driving force for water movement (from high potential (less negative) to low potential (more negative)).

$$\Psi_w = \Psi_p + \Psi_s$$

$\Psi_w$  = cell water potential (always negative)

$\Psi_p$  = cell turgor or pressure potential (positive for living cells)

$\Psi_s$  = osmotic potential (always negative) (Mpelasoka *et al.*, 2003)

With cell wall loosening,  $\Psi_p$  is decreased, which lowers  $\Psi_w$  (becomes more negative) and the increased water potential gradient drives water entry into the berry. As the cell water content increases, the water potential is increased (less negative). In order to maintain the process of cell expansion, the water potential gradient needs to be kept low (more negative) and the vine does this by accumulating solutes to increase  $\Psi_s$  (more negative).



Sucrose is the major solute that accumulates in the berry during period III, but the highly mobile and abundant K can also contribute to the osmotic potential (Ruffner, 1982, Hunter, Skrivan & Ruffner, 1994). Phloem solute composition for different species is almost always the same. Sucrose is present in the highest concentration, secondly K and thirdly Mg, all of them occurring in relatively high concentrations (Mengel & Kirkby, 1987a)

There is evidence that the apoplast:symplast compartmentation breaks down around the time of onset of ripening (Lang & Düring, 1991). These authors propose that the breakdown of compartmentation decreases  $\Psi_w$  of the phloem sieve tubes, thereby increasing the water potential gradient between the leaves and the ripening berry, which stimulates phloem flow into the berry. Sucrolytic enzyme activity in the berry, acidic invertase and sucrose synthase (notably acidic invertase), may also increase  $\Psi_s$  (become more negative) since an incoming sucrose is hydrolysed into glucose and fructose. This also sets up a sucrose gradient between source and sink, which may play an important role in determining the sink strength of the berry (Hunter *et al.*, 1994). There is also evidence that berry transpiration rates may influence the assimilate flow into the berry (Rubucci *et al.*, 1997, Dreier, Stoll & Ruffner, 2000).

The berry becomes a strong sink for carbohydrates after flowering, when the rate of cell division reaches a maximum (Ollat & Gaudillère, 1996). Before véraison the import of assimilates are presumably under hormonal control. After véraison, at the time of onset of ripening, import largely depends on an osmotic pressure gradient, although hormonal control during the entire growing season cannot be excluded (Hunter & Ruffner, 2001).

Osmotic potential in grapevine leaves at full turgor are produced by soluble carbohydrates and inorganic ions. Recent results indicated that soluble carbohydrate is the main contributor in immature leaves while the contribution of inorganic ions increases with leaf age (Patakas, 2000). However, Garcia and coworkers noted significant higher K levels in young apical leaf blades than in mature blades of some rootstock/scion combinations (Garcia *et al.*, 2001a). The same workers reported significantly more Ca in mature leaf blades than in younger blades with no significant differences in Mg content between leaves of different ages.

It is important to realise that this osmotic driven mechanism does not discriminate between osmotic solutes. The osmotic potential gradient needs to be maintained and in the absence of sucrose in the leaves, K may be loaded into the phloem for the maintenance of the osmotic potential gradient. Since water is essentially the material that needs to accumulate in the berry cells in order for the berry to grow, it follows that the route of water supply will dominate nutrient accumulation patterns in the berry.

### 2.6.3 Water supply to the berry

The route of water supply to berries is changed at véraison. The xylem tracheas of vascular bundles are disrupted when the berry suddenly expands a week after rapid sugar accumulation starts (Findlay *et al.*, 1987). Véraison, or the onset of ripening, is generally accepted at the time xylem disruption occurs. From this stage onwards, water and solutes are supplied mainly through the phloem (Creasy, Prince & Lombard, 1993). Before véraison, 75 percent of water supplied to the berry is through xylem flow. After véraison, phloem flow accounts for 80 percent of the water supplied to the berry (Ollat *et al.*, 2002). There is therefore clearly an increase in the relative berry influx of phloem sap compared to xylem sap during the post-véraison harvest period. It implies that berries are supplied with water and solutes (assimilates and ions) from the roots and leaves before véraison but mainly via the leaves after véraison (Lang & Düring, 1991). The amounts and type of nutrients that enter the berry is therefore profoundly influenced by the water supply route.

### 2.6.4 Solute accumulation in the berry

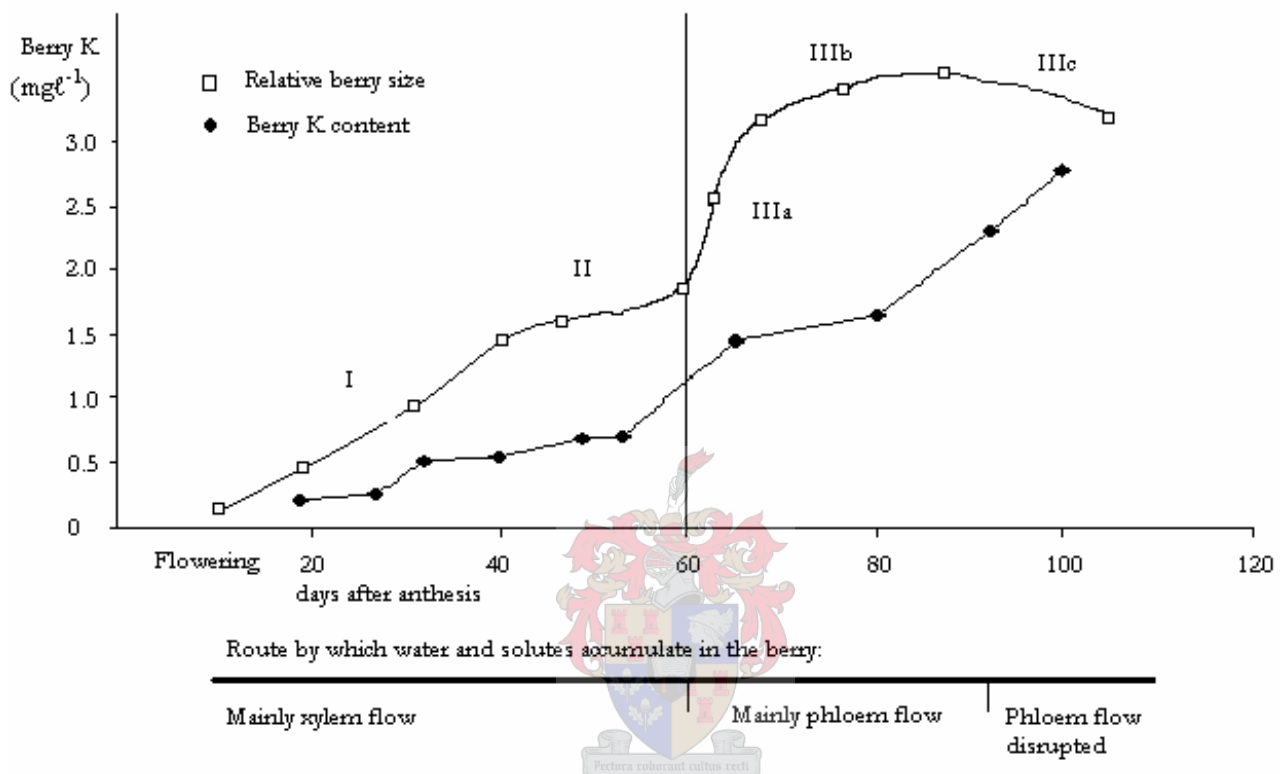
Coombe found that the berry begins to accumulate sucrose from berry softening onwards (In Wang *et al.*, 2003). Esteban and coworkers found that glucose concentration increased dramatically 8 - 12 days after véraison (Period IIIa) after which sugar concentration continued to increase, but with less intensity (Period IIIb) (Esteban, Villanueva & Lissarrague, 1999). Sugar accumulation in berries typically follows a sigmoid curve and K apparently follows the same trend (Freeman & Kliewer, 1983). Conradie (1981a) showed that K is absorbed by Chenin blanc/99 Richter in sand culture from three weeks after budburst until four to five weeks after harvest. During the 35 day period between véraison and harvest, the rate of root K uptake decreases sharply despite the increasing K content of berries. The K content of leaves also drops slightly in the

period after véraison. According to Freeman & Kliewer (1983), the initial rate of sugar storage in the berries is characterised by rapid K uptake, followed by a slowed uptake in the vicinity of véraison (10 - 17°C), followed by a second period of rapid K accumulation. During Period IIIc, berry volume decreases due to possible phloem disruption, interrupting the water and sucrose flow to the berry (McCarthy & Coombe, 1999; Wang *et al.*, 2003). The berry continues to lose water by transpiration, which results in a reduction of fresh berry mass and volume and an increase in the sugar concentration of the berry. However, Ca and K continue to enter Shiraz berries after phloem vessel disruption (Rogiers *et al.*, 2000).

The xylem-phloem import switch has huge repercussions in terms of cation accumulation. The cations that are readily loaded and transported into phloem tissue are K, Mg and phosphate (Salisbury & Ross, 1985b). Potassium accumulation in the berries are slow before véraison but increases dramatically thereafter until ripeness (Freeman & Kliewer, 1983). This increase is proportional to the berries' increased sink strength and phloem water flow (Ollat & Gaudillère, 1996). Potassium ions, therefore, enter grape berries mainly through the phloem after véraison. Cations that are not readily loaded and transported in phloem vessels are  $\text{Ca}^{2+}$ ,  $\text{B}(\text{OH})_3^0$  and iron (Salisbury & Ross, 1985b). Calcium is absorbed after bud burst and this continues until véraison and Ca accumulates when xylem water flow is high. Calcium accumulation in Cabernet Sauvignon slows down after véraison but do not stop (Ollat & Gaudillère, 1996). Xylem flow in the brush zone is disrupted at véraison, but water and ions may still enter the berry through the xylem conduits in the pedicel and then diffuse into the pericarp via a non-vascular route (Rogiers *et al.*, 2001). Rogiers and coworkers found that xylem conduits of Shiraz berries remain functional post-véraison, but the relative contribution from phloem flow remains dominant (Rogiers *et al.*, 2000). The same authors found that Ca accumulation is much more variable than K during the growing season and they attributed this to fluctuation in xylem flow. Xylem flow is more closely linked to variations in soil-vine-atmosphere water-potential gradients than phloem flow is. This influence Ca accumulation in the berry more than it does K accumulation.

Magnesium absorption starts after bud burst and continues until véraison after which absorption slows and ceases with the onset of leaf fall (Conradie, 1981a). Ollat &

Gaudillère (1996) found that Mg accumulation in Cabernet Sauvignon berries are slow pre-véraison but increases at the onset of ripening. Magnesium follows a similar accumulation trend to K but to a lesser extent. This divalent cation is therefore transported via the xylem and the phloem.



**Figure 1.** Berry K accumulation pattern, relative berry growth and growth phases during the growing season (Data on berry K accumulation taken from Ollat & Gaudillère, 1996; data for berry growth from Mpelasoka *et al.*, 2003; growth stages (Periods I, II, IIIa, IIIb & IIIc) from Wang *et al.*, 2003; and routes by which water enter the berry from McCarthy & Coombe, 1999)

Berry K concentration is the result of the berry growth rate and the rate of this ion's accumulation in the berry (Mpelasoka *et al.*, 2003). Berry K concentration will remain constant if berry growth and berry K accumulation is maintained at similar rates. Berry K concentration will increase if rate of K accumulation exceeds the rate of berry growth. Factors that affect the rate of berry growth and/or rate of K accumulation in the berry will affect berry K concentration include the specific cultivar, the crop load, climate and cultural practices. The different berry tissues accumulate K to a different extent. The K

concentration per unit fresh mass is higher in the skin than in the pericarp (Possner & Kliewer, 1985). The K concentration of the seeds is lower than that in the skin but slightly higher than in the pericarp (Storey, 1987). The degree of K distribution between the berry tissues is largely dependent on the variety of rootstock and or scion (Walker *et al.*, 1998). The impact of skin K on juice, must and wine K content depends on the skin K concentration and the ratio of skin weight per berry (Mpelasoka *et al.*, 2003).

The final K concentration of grape juice after crushing is therefore determined by the K content of the different berry tissues, the relative contribution of the specific tissue to the juice volume and the extractability of K from the specific tissue.

### **2.6.5 Re-translocation of potassium**

At harvest, K in bunches accounted for 60 percent or more of the total K content of the above-ground plant parts in a pot study with four year old vines (Conradie, 1981a). Peak berry K accumulation rate is at the onset of ripening (Period IIIa). At this stage there is no significantly higher absorption by the vine roots, and the amount of K accumulated in the berries exceeds the uptake of the cation. Conradie (1981a) also noted the decrease in K content of trunk, roots, shoots and leaves at the onset of ripening, suggesting that the K in these tissues were mobilised during Period III. Freeman (in Storey, 1987) showed that 43 percent of the K imported into the berries came from the leaves. The rest was supposedly provided by soil absorption and the mobilization of reserve K in the trunk, roots and shoots. Williams & Biscay (1991) found no mobilisation of root K during ripening for 20 year old Cabernet Sauvignon vines. The majority of remobilised K came instead from the shoots. It would appear that re-translocation of K from other plant organs depends on soil K availability, K uptake capacity of the roots, rates of K translocation from root to shoot to meet the berry demand for potassium and the reserve status of the vine (Mpelasoka *et al.*, 2003).

### **2.7 Factors affecting berry potassium accumulation**

The amount of K accumulated in a berry depend on root K uptake, the translocation of K from root to shoot to berry or from leaf to berry, the reserve K, the total number of berries and the rate of berry growth in relation to vine vigour (Mpelasoka *et al.*, 2003). These processes are influenced or determined by the soil, the plant (the genetic

characteristics of rootstock and scion and the combination of the two), vine microclimate and cultural practices (Boulton *et al.*, 1998a). These factors are closely interlinked and complicate any explanation of berry K accumulation. Each will be discussed separately as far as possible in the following section.

### 2.7.1 Soil factors

Conradie & Saayman (1989) were of the opinion that high soil levels of K cannot be solely held responsible for must with too high K contents. Studies have shown that there are no significant correlation between soil K content and berry K content at harvest. Boulton (1980a) concluded that ATPase mediated uptake implied that vine K absorption is essentially independent of soil solution K concentration, provided that a deficiency situation does not exist. Nevertheless, soil solution K determines which of Epstein's two absorption systems operates and understanding soil K dynamics is important for K fertiliser recommendations.

#### 2.7.1.1 Soil factors affecting potassium availability to plants

##### *Kinds of clay minerals*

The potassium cation ( $K^+$ ) sources in soil, in contrast to nitrogen and phosphate, are exclusively of inorganic nature (Mengel, 1985). The most important K bearing minerals are feldspars, in particular the alkali feldspars (3 – 12 percent K), and micas (K-mica = muscovite: 6 – 9 percent K; Mg-mica = biotite: 5 – 8 percent K). Soils with more of these minerals would have a larger absolute K content and a higher potassium supplying power. Wooldridge (1988) found that kaolinite was the dominant clay mineral in the granite derived soils of the Western Cape fruit producing areas. Carski & Sparks (1985) found that  $Ca^{2+}$  was preferably adsorbed over  $K^+$  on relatively pure kaolinite. Wooldridge (1985) found that granite derived material induces luxurious K uptake in rye grass. Recent studies confirmed that kaolinite and mica are the dominant clay minerals found in the highly weathered soils of the Western Cape (Bühmann, Nell & Samadi, 2004). According to these workers the mica soil component inherited from the parent material decreases in proportion to current precipitation. An absence of mica in a soil is associated with a zero or very low exchangeable potassium percentage and often with low clay content (<3%). The potassium supplying power of kaolinitic soils could therefore be linked to mica impurities in the clay and/or the low buffer capacity of this clay mineral.

### *Clay content*

It was demonstrated that the K released in a soil depends on the clay content present in the specific soil (Havlin, Westfall & Olsen, 1985). The higher the clay content, the more K is released over time. For soils with a predominantly medium to coarse texture, the sand and silt fractions may also contribute to the K supplying power of the soil (Munn, Wilding & McLean, 1976; Somasiri, Lee & Huang, 1971).

### *Cation exchange capacity (CEC)*

The CEC of a soil is determined by the clay type, clay content and organic material content (Bohn, McNeal & O'Connor, 1985a). Finer textured soils usually have a higher CEC and can hold a greater amount of exchangeable potassium. Due to the higher buffer capacity of these types of soils, the soil solution K may actually be lower than in sandy or low clay content soils (Tisdale, Nelson & Beaton, 1980). Organic material is important source of cation-exchange capacity in many soils. However, the affinity of organic matter for K is low compared to its affinity for Ca and magnesium ions (Thomas & Hipp, 1968).

### *Capacity to fix K*

The fixation of K is normally not a problem in the kaolinite rich soils of the Western Cape. Potassium and  $\text{NH}_4^+$  may however be actively fixed in South African arid and temperate zones through the transformation of 14Å swelling clay minerals to mica in the presence of percentage exchangeable K > 5 (Bühmann *et al.*, 2004).

### *Soil pH*

Liming of acid soils will lead to the precipitation of insoluble  $\text{Al}(\text{OH})_3$  and thus free previously blocked binding sites on the exchange complex (Kotzé & Deist, 1975). Greater amounts of K will then be held by the clay colloids and thus reduce the amount of this nutrient in the soil solution. Liming of acid soil with a low K content could therefore lead to K deficiencies in the plants if sufficient fertiliser K is not added at the same time (Tisdale, Nelson & Beaton, 1980).

### *Ion antagonism*



The effectiveness of soil solution K is influenced by the presence of other cations, particularly Ca and Mg and to a lesser extent Al (very acidic soils) and Na (saline soils). The activity ratio ( $AR_e^K$ ) in a solution in equilibrium with a soil has provided a satisfactory estimate of the availability or potential of potassium (Tisdale, Nelson & Beaton, 1980).

$$AR_e^K = \frac{(a_K)}{\sqrt{a_{Ca+Mg}}}$$

where  $a_K$  = activity of  $K^+$ ,  $a_{Ca+Mg}$  = activity of  $Ca^{2+}$  and  $Mg^{2+}$

Potassium uptake by plant roots will be reduced as Ca and Mg content of the soil solution are increased and *vice versa*. This concept also indicate that the availability of K is more dependent on its concentration relative to that of Ca and Mg, than on the total quantity of K present in the soil solution (Tisdale, Nelson & Beaton, 1980). Potassium deficiency may be induced in saline conditions where Na is the predominant cation. At low external K levels, uptake is highly specific for K, while at higher external K levels ( $>0.5 \text{ mmol l}^{-1}$ ) Na can competitively inhibit K influx. In addition, excess of Na and Cl in saline soils create high ionic imbalances that may impair the selectivity of root membranes (Bohra & Dörffling, 1993). Bohra & Dörffling (1993) reduced Na accumulation in rice by adding K fertilisers to a saline soil. A high K concentration in the soil solution is known to reduce Mg uptake in South African vineyards (Conradie & Saayman, 1989). The opposite, Mg/K antagonism has not been reported. A P/K antagonism has been reported for vines (Conradie & Saayman, 1989) and apples (Kotzé, 2001) under South African conditions.

It is clear that the absolute concentration of soil K is not the only important factor for root absorption, but rather the relative concentration of K and that of the other cations.

### 2.7.1.2 Potassium availability and plant root absorption

All the K in soils are available, both the exchangeable and the non-exchangeable potassium (Grimme, 1980). It differs, however, in the degree of availability: solution K > exchangeable K > fixed or non-exchangeable K > structural or mineral K (Sparks, 1987). These four forms of K are in dynamic equilibrium. The rate and direction of the equilibrium reactions between these forms, and hence K availability to plants, depend on the rates of K uptake by plant roots and soil characteristics. The soil characteristics



include: mineralogy (types and amount of soil minerals; and size and degree of weathering of the mineral particles), soil moisture, pH (soil reaction) and texture (Thomas & Hipp, 1968).

The ability of roots to supply plants with inorganic nutrients depends on nutrient availability in the soil and root absorption of the nutrient. Nutrient availability comprises two aspects: a chemical one and a positional one. The chemical aspect depends on the chemical bonds between element and other ions or the soil matrix, and the concentration of the element in the soil. The positional aspect is related to both the distribution of the element in the rooting volume and its mobility in the soil. Mobility determines the rate of ion transport and thus the amount of and the distance from which the ion can move through the soil towards the surface of a root (Jungk, 2001).

Contact between the root surface and soil nutrients, which are a prerequisite for uptake, are brought about in two ways: growth of roots to the sites where nutrients are located, and transport of nutrients from the bulk soil to the root surface. Only a small percentage of the total K requirement of a plant is satisfied by direct root contact ( $\pm 6 - 10$  percent) and the remainder is chiefly provided through mass flow and diffusion of ions to the root surface (Tisdale, Nelson & Beaton, 1980).

Diffusion is commonly accepted as the more important K supplying mechanism. The K concentration gradient is determined by the soil K levels and the uptake of K by the roots (Tisdale, Nelson & Beaton, 1980). Acquisition of nutrients and water by plant roots creates gradients of water potential and ion concentrations and disturb the ionic equilibria between the solid and the liquid soil phases in the vicinity of the roots. This triggers two types of processes in the soil: transport of water and nutrients through the soil towards the root and exchange of ions between the solid and the liquid soil phases (Jungk, 2001).

The less mobile a nutrient is in the soil solution, the more pronounced the concentration gradient between concentrations present at the root surface and the soil medium. The more strongly a cation is attracted to the negatively charged colloid surface the less mobile it is in the soil. Divalent cations are retained more strongly than monovalent ions and within a valence series the relative strength of adsorption of ions decreases as its dehydrated radius decreases (Bohn, McNeal & O'Connor, 1985b). A highly mobile

nutrient such as  $\text{NO}_3^-$ , will remain at a higher concentration at the root surface for longer periods of time. Potassium ions, less mobile than for example nitrate ions, will quickly be depleted at the root surface but will still be accessible if the roots continue to grow. The volume of soil out of which a root can draw a nutrient depends on the mobility of the nutrient, which in turn is a function of its binding to the soil matrix. Some anions, such as nitrate and chloride, are hardly bound to soil and are very mobile.

Nutrient mobility determines transport from soil to root. If concentrations are too low to make mass flow sufficient, diffusion becomes the major mode of ion transport. In such a case, the parameters of ion diffusion determine the rate of supply. These include soil solution concentration, soil buffer power, soil water-holding capacity, soil bulk density and soil temperature (Jungk, 2001).

Nutrients move from the soil to the roots essentially in solution, which is in equilibrium with ions bound to the solid soil phase. The mobile and the immobile fractions interact by exchanging nutrients between them, a process termed buffering. The buffer power of a nutrient,  $b$ , is defined by

$$b = \frac{dC}{dC_L}$$

$C$  = total diffusible quantity of an ion in the soil, i.e. the sum of ions dissolved in the soil solution plus those sorbed at the solid phase in equilibrium with  $C_L$ , the concentration of this ion in the soil solution (Jungk, 2001). The buffer power often dominates the diffusive transport from soil to root and depends on the chemical and mineralogical nature of the soil material.

The buffering power for K is therefore determined by the mineralogical composition of the clay fraction. The K buffer power of a soil varies with the composition of micaceous minerals (Sparks, 1987). In soils of similar origin and therefore similar mineral composition, the value of  $b$  generally increases with clay content. Plants utilise larger proportions of K from the soil of high diffusion coefficient, which have a low  $b$  value. This explains why luxury K consumption is sometimes encountered in the Western Cape on kaolinite rich soils or soils with low clay content, following potassium fertilisation.

### 2.7.2 Variety, rootstock and rootstock/scion combination

Berry and leaf K concentration vary for different rootstocks (Garcia *et al.*, 2001a) and for different scion varieties grafted onto the same rootstock (Attia *et al.*, 2004).

Research has demonstrated that the rootstock influences the K uptake and eventual berry K accumulation (Brancadora, Valenti & Reina, 1995; Garcia *et al.*, 2001b). Garcia *et al.* (2001b) found that K levels in the leaves of Négrette grafted on 3309 C were lower than the levels found in the same cultivar grafted on 101-14 Mgt or on SO 4 rootstocks. Daverède (in Garcia *et al.*, 2001b) found a positive correlation between K concentration in leaves at véraison and that present in the must of Négrette grapes. The same experiment of Garcia and coworkers (2001b) also showed that high K must concentrations lead to lowered acidity in the wines. Rootstocks, therefore, have the potential to alter the pH of grape juice by affecting vine and berry K content.

Two explanations are offered for the difference in vine and berry K contents for different rootstocks: different microclimatic conditions in the canopy due to vigour differences induced by the different rootstocks; or differential K uptake by and/or distribution in the rootstock (Rühl, 1991). If root interception and diffusion are the major forms of ion uptake, then differences in root growth or root surface area could also be a reason for differences in K absorption. If mass flow is the dominant form of transport, however, the uptake differences may depend on unrestricted water and ion flow, since mass flow is driven by transpiration. Mass flow is commonly regarded as less important for K<sup>+</sup> movement, but may be the major pathway in case of high K supply (Rühl, 1992).

Rühl (1992) conducted experiments to relate work done on other plant species to vine rootstocks. This work confirmed that a Epsteinian dual uptake mechanism exists for grapevine rootstocks: System I, which operates up to about 0.5 mmol<sup>-1</sup> K and is based on an active carrier system; and System II, which operates from about 1 mmol<sup>-1</sup> K upwards, is passive, may use K channels and is possibly driven by the water movement of the transpiration stream. In the same experiment, Rühl found that there was no difference in uptake between Freedom and 140 Ruggeri at low K supply (uptake System I), but 140 Ruggeri took up less K at high K supply (uptake System II). In still the same

experiment he found that relative humidity (transpiration rate) did not influence K uptake at high K supply. This means that different rootstocks may have a different genetic ability to restrict K absorption when System II operates at high K supply. Furthermore, the ion channels in the plasma membranes have the ability to restrict the amount of K uptake at high transpiration rates at high soil solution K concentration even if the absorption process is along a free chemical activity gradient. It is variation in this ability that probably causes different K absorption by different rootstocks. This ion channel restriction means that even if the plant is transpiring at a high rate, with high soil water flux towards the roots in a K rich soil, the amount of K taken up will be the same for this rootstock had the scion transpired at a much lower rate.

There is an increase in must and wine K for Cabernet Sauvignon grafted on 110R with decreasing crop loads (Bravdo *et al.*, 1985) but no significant increases for Carnignane/110R (Bravdo *et al.*, 1984). Given that rootstocks influence K uptake and possibly xylem translocation, it seems fairly obvious for differences in xylem and phloem translocation and berry K accumulation to exist for different scion varieties. Attia *et al.* (2004) also found that different scion varieties grafted on the same rootstock differed in their K absorption and in their leaf and berry accumulation. Riesling for example is a cultivar in which continual K uptake rarely occurs beyond normal sugar maturity (Boulton, 1980a). The author ascribed this to a limitation of cytoplasmic ATP in the later stages of maturity. Cabernet Sauvignon scions, on the other hand, appears to be a very effective accumulator of berry K and very responsive to conditions that would create high levels of petiole and juice K (Morris *et al.*, 1987).

Therefore, both the rootstock and scion variety probably have a genetically fixed K uptake and/or translocation ability; and the actual berry K concentration at harvest is a product of this genetic potential, root circumstances (morphological root properties, root system size), soil solution K activity, the mesoclimate, canopy microclimate, shoot to root ratio, crop load (grape yield to pruning mass ratio) and the scion/rootstock xylem and phloem translocation interaction.

### 2.7.3 Canopy microclimate

Canopy microclimate refers to the climatic conditions existing within the vine canopy and around bunches. These climatic conditions include amount and quality of irradiance reaching the leaves or bunches, relative air humidity, wind speed and temperature. The amount and quality of incoming solar radiation in the Western Cape is usually not a limiting factor (Wooldridge & Beukes, 2005) but it is important that the canopy be structured in such a way that the second and third leaf layers from the canopy surface receive adequate light for photosynthesis.

If the vigour of the vine increases without training system adjustments, self-shading within the canopy will increase. Radiation flux densities and wind speed are the main microclimate changes that will occur in such a situation with canopy temperature and relative humidity changes to a lesser extent (Smart *et al.*, 1985b). These authors proved that a shaded canopy microclimate at véraison produces grape juice and must with lower sugar content and higher malic acid and K concentrations, and higher pH values. Wines made from these musts had higher pH, K concentrations and reduced proportions of ionized anthocyanins. Colour density, total anthocyanins and phenol concentrations were also negatively correlated with within-canopy shade (Smart *et al.*, 1985b).

Shaded leaves are the main sources of K translocation to the berries during ripening and within-canopy shade leads to higher K concentrations in the leaves, petioles and bunch stems at véraison (Smart, 1985). Grapes from heavily shaded canopies have higher juice K concentration and pH at harvest (Rojas-Lara & Morrison, 1989). Shade influences other physiological processes as well. It decreases hexose production and sucrose translocation and berry size, increases malic acid metabolism and decreases tartaric acid metabolism (Smart, 1985). Grape juice composition at maturity is a function of the amount of shaded leaves and berries. Leaf shading reduces berry size and sugar content and increases berry K content and juice pH values whereas shaded bunches lead to lowered fruit phenol, monoterpene and anthocyanin levels and induce herbaceous characters in wine. In excessively exposed bunches phenol concentrations may increase beyond desirable levels (Smart *et al.*, 1990). In shaded canopies (leaf and bunch shading) the malic acid content of berries is often higher and the tartaric acid content often less.

There is a close relationship between irradiance and  $\text{NO}_3^-$  reduction in leaves. In dense canopies the ratio of far red to red wave lengths decreases. This causes phytochrome red to be the dominating phytochrome form present in the leaves. This form of phytochrome is inactive as far as enzyme activation is concerned (Smart, 1987). One of the enzyme activities negatively affected by the reduction in far red to red wave length ratio is nitrate reductase activity (NR). Low activity of NR leads to K accumulation in the leaves which could potentially lead to more K being translocated to the berries. Some workers have proposed that C assimilation is the main factor controlling nitrate NR activity in leaves and not light *per se* (Keller *et al.*, 1995). Be that as it may, both NR activity and C assimilation are negatively affected by within-canopy shade.

It has been conclusively proven that canopy management practices that increases photosynthetic activity of the leaves improves yield and eventual wine quality (Hunter, Skrivan & Ruffner, 1994).

#### 2.7.4 Cultural practices

The previous discussions in this section have dealt with the influence of soil, plant material and microclimate on berry K accumulation. The following subsection discusses the influence of vineyard practises on berry K accumulation.

##### 2.7.4.1 Crop load

Crop load is usually defined as grape yield to dormant pruning mass ratio (Jackson & Lombard, 1993). The original concept was leaf area per unit fruit mass, but crop load was introduced since crop load equates inversely and approximately to the leaf area/fruit mass ratio and because it is easier to determine. Essentially, the term crop load, or level, refers to the balance between source (leaves) and sinks (berries, shoots, trunk, roots) as far as carbohydrate synthesis, translocation and accumulation are concerned. Crop load values of 4 to 10 for single canopy training systems and 5 to 10 for double training systems have been suggested for a number of varieties, including Cabernet Sauvignon (Dokoozlian & Kliewer, 1995). Vines with these crop load values are considered balanced and should produce high quality fruit and wine (Bravdo, 2004).

Berries are strong sinks for K, especially after véraison. Since berries import their K from leaves primarily via the phloem after véraison, it should be possible for crop load to affect the patterns of translocation and distribution of K within the vine. The possible effect of crop load on berry, must and wine K content and wine quality, is still largely unresolved (Mpelasoka *et al.*, 2003).

Petiole K content has been negatively correlated with crop load in before harvest samples but positively at bloom (Hepner & Bravdo, 1985). Crop load had no significant effect on juice pH of Carignane vines, while berry K content tended to rise with decreasing crop load for this cultivar, although not significantly (Bravdo *et al.*, 1984). As crop load and yield decreases, K content of leaves, must and wine increased for Cabernet Sauvignon (Bravdo *et al.*, 1985). Wine K content increased with decreasing crop load for an irrigation experiment conducted on Cabernet Sauvignon/110R. In this particular experiment, wine K content was more influenced by crop load than by irrigation treatments (Bravdo *et al.*, 1985). Cabernet Sauvignon in an Arkansas experiment produced the highest berry K with K fertilisation combined with cluster thinning (reduced crop load) (Morris *et al.*, 1987). The effect of crop load was found to differ for different cultivars. Reduced crop load had no effect on grape juice pH, titratable acidity and K concentrations for Carignane vines (Freeman & Kliewer, 1983). In the same experiment the lower crop load increased berry mass and berry number per cluster (Kliewer, Freeman & Hossom, 1983).

What complicates the concept of crop load is that it gives no indication of the amount of exposed leaves in the canopy, only an idea of the ratio between total leaf amount and yield. The canopy design may vary the amount of leaves exposed to light, which can effectively modify the effective leaf area per unit fruit mass (Jackson & Lombard, 1993). Still, it appears as if berry K content of Cabernet Sauvignon increases with decreasing crop load (more vegetative growth in relation to yield). This relationship will, however, be modified by microclimate (trellis system and canopy management). On the other hand, berry size may decrease for higher crop loads, which may increase the skin to pulp ratio, meaning more K will be extracted during the vinification process.



#### 2.7.4.2 Canopy management

Smart *et al.* (1990) defined canopy management as the alteration of the position or amount of leaves, shoots and fruit in space to achieve an objective (e.g. improved canopy microclimate). The techniques available include winter and summer pruning, shoot positioning, leaf removal, shoot vigour control with tipping and topping and trellis systems. Proper foliage management should improve the microclimate of the canopy and ensure more favorable light interception for high photosynthetic activity and a favorable source:sink relationship for maximum sucrose translocation (Hunter, 1991).

Light quantity and quality are important for grape composition. Smart (1985) showed that 8 – 10 percent of photosynthetically active radiation (PAR) striking a canopy passes through the first leaf; the rest is absorbed, scattered or lost by heat dissipation. Leaf layers should, therefore, be managed in order to ensure maximum photosynthesis on the inside of the canopy. Shaded canopies produce fruit with increased K, pH, malic acid and *Botrytis* bunch rot incidence, and with reduced sugar, tartaric acid, phenol and anthocyanin content (Archer & Strauss, 1989, Smart *et al.*, 1990).

The same microclimate conditions that restrict photosynthesis will also restrict NR activity. Decreased NR activity leads to K accumulation in the cytosol of leaf-cells, increasing the K pool in the leaf available for phloem translocation to the berries. Shaded canopies also typically produce fruit of varying ripeness, reducing the quality of the finished wine. Shade leaves contribute little to canopy photosynthesis and turn yellow in time and abscise (Smart *et al.*, 1990).

Furthermore, a leaf on the inside of the canopy (a shade leaf) lack the capacity to achieve the photosynthetic rate of an exposed leaf (a sun leaf), even when moved into the position of a sun leaf (Hunter & Visser, 1989). A fundamental objective of canopy management is therefore to produce a canopy with minimal internal shade and arrangement of leaves, shoots and fruit for optimum light interception from as early as possible in the season with minimum internal leaf shading (Smart *et al.*, 1990).

Efficient canopy management is important since it greatly affects the translocation and accumulation of assimilates in berries (Hunter, 2000). Photosynthetates are utilised by vegetative growth at berry set, but increasingly transported to the berries after berry set.



The highest accumulation of photosynthetates in berries occurs at véraison. Towards the final stages of ripeness, sugar is again diverted to vegetative and storage sinks (Hunter & Visser, 1990). The sucrose production (photosynthesis) must be kept optimum for maximum sucrose loading into the phloem during the ripening phase (Period IIIa & b). Any factor limiting photosynthesis during this phase will increase phloem translocation of K to the berries (Iland, 1989). By véraison, the bunch must be the main sink for sucrose, the vigor of shoots needs to be controlled so that there is little vegetative growth after véraison (during Period III). Should sucrose transport be diverted from the berry to satisfy energy requirements of new shoot growth, K will be transported to the berry to satisfy the osmoticum requirement of the expanding berry. The rate of photosynthesis and the production of assimilates, depend, among others, on the age of the leaf and consequently, its position on the shoot (Hunter & Visser, 1989). The correct leaf position on the shoot should therefore be exposed at the correct time. The apical leaves have the highest photosynthetic rate while the basal leaves provide bunches with photosynthetates at all stages of bunch development (Hunter & Visser, 1988). Increasing the PAR in the fruiting region of canopy throughout the season, reduced titratable acidity, malic acid concentration, pH and K concentration of Sauvignon blanc grape juice at harvest (Bledsloe, Kliewer & Marois, 1988). Recent studies highlighted the importance of laterals (and their leaves) in supplying bunches with carbohydrates, especially during the later stages of ripening (Hunter, 2000). Removal of laterals induces compensatory growth which negatively affects the availability and distribution of carbohydrates in the canopy.

The correct leaf area to fruit mass ratio or yield to pruning mass ratio (crop load) is necessary to provide the berry with assimilates and this ratio is determined by the assignment of the correct bud load with winter and summer pruning. The spacing between vines determines to a large extent the balance between the amount of shoot growth and the amount of crop. In-row spacing should, therefore, provide sufficient canopy length for a balanced bud load so as to prevent shoot crowding and excessive within-canopy shade. Divided canopies and wide vine spacing have proved to produce fruit with lower malic acid, pH and K, when compared to single canopy trellis and close vine spacing (Kliewer, Wolpert & Benz, 2000).

Canopy management, therefore, dictates to a large degree the photosynthetic activity of the canopy. High photosynthetic activity is vital at all stages of vine growth, but is critical after véraison to prevent high K accumulation in the berries.

### 2.7.4.3 Fertilisation

Potassium ions, which are taken up rapidly by cells, generally compete strongly with cation uptake. However, when other cations are present in high concentrations, K uptake may be reduced. Increasing the supply of one cation species in the nutrient solution, depresses the level of other cation species in a plant. This phenomenon is called cation antagonism (Mengel & Kirkby, 1987c).

If the absorption of charged solutes is generally a non-specific process, the absorption rate of a particular solute will be determined by the chemical potential difference between the solute in the nutrient solution and the cytosol. This means that the activity of the particular solute in the nutrient solution will determine its uptake if nonspecific competition between cation species for the negative charges of the cell occur. The cation species taken up first will decrease the electro-negativity and reduce electrostatic attraction of the cell for the other cation species. The uptake rate is determined by the activity of the cation species in the nutrient solution and the absorption mechanism across the membrane for the specific cation (Mengel & Kirkby, 1987c).

If the root cell membranes are exposed to a high enough  $K^+$  concentration in the nutrient solution ( $> 0.3 - 0.5 \text{ mM l}^{-1}$ ), the absorption of this cation should be passive. The K ions are attracted to the electronegative charge of the epidermis or cortex cells and diffuse through ion channels along a free energy gradient. The activity of the K ions determines the uptake rate (Mengel & Kirby, 1987c). By adding Ca and Mg to the soil solution, the relative concentration of K in the soil solution is decreased and its activity decreased. Additions of Ca and Mg will reduce the K saturation of the exchange complex, which in turn should theoretically with time reduce the K concentration in the nutrient solution. The K concentration of the soil solution should in fact be increased immediately or shortly after the application of the divalent cations. This effect would properly be temporary and disappear after a season when the mobile K had sufficient

time to leach from the root zone. The lowered activity of K in the soil solution should result in decreased K uptake.

Thus, the application of certain fertilisers could theoretically lower the root absorption of K, which in turn will lead to less K transported to the berries, with less K accumulated during the maturation phase of berry development. Gallego (1999) provided evidence for this: CaCO<sub>3</sub> soil applications increased Négrette wine acidity by decreasing K absorption and subsequent accumulation in the berries.

The antagonistic effects of other cations are sporadically reported. Wine K was significantly decreased by P fertigation in one Israeli study for one season but not consistently for different experimental years (Bravdo & Hepner, 1987). Rühl, Fuda & Treeby (1992) found that Mg fertiliser application decreased wine pH but had no effect on the K concentration of grape juice.

Recent nutritional studies in France have produced excellent results under greenhouse conditions employing hydroponics. The titratable acidity of musts and wines of Négrette vines was increased by decreasing the K concentration in the nutrient solution (Daverede & Garcia, 2000). Garcia *et al.* (1999) managed to reduce the K<sup>+</sup> content in Négrette petioles and leaf blades at véraison by 30 percent through Ca enrichment of the nutrient solution. The antagonism between K and Ca was confirmed in subsequent rootstock trials, also using hydroponics (Attia *et al.*, 2004). Gallego (1999) proved that soil applied CaCO<sub>3</sub> increases the wine acidity of Négrette by decreasing K absorption and accumulation in the berries. In a similar experiment Engelbrecht (2002) could find no effect of soil applied CaSO<sub>4</sub> and Ca(OH)<sub>2</sub> on wine acidity.

To extrapolate results obtained with hydroponics to field conditions is always difficult. Rühl (1992) showed that the ability of different rootstocks to restrict K absorption at high K supply is probably determined by differences in the ion channel mediated absorption of potassium (passive absorption through System II). Hydroponic conditions should favour passive K absorption through System II by always providing sufficient water and nutrients to roots. Engelbrecht (2002) suggested that intense K depletion zones surrounding vine roots in the soil under field conditions should always favour active K absorption through System I.

#### 2.7.4.4 Magnesium foliar nutrition

Magnesium foliar sprays are employed in the wine and table grape industry to combat bunch stem necrosis. Bunch stem necrosis is caused by specific soil and climatic conditions and some cultivars may be genetically predisposed to this physiological disorder. The cause of the condition is complex, but Ca and Mg play key roles in its prevention (Keller & Koblet, 1995). Magnesium sulphate and magnesium oxide are used as leaf applications in South Africa and overseas to provide the stem tissue with sufficient magnesium during critical physiological phases. The most effective control is achieved with bunch directed fertilizer sprays at and around véraison.

In soils with high K levels the influx of this ion into roots are usually higher than that of magnesium. The soil-root interface is, therefore, rapidly depleted of K but not of magnesium. In root uptake studies, Mg influx increased abruptly after the K concentration of soil directly in contact with the roots decreased below 20 mmolm<sup>-3</sup> (Jungk, 2001). It may be that K depletion at the root-soil interface is necessary for sufficient Mg uptake in soils with high K content. Supplementing soil Mg with magnesium foliar sprays may be important to supply plants with adequate Mg in K rich soils.

Different Mg salts are absorbed at different rates by the leaves of apple trees (Swietlik & Faust, 1984). Magnesium chloride is more effective in raising leaf Mg levels than MgSO<sub>4</sub> for example. The authors explain this by the fact that MgSO<sub>4</sub> requires 80 percent relative humidity to remain in solution while MgCl<sub>2</sub> requires only 30 percent relative humidity.

Workers have reported that wines made from berries sprayed with magnesium have a lower K/Mg- and Ca/Mg- ratio (Rupp, Fox & Tränkle, 2002). It is, therefore, plausible to consider MgSO<sub>4</sub> foliar sprays as a method to modify the extent of exchange ratio of grape juice by lowering the K concentration in the berries and thereby reducing the pH of the wine. The Mg ion is considered highly phloem mobile in deciduous fruit trees and vines (Tagliavini *et al.*, 2000). According to some workers foliar absorbed Mg is immobile in trees, but not when a deficiency exists. In such a situation, Mg is transported from old leaves to young leaves and fruit (Swietlik & Faust, 1984). In Germany the alcohol, residual sugar, sugar-free extract and wine colour of the cultivar Lemberger

(Blaufränkisch) were not influenced by magnesium foliar treatments when applied at and around véraison (Rupp, Fox & Tränkle, 2002).

#### 2.7.4.5 Irrigation

Warm mesoclimates in the Western Cape produce grapes with low acidity and high pH (Conradie *et al.*, 2002). Water limitation is the most important stress factor in this area during the growing season, and especially during the sucrose accumulating period in January and February. At low external water potentials, cellular growth (root and shoot growth) is firstly decreased. Reduction in cell growth is followed closely by a reduction in cell-wall synthesis. At slightly more negative water potentials, the activity of certain enzymes, notably nitrate reductase, is reduced (Salisbury & Ross, 1985c). At further levels of stress, cell division is inhibited and stomates close. There is some uncertainty whether water stress inhibits photosynthesis through the closing of stomates or depresses photosynthesis directly. In any event, water stress leads to reduced photosynthesis, and according to the osmotic potential model, leads to higher K accumulation in the berries. Reduced NR activity should theoretically lead to K accumulation in the leaves. Irrigation management to prevent high K accumulation in the berries under Western Cape conditions is an area well worth investigating.

Kliewer *et al.* (1983) found that furrow irrigation at a fixed schedule increased berry mass, number of berries per cluster and crop yield. They also noted that this irrigation regime increased vegetative growth about twice as much as it increased crop yields. The larger berries and the possibility of stimulating vegetative growth during Period III necessitates a more careful approach to the irrigation of wine grapes. The irrigation strategy currently favoured by viticulturists in dry areas is the following: vines are well watered until set, followed by a deficit irrigation period between set and véraison to reduce berry size and to reduce vegetative growth; from véraison to harvest vines are stressed enough to minimise new vegetative growth but not to a level to slow sugar accumulation (Dry *et al.*, 1998).

Vines seem to be very susceptible to water stress for four weeks after flowering, and less so after véraison. The reason for this has been linked to the change from mainly xylem to predominantly phloem flow to the berry (Creasey, Prince & Lombard, 1993). Water

deficit between flowering and véraison causes significant reduction in berry mass at harvest (Poni *et al.*, 1993, Sipiora & Gutierrez Granda, 1998). Yield is thus decreased more by early deficits than by late deficits (Matthews, Anderson & Schultz, 1987). Early season stress (around or just following flowering) reduces berry size by reducing cell division in the pericarp. Restoring full irrigation after véraison do not accelerate berry enlargement. The capability of the exocarp to expand is permanently reduced rather than the ability of the cell to enlarge (McCarthy, 1997). Ojeda *et al.* (2002) found that an early post véraison water deficit (Period IIIa) also reduces berry weight per berry.

Pre-véraison stress, with adequate post-véraison irrigation, produces smaller berries which increases the skin:pulp ratio. This increase have been sited as the cause for higher colour densities and higher polyphenolic content for wine made from vines which experienced pre-véraison stress as compared with post-véraison stress (Acevedo *et al.*, 2004). Small berries are generally sought after by winemakers but may have the undesirable effect to cause higher concentrations of K and Cl in wine (Wang *et al.*, 2003). Storey (1987) found that small Terrago berries contained higher K concentrations in the skin than large berries.

It seems that part of the irrigation effect is indirect and comes via the effect of crop load (grape yield to pruning mass ratio) (Hepner & Bravdo, 1985). Early season deficits shortened the period of shoot elongation and node production of Cabernet franc in California and also decreased maximum shoot elongation and node production rates, and accelerated periderm development on current season shoots (Matthews, Anderson & Schultz, 1987). Should irrigation reduce crop load (more vegetative growth in relation to yield) then berry K accumulation could potentially increase. It is, therefore, important to combine irrigation with cultural practices that control crop load, e.g. winter pruning, summer canopy management and trellising (Bravdo & Naor, 1996).

Ojeda *et al.* (2002) found that post véraison water deficit reduced soluble solid content per berry for Shiraz grapes. Other workers have reported an increase in sugar content for vines irrigated sufficiently after véraison (Ortega-Farias *et al.*, 2004).

Evidence of a diurnal variation in K juice content was found in experiments with Shiraz grapes experiencing severe water stress (Dundon & Smart, 1984). Results indicated that

as water stress increased during the day, berry juice K content also increased. As water stress increased diurnally, ambient and grape temperatures also increased, resulting in the limitation of photosynthesis and of sucrose available for translocation. In the presence of K and cytoplasmic ATP in the mesophyll cells, K is actively loaded into the phloem and accumulates in the berry at the expense of sucrose. This exchange consumes ATP, thereby allowing further malic acid respiration to occur, generating additional ATP in the process. Although these results are strictly speaking only applicable to Shiraz vines experiencing severe water stress, it is plausible to accept that water stress will limit photosynthesis and that this may cause K to accumulate in grape berries of all red varieties.

Wang *et al.* (2003) subdivided post-véraison berry growth of Period III into three stages (IIIa, IIIb & IIIc). They found that water stress during Period IIIa, up to 75 days after anthesis (DAA), did not affect sugar unloading of Syrah berries. Water stress during this phase will reduce photosynthesis but also vegetative growth (shoot elongation). McCarthy (1997) found that the rate of shoot elongation is reduced by water stress before any differences in predawn leaf water potential is detectable. A reduction in vegetative growth (i.e. the plant's vigour) can, therefore, compensate for the observed reduction in photosynthetic activity without affecting berry sugar unloading (Wang *et al.*, 2003) and possibly berry K accumulation.

During Period IIIb, after 75 DAA, phloem sugar unloading was clearly greater in the normally watered vines than in the water stressed vines. Wang *et al.* (2003) concluded that enhanced phloem unloading was the reason why the sugar concentration of unstressed berries is greater than stressed berries.

Phloem flow decreases during Period IIIc, leading to a reduction in the amount of sucrose arriving in the berry (McCarthy & Coombe, 1999). The berry continues to lose water by transpiration which leads to a reduction of fresh berry mass and volume and an increase in the sugar concentration of the berry. From 90 DAA and onwards, the accumulation of sugar decreases with water stress (Wang *et al.*, 2003).

It would appear that sugar concentration of berries are not significantly influenced by water stress during Period IIIa and early Period IIIb, but water stress during the late



Period IIIb and IIIc does reduce berry sugar concentration (Wang *et al.*, 2003). Depending on the severity of water stress and the time at which it is applied (or at which it occurs naturally – terroir effect), a reduction in vegetative growth (i.e. vigour of the plant) can compensate for the observed reduction in photosynthetic activity without affecting berry sugar unloading (Wang *et al.*, 2003).

If irrigation can maintain sucrose production during late Period IIIb without stimulating shoot growth, then it can be an effective tool for limiting berry K accumulation during this period. According to literature, however, irrigation of vines generally leads to increased berry K<sup>+</sup> accumulation. Irrigation increased pH and K concentration of Carignane vines (Freeman & Kliewer, 1983). Irrigation produced an increase in dry matter production and increased K export to the berries (Zaballa *et al.*, 1997).

It would appear that irrigation experiments that did not adapt water applications for the different berry growth stages, almost always resulted in increased vine K content (Klein *et al.*, 2000; Esteban, Villanueva & Lissarrague, 1999). However, pre-véraison and post-véraison stress experiments generally had no significant effect on must K concentration (Poni *et al.*, 1993). Three water supply levels after véraison had no effect on juice sugar content, titratable acidity or pH values (Sivilotti *et al.*, 2005). However, Sipiora & Gutierrez Granda (1998) reported a significantly higher juice K content and lower titratable acidity for post-véraison water deficit in comparison with pre-véraison deficit for Cabernet Sauvignon. Water stress leading to reduced photosynthesis and NR activity is required in order for irrigation to lower berry K accumulation. This could be a possible reason why the experiments mentioned above failed.

Some workers have successfully used partial rootzone drying (PRD) to reduce juice pH of Cabernet Sauvignon without affecting berry size (Chalmers, Kelly & Krstic, 2004). Pre-véraison stress, with adequate post-véraison irrigation, produced smaller berries which increases the skin:pulp ratio. This increase have been sited as the cause for higher colour densities and higher polyphenolic content for wine made from vines which experienced pre-véraison stress as compared with post-véraison stress (Acevedo *et al.*, 2004). The increase in skin:pulp ratio may also be the reason why pre-véraison water stress have no effect on the K content of must and wine.



Freeman & Kliewer (1983) found that water stress during the final stages of ripening delayed K accumulation and that soil K content had no effect on fruit quality. These authors concluded that irrigation management was more important than crop thinning or soil K for regulating wine pH and that applying water stress was useful in overcoming high pH problems in the wine as well as to increase wine colour. In the experiment conducted by Freeman & Kliewer (1983), the irrigated vines showed delayed maturity, which could mean that water was not a limiting factor for this experiment.

Theoretically it should be possible to restrict the absorption of K through moderate water stress during Periods I, II and IIIa. Stress-induced K translocation to the berries during Period IIIa may depend on whether the reduction in vegetative growth can compensate for the reduction in photosynthetic activity. Soil water should not severely limit photosynthesis during Period IIIb and IIIc, since this will decrease sucrose loading into the phloem. Water levels needs to be maintained but the stimulation of vegetative growth must be prevented. Shoot growth could cause canopy shading, leading to reduced photosynthesis and NR activity, which could lead to more K being loaded into the phloem, or could divert sucrose translocation from the berries.

The literature agrees that more water generally equals more K uptake, which makes optimum canopy microclimate even more important should the vines be moderately irrigated during Period III. Irrigation schedules and regimes will not be successful in reducing berry K content if proper canopy management is neglected.

### **2.7.5 Environmental effects**

Canopies growing too luxuriously will lead to within-canopy shade, reduction of photosynthesis, NR activity and consequently high phloem loading of K and berry K accumulation (Smart *et al.*, 1990). More vegetative growth can be expected in a season with optimum climatic conditions. Unfavorable climatic conditions, which are hot and dry conditions in the Western Cape, may limit soil water availability especially towards the end of the ripening period (January to March, e.g.) which may lead to stomatas closing early during the day, less photosynthesis and high phloem loading of K and consequently berry K accumulation. The available soil water reservoir, as determined by soil texture and rooting depth will also play an important role. Within-canopy temperature and water

supply to the shoots will also affect malic and tartaric acid production before véraison and malic acid degradation after véraison (Champagnol, 1994).

If vegetative growth is restricted, it follows that less K will be absorbed since the shoots will have lower K requirements. Active shoot growth at véraison may lead to a larger shoot K demand, which could establish a greater reserve K pool for translocation to the berries during the ripening phase should photosynthesis be limited for a reason. Furthermore, high transpiration rates will lead to more K being absorbed, unless the shoot demand for K is low (shoots are not growing), in which case the plants will absorb water with less K along with it (Tromp, 1980).

The environment, soil conditions and site climate, may influence berry K content through two ways: through providing conditions conducive to the stimulation of vegetative growth both pre- and post-véraison, and the reduction of the photosynthetic rate post-véraison.

## 2.8 Conclusions

Potassium ions are the main cation constituent in both xylem and phloem sap. This cation is accumulated in leaves and berries to the highest level of all the cations. This nutrient is highly mobile and is as such indispensable for normal vine physiological functioning. After véraison, the berry becomes the main sink for potassium.

It is important to adapt canopy management, water management and nutrition management of the grapevine to the physiological stages of grape development (Hunter & Ruffner, 2001).

The vine should not experience water stress during the ripening phase to the extent that stomata closes, but mild water stress should prevent vegetative growth, which stimulates: 1) within-canopy shade and; 2) shoot demand for K and subsequent K absorption. The canopy should be open enough for maximum photosynthetically effective leaf area from as early as possible and definitely by véraison.

Any factor that restricts photosynthesis in a leaf could potentially lead to K being loaded into the phloem and translocated to the berry. Smart *et al.* (1985a) proved that the highest

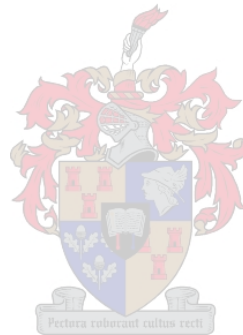
K must concentration is achieved with shaded canopies at véraison. This implies that reduction in leaf photosynthetic activity by shading after véraison in Period III will cause more K translocation to the berries. The higher proportion of inorganic ions contributing to osmotic potential in older leaves (Peuke, 2000) could mean that photosynthetic inhibition of older leaves (lower in the canopy) would cause more K<sup>+</sup> translocation than younger leaves.

The xylem/phloem switch has important repercussions regarding K accumulation in berries. Berries are supplied with this cation mainly by the roots before véraison and by leaves, shoots, roots and the trunk after véraison (Conradie, 1981b). Before véraison, soil K supplying power is important and after véraison leaf K supplying power is important. Leaf supplying power could be defined as reserve K (therefore ultimately soil dependent) and microclimatic effected K translocation. Soil K content may be important in affecting berry K content up and until véraison for a vine that is not K deficient. After véraison photosynthesis and reserve K in the leaves and the shoots may be more important determinants for eventual berry K content at harvest in a vine that is not K deficient.

The ideal situation for the minimum amount of potassium in grape juice without affecting the normal physiological functioning of the vine, could be: restricted water availability during Periods I and II of berry development to prevent high K absorption by the roots in a soil without high K saturation of the exchange complex; the prevention of water stress that cause stomatal closing during Period III, to ensure optimum photosynthesis without stimulating excessive growth ; optimum light interception by basal leaves from berry set to harvest through judicious canopy management; laterals above the bunch zone should not be removed to prevent compensatory growth that will negatively affect carbohydrate distribution in the canopy.

Vine cultivation practices with berry K restriction as objective are therefore cumulative. The correct cultivar/rootstock combination needs to be selected for the correct location. The soil need to be prepared and ameliorated to establish optimum physical and chemical conditions for growth and grape quality. The row direction must ensure optimum light interception. The interplant spacing and trellis system must accommodate the eventual natural vigour, or lack thereof, of the vine. Judicious canopy management from the first

season is critical to ensure correct yield to effective leaf surface ratios and optimum light interception by the photosynthetically active leaves. Finally, to prevent severe water stress during the ripening phase, an integrated irrigation approach may be all important in warm wine producing areas such as the Paardeberg area.

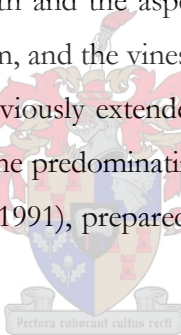


### 3. MATERIALS AND METHODS

#### 3.1 Layout of field experiment

The experimental sites were selected on the twin basis of high soil K content and a history of luxurious K uptake by wine grapes and corresponding high K levels in must and wine (Engelbrecht, 2002). The Paardeberg area near the town of Wellington in the Western Cape is a well known warm wine producing area in the Western Cape (30 yr. MFI = 23.6 °C).

A five-year-old vineyard, *Vitis vinifera* L. var. Cabernet Sauvignon, grafted onto 101-14 Mgt. (*Vitis Riparia* X *Vitis rupestris* var. du Lot) was used at Kersfontein. The row direction was magnetic north – south and the aspect magnetic easterly, with a 12-15% slope. The plant spacing was 1.2 x 3 m, and the vines were trellised on a three-wire Perold trellising-system. This trellis was previously extended to support an extra set of canopy wires 30cm above the original set. The predominating soil form was classified as Oakleaf 2120 (Grondklassifikasiewerkgroep, 1991), prepared with a mix delve plough to a depth of 70 cm.



On Meerlus a five-year-old *Vitis vinifera* L. var. Cabernet franc, grafted on 99 Richter (*Vitis Berlandieri* var. Las Sorres x *Vitis rupestris* var. du Lot) was used. The row direction was magnetic north-south and the aspect magnetic southerly, with a 5-7% slope. The predominating soil forms were classified as Oakleaf 2110 and Tukulu 2120, prepared with a mix delve plough to a depth of 110 cm.

Both farms received irrigation, with Meerlus being irrigated with micro jets and Kersfontein being irrigated with over head sprinklers.

Climatic data for Boland Agriculture School was obtained from ARC-Infruitec/Nietvoorbij, Stellenbosch. The school is located approximately 15 km and 20km from Meerlus and Kersfontein, respectively.

### 3.2 Experiment treatments

#### 3.2.1 Fertiliser treatments

Fertiliser treatments were applied once-off before harvest in February 1998 (Engelbrecht, 2002). Treatments were none (control), 5 tons  $\text{CaSO}_4$  per hectare and equivalent amounts of  $\text{Ca}(\text{OH})_2$ , and magnesium sulphate. The fertilizers were spread on the surface 30 cm on either side of the vine and mixed in by shovel to 10-15 cm depth.

#### 3.2.2 Canopy and foliar spray treatments

Canopy manipulations were repeated yearly on the same treatment vines from 1998/99 to 2000/01. Six vines were used for each treatment but only the central four vines were sampled. The treatments consisted of:

1. **Canopy 1** (least dense):
  - Shoots were thinned to two shoots/bearer at 15 cm shoot length
  - Vertical shoot positioning as necessary throughout the season
  - Tip (removal of top 5 cm of shoot) as necessary. Actively growing shoots were tipped weekly to ensure a main shoot length of 90 cm. In 1999/00 the first tip action was after anthesis but closer to véraison, in 2000/01 the first tip was closer to anthesis for both farms.
  - Removal of lateral shoots in the bunch zone at véraison
  - Removal of yellow leaves in the bunch zone after véraison
2. **Canopy 2** (intermediately dense):
  - Shoots were thinned to three shoots/bearer at 15 cm shoot length
  - Vertical shoot positioning as necessary through the season
  - Topping of shoots back to a main shoot length of 90 cm before véraison
3. **Canopy 3** (control/dense):
  - Vertical shoot positioning as necessary through the season
  - Topping of shoots back to a main shoot length of 90 cm before véraison

The results will be presented and discussed in terms of “Canopy 1”, “Canopy 2” and “Canopy 3” hereafter.

Magnesium sulfate sprays were applied at and two weeks after véraison for two seasons (1999/00 and 2000/01) at 10kg/100lit per application (10 percent concentration). Sprays

were applied to bunches and leaves in the bunch zone on both sides of the canopy to dripping point. The absolute spray volume differed for the different canopy treatments (spray volume not recorded).

### 3.3 Analyses

#### 3.3.1 Determination of growth, yield and yield components

Canopy densities were determined using the point quadrat method (Smart *et al.*, 1990) on the 25-26 January, 2000, 2001. Ten point quadrats per treatment replicate were taken by randomly inserting a 1m needle through the canopy at a 90° angle in the bunch zone. The nature of each contact was recorded.

Mass and length of dormant cane prunings from each vine was recorded for two seasons. It is common practice in South African vineyards to divide winter pruning into two actions. This is done to even the workload of laborers during the winter. The shoots are first prepruned (stompsnoei) to 30cm in length any time during April to August. The shoots are then pruned for a second time (skoonsnoei), three weeks before bud break, to two buds per bearer. Due to this practice, data for pruning mass per bearer, average shoot mass and average shoot length was lost at Kersfontein for the 1999/2000 and the 2000/2001 season.

Yield per vine and the number of clusters per vine were determined at harvest. The cluster mass was calculated from total cluster mass per vine. Berry mass was calculated by counting the berries sampled for juice analyses taken at harvest and weighing the total sample per treatment. The berries were not clipped through the pedicel from the bunch (Van Schalkwyk, 2004) with the result that the brush was not included in the weighted tissue. The berry mass may therefore be lower than “normal”.

#### 3.3.2 Soil analyses

Soil samples were taken in the 1998/99 season (Engelbrecht, 2002) and in the 2000/01 season at standardized depths 0-30cm, 30-60cm and 60-90cm with a soil auger. Four sub samples were taken between sample vines 1 & 2 and 3 & 4 and on both sides of the plant row.

The samples were analysed for extractable cations (0.2M NH<sub>4</sub>Oac. pH 7) and for water soluble cations and anions (The Non-Affiliated Soil Analyses Work Committee, 1990).

The particle size distribution of the soil horizons was determined using the pipette method (The Non-Affiliated Soil Analysis Work Committee, 1990) and verified by Dr. F. Ellis (senior soil scientist, University of Stellenbosch). The soils were classified using the South African classification system (Soil Classification Working Group, 1991).

The mineralogical composition of the coarse, medium, fine and very fine sand, fine silt and clay fractions were determined at the Dept. of Geology, Stellenbosch University, using X-ray diffraction.

### 3.3.3 Plant tissue analyses

Leaves were sampled every season from 1998/99 to 2000/01 (1998/99 by Engelbrecht). Leaf blades and petioles were immediately separated at sampling. Samples were taken at pea size, véraison and harvest, 32 samples per treatment on either side of the canopy in the bunch zone. Leaf blades and petioles were analysed according to the standard method of Stellenbosch University (Du Preez, Carstens & Van Wyk, 1981).

A composite berry sample consisting of 150 berries per treatment were taken at pea size, véraison and harvest. Berry samples were weighed, crushed by hand and pressed through Nylal-cloth (nr. 12XXX-112). The juice volume was measured and the skins dried at 80°C. The juice were analysed for sugar (°Balling), titratable acidity (to end point 7 with sulfuric acid) and pH according to Iland, Eward & Sitters (1993), the standard procedure of the Stellenbosch University. Afterwards the juice was stored at 5°C with the preservative *Actistab*<sup>®</sup>. The skins were analysed for cations (Du Preez, Carstens & Van Wyk, 1981). Due to the hand pressing, the possibility exists that relative unequal amounts of K was pressed from the especially the skins, potentially affecting the juice K concentrations determined.

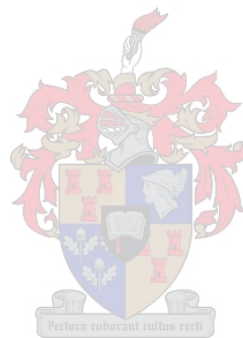
### 3.3.4 Statistical analyses

The trial was a 4 x 3 factorial experiment lay-out in each of the Cabernet Sauvignon/101-14 Mgt and Cabernet franc/99 R vineyards and measurements repeated for 3 seasons (1998/99, 1999/00 and 2000/01). The factors were four fertiliser



treatments (None,  $\text{CaSO}_4$ ,  $\text{Ca}(\text{OH})_2$ ,  $\text{MgSO}_4$ ) and three canopy treatments (Canopy 1, Canopy 2 and Canopy 3). The experimental plots consisted of 6 vines each with the central four as data vines. The experimental plots were split in the 1999/00 and 2000/01 seasons to allow the application of  $\text{MgSO}_4$  foliar sprays to the randomised treatments.

Combined analysis of variance or split-plot ANOVA was performed using SAS version 8.2 (SAS, 1999). The Shapiro-Wilk test was performed to test for non-normality (Shapiro & Wilk, 1965). Student's t-Least Significant Difference was calculated at the 5% confidence level to compare treatment means of significant effects (Snedecor & Cochran, 1967).



## 4. RESULTS AND DISCUSSION

The results are discussed in four parts. The first part deals with the influences of the soil fertiliser applications on the cation composition of the soil. The following three part deals with the influence of canopy treatments, fertiliser applications and MgSO<sub>4</sub> foliar sprays on vine growth, vine tissue cation composition, and on harvest grape juice composition and wine components. At the end of each part a short, summarising discussion is given, with the final conclusions provided at the very end. Attached are appendixes A and B.

### 4.1 The effect of specific fertilisers on soil cation composition

#### 4.1.1 Soil mineral and particle composition

The dominant clay mineral in the soils from the two farms was kaolinite (data not shown). In fact, the X-ray diffraction analyses revealed no trace of mica or biotite. This is in agreement with Wooldridge (1988) who reported that kaolinite is the main soil clay mineral constituent of soils in the fruit producing areas in the Western Cape.

**Table 1. Particle size fractions for the dominate soil form in the experimental vineyards at Kersfontein and Meerlus, Paardeberg**

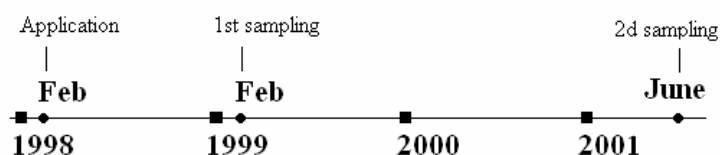
Farm	Soil form	Horizon	Depth (cm)	Coarse fraction (%)	Sand (%)	Clay (%)	Silt (%)
Kersfontein	Oakleaf	A	0-30	4	74	15	12
		B1	30-65	3	52	34	15
		B2	65+	5	63	25	13
Meerlus	Tukulu	A	0-40	32	77	8	15
		B	40-115	39	66	22	13
		C	115+	30	20	58	22

A fair amount of cation leaching can be expected in the soils of the Paardeberg region under irrigated conditions. There is a lot of gravel in the soil at Meerlus whilst almost none in the soil at Kersfontein. Kersfontein have a higher A and B horizon clay content and lower coarse particle content than Meerlus (Table 1). Less leaching of mineral cations

can be expected in the soil at Kersfontein since kaolinite is the dominant clay mineral at both locations (data not shown).

#### 4.1.2 Soil chemical composition

The first set of soil samples were taken and analysed by Engelbrecht (2002) in 1999, one season after application. The second set was taken in 2001, three seasons after application. Only extractable cations were determined for the second sample set.



The interpretation of extractable cations is complicated by the fact that lime was accidentally applied to the experimental plots at Kersfontein by the owner of the farm. The CEC was not determined for the samples taken in 2001. The CEC would presumably be increased by the addition of lime (Tisdale, Nelson & Beaton, 1980). The S-value ( $\text{Ca} + \text{Mg} + \text{Na} + \text{K}$  in  $\text{cmol}_c \text{kg}^{-1}$ ) increased significantly from 1999 and 2001. The figures on the following pages give the soil cation content expressed in absolute amounts ( $\text{cmol}_c \text{kg}^{-1}$  clay) and as a fraction of the S value in appendix A.

##### 4.1.2.1 Kersfontein

Exchangeable Mg, K and Na differed significantly between the different sampling depths, while Ca, Mg and Na levels across sampling depths were influenced by the fertiliser treatments (Fig. 2). Exchangeable K was not significantly influenced by fertiliser applications but decreased significantly in all soil layers from 1999 to 2001 (Fig. 2), possibly due to leaching and/or active root absorption.

##### *Exchangeable calcium*

One year after fertiliser application, the  $\text{CaSO}_4$  and  $\text{Ca}(\text{OH})_2$  treatments significantly increased the exchangeable Ca content of the topsoil (0-30 cm) compared to that of the control (Fig. 2). Three years after application (2001 samples), the Ca content of the control had increased, presumably due to the accidental liming of the experimental sites.

The  $\text{CaSO}_4$  and  $\text{Ca}(\text{OH})_2$  treatments, therefore, had no significant effect on exchangeable Ca content in 2001 when compared with the control. The  $\text{MgSO}_4$  treatment reduced exchangeable Ca slightly one year after application but not significantly. Three seasons later, the  $\text{MgSO}_4$  treatment reduced the exchangeable Ca content significantly when compared to the Ca treatments and the control.

For the 30-60 cm soil layer, the  $\text{MgSO}_4$  treatment significantly lowered exchangeable Ca to a depth of 50/60 cm one and three years after application, whilst the influence of gypsum and  $\text{Ca}(\text{OH})_2$  on exchangeable Ca content was still limited to the topsoil after three seasons.

#### *Exchangeable magnesium*

The exchangeable Mg content of the 0-30 cm topsoil was significantly decreased by gypsum in the first season after application (Fig. 2). By the third season, this effect had disappeared. The  $\text{MgSO}_4$  application significantly increased the exchangeable Mg one year after application and this increase was still significant after three years. The  $\text{MgSO}_4$  application proved to significantly increase the exchangeable Mg content up to a depth of 80/90 cm one year following application. This effect on the subsoil was still significant three years after application. The Mg ion is, therefore, extremely mobile in this particular soil.



#### *Exchangeable sodium*

The sodium content of the topsoil (0-30 cm) was significantly reduced by the  $\text{MgSO}_4$  application in 1999 (Fig. 2). By 2001 this effect had disappeared. Interestingly, the effect of fertiliser applications on exchangeable Na levels was more pronounced in the 30-60 cm soil layer three years after application. Here the  $\text{CaSO}_4$  and  $\text{Ca}(\text{OH})_2$  treatments significantly reduced exchangeable Na content. The exchangeable Na content of the 60-90 cm soil layer increased slightly during the three seasons between sampling due to irrigation water with possible moderate Na contents ( $\text{EC} = 78.3 \text{ mS m}^{-1}$  for irrigation dam, Na content not determined). The cation seems to have leached swiftly from the topsoil and accumulated in the subsoil with the higher clay content (see Table 1).

#### *Exchangeable potassium*

Exchangeable K levels significantly decreased in the 0-30 cm soil layer over three seasons for all treatments, including the control (Fig 2). This could be due to leaching and/or plant uptake. Most of the 101-14 Mgt roots were located within the top 50 cm (Engelbrecht, 2002). Nevertheless, the  $\text{MgSO}_4$  application significantly reduced the exchangeable K content of the topsoil one year after application, with the Ca treatments doing so to a lesser extent (not significantly). These effects disappeared after three years when none of the fertiliser applications had any effect on the exchangeable K content.

None of the treatments affected exchangeable K content in the 30-60 cm soil layer in both sample sets. The levels of this nutrient dropped from 1999 to 2001 in this layer but only significant with the  $\text{CaSO}_4$  and  $\text{Ca(OH)}_2$  treatments. It could be hypothesised that the Ca applications increased the Ca saturation of the topsoil during the first season after application at the expense of exchangeable K. The exchanged K had sufficient time to leach to the 30-60 cm soil layer and to slightly increase the K saturation of these treatments in 1999 (not significantly). The overall higher Ca content in the soils of these treatments (not significantly) could have lead to a more pronounced K exchange and more leaching losses over the following two seasons. The other possibility is that the gypsum and  $\text{Ca(OH)}_2$  produced more favorable conditions for root growth in the 0-50/60 cm soil layer, which lead to more K uptake by the roots. These favorable conditions do not include increases in the exchangeable Ca content though.

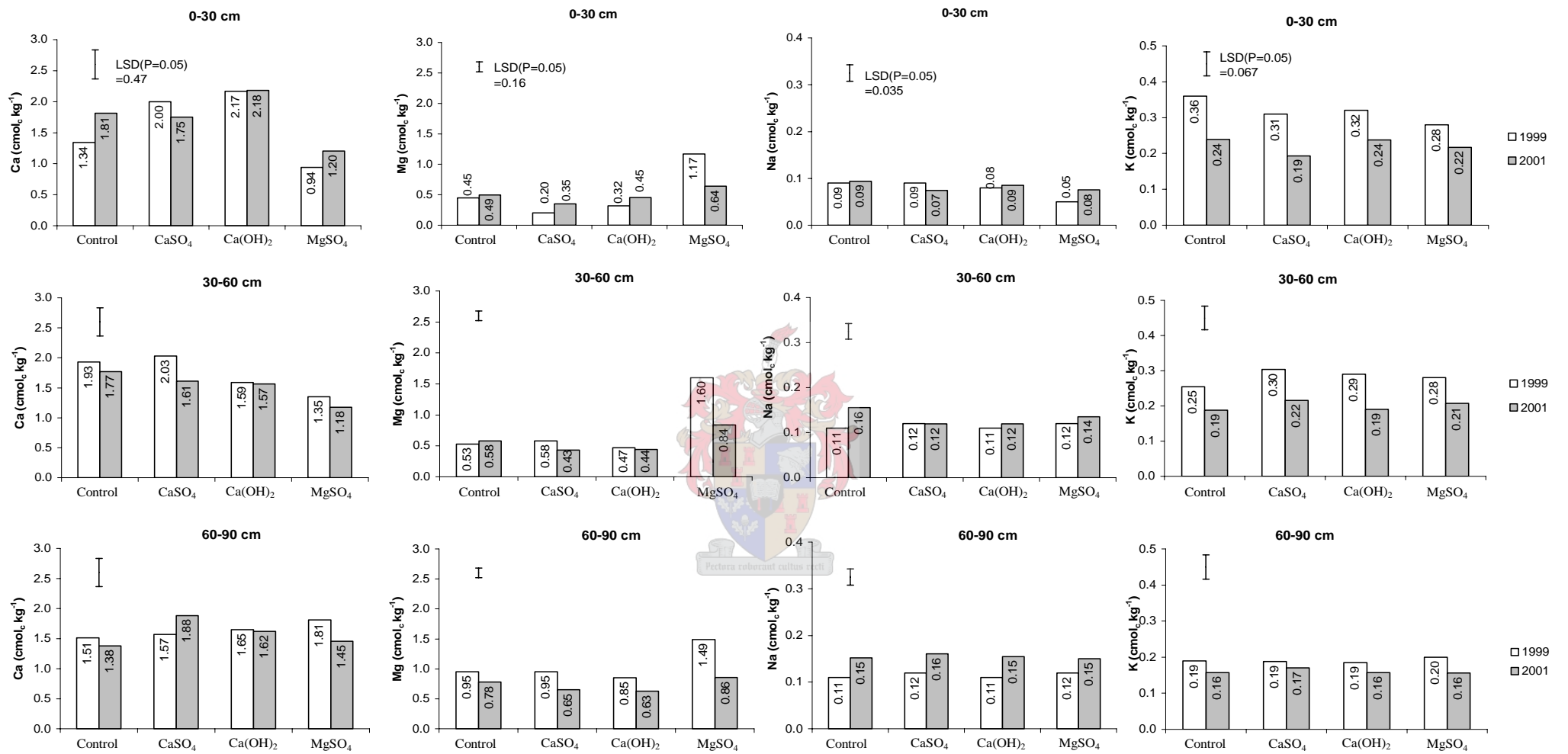


Figure 2. Changes in soil cation content for Kersfontein plots in 1999 and 2001 after fertiliser application in 1998 (LSD values valid for treatment effects across years and depths for a cation specie)

#### 4.1.2.2 Meerlus

##### *Exchangeable calcium*

Exchangeable Ca in the topsoil (0-30 cm) was significantly increased by  $\text{CaSO}_4$  and  $\text{Ca}(\text{OH})_2$  applications one year after application (Fig. 3). This effect was still visible after three seasons but was no longer significant. After three seasons the  $\text{MgSO}_4$  induced significantly lower exchangeable Ca in comparison with  $\text{CaSO}_4$  but not when compared to that of the control. Gypsum significantly increased the Ca content of the 30-60 cm soil layer one year after application but this effect had disappeared in the following two seasons.

##### *Exchangeable magnesium*

The exchangeable Mg content of the topsoil was not influenced by the fertilisers one year after application (Fig 3). The 30-60 and 60-90 cm soil layer exchangeable Mg was, however, increased by the  $\text{MgSO}_4$  treatment. The cation appeared to have leached from the topsoil without influencing the exchangeable Mg content there and accumulated in the subsoil. By the third season the  $\text{MgSO}_4$  treatment increased the exchangeable Mg content of the topsoil, but not significantly when compared to the control. Gypsum slightly reduced the Mg content of the topsoil over three seasons although this reduction was not significant when compared to the exchangeable Mg content of the control. The  $\text{MgSO}_4$  increased exchangeable Mg content in the soil up to a depth of 80/90 cm one year after application. This effect was still slightly visible after three years but was no longer significant. Exchangeable Mg content significantly decreased over three seasons regardless of fertiliser treatment. The reduction constitutes a fair amount of leaching and it could be due to the lower clay and high gravel contents of the soils of Meerlus when compared to those of Kersfontein (see Table 1).

##### *Exchangeable sodium*

None of the fertilizer applications had any effect on the exchangeable Na content (Fig. 3). The significant difference between the control treatment and the fertiliser treatments in the 30-60 cm layer could be due to a sampling or analytical error during the 2001 sampling.

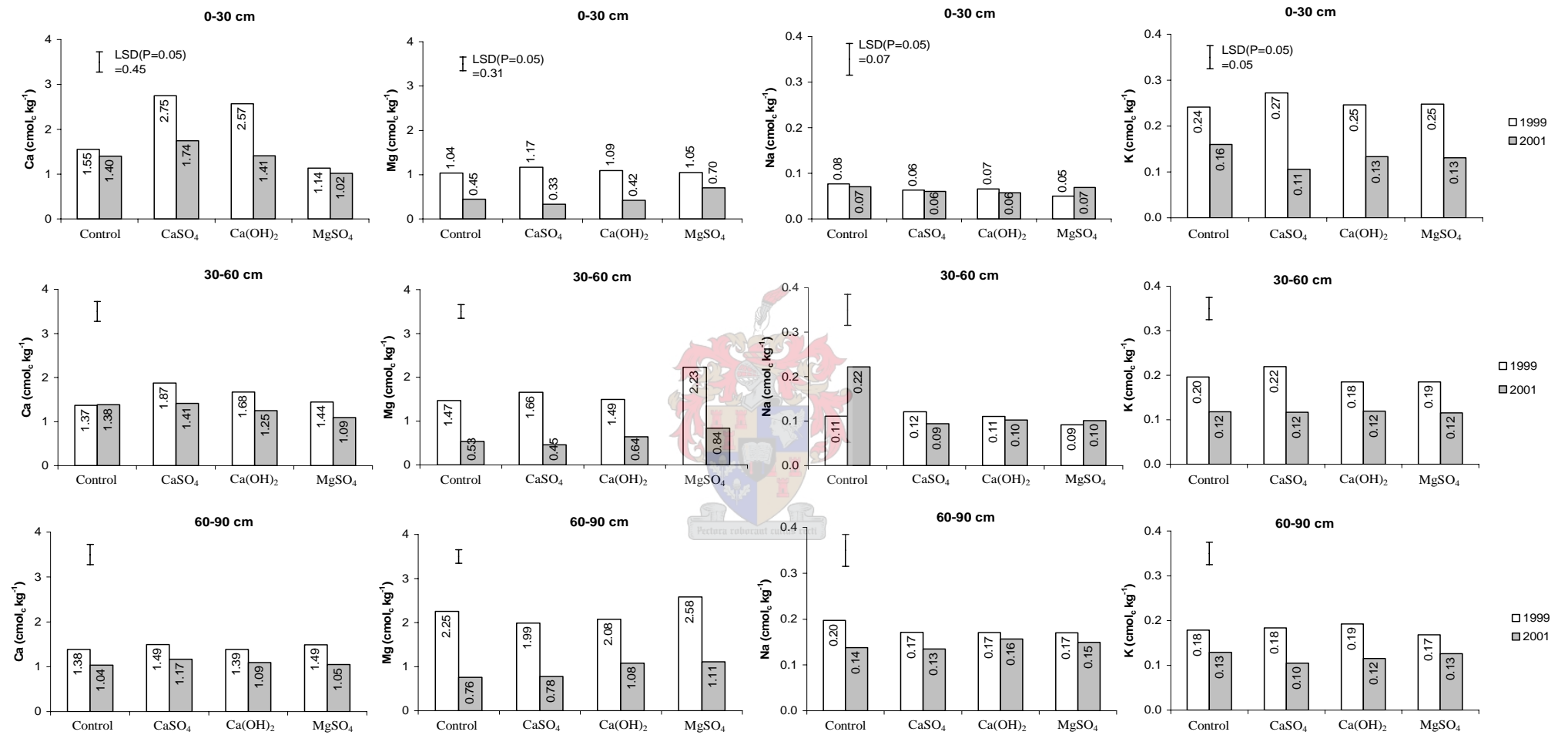


Figure 3. Changes in soil cation content for Meerlus plots in 1999 and 2001 after fertiliser application in 1998 (LSD values valid for treatment effects across years and depths for a cation specie)



### *Exchangeable potassium*

The fertilisers had no effect on the exchangeable K content of the topsoil one year after application (Fig. 3). Three seasons after application the gypsum had significantly reduced the exchangeable K content when compared to that of the control. No effect was visible in the 30-60 and 60-90 cm sampling depths. Overall and regardless of fertiliser application, the exchangeable K decreased significantly in the three years of the experiment. This confirms a high K leaching potential for the Meerlus' lower clay and higher gravel content soils.

### **4.1.3 Discussion**

The relative ease of ion exchange from a specific colloid could be written as:  $\text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$  (Bohn, McNeal & O'Connor, 1985b). Carski & Sparks (1985) found that Ca was preferably adsorbed over  $\text{K}^+$  on relatively pure kaolinite. Theoretically  $\text{CaSO}_4$  and  $\text{Ca}(\text{OH})_2$  should, therefore, replace K more easily than  $\text{MgSO}_4$  on a kaolinite dominated, organic material poor colloidal complex (top soil carbon content for Kersfontein = 0.53 percent; Meerlus = 0.64 percent (Engelbrecht, 2002)). The order of solubility of the applied chemicals in water at 18°C are:  $\text{MgSO}_4$  (35.64 g 100 cm<sup>-3</sup>) >  $\text{CaSO}_4$  (0.2 g 100 cm<sup>-3</sup>) >  $\text{Ca}(\text{OH})_2$  (0.17 g 100 cm<sup>-3</sup>) (Hodgman, 1950). Magnesium sulphate might, therefore, be more effective in exchanging K from the soil complex simply because of its higher solubility. The increase in pH brought about by  $\text{Ca}(\text{OH})_2$ , should also result in an increase in the CEC (Thomas & Hipp, 1968). This should provide more negative binding sites on the clay minerals and consequently more K retention should the Ca levels not increase sufficiently at the same time. The additional Ca in cmol<sub>c</sub> kg<sup>-1</sup> should therefore equal the Al cmol<sub>c</sub> kg<sup>-1</sup> plus the exchangeable  $\text{K}^+$  that needs to be removed from the exchange complex.

The gypsum treatment increased exchangeable Ca content of the topsoil after one season at both farms. Gypsum lowered exchangeable K at Kersfontein in the topsoil one year after application but not significantly. Three years after application this treatment still induced a slightly lower exchangeable K content (not significant). At Meerlus the gypsum did not significantly affect topsoil exchangeable K one year after application, but after three years this treatment had significantly reduced exchangeable K content. Gypsum can, therefore, be used to reduce the exchangeable K content of soils similar to those of this experiment.

The  $\text{Ca}(\text{OH})_2$  treatment significantly increased topsoil exchangeable Ca at both farms one year after application. This effect was still significant two years later for Kersfontein but not at Meerlus. This fertiliser also generally lowered exchangeable K in the 0-30 cm layer one and three years after application but never significantly. The expected increase in CEC caused by the pH increase, could be accountable for the low reduction in K in this treatment. The CEC should increase with the precipitation of insoluble  $\text{Al}(\text{OH})_3$  allowing increased Ca saturation with the Ca-fertiliser applications but without significantly influencing potassium saturation (Kotzé & Deist, 1975).

The  $\text{MgSO}_4$  fertiliser application significantly increased the exchangeable Mg content of the 0-30, 30-60 and 60-90 cm soil layer one year after applications and the effect was still discernable after three seasons, although not always significant. Magnesium application significantly reduced the exchangeable K content at Kersfontein one year after application in the 0-30 cm soil layer but this effect had disappeared after three years. At Meerlus,  $\text{MgSO}_4$  had no significant effect on the exchangeable K levels. The reason why the increase in Mg content did not always result in a parallel reduction in K content is unclear. Magnesium sulphate was, therefore, successful in reducing K content at one farm one year after application but the decrease was of short duration.

The overall reduction of K saturation of the exchange complexes of the control treatments at both locations suggests that the plant available K decreased over the three years studied. At Kersfontein this normal leaching would have been enhanced by the additional liming.

In general, the Ca and Mg fertilisers increased the exchangeable Ca and Mg content of the topsoil without markedly reducing exchangeable K content over three seasons, but it appears that gypsum should preferentially be used in reducing high exchangeable K levels in soils that require no liming.

#### **4.2 The effect of season, canopy treatment and fertilisers on vine growth and yield components**

The different seasons induced significant differences in vine growth and canopy density. In some cases, data from Engelbrecht's (2002) study (1998/99 season) was included in the statistical analyses in an attempt to even out seasonal effects. Even so, vine physiology is

modified by the environment and the lack of site specific climate measurements severely complicated the interpretation of some of the following results. The possible seasonal effect on canopy density, yield and yield components is discussed first to provide the reader with a clear picture of the environmental conditions experienced at the experimental sites.

#### 4.2.1 Seasonal effects

Interpretation of plant data gathered in the field is difficult without the benefit of site specific climate information and soil water measurements for the growing season. Table 2 provides a brief and general summary of climatic variables recorded at the Boland Agricultural school situated near the experimental sites (see appendix A for detail data).

**Table 2. Selected climate variables (Boland Agriculture High School)**

Season	Growing season (Sept – March)			Bloom – Véraison (Nov-Dec)			Véraison – Harvest (Jan-Feb)		
	Rainfall	Temp.	Evap.	Rainfall	Temp.	Evap.	Rainfall	Temp.	Evap.
1998/99	134	21.1	7.4	80.0	21.1	8.3	2.0	24.5	8.3
1999/00	177	21.6	7.4	27.5	22.8	8.4	10.5	24.3	9.2
2000/01	138	20.6	8.2	42.5	20.9	8.7	19.5	23.9	10.6

Rainfall provided in total mm, Temp. = mean of min. and max. temp. (°C), Evap. = mean A-pan evaporation, mm day<sup>-1</sup>

From Table 2, and ignoring the fact that both farms were irrigated, it is possible that the vines experienced water stress in 1999/00 during the cell division and berry growth lag period and that water stress during period IIIa, b & c could have reduced photosynthesis and consequent berry sugar accumulation (Wang *et al.*, 2003). The 2000/01 season produced conditions relatively more favorable for pre-véraison cell division and period III photosynthesis and berry sugar accumulation. Berry K accumulation is linked to photosynthesis and consequently to the availability of sucrose.

**Table 3. Physiological stages for two farms at Paardeberg**

Farm	Season	Pea size (Week no.)	Véraison (Week no.)	Harvest (Week no.)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	1999/00	48	1	8
	2000/01	47/48	1	7
<b>Meerlus</b> (Cab. franc /99 R)	1999/00	49	2	9
	2000/01	47/48	2	8/9

Dry and warm conditions during the ripening phase as indicated by day A-pan evaporation (Table 2), especially period IIIa and IIIc, could have lowered water potential in the soil and so reduced photosynthesis during the 2000/01 season.

Time of bud burst was not recorded. The 2000/2001 pea size stage for Cabernet Sauvignon/101-14Mgt (Kersfontein) and Cabernet franc/R99 (Meerlus) was slightly earlier than the 1999/2000 season (Table 3), possibly due cooler spring in 1999/00 that could have delayed bud break for a week or two. Kersfontein reached véraison earlier than Meerlus for both experimental seasons, which could be the result of water stress at Kersfontein. Both the cultivars were harvested at the end of February but the harvesting dates do not always reflect optimum grape maturity.

Vines of both farms showed signs of water stress during the ripening phase (turned leaves) in 1999/00, but the Cabernet Sauvignon on Kersfontein showed drought symptoms (yellowing of leaves and partial leaf drop at the shoot base) towards the end of ripening to such an extent that almost no basal leaves were left at harvest. Less signs of stress and no drought symptoms were noted for both farms during the 2000/01 season, probably because of the higher rainfall for the bloom to harvest period (Table 2).

The season significantly affected the leaf layer number (LLN), percentage shaded leaves and percentage shaded bunches at both farms (Table 4). At Kersfontein the season significantly affected LLN and percentage shaded leaves but not the percentage shaded bunches. At Meerlus, LLN and percentage shaded bunches were significantly affected by season but not the percentage shaded leaves.

For both seasons the vines at both farms showed relatively low vigour, but the lack of growth was always more pronounced for the Cabernet Sauvignon/101-14 Mt at Kersfontein. This could be a combination of the medium vigour induced by the 101-14 Mgt rootstock, the hotter eastern aspect of the vineyard and the lower system effectivity of overhead systems compared to that of micro jet systems. The scion cultivars, Cabernet Sauvignon and Cabernet franc, have the same natural vigour (Engelbrecht, 2002). The shallower root system of the 101-14 Mgt rootstock (see Engelbrecht, 2002 for rooting depth and percentage root growth per depth) and the more shallow soil preparation ( $\pm 70$  cm)

would also restrict the available water reservoir at Kersfontein. The water holding capacity of the 0-80 cm soil layers at Kersfontein should be higher than that of Meerlus, though. The soils at Kersfontein have higher clay content and less gravel when compared to the soil at Meerlus.

**Table 4. Seasonal comparison for each farm and farm comparison over seasons in mean canopy density variables (Sampled on the 25, 26<sup>th</sup> January)**

Farm	Season*	Leaf layer number	Shaded leaves (%)	Shaded clusters (%)	Canopy gaps (%)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	1999/00	2.0 a	26 a	43 a	7 a
	2000/01	3.0 b	36 b	52 a	3 a
<b>Meerlus</b> (Cab. Franc /99 R)	1999/00	2.2 a	32 a	52 a	1 a
	2000/01	3.0 b	39 a	62 b	1 a

\*No canopy densities recorded for 1998/00 season

Means for the respective farms followed by the same letter do not differ significantly at  $P \leq 0.05$

The low vigour of the vines at both experimental locations for the 1999/00 and 2000/01 seasons is illustrated by the low leaf layer numbers for both farms (Table 4). The 99 R rootstock produced more shaded (interior) leaves and clusters at Meerlus. This could be expected since 99 R is a more vigorous rootstock than 101-14Mgt and there is no difference in vigour between the Cabernet franc and Cabernet Sauvignon scions (Engelbrecht, 2002). Also, Cabernet franc at Meerlus showed less water stress symptoms and no drought symptoms during the experiment. Both varieties grew more vigorous during the 2000/01 season than during the 1999/00 season. The optimum LLN for quality red wine production in the Wellington area can be accepted to be three to four (Smart 1985, Engelbrecht, 2002). Both seasons produced a LLN lower than four.

The 2000/01 season produced more shaded leaves (or more interior leaves) for Kersfontein while the percentage bunch shading (or interior clusters) remained constant. At Meerlus, bunches were more shaded during 2000/01 while the percentage shaded leaves remained constant for both seasons. Grape composition at harvest is a function of the amount of shade and the shaded organ and the physiological stage of the vine when the specific organ is shaded (Rojas-Lara & Morrison, 1989). Kersfontein (Cabernet Sauvignon/101-14 Mgt) had a larger crop during the 1999/00 season (Table 5). The larger crop in combination with

the drier season could have reduced vigour and produced the large amount of canopy gaps recorded (Table 4). The Cabernet franc/R99 vines at Meerlus showed more vigor and more interior bunch shading for both seasons than did Kersfontein.

**Table 5. Effect of season and site/variety on yield and yield components of Cabernet Sauvignon & Cabernet franc, Paardeberg**

Farm	Season	Yield (kg vine <sup>-1</sup> )	Number of bunches vine <sup>-1</sup>	Berry mass (g)	Bunch mass (g)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	1999/00	3.13 a	35 a	1.07 a	95 a
	2000/01	2.65 a	32 a	1.12 a	85 b
<b>Meerlus</b> (Cab. franc /99 R)	1999/00	4.35 a	38 a	1.44 a	118 a
	2000/01	4.44 a	52 b	1.33 b	88 b

Means for the respective farms followed by the same letter do not differ significantly at  $P \leq 0.05$

Berry mass was higher for Cabernet franc/99R (Meerlus) than for Cabernet Sauvignon/101-14 Mgt (Kersfontein)(Table 5). The higher yield at Kersfontein for the 1999/00 season could be responsible for the observed lower vigour during this season. Alternatively, the observed low vigour could have been caused by pre-véraison water stress and earlier than usual termination of shoot growth. The 2000/01 season possibly produced more vegetative growth and lower yield at Kersfontein.

At Meerlus the number of bunches per vine, bunch mass and berry mass were significantly influenced by season. There was no difference in yield (Table 5) although the vines had denser canopies during the 2000/01 when compared to the 1999/00 season (Table 4) and more shoots per vine (Table 6). This could account for the increased number of bunches per vine.

**Table 6. Effect of season on mean shoot growth variables for Meerlus (Cabernet franc/99R), Paardeberg**

Season	Number of shoots per m cordon	Pruning mass per vine (g)	Shoot mass (g)	Shoot length (cm)	Crop load*
1999/00	19	647	30	75	7
2000/01	23	655	25	62	7

\* Crop load = yield/dormant pruning mass ratio per vine

#### 4.2.2 The effect of canopy treatments

Canopy 1 resulted in very low LLN at Kersfontein in the 1999/00 season and leaf area might have been limiting in this treatment. Engelbrecht (2002) noted that the early tipping of the Canopy 1 treatment stimulated lateral shoot growth. Since only the lateral shoots in the bunch zone were removed, the remaining laterals could have significantly increased the leaf area of this treatment.

Canopy 1 produced significantly less interior or shaded leaves in the bunch zone when compared to Canopy 3 for both locations in both seasons. Canopy 1 also produced significantly more exposed bunches compared to Canopy 3 at both locations.

The crop load (crop yield to dormant pruning mass) was not determined for Kersfontein but Meerlus had a crop load of  $\pm 6$  for the Canopy 1 treatment (table 8). Bravdo *et al.* (1985) suggested a crop load of 10 for Cabernet Sauvignon in Israel and Smart *et al.* (1990) have suggested values of 6 – 10. The less vigorous Cabernet Sauvignon vines at Kersfontein would probably have had higher crop load values. At Meerlus, Canopy 1 vines had less shoots per meter cordon (Table 8). These shoots were heavier and longer compared to the shoots of the Canopy 2 & 3 treatments. Canopy 2 and Canopy 3 treatments had shoot densities higher than the 15 shoots per meter cordon suggested by Smart *et al.* (1990). The possibility that Canopy 2 & 3 treatments caused within-canopy shade, is higher at Meerlus than at Kersfontein.



**Table 7. Effect of canopy treatments, season and farm/variety on mean canopy density variables, Paardeberg (measured on the 25, 26<sup>th</sup> January)**

Farm	Season	Canopy treatment	Leaf layer number (LLN)	Shaded leaves (%)	Shaded clusters (%)	Canopy gaps (%)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	1999/00	Canopy 1	0.9 a	8 a	14 a	17 a
		Canopy 2	1.9 b	26 b	38 b	3 b
		Canopy 3	3.3 c	45 c	76 c	1 b
	2000/01	Canopy 1	1.9 a	26 a	30 a	5 a
		Canopy 2	2.5 a	33 a	52 b	3 a
		Canopy 3	4.5 b	48 b	73 c	0 a
<b>Meerlus</b> (Cab. franc /99 R)	1999/00	Canopy 1	1.3 a	16 a	32 a	4 a
		Canopy 2	2.1 b	32 b	48 a	0 b
		Canopy 3	3.3 c	48 c	76 b	0 b
	2000/01	Canopy 1	2.2 a	32 a	47 a	3 a
		Canopy 2	2.7 b	34 a	66 b	0 b
		Canopy 3	4.1 c	51 b	73 b	0 b

Means followed by the same letter do not differ significantly at  $P \leq 0.05$

**Table 8. Effect of canopy treatments and season on mean shoot growth variables for Meerlus (Cabernet franc/99R), Paardeberg**

Season	Canopy treatment	Number of shoots per m cordon	Pruning mass per vine (g)	Shoot mass (g)	Shoot length (cm)	Crop load*
1999/00	Canopy 1	15	613	35	80	6
	Canopy 2	18	651	32	78	7
	Canopy 3	24	677	24	66	7
2000/01	Canopy 1	19	675	30	69	6
	Canopy 2	22	647	25	63	7
	Canopy 3	28	644	19	54	7

\*Crop load = yield/dormant pruning mass ratio per vine

Canopy 1 (least dense): Thin to two shoots/bearer, vertical shoot positioning, tip as necessary and removal of yellow leaves and lateral shoots in the bunch zone

Canopy 2 (intermediately dense): Thin to three shoots/bearer, vertical shoot positioning and topping of shoots before véraison

Canopy 3 (dense): Vertical shoot positioning and topping of shoots before véraison



Canopy 1 at Kersfontein consistently induced a smaller crop and less bunches per vine that was significantly heavier than those of Canopy 2 and 3 treatments (Table 9). The berry mass was not affected by canopy treatments, implying that more berries were set per bunch for the Canopy 1 than for the Canopy 3 treatment. This could be due to the increased light penetration to the base of the shoot in November and consequent better berry induction and differentiation (Zeeman & Archer, 1981). The higher yield for Canopy 3 was due to more shoots per vine, resulting in more bunches per vine. Since the climatic and site conditions for both farms were not conducive to vigorous vegetative growth, and the Canopy 3 treatment had a more favorable leaf area to fruit mass ratio when compared to that of Canopy 1, yield was increased by the Canopy 3 treatment.

There was significant interaction between season and canopy treatment on the number of bunches per vine for Kersfontein (interaction not shown in Table 9). In the dry 1999/00 season Canopy 1 vines produced significantly less clusters per vine in comparison with Canopy 3 vines of the same season and Canopy 1 vines of the following, less dry season. This might confirm that yield is more influenced by early season water stress (Matthews, Anderson & Schultz, 1987). In this experiment, season (due to possible water stress) may have been more important in determining yield than the canopy treatments. The influence of season on yield could be related to transpiration rate of the vines and water potentials in the soil.

Canopy treatments for Cabernet franc/99 R at Meerlus significantly influenced berry mass, bunch mass, number of bunches per vine but not yield (Table 10). Canopy 1 vines had a significantly lower crop than those of Canopy 3. The Canopy 1 treatment significantly reduced the number of bunches per vine while significantly increasing berry mass and bunch mass. Presumably the improved light conditions at the base of shoots in November stimulated induction and differentiation of berries (Zeeman & Archer, 1981). Meerlus experienced less stress than Kersfontein during the ripening phase for both experimental seasons leading to sustained photosynthesis and possibly enhanced berry enlargement. Cabernet franc normally also has a larger berry than Cabernet Sauvignon (Prof. P. G. Goussard, Dept. of Viticulture, University of Stellenbosch, 2000, personal communication).

**Table 9. Effect of season and canopy treatments on yield and yield component means of Cabernet Sauvignon/101-14 Mgt at Kersfontein, Paardeberg**

Season	Canopy treatment	Yield (kg vine <sup>-1</sup> )	Number of bunches per vine	Berry mass (g)	Bunch mass (g)
1999/00	Canopy 1	2.77 a	26 a	1.11 a	113 a
	Canopy 2	2.82 a	32 a	1.07 a	90 b
	Canopy 3	3.80 b	47 b	1.02 a	82 b
2000/01	Canopy 1	2.62 a	29 a	1.14 a	91 a
	Canopy 2	2.56 a	32 a	1.15 a	81 a
	Canopy 3	2.76 a	34 a	1.09 a	83 a
LSD (P=0.05)		0.82	6.80	0.16	20.12
Mean	Canopy 1	2.69 a	27 a	1.13 a	100 a
	Canopy 2	2.69 a	32 ab	1.11 a	89 b
	Canopy 3	3.28 a	40 b	1.05 a	81 b
LSD (P=0.05)		0.76	8.23	0.12	12.24

Means for the respective seasons followed by the same letter do not differ significantly at  $P \leq 0.05$

**Table 10. Effect of season and canopy treatments on yield and yield component means of Cabernet franc/99R at Meerlus, Paardeberg**

Season	Canopy treatment	Yield (kg vine <sup>-1</sup> )	Number of bunches per vine	Berry mass (g)	Bunch mass (g)
1999/00	Canopy 1	3.47 a	28 a	1.44 a	123 a
	Canopy 2	4.78 b	38 b	1.44 a	129 a
	Canopy 3	4.81 b	47 c	1.43 a	103 b
2000/01	Canopy 1	4.16 a	42 a	1.50 a	100 a
	Canopy 2	4.34 a	48 a	1.30 b	90 a
	Canopy 3	4.83 a	65 b	1.26 b	75 b
Mean	Canopy 1	3.82 a	35 a	1.47 a	111 a
	Canopy 2	4.56 ab	43 b	1.37 b	110 a
	Canopy 3	4.82 b	56 c	1.34 b	89 b

Means for the respective seasons followed by the same letter do not differ significantly at  $P \leq 0.05$

Canopy 1 (least dense): thin to two shoots/bearer, vertical shoot positioning, tip as necessary and removal of yellow leaves and lateral shoots in the bunch zone

Canopy 2 (intermediately dense): thin to three shoots/bearer, vertical shoot positioning and topping of shoots before véraison

Canopy 3 (dense): Vertical shoot positioning and topping of shoots before véraison

The LLN values never exceeded four for both farms, suggesting that within-canopy shade, even for the Canopy 3 treatment, was not limiting during this experiment. The yield to pruning mass ratio never exceeded 10 for the 1999/00 and 2000/01 seasons at Meerlus (Table 8). Canopy microclimate in all the canopy treatments, as measured by these criteria, should not have been negatively affected by within-canopy shade (Smart *et al.*, 1990).

Canopy 1 vines produced an average of 0.6 – 1 t ha<sup>-1</sup> less grapes than the Canopy 3 vines for Cabernet Sauvignon and Cabernet franc. The number of bunches were reduced as the number of shoots were reduced (increase in thinning severity). The more severe the thinning, the more bunch mass was increased, as was berry mass for Meerlus. This is in accordance with the results of Engelbrecht (2002). Lateral shoot development was stimulated by early tipping in the Canopy 1 treatment. As only the laterals in the bunch zone for Canopy 1 vines were removed, the remaining lateral shoots could have contributed significantly to the effective leaf surface towards the end of ripening.

#### 4.2.3 The effect of fertiliser applications

The fertiliser treatments had no significant effect on vine vigour and did not affect canopy densities measured with the point quadrat method. Generally the foliage was slightly denser in the 2000/2001 season. It would appear as if the Ca(OH)<sub>2</sub> and MgSO<sub>4</sub> treatments did slightly stimulate vigour in some seasons for both locations and this lead to slightly higher LLN and more shaded leaves and/or clusters. These effects were not significant, however. The MgSO<sub>4</sub> application could be expected to stimulated growth if the plant was Mg deficient, but no such deficiency existed according to South African norms for pea size (set) and véraison laminae and petioles for wine grapes (Conradie, 1994) or was visually evident. The reason for slightly better growth with the MgSO<sub>4</sub> supplement is not clear since leaf sulfate content was not determined. Plant roots normally absorb sufficient amounts of sulfur as the SO<sub>4</sub><sup>2-</sup> ion (Salisbury & Ross, 1985a). The vines also received anti-fungal S-treatments, so an S deficiency is very unlikely.

Fertiliser applications had no effect on vine growth variables recorded at Meerlus (Table 12). The impression exists that the fertiliser treatments slightly suppressed pruning mass for

**Table 11. Effect of farm/variety and fertiliser treatments on means of canopy density variables, means for 1999/00 – 2000/01, Paardeberg (measured on the 25, 26<sup>th</sup> January)**

Farm	Fertiliser treatment	Leaf layer number (LLN)	Shaded leaves (%)	Shaded bunches (%)	Canopy gaps (%)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	Control	2.3 a	31 a	42 a	7 a
	CaSO <sub>4</sub>	2.4 a	27 a	49 a	6 a
	Ca(OH) <sub>2</sub>	2.5 a	35 a	43 a	3 a
	MgSO <sub>4</sub>	2.6 a	31 a	54 a	4 a
<b>Meerlus</b> (Cab. franc /99 R)	Control	2.5 a	31 a	58 a	4 a
	CaSO <sub>4</sub>	2.5 a	35 a	52 a	1 a
	Ca(OH) <sub>2</sub>	2.8 a	37 a	63 a	0 a
	MgSO <sub>4</sub>	2.7 a	38 a	56 a	0 a

Means for the respective farms followed by the same letter do not differ significantly at  $P \leq 0.05$

Fertilizers applied in February 1998

Fertilizer application rates: 5 t.ha<sup>-1</sup> CaSO<sub>4</sub> and equivalent amounts of Ca(OH)<sub>2</sub> & MgSO<sub>4</sub>.7H<sub>2</sub>O

**Table 12. Effect of season and fertiliser treatments on mean shoot growth variables for Meerlus (Cabernet franc/99R), Paardeberg**

Season	Fertiliser treatment	Number of shoots per m cordon	Pruning mass per vine (g)	Shoot mass (g)	Shoot length (cm)	Crop load*
1999/00	Control	19	672	31	76.6	7.0
	CaSO <sub>4</sub>	19	635	29	73.4	6.8
	Ca(OH) <sub>2</sub>	19	625	29	73.4	6.7
	MgSO <sub>4</sub>	18	658	31	74.6	6.4
2000/01	Control	24	704	26	64.6	6.0
	CaSO <sub>4</sub>	23	671	25	62.8	6.6
	Ca(OH) <sub>2</sub>	23	600	22	59.6	7.2
	MgSO <sub>4</sub>	23	646	24	60.6	7.6

\*Crop load = yield/dormant pruning weight per vine

Fertilizers applied in February 1998

Fertilizer application rates: 5 t.ha<sup>-1</sup> CaSO<sub>4</sub> and equivalent amounts of Ca(OH)<sub>2</sub> & MgSO<sub>4</sub>.7H<sub>2</sub>O

**Table 13. Effect of season and fertiliser treatments on yield and yield component means of Cabernet Sauvignon/101-14 Mgt at Kersfontein, Paardeberg**

Season	Fertiliser treatment	Yield (kg vine <sup>-1</sup> )	Number of bunches per vine	Berry mass (g)	Bunch mass (g)
1999/00	Control	3.51 a	35 ab	1.14 a	102 a
	CaSO <sub>4</sub>	3.08 a	35 ab	1.01 a	92 a
	Ca(OH) <sub>2</sub>	2.88 a	30 a	1.08 a	102 a
	MgSO <sub>4</sub>	3.06 a	38 b	1.05 a	84 a
2000/01	Control	2.82 a	35 a	1.11 a	82 a
	CaSO <sub>4</sub>	2.56 a	28 a	1.12 a	94 a
	Ca(OH) <sub>2</sub>	2.74 a	35 a	1.07 a	78 a
	MgSO <sub>4</sub>	2.47 a	29 a	1.20 a	87 a
Mean	Control	3.16 a	35 a	1.12 a	92 a
	CaSO <sub>4</sub>	2.82 a	31 a	1.06 a	93 a
	Ca(OH) <sub>2</sub>	2.81 a	33 a	1.07 a	90 a
	MgSO <sub>4</sub>	2.76 a	33 a	1.13 a	85 a

Spacing: 3m x 1.2m spacing (2776 vines/ha)

Means for the respective seasons followed by the same letter do not differ significantly at P≤0.05

Fertilizers applied in February 1998

Fertilizer application rates: 5 t.ha<sup>-1</sup> CaSO<sub>4</sub> and equivalent amounts of Ca(OH)<sub>2</sub> & MgSO<sub>4</sub>.7H<sub>2</sub>O

**Table 14. Effect of season and fertiliser treatments on yield and yield component means of Cabernet franc/99R at Meerlus, Paardeberg**

Season	Fertiliser treatment	Yield (kg vine <sup>-1</sup> )	Number of bunches per vine	Berry mass (g)	Bunch mass (g)
1999/00	Control	4.72 a	40 a	1.43 a	122 a
	CaSO <sub>4</sub>	4.29 a	39 a	1.43 a	114 a
	Ca(OH) <sub>2</sub>	4.21 a	37 a	1.45 a	114 a
	MgSO <sub>4</sub>	4.20 a	35 a	1.44 a	123 a
2000/01	Control	4.16 a	50 a	1.32 a	89 a
	CaSO <sub>4</sub>	4.37 a	53 a	1.34 a	83 a
	Ca(OH) <sub>2</sub>	4.35 a	50 a	1.38 a	91 a
	MgSO <sub>4</sub>	4.89 a	55 a	1.35 a	91 a
Mean	Control	4.44 a	45 a	1.38 a	106 a
	CaSO <sub>4</sub>	4.33 a	46 a	1.38 a	98 a
	Ca(OH) <sub>2</sub>	4.28 a	43 a	1.42 a	102 a
	MgSO <sub>4</sub>	4.54 a	45 a	1.39 a	107 a

Meerlus: 1.2m x 2.7m spacing (3089 vines/ha)

Means for the respective seasons followed by the same letter do not differ significantly at P≤0.05

Fertilizers applied in February 1998

Fertilizer application rates: 5 t.ha<sup>-1</sup> CaSO<sub>4</sub> and equivalent amounts of Ca(OH)<sub>2</sub> & MgSO<sub>4</sub>.7H<sub>2</sub>O

Cabernet franc/99R and more so in the case of the  $\text{Ca}(\text{OH})_2$  treatment (data not statistically analysed).

Fertiliser treatments had no effect on vine growth as indicated by the measurements taken in this experiment. There was furthermore no interaction between canopy and fertiliser treatments.

#### **4.2.4 The effect of $\text{MgSO}_4$ foliar applications**

The foliar sprays significantly increased yield during the second season of application for Kersfontein (Cabernet Sauvignon/101-14 Mgt) by increasing the amount of bunches per vine (Table 15). The leaf analyses showed no Mg deficiency (Table 16). The vines at Kersfontein reacted on applications which suggest that the vines were slightly deficient in this nutrient.

Keller *et al.* (1995) found that reduced photosynthesis limits nutrient absorption and especially that of magnesium. Presumably the vines at both locations experienced water stress during the 1999/00 season. This would have depressed photosynthesis and ATP production, leading to reduced Mg uptake, particularly after véraison. At Kersfontein the water stress was more severe (visually evident) in 1999/00 than at Meerlus, so much so that other physiological processes beside Mg absorption was probably negatively affected by the reduced photosynthesis and the additional Mg failed to influence yield (Table 15). In the 2000/01 season, Kersfontein experienced less severe water stress and the Cabernet Sauvignon vines reacted upon foliar sprays in terms of increased yield. The Cabernet franc at Meerlus, however, experienced only moderate water stress (if at all) in the 2000/01 season, photosynthesis proceeded normally and sufficient Mg was probably absorbed through the root system so that the vines did not react upon further Mg foliar supplementation.

#### **4.2.3 Discussion**

The low LLN values at both farms and the low vigour of the experimental vines is thought to be linked to low soil water potentials. Unfortunately no soil water measurements were determined during this experiment.

Table 15. Effect of farm/variety, season and MgSO<sub>4</sub> foliar sprays on yield and yield component means of vines, Paardeberg

Farm	Season	Treatment	Yield (kg vine <sup>-1</sup> )	Number of bunches per vine	Berry mass (g)	Bunch mass (g)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	1999/00	Control	3.13 a	35 a	1.07 a	95 a
		MgSO <sub>4</sub>	3.42 a	38 a	1.07 a	95 a
	2000/01	Control	2.65 a	32 a	1.12 a	85 a
		MgSO <sub>4</sub>	3.24 b	40 b	1.22 a	83 a
	<b>Mean</b>	Control	2.89 a	33 a	1.09 a	90 a
		MgSO <sub>4</sub>	3.33 b	39 b	1.14 a	89 a
<b>Meerlus</b> (Cab. Franc /99 R)	1999/00	Control	4.35 a	38 a	1.45 a	118 a
		MgSO <sub>4</sub>	5.01 b	42 b	1.43 a	121 a
	2000/01	Control	4.44 a	52 a	1.36 a	88 a
		MgSO <sub>4</sub>	4.58 a	53 a	1.44 a	89 a
	<b>Mean</b>	Control	4.40 a	45 a	1.39 a	103 a
		MgSO <sub>4</sub>	4.79 b	48 b	1.40 a	105 a

Means for the respective seasons per farm followed by the same letter do differ significantly at  $P \leq 0.05$   
MgSO<sub>4</sub> foliar sprays: 2x10kg/100lit at véraison



According to the norms suggested by Smart *et al.* (1990), within-canopy shade was not a limiting factor during this experiment and should therefore not have affected berry K accumulation.

Judging by water stress and drought symptoms, it is concluded that the Cabernet Sauvignon vines at Kersfontein experienced more water stress than the Cabernet franc vines at Meerlus. The water stress would reduce photosynthesis and stimulate K accumulation in the berries.

### **4.3 The effect of season, canopy treatments and fertilisers on vine tissue cation composition**

#### **4.3.1 Seasonal effects**

Nutrient content for selected plant material is summarised in Table 16 for both farms. Daverède (in Garcia *et al.*, 2001a) found a positive correlation between K concentration in leaves at véraison and that present in the must of Négrette grapes. No relationship was, however, found between petiole and/or leaf blade K content at véraison and berry K content at harvest for this experiment. The dryer 1999/00 season produced the highest berry K for Kersfontein. Juice K concentration at véraison for both farms decreased significantly from the 1998/99 to the 2000/01 season. This could be explained by the significant decrease in exchangeable soil K found at both farms and could support the idea that there is a possible correlation between soil K and pre-véraison berry K content, at which stage K is mainly transported in the xylem. Harvest juice K concentration showed no such trend and appears to be more closely linked to climate and vine growth (Table 17).

The véraison K content of the petioles at both farms were well above the South African norm of 1.8 percent at véraison (Conradie, 1994). The low vigour of the plants could have resulted in smaller than normal leaves, which could have concentrated the K content in the leaf material. The leaf blade K content at véraison was, however, within the South African norm. According to Conradie (1994), nutrient content of petioles vary more within the same vineyard at the same physiological stage than the nutrient content of leaf blades.



**Table 16. The mean nutrient content of selected vine plant material at véraison and harvest for Kersfontein and Meerlus, Paardeberg, for three seasons**

Farm	Sample material	Season	K		Ca		Mg		Na	
			Véraison	Harvest	Véraison	Harvest	Véraison	Harvest	Véraison	Harvest
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	Petioles (%dm)	1998/99	3.58 a	3.56 a	1.40 a	1.53 a	1.63 a	1.90 a	0.22 a	0.27 a
		1999/00	2.60 b	*	1.37 a	*	1.95 b	*	0.27 b	*
		2000/01	3.11 c	2.17 b	1.46 a	2.58 b	1.93 b	2.09 b	0.17 c	0.20 b
	Leaf blades (%dm)	1998/99	0.84 a	0.80 a	2.10 a	2.41 a	0.56 a	0.63 a	0.11 a	0.09 a
		1999/00	0.73 b	*	2.13 a	*	0.74 b	*	0.06 b	*
		2000/01	0.87 a	0.85 a	1.80 b	2.14 b	0.60 a	0.64 a	0.06 b	0.06 b
	Berry skins (%dm)	1998/99	1.37 a	1.26 a	0.21 a	0.18 a	0.069 a	0.091 a	0.030 a	0.043 ab
		1999/00	1.26 b	1.18 a	0.20 a	0.15 b	0.098 a	0.080 b	0.034 ab	0.033 a
		2000/01	1.77 c	1.73 b	0.28 b	0.18 a	0.148 b	0.109 c	0.044 b	0.054 b
	Juice (mg l <sup>-1</sup> )	1998/99	949 a	1518 a	45.7 a	40.4 a	83.2 a	102.7 a	57.7 a	63.5 a
		1999/00	888 b	1919 b	35.6 b	51.8 b	79.9 b	124.5 b	57.1 a	73.3 b
		2000/01	733 c	1284 c	39.6 c	52.9 b	61.7 c	105.6 a	33.3 b	65.7 ab
<b>Meerlus</b> (Cab. Franc /99 R)	Petioles (%dm)	1998/99	2.45 a	2.08 a	1.64 a	2.11 a	1.44 a	1.73 a	0.12 a	0.18 a
		1999/00	2.45 a	1.87 a	1.71 a	1.96 a	1.50 ab	1.62 a	0.13 a	0.13 b
		2000/01	2.25 a	1.87 a	1.66 a	2.13 a	1.56 b	1.81 a	0.20 b	0.23 c
	Leaf blades (%dm)	1998/99	0.75 a	0.78 a	2.10 a	2.37 a	0.51 a	0.45 a	0.03 a	0.05 a
		1999/00	0.77 a	0.81 a	2.20 b	2.34 a	0.49 a	0.55 b	0.02 a	0.02 b
		2000/01	0.77 a	0.70 b	2.03 a	2.15 b	0.46 b	0.44 a	0.05 b	0.05 a
	Berry skins (%dm)	1998/99	1.06 a	1.21 a	0.19 a	0.21 a	0.106 a	0.095 a	0.013 a	0.020 a
		1999/00	1.34 b	1.55 b	0.25 b	0.25 b	0.094 b	0.102 b	0.007 a	0.011 a
		2000/01	1.26 b	1.17 a	0.22 c	0.15 c	0.096 b	0.081 c	0.033 b	0.047 b
	Juice (mg l <sup>-1</sup> )	1998/99	974 a	1572 a	38.6 a	36.9 a	57.8 a	79.5 a	10.1 a	14.3 a
		1999/00	895 b	1427 b	31.5 b	54.9 b	64.1 b	105.5 b	11.1 a	16.4 a
		2000/01	764 c	1112 c	33.4 b	45.6 c	51.4 c	80.6 a	15.8 b	22.6 b

\*Missing data

Means for the respective farms and tissue analyses followed by the same letter do not differ significantly at P≤0.05

The nutrient content of petioles, however, varied more between vineyards at the same physiological stage and may consequently be more sensitive indicators of nutritional status of the vineyards. The amount of K in the xylem seems to be linked to shoot demand and is, therefore, growth related (Drew & Saker, 1984). The amount of K in the phloem could be closely linked to the photosynthetic activity of the leaves (Dundon & Smart, 1984). Vine growth (xylem K level) and photosynthetic activity (phloem K content) could, therefore, influence total petiole K content on the day of sampling. This could help explain the difference between petiole and leaf blade K content at véraison.

The harvest juice K concentration for this experiment near Paardeberg appears to be more related to climate and vine growth than to véraison leaf K levels (both petioles and blades). An investigation of harvest juice K concentration for the Paardeberg field trials should, therefore, take into consideration the effect of climate and soil conditions, and especially soil water potential, on vine growth. If we assume the following:

1. Post-véraison inhibition of photosynthesis in this experiment was mostly caused by water stress.
2. Pre-véraison vine K content is related to soil K and transport of K in the xylem. Xylem K content is controlled by shoot demand and is, therefore, a function of the amount or intensity of shoot tip growth at véraison.
3. The higher the levels of exchangeable K in the soil, the greater the possibility of passive ion absorption through system II becomes and the relatively less important the soil K content becomes, especially in a soil with a liming history where high exchangeable Ca and/or Mg can be expected.

According to the LLN values, within-canopy shading from and after véraison was probably negligible for this experiment. The exchangeable K content of the soil was determined for 1998 and 2001 and juice K concentration at harvest was determined for the 1999/00 and 2000/01 seasons.

Using these assumptions and measurements, a relative value was assigned to each and a relative index developed as in Table 17 below.

**Table 17. Index to relate 0-30cm soil K content, vine growth and vine stress to juice K concentration at harvest at Kersfontein and Meerlus, Paardeberg**

Farm	Season	Soil K (mg kg <sup>-1</sup> )	A	B	C	D	E	F
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	1998/99	124	1	1.5	1	2	5.5	1518
	1999/00	106*	1	1	1	3	6	1919
	2000/01	88	0.75	1.5	1	1.5	4.75	1284
<b>Meerlus</b> (Cab. Franc /99 R)	1998/99	99	1	2	1	1.5	5.5	1572
	1999/00	76*	0.75	1.5	1	2	5.25	1427
	2000/01	52	0.5	1.5	1	1	4	1112

\* Values estimated, not determined: estimated at halfway between the values of 1998/99 and 2000/01

A. Soil K levels 0-30 cm: 0.25 (< 35 mg kg<sup>-1</sup>); 0.5 (35-70 mg kg<sup>-1</sup>); 0.75 (70-90 mg kg<sup>-1</sup>); 1 (> 90 mg kg<sup>-1</sup>)

B. Active shoot growth at véraison: 1 (none); 1.5 (moderate); 2 (strong)

C. Within-canopy shade at and after véraison: 1 (no); 2 (yes)

D. Water stress during the ripening phase: 1 (normal); 2 (moderate); 3 (severe)

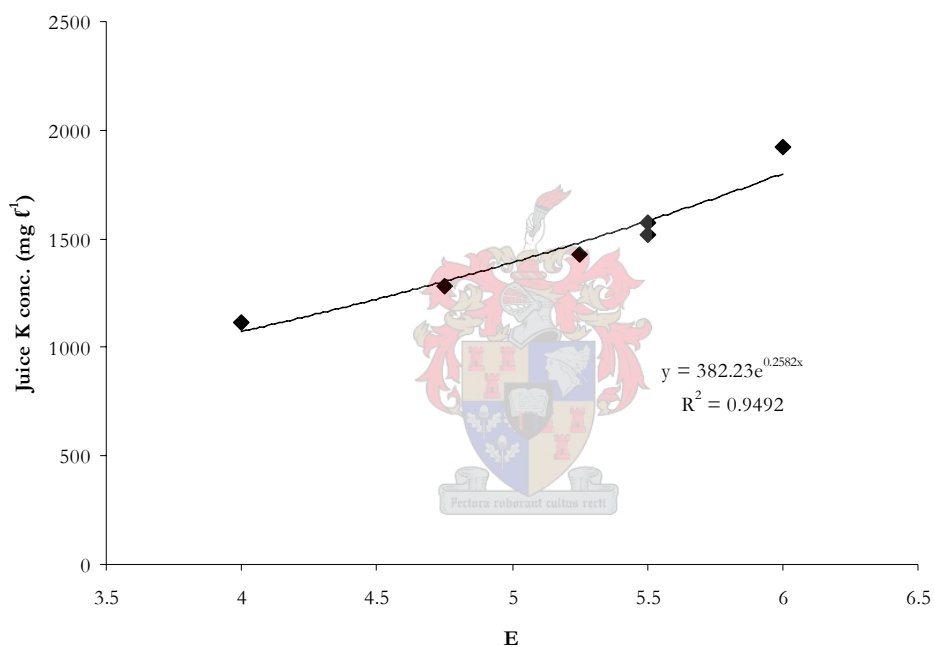
E. Juice K concentration potential = A + B + C + D

F. Measured juice K concentration at harvest (mg ℓ<sup>-1</sup>) – not at equal sugar (°B) levels

The higher the final index value (E), the higher the juice K concentration. The index values and measured harvest juice K concentration produced a trend line with a 95 percent predictability value ( $r^2 = 0.949$ , see Fig. 4). It must be noted that the berries were harvested at different maturities for the different seasons. Maturity, measured as °B and acidity, is of course also influenced by vine vigour, within-canopy shade and water stress during the ripening stages.

As conditions were more favorable for K accumulation in the berries, the curvature increased logarithmically (Fig. 4), suggesting that the effect of soil, vine growth and stress on eventual berry K content is cumulative. Although the active shoot growth and water stress levels during ripening was visually estimated and not measured and the soil K content for the 1999/00 was estimated, the index and figure 4 nevertheless indicates that eventual berry K concentration at harvest is a function of soil K content, of vine growth and vine water stress after véraison.

The relative importance of these contributing factors for this experiment is proposed to be: water stress after véraison >> shoot growth at véraison  $\geq$  within-canopy shade > soil K content. The relationship will not be as simple as this when vines in general is considered since many factors can influence soil K availability, shoot growth and photosynthesis after véraison and the relationship between them. Further investigation is, therefore, required to confirm the connection (if any) between active shoot growth at véraison and water stress during ripening and berry K content at harvest in the warm wine producing area of Paardeberg.



**Figure 4. The relationship between the suggested juice K concentration index (E) and actual harvest juice K concentration for Kersfontein and Meerlus, Paardeberg**

#### 4.3.2 The effect of canopy treatments

At Kersfontein, canopy treatments had no effect on the mean leaf blade and petiole K content of Cabernet Sauvignon/101-14 Mgt at véraison over three seasons (1998/99 – 2000/01). Canopy treatments also had no effect on the mean juice K concentration at harvest (Fig. 5) over the three seasons. Juice K concentration did increase slightly with an increase in canopy density and topping of treatments but the increase was not significant.

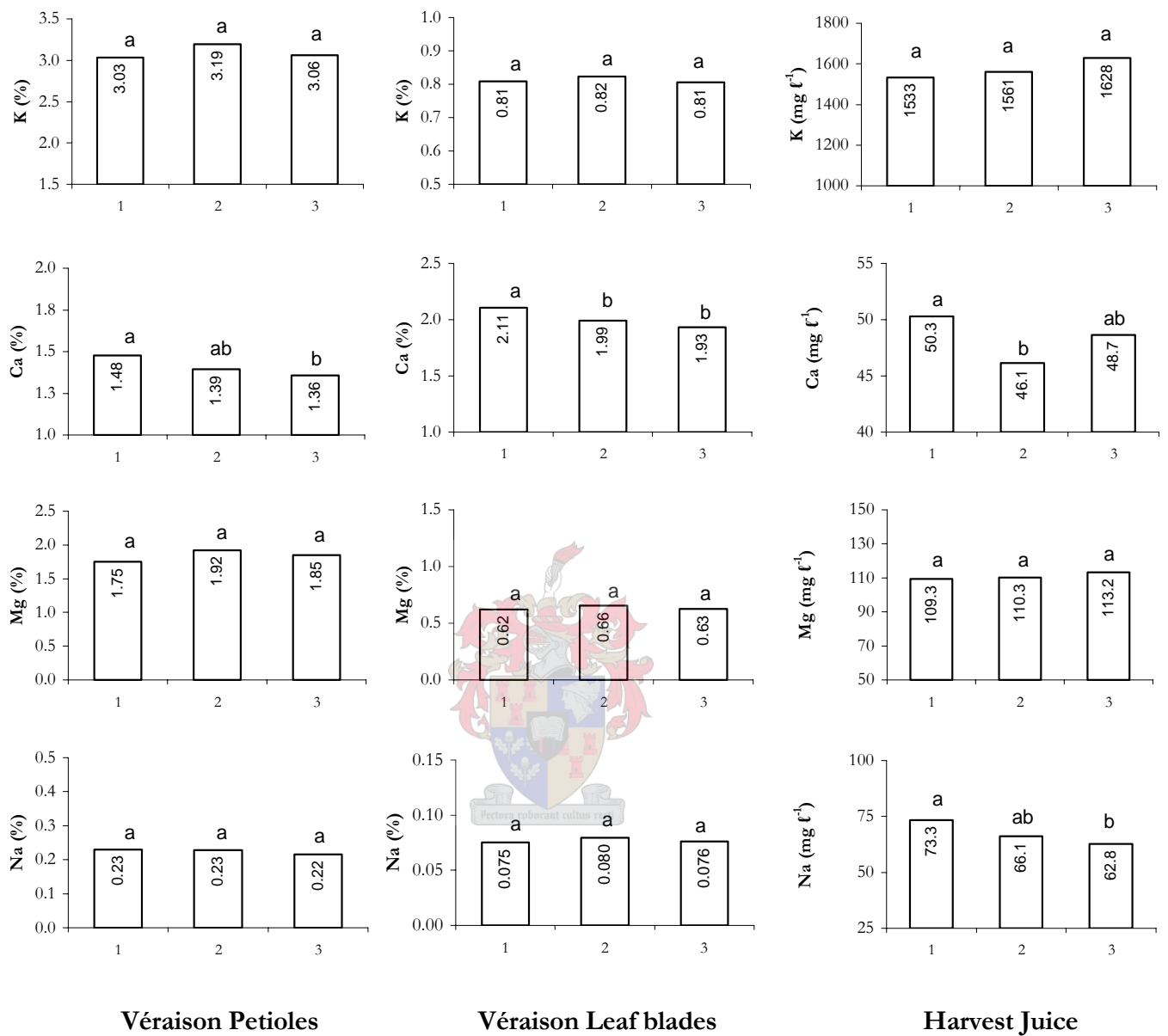


Figure 5. The mean effect of canopy treatments over three years (1999-2001) for Kersfontein, Paardeberg, Cabernet Sauvignon/101-14 Mgt, on the nutrient contents of leaf blades and petioles (% dm) sampled at véraison and juice sampled at ripeness; 1 = Canopy 1, 2 = Canopy 2; 3 = Canopy 3; means with the same letter do not differ significantly at  $P \leq 0.05$

This confirms that within-canopy shade at véraison and during the ripening phase was not a limiting factor for the Cabernet Sauvignon at Kersfontein for this experiment.

Calcium content of blades and petioles was significantly lower in Canopy 3 at véraison. Calcium supply to an above-ground organ mainly depends on transpiration intensity (Mengel & Kirkby, 1987a). Canopy 3 had a larger absolute amount of leaves than Canopy 1 and per leaf transpiration rates for Canopy 3 could have been lower. If Canopy 3 resulted in significantly more within-canopy shade then the limited photosynthesis would have limited ATP production, root growth and nutrient absorption.

Since Mg content of leaves and juice were not affected by canopy treatments, and the canopies were not dense, differential photosynthetic activity between canopy treatments would not account for the lower Ca content of the Canopy 3 treatment. The sodium concentration of harvest juice was significantly lower for Canopy 3. The reason could be the slight increase in juice K concentration for the dense canopy treatment. According to Boulton (1980b), K and Na are transported across cell membranes via the same ATPase mediated carrier. These two cations should, therefore, be antagonistic. The reasons for the significantly higher Na content of Canopy 1 berries are nonetheless unclear.

At Meerlus, Canopy 3 significantly decreased mean petiole K content over the three seasons (Fig. 6). The leaf blade mass at véraison of Canopy 3 did not differ from that of Canopy 1 in the 2000/01 season (2.55 vs. 2.58 g). It is probable that the petiole mass also did not differ between these treatments (not recorded). Leaves of thinned shoots have higher rates of photosynthesis because of the lower source to sink ratio (Hunter, 1991). Canopy 3 could have had a lower photosynthesis rate, a lower transpiration rate and a lower K sink strength. This would reduce the xylem K content and since the within-canopy shade was probably not limiting, the phloem K content would also have been low. Canopy treatments had no effect on the juice K concentration over three seasons. This confirms that within-canopy shading at véraison and during the ripening phase was not a limiting factor for the Cabernet franc at Meerlus in this experiment.

Calcium content of petioles and blades were significantly reduced in Canopy 3. This could be due to a dilution effect where a limited amount of nutrient is divided among many leaves,

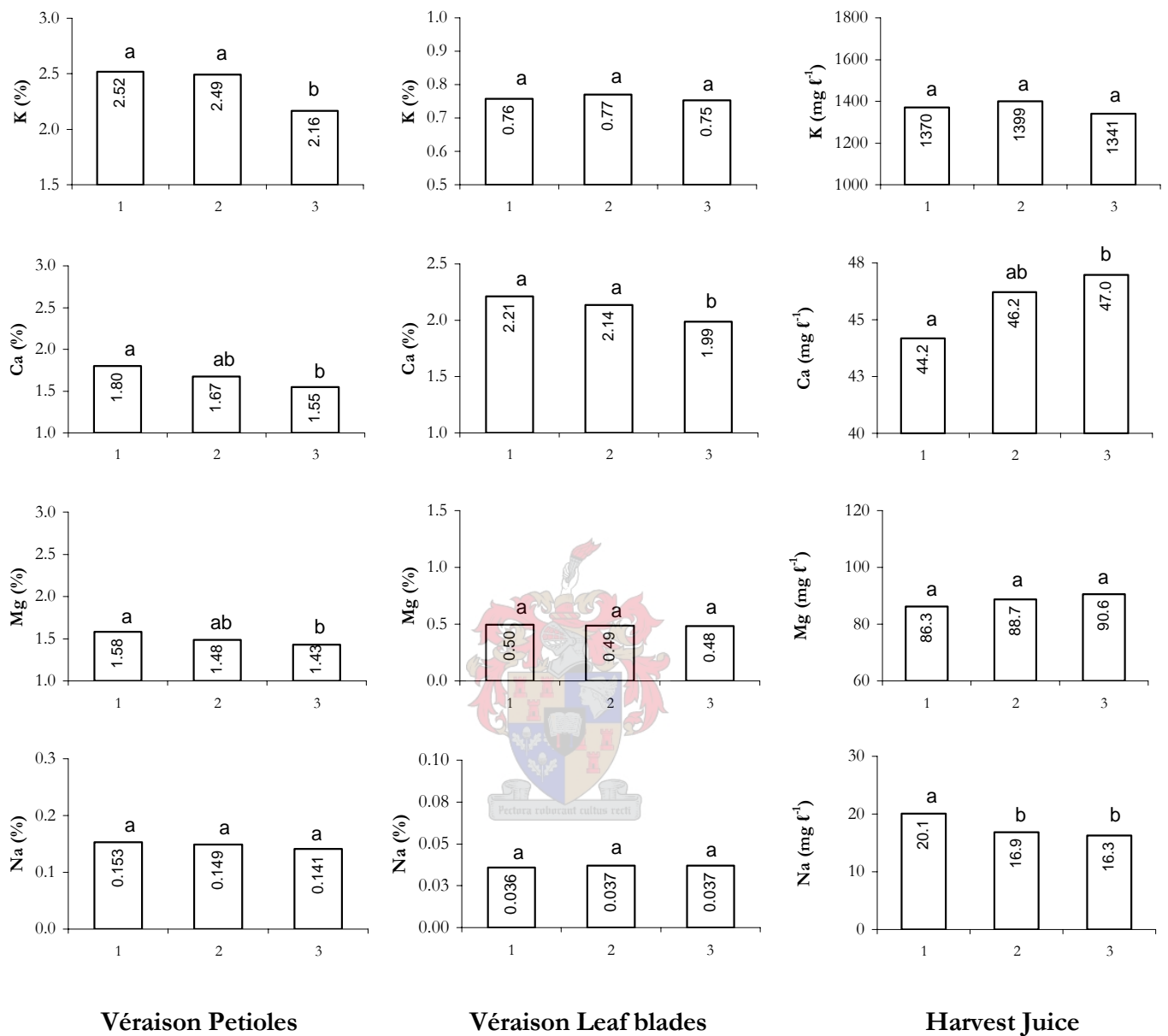
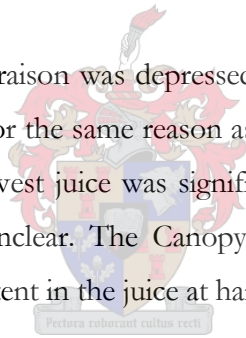


Figure 6. The mean effect of canopy treatments over three years (1999-2001) for Meerlus, Paardeberg, Cabernet franc/99 Richter, on the nutrient contents of leaf blades and petioles (% dm) sampled at véraison and juice sampled at ripeness; 1 = Canopy 1, 2 = Canopy 2, 3 = Canopy 3; means with the same letter do not differ significantly at  $P \leq 0.05$

lower respiration rates per leaf or a lack of root growth caused by within-canopy shade. A larger canopy, consisting of more leaves, will show water stress before a smaller canopy with less leaves on the same soil with the same water potential. It could be argued that a vine with a large canopy will experience lower photosynthetic rates than a vine with a smaller canopy at the same water potential. The Ca and Mg content of the large canopy could, therefore, be lower than that of the smaller canopy should the soil water potential be limited.

However, Canopy 3 produced a significantly higher Ca concentration in the grape juice. Directly following the top action for this canopy treatment, shoot growth would have been retarded. During this retarded shoot growth and before the development of laterals, the berries were established as the main sink. This did not happen at Kersfontein presumably because of too negative soil water potentials at véraison, therefore restricting transpiration and the transport of Ca to the berries.

Magnesium content of petioles at véraison was depressed in the Canopy 3 treatment. This could be due to a dilution effect or for the same reason as argued for Ca levels in Canopy 3 leaves. The Na concentration of harvest juice was significantly increased by the Canopy 1 treatment. The reason for this is unclear. The Canopy 1 treatment at Kersfontein also produced significantly higher Na content in the juice at harvest.

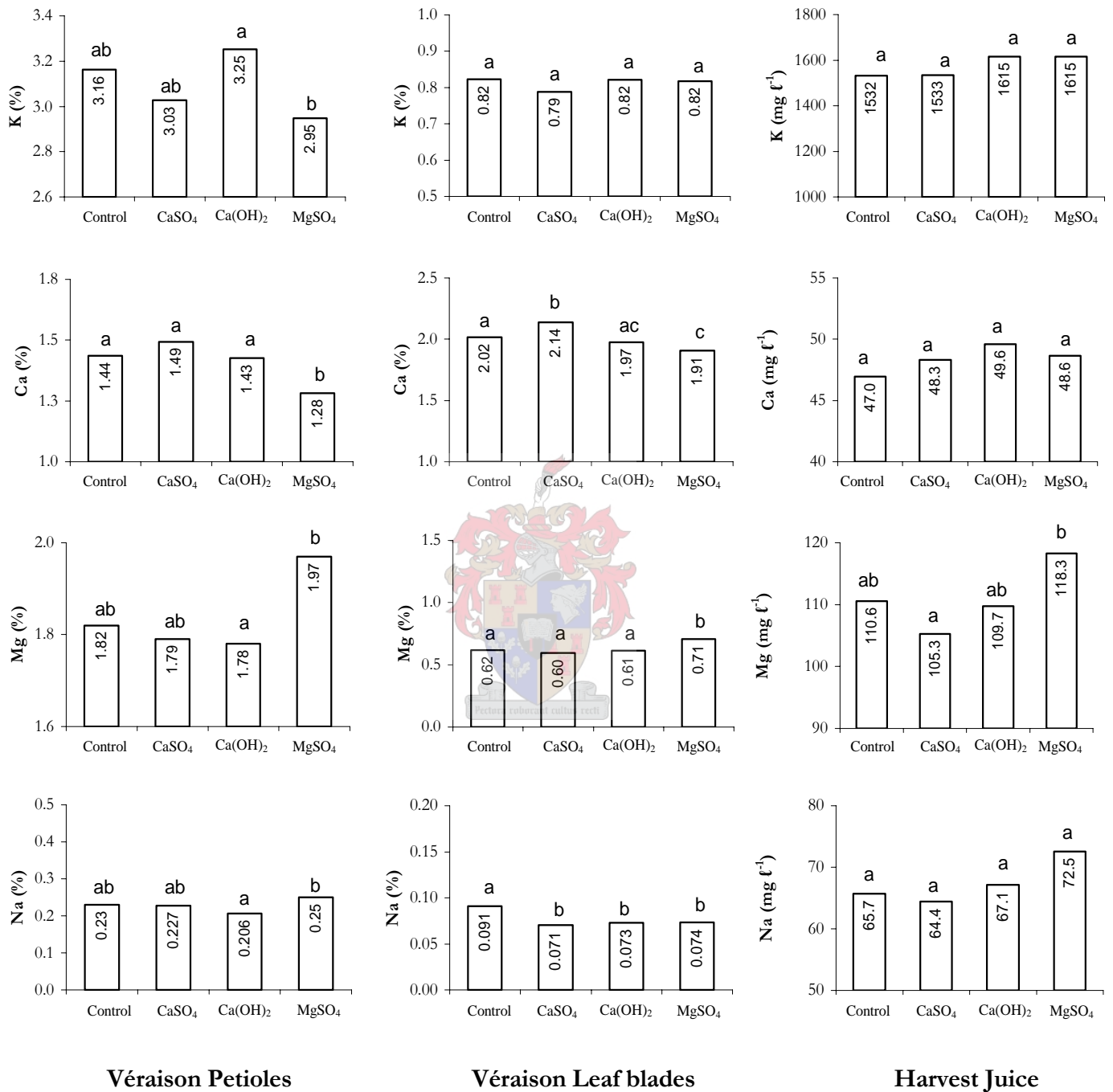


#### **4.3.3 The effect of fertiliser applications**

The effect of soil applied Ca and Mg on plant material nutrient levels for Kersfontein (Cabernet Sauvignon/101-14 Mgt) is shown in Fig. 7. The graphs represent the mean value for three seasons (1998/99, 1999/00 & 2000/01).

The  $\text{MgSO}_4$  treatment reduced petiole K content at véraison, although not significant. The soil exchangeable Mg content was increased relative to Ca, Na and K content (Fig. 2) and a K/Mg antagonism could be responsible for the reduced K content of the petioles at véraison. The  $\text{Ca(OH)}_2$  treatment produced a slightly higher véraison petiole K and a slightly higher Ca concentration in the must. These effects were not significant, but may confirm the positive effect that  $\text{Ca(OH)}_2$  have on root growth of the 101-14 Mgt rootstock (Conradie, 1983).





**Figure 7.** The mean effect of fertiliser treatments over three years (1999-2001) for Kersfontein, Paardeberg, Cabernet Sauvignon/101-14 Mgt, on the nutrient contents of leaf blades and petioles (% dm), sampled at véraison and juice sampled at ripeness. Means with the same letter do not differ significantly for  $P \leq 0.05$

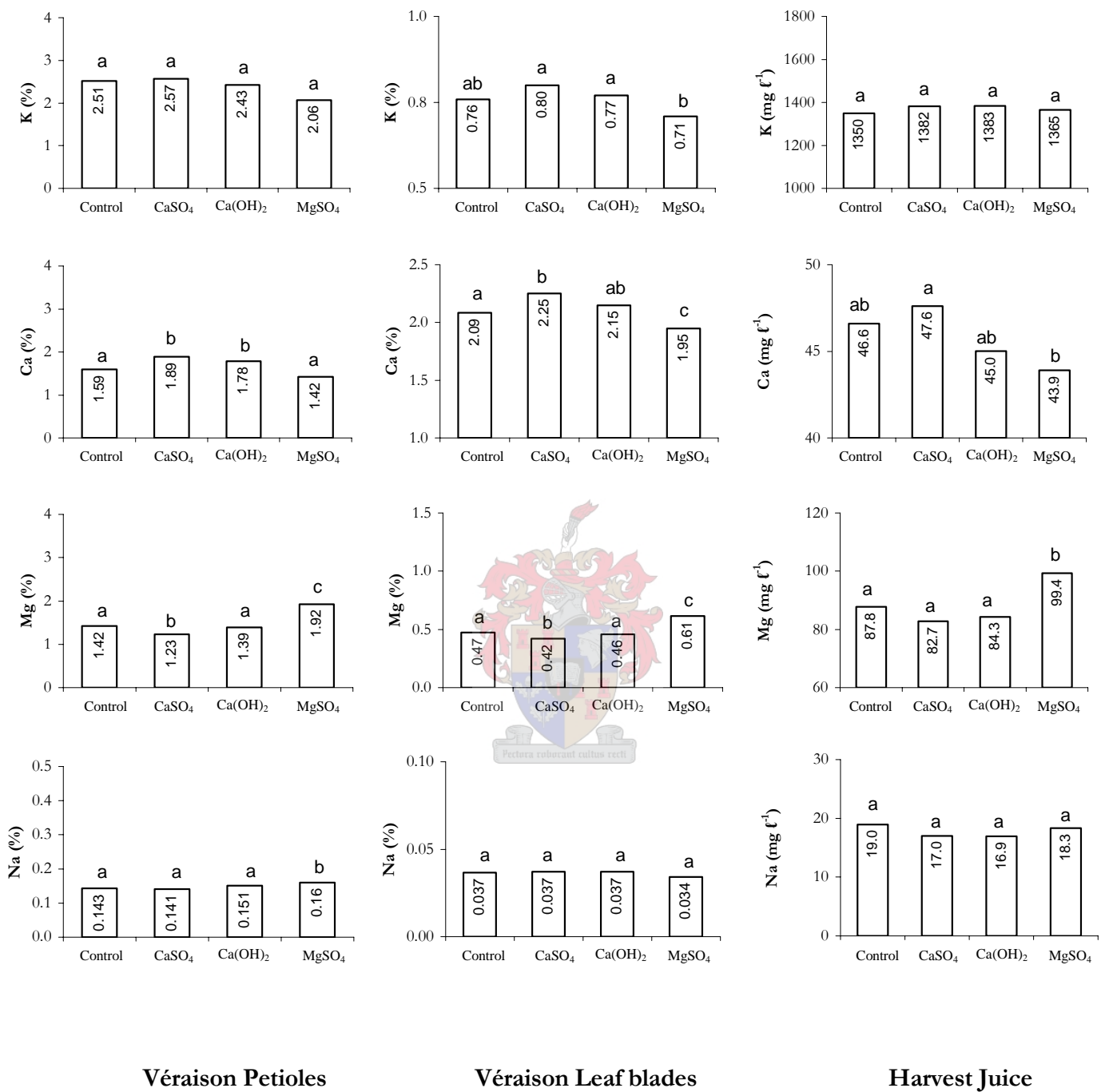
The possibility also exists that  $\text{Ca}(\text{OH})_2$  may advance maturity for this variety under the experimental conditions (section 4.4 in this thesis; Engelbrecht, 2002). Advanced maturity would mean higher juice K concentration. Overall, none of the fertiliser treatments influenced harvest juice K concentration.

Calcium content of véraison petioles was highest in the  $\text{CaSO}_4$  and  $\text{Ca}(\text{OH})_2$  treatments, but this effect was not significant. The  $\text{CaSO}_4$  treatment significantly increased the Ca content of véraison leaf blades. The  $\text{MgSO}_4$  treatment significantly depressed petiole Ca content which suggests an Mg/Ca antagonism. Calcium content of blades was similarly significantly depressed by the  $\text{MgSO}_4$  treatment. None of the fertiliser treatments had an effect on harvest juice Ca concentration. Magnesium content of véraison petioles was greatly and significantly increased by soil applied magnesium sulphate. All the treatments produced values well above the maximum of 1.45 percent as proposed by Conradie (1986). The  $\text{MgSO}_4$  treatment significantly increased blade Mg content and harvest juice Mg concentration. The gypsum treatment seems to reduce the juice Mg concentration slightly, but this effect was not significant.

Sodium content of véraison petioles and harvest juice was higher with the  $\text{MgSO}_4$  treatment, but not significantly so when compared to the control treatment. This could be due to this fertiliser application reducing petiole K content. All fertilisers produced significantly less blade Na at véraison, but did not significantly reduce Na concentration in harvest juice.

At Meerlus (Cabernet franc/99 Richter), the  $\text{MgSO}_4$  treatment produced a significantly lower blade K content at véraison (Fig. 8). No fertiliser treatments significantly affected harvest juice K concentration.

Calcium content of véraison petioles was significantly increased by the  $\text{CaSO}_4$  treatment, although not when compared to the control. The same trend is evident for the Ca content of the leaf blades. This was also reflected to a limited degree in the grape juice composition at harvest. Here the  $\text{CaSO}_4$  treatment significantly increased juice Ca concentration relative to the magnesium sulphate treatment or  $\text{MgSO}_4$  lowered juice Ca content compared to that of the  $\text{CaSO}_4$  treatment.



**Figure 8.** The mean effect of fertilizer treatments over three years (1999-2001) for Meerlus, Paardeberg, Cabernet franc/99 Richter, on the nutrient contents of leaf blades and petioles (% dm) sampled at véraison and juice sampled at ripeness; means with the same letter do not differ significantly for  $P \leq 0.05$

Magnesium content of véraison petioles and leaf blades was significantly increased by  $\text{MgSO}_4$  soil application and significantly decreased by gypsum application. Juice Mg concentration was significantly increased by  $\text{MgSO}_4$  application.

Sodium content of véraison petioles was increased by the  $\text{MgSO}_4$  treatment. None of the fertiliser treatments significantly affected juice Na concentration at harvest.

Engelbrecht (2002) found that the exchangeable K content of the topsoil (0-30 cm) at Meerlus correlated positively with petiole K content at pea-size. The nutrient content of berries at pea-size should represent mainly nutrient accumulation via the xylem and to a far lesser extent phloem transported nutrient accumulation. At this stage the berries are a weak sink for assimilates and cell division is the main physiological activity in the berry.

Engelbrecht (2002) found that the pre-véraison petiole content is significantly affected by soil exchangeable K content. This supports the theory that vine K content is influenced by soil K levels before véraison and to a lesser extent thereafter. Engelbrecht (2002) accordingly found no correlation between soil K content and grape juice at harvest. In this experiment, Ca content of berries and petioles at pea-size increased with increasing exchangeable Ca levels in the soil (data not shown).



There are furthermore definite signs of a Ca/Mg and Mg/Ca soil antagonism on root absorption at Meerlus (see Appendix A). According to Salisbury & Ross (1985) and Mengel & Kirkby (1987), the reason for Ca and Mg antagonism may be the fact that these two divalent cations compete for the same carrier in the plasmalemma of root cells. This means that while the divalent cations antagonism is linked to a common carrier, their effect on K absorption by the root is restricted to other, non-carrier, effects. These other effects may be the influence of hydrated Ca and Mg and perhaps their anions on the activity of K in the soil solution. Should this be the case, then the divalent cations will only affect K absorption while the passive system II is operating. When the active system I is operating at low external K concentration, or activity, then the effect of Ca and Mg on K absorption should be much less important. If it is furthermore assumed that no intensely depleted K zone can exist around the active absorbing roots in order for passive System II absorption to operate,

it follows that water potentials around the root zone should be sufficiently high for Ca and Mg to antagonize K absorption.

Calculated activity values for K, Ca, Mg and Na and ratios such as  $AR_v^K$  yielded no relationship with cation content of vine plant material sampled at pea-size stage (results not shown). It nonetheless remains an interesting area to investigate in future. The soil samples were taken the winter of 2001 and not during pea-size stage. As Figs. 2 and 3 illustrate, the exchangeable K content of both farms decreased during the three years of the experiment due to leaching and active root absorption. A potential relationship between the calculated K activity and vine K content at pea-size stage could still exist and soil sampling at pea-size stage is suggested for future research. The exchangeable Ca and Mg content decreased at a much slower rate than did the exchangeable K content. Evidence of possible relationships between divalent cations in the soil and Ca and Mg content of petioles and berries were indeed found at Meerlus (see Appendix A). However, no clear relationship between soil and plant material Ca and Mg at pea-size was found at Kersfontein (data not shown).

At both farms the  $MgSO_4$  fertilizer treatment was the only one that significantly influenced plant material cation composition at pea-size (Table 18). Magnesium sulphate reduced blade and petiole K and Ca content and decreased the berry Ca content of Cabernet Sauvignon/101-14 Mgt at Kersfontein. Magnesium did not significantly affect berry Ca and K content for Cabernet Sauvignon and Cabernet franc at pea-size stage.

This confirms the results of Engelbrecht (2002) of a K/Mg antagonism that reduced the petiole K content at pea-size for Cabernet Sauvignon at Kersfontein. Since the developing shoots and leaves are the main sinks at this time of vine growth, it would seem logical that these tissues will be more affected by any nutrient antagonism that exists at the root surface. As seen from Figs. 7 and 8, the proposed antagonistic effect of Mg did not affect juice composition at harvest.

**Table 18. Influence of fertiliser treatments on the nutrient content means of plant material of pea size stage at Kersfontein and Meerlus, Paardeberg**

Farm	Plant material	Fertiliser treatment	K (% dm)	Ca (% dm)	Mg (% dm)	Na (% dm)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	Leaf blades	Control	0.94 a	1.58 a	0.48 a	0.068 a
		CaSO <sub>4</sub>	0.92 a	1.65 a	0.47 a	0.067 a
		Ca(OH) <sub>2</sub>	0.91 a	1.57 ab	0.48 a	0.064 a
		MgSO <sub>4</sub>	0.84 b	1.43 b	0.57 b	0.059 a
	Petioles	Control	3.25 a	1.19 a	1.19 a	0.128 a
		CaSO <sub>4</sub>	3.17 a	1.23 a	1.15 a	0.131 a
		Ca(OH) <sub>2</sub>	3.21 a	1.26 a	1.21 a	0.126 a
		MgSO <sub>4</sub>	2.86 b	1.07 b	1.45 b	0.139 a
	Berries	Control	1.42 a	0.28 a	0.17 a	0.023 a
		CaSO <sub>4</sub>	1.44 a	0.30 a	0.18 a	0.023 a
		Ca(OH) <sub>2</sub>	1.39 a	0.29 a	0.17 a	0.023 a
		MgSO <sub>4</sub>	1.40 a	0.27 b	0.19 a	0.027 a
<b>Meerlus</b> (Cab. Franc /99 R)	Leaf blades	Control	0.89 a	1.80 a	0.42 a	0.043 a
		CaSO <sub>4</sub>	0.91 a	1.86 a	0.39 a	0.044 a
		Ca(OH) <sub>2</sub>	0.90 a	1.76 a	0.40 a	0.044 a
		MgSO <sub>4</sub>	0.96 a	1.75 a	0.57 b	0.046 a
	Petioles	Control	2.15 ab	1.51 a	0.89 ab	0.138 a
		CaSO <sub>4</sub>	2.30 a	1.60 a	0.82 b	0.137 a
		Ca(OH) <sub>2</sub>	2.33 a	1.39 b	1.00 ac	0.124 a
		MgSO <sub>4</sub>	2.04 b	1.36 b	1.11 c	0.137 a
	Berries	Control	1.41 a	0.30 a	0.15 ab	0.043 a
		CaSO <sub>4</sub>	1.39 a	0.31 a	0.14 c	0.040 a
		Ca(OH) <sub>2</sub>	1.44 a	0.30 a	0.15 b	0.037 a
		MgSO <sub>4</sub>	1.45 a	0.30 a	0.16 a	0.038 a

Means for the respective farms and plant material followed by the same letter do not differ significantly at  $P \leq 0.05$

Fertilisers applied in February 1998

Fertiliser application rates: 5 t.ha<sup>-1</sup> CaSO<sub>4</sub> and equivalent amounts of Ca(OH)<sub>2</sub> & MgSO<sub>4</sub>.7H<sub>2</sub>O

#### 4.3.4 The effect of MgSO<sub>4</sub> foliar applications

Table 19 summarises the effect of two 10% MgSO<sub>4</sub> foliar sprays, applied at véraison to leaves and bunches in the bunch zone. The foliar spray significantly increased petiole Mg and petiole K content at harvest for Kersfontein. This could be due to low soil water potentials that reduced normal root Mg absorption. Magnesium juice concentration at harvest was significantly increased by the foliar spray for both farms. Juice K concentration of both varieties was unaffected.

#### 4.3.5 Discussion

At Meerlus, the Canopy 3 treatment resulted in a significant decrease in petiole K content. The reason for this is not clear. The MgSO<sub>4</sub> treatment significantly reduced véraison petiole K content at Kersfontein and significantly reduced blade K content at Meerlus. None of the fertiliser treatments significantly affected harvest juice K concentrations. Canopy treatments, fertiliser and foliar Mg applications had no significant effect on harvest juice K concentrations, nor were there any significant interactions between the treatments (see Appendix B for ANOVA tables).

Juice K concentration appeared to be a function of soil K content, vine growth at véraison and stress conditions after véraison during the ripening phase of the berries. Within-canopy shade was in all probability not limiting for the experimental sites and water stress after véraison is proposed as the principle photosynthesis limiting factor for this experiment.

Calcium content of petioles and blades at véraison were significantly lower in Canopy 3 vines for both farms and cultivars. Canopy 3 induced a significantly higher Ca concentration in the grape juice at Meerlus. At Kersfontein the canopy treatments influenced the Ca content of blades and petioles at pea-size stage. Generally the pea-size plant material Ca content of Canopy 3 was lower than that of Canopy 1 (data not shown). Moreover, only Ca leaf content was influenced by canopy density and/or topping of shoots. The topped vines,

**Table 19. The effect of farm/variety and MgSO<sub>4</sub> foliar sprays applied at véraison on the mean nutrient content of plant material at véraison and harvest, Paardeberg, 1999/00 – 2000/01**

Farm/variety	Stage	Sample material	K		Ca		Mg		Na	
			Control	MgSO <sub>4</sub>	Control	MgSO <sub>4</sub>	Control	MgSO <sub>4</sub>	Control	MgSO <sub>4</sub>
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	<b>Véraison</b>	Petioles (% dm)	2.86 a	2.72 b	1.41 a	1.44 a	1.95 a	1.88 a	0.13 a	0.09 b
		Leaf blades (% dm)	0.80 a	0.79 a	1.97 a	1.96 a	0.67 a	0.68 a	0.06 a	0.07 a
		Berry skins (% dm)	1.51 a	1.47 a	0.24 a	0.26 a	0.12 a	0.13 a	0.04 a	0.04 a
		Juice (mg ℓ <sup>-1</sup> )	810.8 a	809.4 a	37.6 a	36.9 a	70.8 a	77.9 a	45.2 a	45.4 a
	<b>Harvest</b>	Petioles (% dm)	2.17 a	2.47 b	2.58 a	1.99 b	2.09 a	2.20 b	0.20 a	0.21 a
		Leaf blades (% dm)	0.85 a	0.80 a	2.14 a	2.04 b	0.64 a	0.68 a	0.06 a	0.07 a
		Berry skins (% dm)	1.45 a	1.48 a	0.17 a	0.19 a	0.09 a	0.10 a	0.04 a	0.04 a
		Juice (mg ℓ <sup>-1</sup> )	1601.9 a	1576.1 a	52.3 a	53.0 a	115.1 a	126.1 b	69.5 a	63.3 b
<b>Meerlus</b> (Cab. Franc /99 R)	<b>Véraison</b>	Petioles (% dm)	2.35 a	2.31 a	1.68 a	1.68 a	1.53 a	1.50 a	0.161 a	0.158 b
		Leaf blades (% dm)	0.77 a	0.77 a	2.12 a	2.08 b	0.48 a	0.49 a	0.038 a	0.040 a
		Berry skins (% dm)	1.30 a	1.29 a	0.24 a	0.23 a	0.09 a	0.09 a	0.020 a	0.020 a
		Juice (mg ℓ <sup>-1</sup> )	829.4 a	844.2 a	32.5 a	34.7 a	57.8 a	65.3 b	13.4 a	14.6 b
	<b>Harvest</b>	Petioles (% dm)	1.82 a	1.82 a	2.04 a	2.06 a	1.71 a	1.75 a	0.180 a	0.186 a
		Leaf blades (% dm)	0.76 a	0.74 a	2.25 a	2.18 a	0.49 a	0.54 b	0.035 a	0.039 a
		Berry skins (% dm)	1.36 a	1.38 a	0.20 a	0.20 a	0.09 a	0.09 a	0.029 a	0.028 a
		Juice (mg ℓ <sup>-1</sup> )	1269.8 a	1267.5 a	50.2 a	51.4 a	93.0 a	117.8 b	19.5 a	20.2 b

MgSO<sub>4</sub> foliar sprays: 2x10kg/100lit (10%) at véraison

Means of the control and spray treatment followed by the same letter do not differ significantly at P≤0.05



therefore, accumulated lower Ca content in its leaves. It was not possible to distinguish between the effect of dense canopies and the effect of topping with the measurements taken. The  $\text{CaSO}_4$  treatment significantly increased the véraison blade Ca content at Kersfontein and the petiole Ca content at Meerlus. Petiole Ca content at véraison was significantly reduced by the  $\text{MgSO}_4$  treatment at both farms. At Meerlus the  $\text{MgSO}_4$  treatment lowered juice Ca concentration compared to the  $\text{CaSO}_4$  treatment, but at Kersfontein none of the fertiliser applications influenced juice Ca concentration.

Magnesium content of leaves and juice were not affected by canopy treatments at Kersfontein. Magnesium content of petioles at véraison was lower for Canopy 3 at Meerlus.

Magnesium content of véraison petioles and blades was significantly increased by soil applied  $\text{MgSO}_4$  at both farms. This treatment also significantly increased harvest juice Mg concentration at both farms. Gypsum significantly decreased véraison petiole and blade Mg content at Meerlus.

The sodium concentration of harvest juice was significantly lower for the Canopy 3 treatment at Kersfontein. The Na concentration of harvest juice was significantly higher for Canopy 1 at Meerlus. The reason for this is unclear. Sodium content of véraison petioles was significantly higher with the  $\text{MgSO}_4$  treatment at both farms. At Kersfontein the  $\text{MgSO}_4$  treatment significantly increased juice Na concentration. Gypsum induced significantly less blade Na at véraison at Kersfontein.

It is possible that low soil water potential dominated plant nutrient accumulation to such an extent that no conclusive argument can be made for or against fertiliser effects on juice K content.

Sugar contents for the 1999/00 season ranged from 25°B for the Cabernet Sauvignon/101-14Mgt (Kersfontein) to 26°B for the Cabernet franc/99R (Meerlus). In 2001 the Cabernet Sauvignon was harvested at 21°B and the Cabernet franc at 23°B and therefore more in line with the 22-24°B norms.

## 4.4 The effect of season, canopy treatments and fertilizers on grape juice and wine components

### 4.4.1 Seasonal effects

The average sugar content for Cabernet franc and Cabernet Sauvignon is 22-24°B at maturity for the Stellenbosch area (Carstens, Burger & Kriel, 1981). The average sugar contents for the 1999/00 season ranged from 25 °B for the Cabernet Sauvignon/101-14Mgt (Kersfontein) to 26 °B for the Cabernet franc/99R (Meerlus) (Table 20). In 2001 the Cabernet Sauvignon was harvested at 21 °B and the Cabernet franc at 23 °B and therefore more in line with the 22-24 °B norms (Table 20).

The normal pH range for Cabernet Sauvignon wine is 3.5 – 3.8 (L. Ellis, Department of Enology, Stellenbosch University, presently Elsenburg Agricultural College, personal communication, 2000). The wine pH of the Cabernet Sauvignon ranged from 3.8-4.1 and between 3.6 and 3.9 for the Cabernet franc (Table 20). In practice tartaric acid would have been added to modify the decrease the pH. Since this was not done the high pH values of the wine from the two farms are understandable.

Colour density describes the intensity of the wine colour and represents the amount of colour. Generally values of 0 – 6 OD units (OD = Optical Density at certain wave lengths) are described as lightly coloured, 6-10 OD units are described as medium red colour and >10 OD units as deep red. Both Kersfontein and Meerlus produced deeply coloured wines for the experimental seasons (Table 20).

The total phenolic material in the wine gives an indication of the complexity of the wine. It is the tannic component of wine that imparts the bitterness and astringency and is an important component of flavour. The values in Table 20 show that all the seasons and both the cultivars produced a medium bodied wine as far as phenolic compounds are concerned (<35 OD – thin wine; 35-45 OD – medium; >60 OD– astringent).

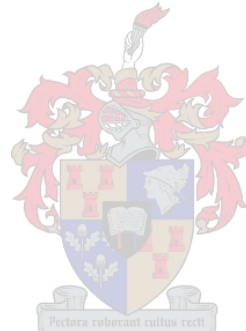
Total red pigment colour provides an estimate of the concentration of the total pigments (both anthocyanins and tannins) in the wine. Higher values indicate more full bodied

Table 20. Influence of farm and season on harvest juice and wine components, 1999/00 – 2000/01

Farm	Treatment	Harvest juice pH	Harvest juice titratable acid (g.dm <sup>-3</sup> )	Harvest juice sugar (°B)	Wine pH	Wine colour density (Abs. 420nm + Abs. 520nm)	Modified wine colour density* (Abs. 420nm + Abs. 520nm)	Wine total phenolics (Abs. 420nm)	Total red pigment colour (Abs. 520nm)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	1999/00	3.93 a	6.38 a	26.2 a	4.14 a	13.3 a	14.5	40.8 a	17.8 a
	2000/01	3.66 b	7.38 b	21.2 b	3.84 b	11.9 a	14.0	48.1 b	25.0 b
<b>Meerlus</b> (Cab. Franc /99 R)	1999/00	3.93 a	4.01 a	25.0 a	3.65 a	11.0 a	11.1	35.5 a	16.1 a
	2000/01	3.70 b	4.58 a	23.4 b	3.98 b	11.4 a	12.9	47.5 b	23.7 b

\*Means for 1998/99 – 1999/00 seasons

Means followed by the same letter do not differ significantly at P=0.05



wines. The 1999/00 season produced wines with significantly lower pigmentation than that of the 2000/01 season.

The relatively dry conditions experienced in the 1999/00 season (see Table 1) induced high pH and sugar content, low titratable acidity and high K content in musts. No direct correlation was found between juice pH and K content, which confirms previous research (Boulton, 1980). Kersfontein has higher exchangeable K levels in the soil than Meerlus, had less dense canopies (lower LLN values) than Meerlus and probably experienced more intense water stress. The combined effect of these factors could have induced the high juice K content and high wine pH values for wine from Kersfontein (Table 20).

The 2000/01 season produced more shaded leaves (or more interior leaves) for Kersfontein while the percentage shaded bunches remained the same (Table 4). At Kersfontein the more shaded leaves of the 2000/01 season could have reduced within canopy temperatures which led to increased tartaric acid and anthocyanin production for the normally hot Kersfontein (Table 20). The increased tartaric acid content would account for the lower wine pH of the 2000/01 season since the bunches were exposed to the same extent as the previous season. The exposed bunches presumably would have experienced the same amount of malic acid degradation.

At Meerlus, bunches were more shaded during 2000/01 while the percentage shaded leaves remained constant for both seasons (Table 4). The shaded bunches could have retarded malic acid degradation during the ripening period in 2000/01, which led to the relatively high juice acid content of this season. Malo-lactic fermentation would have reduced the high malic acid content which resulted in the high wine pH for Meerlus in the 2000/01 season (Table 20).

The Cabernet franc berries at Meerlus were significantly smaller in 1999/00 compared to that of 2000/01 (Table 5), suggesting that the skin:pulp ratio could have been higher. In such a case, more K would be extracted during the crushing process. This could have contributed to the high wine pH for the 2000/01 season (Table 20).

In summary: the hot and stressful conditions of the 1999/00 season significantly influenced the cation accumulation of berries, eventual sugar content, pH and acidity of the grape juice and wine quality as far as pH is concerned.

#### 4.4.2 The effect of canopy treatments

Increasing canopy density and topping of decreased sugar content of harvest juice of Cabernet franc/99R at Meerlus in 1998/99 (Engelbrecht, 2002). The delayed maturity was attributed to within-canopy shade. The author noted that the topping of shoots and the subsequent diminished effective leaf surface could also depress maturity and that the effect of topping and over shadowing could not be separated in this experiment.

Canopy treatments at Kersfontein had no significant effect on the mean pH for Cabernet Sauvignon juice at harvest for the 1999/00 and 2000/01 seasons. This was probably due to the low LLN values achieved during the experiment (Table 21), indicating that within-canopy shade was not limiting for the control vines (Canopy 3) at Kersfontein. Canopy 2 did, however, produce significantly higher juice titratable acidity (Table 21). This canopy treatment produced significantly higher shade bunch percentages (Table 7). The temperature of bunches for this treatment may have been lower than those of the Canopy 1 treatment and the lower temperature could have retarded malic acid degradation during the ripening period for the Canopy 2 treatment. This is supported by the fact that there were no significant differences in the wine pH values between Canopies 1 and 2.

At Meerlus, the Canopy 3 treatment produced significantly higher pH values for the Cabernet franc juice at harvest (Table 21), despite the fact that there was no significant increase in juice K concentration at harvest for this denser canopy treatment (Fig. 6). Furthermore, Canopy 3 did not increase wine pH compared to the Canopy 1 and 2 treatments. This suggests that Canopy 3 influenced the malic and tartaric acid composition of the juice (malic and tartaric acid concentrations not determined due to technical difficulties). The canopy treatments had no effect on juice titratable acidity, sugar content or wine pH. Canopy 3 did produce significantly lower colour density values than the Canopy 1 and 2 treatments (Table 21).

Table 21. The effect of farm/variety and canopy treatments and of farm/variety and fertiliser treatments on harvest juice and wine components at Kersfontein and Meerlus, Paardeberg, 1999/00 – 2000/01

Farm/variety	Treatment	Harvest juice pH	Harvest juice titratable acid (g l <sup>-1</sup> )	Harvest juice sugar (°B)	Wine pH	Wine colour density (Abs. 420nm + Abs. 520nm)	Modified wine colour density* (Abs. 420nm + Abs. 520nm)	Wine total phenolics (Abs. 420nm)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	Canopy 1	3.79 a	6.60 a	23.6 a	4.01 a	12.8 a	14.6 a	41.9 a
	Canopy 2	3.78 a	7.18 b	24.0 a	4.00 a	12.2 a	14.7 a	41.6 a
	Canopy 3	3.81 a	6.86 ab	23.6 a	4.11 b	12.1 a	13.4 a	41.5 a
<b>Meerlus</b> (Cab. franc /99 R)	Canopy 1	3.79 a	4.48 a	24.0 a	3.82 a	10.6 a	12.1 a	40.4 a
	Canopy 2	3.80 a	4.19 a	24.2 a	3.82 a	10.1 a	12.2 a	38.5 ab
	Canopy 3	3.85 b	4.20 a	24.4 a	3.78 a	8.7 b	11.7 a	35.6 b
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	Control	3.78 ab	6.86 a	23.3 a	4.03 a	11.3 a	14.1 ab	42.6 ab
	CaSO <sub>4</sub>	3.81 ab	6.92 a	23.9 ab	4.06 a	11.5 a	13.4 a	38.5 a
	Ca(OH) <sub>2</sub>	3.85 a	6.76 a	24.3 b	4.04 a	12.8 ab	14.8 ab	41.2 ab
	MgSO <sub>4</sub>	3.75 b	6.98 a	23.5 ab	4.03 a	13.9 b	16.3 b	44.4 b
<b>Meerlus</b> (Cab. franc /99 R)	Control	3.83 a	4.25 a	23.4 a	3.77 a	10.4 a	12.2 a	39.1 a
	CaSO <sub>4</sub>	3.81 a	4.00 a	23.3 a	3.80 a	9.7 ab	12.0 a	37.5 a
	Ca(OH) <sub>2</sub>	3.80 a	4.26 a	23.3 a	3.85 a	10.0 ab	12.5 a	39.4 a
	MgSO <sub>4</sub>	3.82 a	4.67 a	23.3 a	3.81 a	9.1 b	11.2 a	36.8 a

\*Means for 1998/99 – 1999/00 seasons

Means for the respective farms followed by the same letter do not differ significantly at P≤0.05

Canopy 1 (least dense): thin to two shoots/bearer, vertical shoot positioning, tip as necessary and removal of yellow leaves and lateral shoots in the bunch zone

Canopy 2 (intermediately dense): thin to three shoots/bearer, vertical shoot positioning and topping of shoots before véraison

Canopy 3 (dense): Vertical shoot positioning and topping of shoots before véraison

Fertilizers applied in February 1998; application rates: 5 t ha<sup>-1</sup> CaSO<sub>4</sub> and equivalent amounts of Ca(OH)<sub>2</sub> and MgSO<sub>4</sub>.7H<sub>2</sub>O

The inconclusive results of the canopy treatments were probably due to the low canopy density of Canopy 3 (control). The low vigour of the Canopy 3 treatments and the vines in general is suspected to be connected to water stress during the growing and ripening period of vine development. This water stress is suspected to have affected the Cabernet Sauvignon/101-14 Mgt on the hotter easterly slope of Kersfontein more than it did the Cabernet franc/99 R at Meerlus.

#### 4.4.3 The effect of fertilisers

Engelbrecht (2002) reported higher harvest juice sugar content for the  $\text{Ca}(\text{OH})_2$  and  $\text{MgSO}_4$  treatments for Cabernet Sauvignon/101-14 Mgt (Kersfontein) for the 1998/99 season. For the following two seasons the  $\text{Ca}(\text{OH})_2$  treatment slightly increased juice pH at harvest and  $\text{MgSO}_4$  slightly decreased juice pH when compared to the control. These effects were not significant when compared to the control but significant when compared to one another. Furthermore,  $\text{Ca}(\text{OH})_2$  significantly increased the sugar content of harvest juice when compared to the control and slightly (not significantly) decreased titratable acidity. The reason for the higher sugar content for Cabernet Sauvignon/101-14 Mgt with the  $\text{Ca}(\text{OH})_2$  treatment could be due to the positive effect that liming and higher soil pH values have on the root mass of the 101-14 Mgt rootstock (Conradie, 1983). It would appear that  $\text{Ca}(\text{OH})_2$  in the amounts applied and under the experimental conditions advances maturity of Cabernet Sauvignon/101-14 Mgt (i.e. higher °B, lower titratable acidity and higher pH). This treatment also produced slightly higher petiole K content at véraison for this variety (Fig. 7). The  $\text{MgSO}_4$  fertiliser treatment resulted in a significant increase in the wine colour density for Cabernet Sauvignon juice at Kersfontein but this treatment significantly suppressed the colour density values for Cabernet franc juice at Meerlus. According to Figs. 7 and 8,  $\text{MgSO}_4$  fertiliser application did not affect K content of harvest juice. These contrasting reactions might be due to an interaction between Mg nutrition and variety (Cabernet Sauvignon vs. Cabernet franc), vine growth (poor at Kersfontein vs. moderate at Meerlus), canopy temperature (presumably high at Kersfontein vs. presumably lower at Meerlus) or soil water potentials and photosynthesis (water stress and lower photosynthesis at Kersfontein vs. less water stress and higher photosynthesis at Meerlus). The precise reason for this effect is therefore unclear.

#### 4.4.4 The effect of MgSO<sub>4</sub> foliar applications

The MgSO<sub>4</sub> treatment decreased juice pH significantly for both varieties (Table 22). Juice titratable acidity was increased, but only significantly at Meerlus for Cabernet franc. Wine pH was reduced by the foliar application but significantly only at Kersfontein. The foliar spray did not affect K content of juice at harvest (Table 19). The positive effect that this application had on the cation, anion mixture of harvest juice and wine is presumably due to an effect on the anion component, malic and tartaric acid content and the ratio between them. Malic and tartaric acid contents were unfortunately not determined for this experiment due to technical difficulties.

#### 4.4.4 Discussion

Seasons significantly influenced juice and wine components for both farms. The hot and dry 1999/00 season produced the highest juice K concentration at the warmer location (Kersfontein) and the highest wine pH values (Table 20).

Canopy treatments had no effect on juice pH at harvest for Kersfontein, but Canopy 1 and 2 did induce a significantly lower juice pH compared to Canopy 3 for Cabernet franc/99 R at the relatively cooler Meerlus. However, the canopy treatments at both farms did not influence juice K concentration (Figs. 5 and 6). Cabernet franc at Meerlus grew more vigorously than the Cabernet Sauvignon at Kersfontein and a certain amount of within-canopy shading could have influenced acid composition at Meerlus. The canopy treatments did not influence wine pH values at Meerlus though. Canopy 1 and 2 produced a wine pH value significantly lower than that of Canopy 3 at Kersfontein. This was not due to a lower juice K concentration (Fig. 5). The acid composition of the juice, must and wine is therefore the reason for this reduction in wine pH.



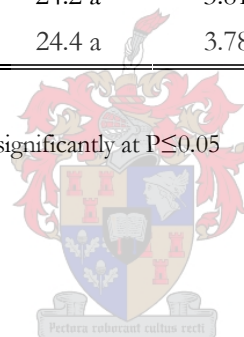


**Table 22. The influence of MgSO<sub>4</sub> foliar applications on grape juice properties at harvest for Cabernet Sauvignon/101-14 Mgt and Cabernet franc/99R, Kersfontein and Meerlus, Paardeberg, 1999/00-2000/01**

Farm	Treatment	Juice pH	Juice titratable acid (g l <sup>-1</sup> )	Juice sugar (°B)	Wine pH	Wine colour density	Wine total red pigment colour	Wine total Phenolics
						(Abs. 420nm + Abs. 520nm)	(Abs. 520nm)	(Abs. 420nm)
<b>Kersfontein</b> (Cab. Sauv. /101-14 Mgt)	Control	3.80 a	6.88 a	23.7 a	4.04 a	12.4 a	24.2 a	41.7 a
	MgSO <sub>4</sub>	3.75 b	6.99 a	23.7 a	3.94 b	13.0 b	22.6 a	44.7 b
<b>Meerlus</b> (Cab. franc /99 R)	Control	3.81 a	4.29 a	24.2 a	3.81 a	9.8 a	20.5 a	38.2 a
	MgSO <sub>4</sub>	3.76 b	4.92 b	24.4 a	3.78 a	11.3 b	20.0 a	40.9 b

MgSO<sub>4</sub> foliar sprays: 2x10kg/100lit (10% solution) at véraison

Means for the respective farms followed by the same letter do not differ significantly at P≤0.05



The presence of lateral shoot growth for Canopy 1 and possibly Canopy 2 might have contributed to the lower wine pH at Kersfontein and the higher wine colour density at Meerlus. The lack of vigour and the failure to develop sufficient lateral shoot growth for Cabernet Sauvignon at Kersfontein could be the reason why the canopy treatments here did not influence juice and wine components to the extent it did for the Cabernet franc at Meerlus. This in effect supports Engelbrecht's (2002) findings that the lack of vigour and consequently within-canopy shade for Canopy 3 (control) resulted in no significant effects.

Fertiliser applications failed to produce significant and/or consistent trends in juice and wine components. The reason for this could also be related to vine growth and general performance modified by climate and soil water potentials. The  $\text{MgSO}_4$  fertiliser treatments significantly increased colour density for Cabernet Sauvignon/101-14 Mgt over two seasons. The reason for this is unclear since the various plant materials did not show a distinct Mg deficiency according to the South African nutrient norms for wine grapes (Conradie, 1994).



## CONCLUSIONS

Water stress during the growing and ripening phases of the vines appears to be the main reason why techniques to limit berry K accumulation failed to produce consistent results at Paardeberg.

It appears that, for these trials at Paardeberg at least; the most important process affecting berry K accumulation is photosynthetic activity after véraison. Photosynthetic activity is negatively affected by within-canopy shade but also by low soil water potentials (very negative). The factor most commonly limiting both fruit tree and vine performance in the warm fruit and wine producing areas of the Western Cape is generally water availability from the end of December up and until harvest.

From the literature it is clear that the effect of canopy treatments, and to a lesser extent fertilisation, on berry K accumulation and wine pH have been studied extensively. The combined effect of nutrition, canopy management and irrigation on berry K accumulation and eventual wine pH and quality, however, have not been studied sufficiently under South African field conditions.

The proposed index (Table 17) suggests that soil K content before véraison, vine growth at and after véraison, within-canopy shade at and after véraison and especially water stress after véraison are the more important factors determining juice K content at harvest for the Paardeberg area. It is therefore advisable to conduct further research in the Paardeberg area and to include measurements of vine growth, climatic conditions, soil water potential and photosynthetic activity in relation to physiological stage in the observations made.

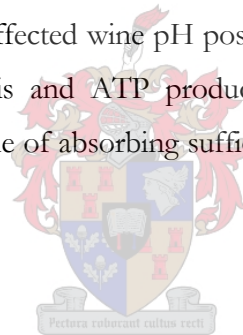
Based on the above, the following are suggested for future field research concerning berry K accumulation and wine pH values and quality in warm wine producing areas:

- Portable weather stations for each experimental site measuring evapotranspiration, wind speed, relative humidity and rainfall.

- Water content measurements using neutron water meters, or other reliable soil water meters.
- Measurement of leaf photosynthetic activity after véraison.
- Determining malic and tartaric acid content in harvest juice and wine.

This information will greatly simplify interpretation concerning tissue nutrient levels, seasonal variations in K-uptake, and sugar and acid dynamics.

Canopy treatments failed to reduce juice K concentration, possibly because within-canopy shade was generally not limiting for this experiment. The  $\text{MgSO}_4$  soil application significantly increased juice Mg content at harvest of Cabernet berries. The gypsum and  $\text{Ca(OH)}_2$  treatments increased the juice Ca content at harvest to a limited extent. Potassium and Na concentrations in harvest juice were unaffected by fertiliser treatments. Magnesium sulphate foliar sprays affected wine pH positively but only, it would appear, if some factor limited photosynthesis and ATP production in the vines. Otherwise it appeared that the vines were capable of absorbing sufficient amounts of Mg through their roots.



## LITERATURE CITED

- ACEVEDO, C., ORTEGA-FARIAS, S., MORENO, Y. & CORDOVA, F., 2004. Effects of different levels of water application in pre- and post-veraison on must composition and wine colour (cv. Cabernet Sauvignon). *Acta Hort.* 664, 483-489.
- ARCHER, E., 1981. Fisiologie van die Wingerdstok. In: J. Burger & J. Deist (eds.). *Wingerdbou in Suid Afrika*. VORI, Private Bag X5026, Stellenbosch, 7599.
- ARCHER, E. & STRAUSS, H. C., 1989. Effect of shading on the performance of *Vitis vinifera* L. cv. Cabernet Sauvignon. *S. Afr. J. Enol. Vitic.* 10, 74-76.
- ATTIA, F., IBRAHIM, H., CADET, A. & GARCIA, M., 2004. Evaluation of leaf, must and wine cation contents and of must and wine acidity of five red wine grape cultivars (*Vitis vinifera* L.) grafted onto 3309 Couderc and grown hydroponically. *Acta Hort.* 652, 255-263.
- BERINGER, H., 1980. The role of potassium in crop production. Proc. International Seminar: The role of potassium in crop production. Pretoria, 1979. FSSA publication no. 75, 25-32.
- BLEDSLOE, A. M., KLEWER, W. M. & MAROIS, J. J., 1988. Effects of timing and severity of leaf removal on yield and fruit composition of Sauvignon blanc grapevines. *Am. J. Enol. Vitic.* 39, 49-54.
- BOHN, H. L., McNEAL, B. L. & O'CONNOR, G. A., 1985a. The Solid Phase. In: *Soil Chemistry*. 2d edition, John Wiley & Sons.
- BOHN, H. L., McNEAL, B. L. & O'CONNOR, G. A., 1985b. Cation Retention. In: *Soil Chemistry*. 2d edition, John Wiley & Sons.
- BOHRA, J. S. & DÖRFFLING, K., 1993. Potassium nutrition of rice (*Oryza sativa* L.) varieties under NaCl salinity. *Plant and Soil* 152, 299-303.
- BOULTON, R. B., SINGLETON, V. L., BISSON, L. F. & KUNKEE, R. E., 1998b. The Physical and Chemical Stability of Wine. In: *Principles and Practices of Winemaking*. Aspen Publishers, Gaithersburg, Maryland.
- BOULTON, R. B., SINGLETON, V. L., BISSON, L. F. & KUNKEE, R. E., 1998a. Juice and Wine Acidity. In: *Principles and Practices of Winemaking*. Aspen Publishers, Gaithersburg, Maryland.

- BOULTON R. B., SINGLETON, V. L., BISSON, L. F. & KUNKEE, R. E., 1998c. Viticulture for winmakers. In: Principles and practices of winemaking. Aspen Publishers, Gaithersburg, Maryland.
- BOULTON, R., 1980a. A hypothesis for the presence, activity, and role of potassium/hydrogen, adenosine triphosphatase in grapevines. *Am. J. Enol. Vitic.* 31, 283-287.
- BOULTON, R., 1980b. The relationship between total acidity, titratable acidity and pH in wine. *Am. J. Enol. Vitic.* 31, 76-80.
- BRANCADORA, L., VALENTI, L. & REINA, A., 1995. Rootstock effect on potassium content of grapevine. *Acta Hort.* 383, 115-124.
- BRAVDO, B., 2004. Effects of cultural practises and enviromental factors on wine production and quality. *Acta Hort.* 652, 119-124.
- BRAVDO, B. & HEPNER, Y., 1987. Irrigation management and fetigation to optimize grape composition and vine performance. *Acta Hort.* 206, 49-67.
- BRAVDO, B., HEPNER, Y., LOINGER, C., COHEN, S. & TABACMAN, H., 1984. Effect of crop level on growth, yield and wine quality of a high yielding Carignane vineyard. *Am. J. Enol. Vitic.* 35, 247-252.
- BRAVDO, B., HEPNER, Y., LOINGER, C., COHEN, S. & TABACMAN, H., 1985. Effect of crop level and crop load on growth, yield, must and wine composition and quality of Cabernet Sauvignon. *Am. J. Enol. Vitic.* 36, 125-131.
- BRAVDO, B. & NAOR, A., 1996. Effect of water regime on productivity and quality of fruit and wine. *Acta Hort.* 427, 15-26.
- BÜHMANN, C., NELL, J. P. & SAMADI, M., 2004. Clay mineral associations in soils formed under Mediterranean-type climate in South Africa. *S. Afr. J. Plant Soil* 21, 166-170.
- CARSKI, T. H. & SPARKS, D. L., 1985. A modified miscible displacement technique for investigating adsorption-desorption kinetics in soils. *Soil Sci. Soc. Am. J.* 44, 265-268.
- CARSTENS, W. J., BURGER, J. D. & KRIEL, G. le R., 1981. Cultivarbeleid, Cultivareienskappe en Plantverbetering. In: J. Burger & J. Deist (eds.) Wingerdbou in Suid Afrika. VORI, Private Bag X5026, Stellenbosch, 7599.
- CHALMERS, Y. M., KELLY, G. & KRSTIC, M. P., 2004. Partial rootzone drying of *Vitis vinifera* cv. Shiraz winegrapes in a semi-arid climate. *Acta Hort.* 664, 133-138.
- CHAMPAGNOL, F., 1994. Facteurs agronomiques de l'acidité des moûts et des vins. *Progrès Agricole et Viticole* 111, 469-481.

- CONRADIE, W. J., 1981a. Nutrient consumption by Chenin blanc grown in sand culture and seasonal changes in the chemical composition of leaf blades and petioles. *S. Afr. J. Enol. Vitic.* 2, 15-18.
- CONRADIE, W. J., 1981b. Seasonal uptake of nutrient by Chenin blanc in sand culture: II. Phosphorus, Potassium, Calcium and Magnesium. *S. Afr. J. Enol. Vitic.* 2, 7-13.
- CONRADIE, W. J., 1983. Liming and choice of rootstocks as cultural techniques for vines in acid soils. *S. Afr. J. Enol. Vitic.* 4, 39-44.
- CONRADIE, W. J., 1994. Wingerdbemesting. Handelinge van die werksessie oor wingerdbemesting, gehou te Nietvoorbij op 30 September 1994. LNR-NIWW, Privaatsak X5026, Stellenbosch, 7599.
- CONRADIE, W. J., CAREY, V. A., BONNARDOT, V., SAAYMAN, D. & VAN SCHOOR, L. H., 2002. Effect of different environmental factors on the performance of Sauvignon blanc grapevines in the Stellenbosch/Durbanville districts of South Africa. I. Geology, soil, climate, phenology and grape composition. *S. Afr. J. Enol. Vitic.* 23, 78-90.
- CONRADIE W. J. & SAAYMAN D., 1989. Effects of long-term nitrogen, phosphorus and potassium fertilization on Chenin blanc vines: II. Leaf analyses and grape composition. *Am. J. Enol. Vitic.* 40, 91-98.
- CREASY, G. L., PRINCE, S. F., & LOMBARD, P. B., 1993. Evidence for xylem discontinuity in Pinot noir and Merlot grapes: dye uptake and mineral composition during berry maturation. *Am. J. Enol. Vitic.* 44, 187-190.
- DAVEREDE, C. & GARCIA, M., 2000. Effect of various K-Ca ratios on the lack of acidity of musts and wines of *Vitis vinifera* L. cv. Negrette grafted on 101-14 Mgt and grown hydroponically. Accepted for *Am. J. Enol. Vitic.*
- DOKOOZLIAN, N. K. & KLIEWER, W. M., 1995. The light environment within grapevine canopies. II. Influence of leaf area density on fruit zone light environment and some canopy assessment parameters. *Am. J. Enol. Vitic.* 46, 219-227.
- DREIER, L. P., STOLL, G. S. & RUFFNER, H. P., 2000. Berry ripening and evapotranspiration in *Vitis vinifera* L. *Am. J. Enol. Vitic.* 51, 341-346.
- DREW, M. C. & SAKER, L. R., 1984. Uptake and long-distance transport of phosphate, potassium and chloride in relation to internal ion concentrations in barley: evidence of non-allosteric regulation. *Planta* 160, 500-507.
- DRY, P. R., LOVEYS, B. R., ILAND, P. G., BOTTING, D. G., MCCARTHY, M. G. & STOLL, M., 1998. Vine manipulation to meet fruit specifications. In Proc. Tenth Australian Wine Industry Technical Conference, Sydney, 208-214.



- DU PREEZ, M., CARSTENS, J. & VAN WYK, E., 1981. Voorbereiding en droogverassing van blaarmonsters vir ontleding. NIVV Prosedures en Tegnieke. Navorsingsinstituut vir Vrugte en Vrugtetegnologie, Privaatsak X5026, Stellenbosch, 7599.
- DUNDON, C. G. & SMART, R. E., 1984. Effects of water relations on the potassium status of Shiraz vines. *Am. J. Enol. Vitic.* 35, 40-45.
- ENGELBRECHT, G. P., 2002. 'n Ondersoek na die invloed van bemesting en lowerbestuur op die kaliuminhoud en pH van Cabernet sap en wyn. M.Sc. tesis. Univ. Stellenbosch, Private Bag X1, Matieland, 7602.
- ENGELS, C. & MARSCHNER, H., 1992. Adaptation of potassium translocation into the shoot of maize (*Zea mays*) to shoot demand: evidence for xylem loading as a regulatory step. *Physiologia Plantarum* 86, 263-268.
- EPSTEIN, E., 1965. Mineral Metabolism. In: Plant Biochemistry. J. Bammer & J. E. Varner (eds.). Academic Press, New York. 438-468.
- ESTEBAN, M. A., VILLANUEVA, M. J. & LISSARRAGUE, J. R., 1999. Effect of irrigation on changes in berry composition of Tempranillo during maturation. Sugars, organic acids and mineral elements. *Am. J. Enol. Vitic.* 50, 418-434.
- ETOURNEAUD, F., 1996. The Role of Potassium as One Parameter Monitoring the Acidity of Wines: Consequences on Potash Fertilization of the Vine. SCPA Agronomic Research Center.
- FINDLAY, N., OLIVER, K. J., NII, N. & COOMBE, B. G., 1987. Solute accumulation by grape pericarp cells. *J. of Exp. Bot.* 38, 668-679.
- FREEMAN, B. M. & KLIEWER, W. M., 1983. Effect of irrigation, crop level and potassium fertilization on Carignane vines. II. Grape and wine quality. *Am. J. Enol. Vitic.* 34, 197-207.
- GALLEGO, P., 1999. Influence des terroirs de l'appellation d'origine contrôlée Cotes des Frontonnais sur la nutrition cationique et le manique d'acidité des mouts et des vins de Negrette (*Vitis vinifera* L.) greffée sur 3309 C. These de l'Institut National Polytechnique de Toulouse, France.
- GARCIA, M., DAVEREDE, P., GALLEGRO, P. & TOUMI, M., 1999. Effect of various potassium-calcium ratios on cation nutrition of grape grown hydroponically. *J. Plant Nutr.* 22, 417-425.
- GARCIA, M., GALLEGRO, P., DAVERÈDE, C. & IBRAHIM, H., 2001a. Effect of three rootstocks on grapevine (*Vitis vinifera* L.) cv. Negrette grown hydroponically. I. Potassium, calcium and magnesium nutrition. *S. Afr. J. Enol. Vitic.* 22, 101 - 103.

- GARCIA M., IBRAHIM H., GALLEGRO P. & PUIG Ph., 2001b. Effect of three rootstock on grapevine (*Vitis vinifera* L.) cv. Négrette, grown hydroponically. II. Acidity of musts and wines. *S. Afr. J. Enol. Vitic.* 22, 104-106.
- GRIMME, H., 1980. Factors controlling potassium availability to plants. Proc. International Seminar: The role of potassium in crop production. Pretoria, 1979. FSSA publication no. 75. 33-42.
- GRONDKLASSIFIKASIEWERKSGROEP, 1991. Grondklassifikasie - 'n Taksinomiese sisteem vir Suid Afrika, 2de ed. Dept. van Landbou-ontwikkeling, Pretoria.
- HAVLIN, J.L., WESTFALL, D. G. & OLSEN, S. R., 1985. Mathematical models for potassium release kinetics in calcareous soils. *Soil Sci. Soc. Am. J.* 49, 371 - 376.
- HEPNER, Y. & BRAVDO, B., 1985. Effect of crop level and drip irrigation scheduling on the potassium status of Cabernet Sauvignon and Carignane vines and its influence on must composition and quality. *Am. J. Enol. Vitic.* 36, 140-147.
- HODGMAN, C. D., 1950. Handbook of Chemistry and Physics: A Ready-reference Book of Chemical and Physical Data, 32<sup>nd</sup> ed. Chemical Rubber Publishing Co., Cleveland, Ohio.
- HOWELL, G. S., 2001. Sustainable grape productivity and the growth-yield relationship: a review. *Am. J. Enol. Vitic.* 53, 165-174.
- HUNTER, J. J., 1991. Physiological implications of partial defoliation of grapevine (*Vitis vinifera* L. cv. Cabernet Sauvignon). Ph.D. thesis. Univ. of Stellenbosch, Private Bag X1, Matieland, 7602.
- HUNTER, J. J., 2000. Implications of seasonal canopy management and growth compensation in grapevine. *S. Afr. J. Enol. Vitic.* 21, 81-91.
- HUNTER, J. J. & LE ROUX, D. J., 1992. The effect of partial defoliation on development and distribution of roots of *Vitis vinifera* L. cv. Cabernet Sauvignon grafted onto rootstock 99 Richter. *Am. J. Enol. Vitic.* 43, 71-78.
- HUNTER, J. J. & RUFFNER, H. P., 2001. Assimilate transport in grapevines - effect of phloem disruption. *Aust. J. of Grape and Wine Res.* 7, 119-126.
- HUNTER, J. J., SKRIVAN, R. & RUFFNER, H. P., 1994. Diurnal and seasonal physiological changes in leaves of *Vitis vinifera* L.: CO<sub>2</sub> assimilation rates, sugar levels and sucrolytic enzyme activity. *Vitis* 33, 189-195.
- HUNTER, J. J. & VISSER, J. H., 1988. Distribution of <sup>14</sup>C-photosynthetate in the shoot of *Vitis vinifera* L. cv. Cabernet Sauvignon I. The effect of leaf position and development stage of the vine. *S. Afr. J. Enol. Vitic.* 9, 3-9.

- HUNTER, J. J. & VISSER, J. H., 1989. The effect of partial defoliation, leaf position and development stage of the vine on leaf chlorophyll concentration in relation to the photosynthetic activity and light intensity in the canopy of *Vitis vinifera* L. cv. Cabernet Sauvignon. *S. Afr. J. Enol. Vitic.* 10, 67-73.
- HUNTER, J. J. & VISSER, J. H., 1990. The effect of partial defoliation on growth characteristics of *Vitis vinifera* L. cv. Cabernet Sauvignon II. Reproductive growth. *S. Afr. J. Enol. Vitic.* 11, 26-32.
- ILAND, P., 1989. Grape berry composition - the influence of environment and viticultural factors. *Austr. Grapegrower & Winemaker* 308, 74-76.
- ILAND, P., EDWARDS, A. & SITTERS, J., 1993. Techniques for Chemical Analyses and Stability Tests of Grape Juice and Wine. Patrick Iland Wine Promotions, Campbelltown, South-Australia.
- JACKSON, D. I. & LOMBARD, P. B., 1993. Environmental practices affecting grape composition and wine quality - a review. *Am. J. Enol. Vitic.* 44, 409-430.
- JUNGK A. O., 2001. Dynamics of Nutrient Movement at the Soil-root Interface. In: Plant Roots, The Hidden Half. Y. Waisel, A. Eshel & U. Kafkafi (eds). 3d edition, Marcel Dekker, New York. 587-616.
- KELLER, M. & KOBLET, W., 1995. Stress induced development of inflorescence necrosis and bunch-stem necrosis in *Vitis vinifera* L. in response to environmental and nutritional effects. *Vitis* 34, 145-150.
- KELLER, M., HESS, B., SCHWAGER, H., SCHÄRER, H. & KOBLET, W., 1995. Carbon and nitrogen partitioning in *Vitis vinifera* L.: responses to nitrogen supply and limited irradiance. *Vitis* 34, 19-26.
- KLEIN, I., STRIME, M., FANBERSTEIN, L. & MANI, Y., 2000. Irrigation and fertigation effects on phosphorus and potassium nutrition of wine grapes. *Vitis* 39, 55-62.
- KLIEWER, W. M., 1971. Effect of day temperature and light intensity on concentration of malic and tartaric acids in *Vitis vinifera* L. grapes. *J. Amer. Soc. Hort. Sci.* 96, 372-377.
- KLIEWER, W. M., FREEMAN, B. M. & HOSSOM, C., 1983. Effect of irrigation, crop level and potassium fertilization on Carignane vines. I. Degree of water stress and effect on growth and yield. *Am. J. Enol. Vitic.* 34, 186-196.
- KLIEWER, W. M., WOLPERT, J. A. & BENZ, M., 2000. Trellis and vine spacing effects on growth, canopy microclimate, yield and fruit composition of Cabernet Sauvignon. *Acta Hort.* 526, 21-31.

- KOTZÉ, W. A. G., 2001. Voeding van Bladwisselende Vrugtebome, Bessies, Neute en Ander Gematigde Klimaat Gewasse in Suid-Afrika. LNR Infruitec-Nietvoorbij, Privaatzaak X5026, Stellenbosch, 7599.
- KOTZÉ, W. A. G. & DEIST, J., 1975. Amelioration of subsurface acidity by leaching of surface applied amendments. A laboratory study. *Agrochemophysica* 7, 39-46.
- KRIEDEMANN, P. E., KLIEWER, W. M., & HARRIS, J. M., 1970. Leaf age and photosynthesis in *Vitis vinifera* L. *Vitis* 9, 97-104.
- LANG, A. & DÜRING, H., 1991. Partitioning control by water potential gradient: evidence for compartmentation breakdown in grape berries. *J. of Exp. Bot.* 42, 1117-1122.
- LINDHAUER, M. G., 1986. The role of potassium in the plant with emphasis on stress conditions (water, temperature, salinity). Proc. Potassium Symposium, Pretoria, 1985. 95-104.
- MAATHUIS, J. M. & SANDERS, D., 1996. Mechanisms of potassium absorption by higher plant roots. *Physiol. Plant.* 96, 158-168.
- MATTHEWS, M. A., ANDERSON, M. M. & SCHULTZ, H. R., 1987. Phenologic and growth responses to early and late season water deficits in Cabernet franc. *Vitis* 26, 147-160.
- MCCARTHY, M. G., 1997. The effect of transient water deficit on berry development of cv. Shiraz (*Vitis vinifera* L.). *Aust. J. of Grape and Wine Res.* 3, 102-108.
- MCCARTHY, M. G. & COOMBE, B. G., 1999. Is weight loss in ripening grape berries cv. Shiraz caused by impeded phloem transport? *Aust. J. of Grape and Wine Res.* 5, 17-21
- MENGEL K., 1985. Physicochemical and biological factors of potassium availability in soils. Potassium Symp. Potassium Symp. Organizing Committee, Pretoria, 9 - 13.
- MENGEL, K. & KIRKBY, E. A., 1987a. Plant Water Relationships. In: Principles of Plant Nutrition. International Potash Institute. Bern.
- MENGEL, K. & KIRKBY, E. A., 1987b. Calcium. In: Principles of Plant Nutrition, 4<sup>th</sup> ed. International Potash Institute, Bern.
- MENGEL, K & KIRKBY, E. A., 1987c. Nutrient Uptake and Assimilation. In: Principles of Plant Nutrition, 4<sup>th</sup> ed. International Potash Institute, Bern.
- MENGEL, K. & KIRKBY, E. A., 1987d. Potassium. In: Principles of Plant Nutrition, 4<sup>th</sup> ed. International Potash Institute, Bern.

- MORRIS, J. R., SIMS, C. A., STRIEGLER, R. K., CACKLER, S. D. & DONLEY, R. A., 1987. Effects of cultivar, maturity, cluster thinning and excessive potassium fertilization on yield and quality of Arkansas wine grapes. *Am. J. Enol. Vitic.* 38, 260-264.
- MPELASOKA, B. S., SCHACHTMAN, D. P., TREEBY, M. T. & THOMAS, M. T., 2003. A review of potassium nutrition in grapevines with special emphasis on berry accumulation. *Aust. J. of Grapes and Wine Res.* 9, 154-168.
- MUNN D. A., WILDING, L. P. & MCLEAN, E. O., 1976. Potassium release from sand, silt, and clay soil separates. *Soil Sci. Soc. Am. J.* 40,
- NEUMANN, G. & RÖMHELD, V., 2001. Root-induced Changes in the Availability of Nutrients in the Rhizosphere. In: Plant Roots, the Hidden Half. Y. Waisel, A. Eshel & U. Kafkafi (eds). 3d edition, Marcel Dekker, New York.
- OJEDA, H., ANDARY, C., KRAEVA, E., CARBONNEAU, A. & DELOIRE, A., 2002. Influence of pre- and postveraison water deficit on synthesis and concentration of skin phenolic compounds during berry growth of *Vitis vinifera* cv. Shiraz. *Am. J. Enol. Vitic.* 53, 261-267.
- OLLAT N. & GAUDILLÈRE J. P., 1996. Investigation of assimilate import mechanisms in berries of *Vitis vinifera* var. Cabernet Sauvignon. *Acta Hort.* 427, 141-149.
- OLLAT, N., DIAKOU-VERDIN, P., CARDE, J. P., BARRIEU, F., GAUDILLÈRE, J. P. & MOING, A., 2002. Grape berry development: a review. *J. Int. Sci. Vigne Vin* 36, 109-131.
- ORTEGA-FARIAS, S., DUARTE, M., ACEVEDO, C., MORENO, Y. & CORDOVA, F., 2004. Effect of four levels of water application on grape composition and midday stem water potential of *Vitis vinifera* L. cv. Cabernet Sauvignon. *Acta Hort.* 664, 491-497.
- PATAKAS, A., 2000. Changes in the solutes contributing to osmotic potential during leaf ontogeny in grapevine leaves. *Am. J. Enol. Vitic.* 51, 223-226
- PEUKE, A., 2000. The chemical composition of xylem sap in *Vitis vinifera* L. cv. Riesling during vegetative growth on three different Franconian vineyard soils and as influenced by nitrogen fertilizer. *Am. J. Enol. Vitic.* 51, 329-339.
- PONI, S., LAKSO, A. N., TURNER, J. R. & MELIOUS, R. E., 1993. The effects of pre- and post-veraison water stress on growth and physiology of potted Pinot noir grapevines at varying crop levels. *Vitis* 32, 207-214.
- POSSNER, D. R. E. & KLIEWER, W. M., 1985. The localisation of acids, sugars, potassium and calcium in developing grape berries. *Vitis* 24, 229-240.

- ROGIERS, S. Y., KELLER, M., HOLZAPFEL, B. P. & VIRGONA, J. M., 2000. Accumulation of potassium and calcium by ripening berries on field vines of *Vitis vinifera* (L.) cv. Shiraz. *Aust. J. of Grape and Wine Res.* 6, 240-243.
- ROGIERS, S. Y., SMITH, J. A., WHITE, R., KELLER, M., HOLZAPFEL, B. P. & VIRGONA, J. M., 2001. Vascular function in berries of *Vitis vinifera* (L.) cv. Shiraz. *Aust. J. of Grape and Wine Res.* 7, 47-51.
- ROJAS-LARA, B. A. & MORRISON, J. C., 1989. Differential effects of shading fruit or foliage on the development and composition of grape berries. *Vitis* 28, 199-208.
- RUBUCCI, B., PONI, S., INTRIERI, C., MAGNANINI, E. & LAKSO, A. N., 1997. Effects of manipulated grape berry transpiration on post-veraison sugar accumulation. *Aust. J. of Grape and Wine Res.* 3, 57-65.
- RUFFNER, H. P., 1982. Metabolism of tartaric and malic acids in *Vitis*: A review - part A. *Vitis* 21, 245-259.
- RÜHL, E. H., 1991. Effect of potassium supply on cation uptake and distribution in grafted *Vitis champinii* and *Vitis berlandieri* x *Vitis rupestris* rootstocks. *Australian Journal of Experimental Agriculture* 31, 687-691.
- RÜHL, E. H., 1992. Effect of K supply and relative humidity on ion uptake and distribution on two grapevine rootstock varieties. *Vitis* 31, 23-33.
- RÜHL, E. H. FUDA, A. P. & TREEBY, M. T., 1992. Effect of potassium, magnesium and nitrogen supply on grape juice composition of Riesling, Chardonnay and Cabernet Sauvignon vines. *Aust. J. of Exp. Agric.* 32, 645-649.
- RUPP, D., FOX, R. & TRANKLE, L., 2002. Foliar application of magnesium fertilizer in grapevines: effects on wine quality. *Acta Hort.* 594, 149-155.
- SAS, 1999. SAS/STAT User's Guide, Version 8, 1<sup>st</sup> printing, Volume 2. SAS Institute Inc, SAS Campus Drive, Cary, North Carolina
- SALISBURY, F. B. & ROSS, C. W., 1985a. Absorption of Mineral Salts. In: Plant Physiology, 3<sup>d</sup> ed. Wadsworth Publishing Company, Belmont.
- SALISBURY, F. B. & ROSS, C. W., 1985b. Transport in the Phloem. In: Plant Physiology, 3<sup>d</sup> ed. Wadsworth Publishing Company, Belmont.
- SALISBURY, F. B. & ROSS, C. W., 1985c. Stress Physiology. In: Plant Physiology. 3<sup>d</sup> ed, Wadsworth Publishing Company, Belmont.
- SHAPIRO, S. S. & WILK, M. B., 1965. An analysis of variance test for normality (complete samples). *Biometrika* 52, 591-611.



- SIEGFRIED, H. P., 1993. The Malmesbury batholith and its relationship to granitic plutons in the Swartland tectonic domain. Ph. D. thesis. Univ. of Stellenbosch, Private Bag X1, Matieland, 7602.
- SIPIORA M. J. & GUTIERREZ GRANDA, M., 1998. Effects of pre-veraison irrigation cutoff and skin contact time on the composition, color, and phenolic content of young Cabernet Sauvignon wines in Spain. *Am. J. Enol. Vitic.* 29, 152-162.
- SIVILOTTI, P., BONETTO, C., PALADIN, M. & PETERLUNGER, E., 2005. Effect of soil moisture availability on Merlot: from leaf water potential to grape composition. *Am. J. Enol. Vitic.* 56, 9-18.
- SMART, R. E., 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review. *Am. J. Enol. Vitic.* 36, 230-239.
- SMART, R. E., 1987. Influence of light on composition and quality of grapes. *Acta Hort.* 206, 37-47.
- SMART, R. E., DICK, J. K., GRAVETT, I. M. & FISHER, B. M., 1990. Canopy management to improve grape yield and wine quality - Principles and practices. *S. Afr. J. Enol. Vitic.* 11, 3-17.
- SMART, R. E., ROBINSON, J. B., DUE, G. R. & BRIEN, C. J., 1985a. Canopy microclimate modifications for the cultivar Shiraz II. Effects on must and wine composition. *Vitis* 24, 119-128.
- SMART, R. E., ROBINSON, J. B., DUE, G. R. & BRIEN, C. J., 1985b. Canopy microclimate modifications for the cultivar Shiraz I. Definition of microclimate. *Vitis* 24, 17-31.
- SNEDECOR, G. W. & COCHRAN, W. G., 1967. Statistical Methods, 6<sup>th</sup> ed. The Iowa State University Press, Ames, Iowa.
- SOMASIRI, S. LEE, S. Y. & HUANG, P. M., 1971. Influence of certain pedogenic factors on potassium reserves of selected Canadian prairie soils. *Soil Sci. Soc. Am. J.* 53, 500.
- SOMERS, T. C., 1977. A connection between potassium levels in the harvest and relative quality in Australian red wines. Proc. OIV Symp. Qual. Vint. Cape Town, 143 - 150.
- SPARKS, D. L., 1987. Potassium dynamics in soils. *Advances in Soil Science* 6, 1-63.
- STOREY, R., 1987. Potassium localization in the grape berry pericarp by energy-dispersive X-ray microanalysis. *Am. J. Enol. Vitic.* 38, 301-309.
- SWANTON, B. A. & KLIEWER, W. M., 1989. Characterizing potassium uptake and accumulation by grape rootstocks: the xylem potassium approximation. *Journal of plant nutrition* 12, 145-158.

- SWIETLIK, D. & FAUST, M., 1984. Foliar Nutrition of Fruit Crops. *Horticultural Reviews*, Vol. 6, 287-355.
- TAGLIAVINI, M., ZAVALLONI, C., ROMBOLA, A. D., QUARTIERI, M., MALAGUTI, D., MAZZANTI, F., MILLARD, F. & MARANGONI, B., 2000. Mineral nutrient partitioning to fruits of deciduous trees. *Acta Hort.* 512
- THE NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE, 1990. Handbook of Standard Soil Testing Methods for Advisory Purposes. Soil Science Society of South Africa, Pretoria.
- THOMAS, G. W. & HIPPEL, B. W., 1968. Soil Factors Affecting Potassium Availability. In V. J. Kilmer, S. E. Younts & N. C. Brady (eds). *The Role of Potassium in Agriculture*. Am. Soc. Agron. Madison, Wis.
- TISDALE, S. L., NELSON, W. L. & BEATON, J. D., 1980. Soil and Fertilizer Potassium. In: *Soil Fertility and Fertilizers*. 4<sup>th</sup> edition, Macmillan.
- TROMP, J., 1980. Mineral Absorption and Distribution in Young Apple Trees under Various Environmental Conditions. In: J. Atkinson, J. E. Jackson, R. O. Sharples & W. M. Waller (eds.). *Mineral Nutrition of Fruit Trees*. Butterworths.
- VAN SCHALKWYK, D., 2004. Metodes om korrelmassa, korrelvolume en trosmassa te bepaal. *Wynland* Sept., 111-112.
- WALKER, R. R., CLINGELEFFER, P. R., KERRIDGE, G. H., RÜHL, E. H., NICHOLAS, P. R. & BLACKMORE, D. H., 1998. Effects of the rootstock Ramsey (*Vitis champini*) on ion and organic acid composition of grapes and wine, and on wine spectral characteristics. *Aust. J. of Grape and Wine Res.* 4, 100-110.
- WANG, Z. P., DELOIRE, A., CARBONNEAU, A., FEDERSPIEL, B. & LOPEZ, F., 2003. Study of sugar phloem unloading in ripening grape berries under water stress conditions. *J. Int. Sci. Vigne Vin* 37, 213-222.
- WILLIAMS, L. E. & BISCAY, P. J., 1991. Partitioning of dry weight, nitrogen and potassium in Cabernet Sauvignon grapevines from anthesis until harvest. *Am. J. Enol. Vitic.* 42, 113-117.
- WINKLER, A. J., 1962. Development and Composition of Grapes. In: *General Viticulture*. University of California Press, Berkeley 4.
- WOOLDRIDGE, J., 1985. The potassium supplying power of orchard soils of the Western Cape. Potassium Symp. Potassium Symp. Organising Committee, Pretoria. 55-61.



- WOOLDRIDGE, J., 1988. The potassium supplying power of certain virgin upland soils of the Western Cape. M. Sc. thesis. Univ. of Stellenbosch, Private Bag X1, Matieland, 7602.
- WOOLDRIDGE, J. & BEUKES, H., 2005. Radiant solar energy interception in the Western Cape. *Wineland* February, 66-68.
- ZABALLA, O., GRACÍA-ESCUADERO, E., CHAVARRI, J B., MEDRANO, H. & ARROYO, M. C., 1997. Influence of vine irrigation on potassium nutrition. *Acta Hort.* 448, 219-224.
- ZEEMAN, A. S. & ARCHER, E., 1981. Stokontwikkeling, Wintersnoei en Somerbehandelings. In: J. Burger & J. Deist (eds.). *Wingerdbou in Suid-Afrika*. VORI, Private Bag X5026, Stellenbosch, 7599.

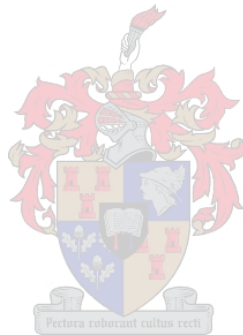


## APPENDIX A

**Table A1. Climatic variables recorded Boland Agricultural School**

**Fig. A1 & A2. Base saturation of soils at Kersfontein and Meerlus**

**Fig. A3a&b. Graphs showing the relationship between exchangeable divalent cations and vine plant material at pea-size for Cabernet franc, Meerlus, Paardeberg**



## APPENDIX B

**ANOVA tables for all analyses**



**Table A1. Climate variables recorded at the Boland Agriculture High School, situated 20km from Meerlus and 30km from Kersfontein, for the 1998/1999 to 2000/2001 growing seasons.**

<b>HLS Boland</b>	1998	1998	1999	1999	1999	1999	2000	2000	2000	2000	2001	2001
Agter Paarl	Nov	Des	Jan	Feb	Nov	Des	Jan	Feb	Nov	Des	Jan	Feb
Maximum temperature (°C)	25.3	29.1	31.0	31.4	26.8	31.7	30.6	30.7	26.7	27.8	29.3	31.9
Minimum temperature (°C)	13.4	16.6	17.3	18.2	14.0	18.8	18.6	17.5	14.5	14.6	16.4	18.0
Daily mean temperature (°C)	19.4	22.9	24.2	24.8	20.4	25.3	24.6	24.1	20.6	21.2	22.9	24.9
Total rainfall (mm)	55.5	24.5	1	1	21.5	6	10.5	0	33	9.5	11.5	8
Average evaporation (mm)	7.6	8.9	8.4	8.2	7.3	9.4	9.8	8.5	8.2	9.1	10.1	11.1
Wind (km)	149.7	166.7	158.7	158.6	153.9	149.2	183.8	159.7	134.0	160.4	155.5	167.6
Maximum humidity (%)	84.1	81.3	80.8	74.8	82.1	76.2	68.0	78.0	84.0	85.2	79.6	75.9
Minimum humidity (%)	38.9	37.5	35.8	34.5	36.3	33.7	31.3	34.1	41.7	37.0	37.6	32.8
Total rainfall Aug-Feb (mm)	164				278				178			
Total rainfall Nov-Feb (mm)	82				38				62			
Total evaporation Nov-Feb (mm)	33				35				38.5			
<b>HLS Boland</b>	<b>Long term averages (30yrs)</b>											
Agter Paarl	<b>Nov</b>	<b>Des</b>	<b>Jan</b>	<b>Feb</b>								
Daily mean temperature (°C)	20.0	21.5	22.9	23.6								
Rainfall (mm)	19.7	19.0	10.7	11.4								
Evaporation (mm)	8.4	9.5	10.0	9.5								
Wind (km)	193.1	197.2	195.8	192.2								
Maximum humidity (%)	79.0	79.1	79.4	77.6								
Minimum humidity (%)	32.5	33.0	32.4	32.2								
Total average rainfall Nov-Feb	60.8 mm											
Total average evaporation Nov-Feb	37.4 mm											

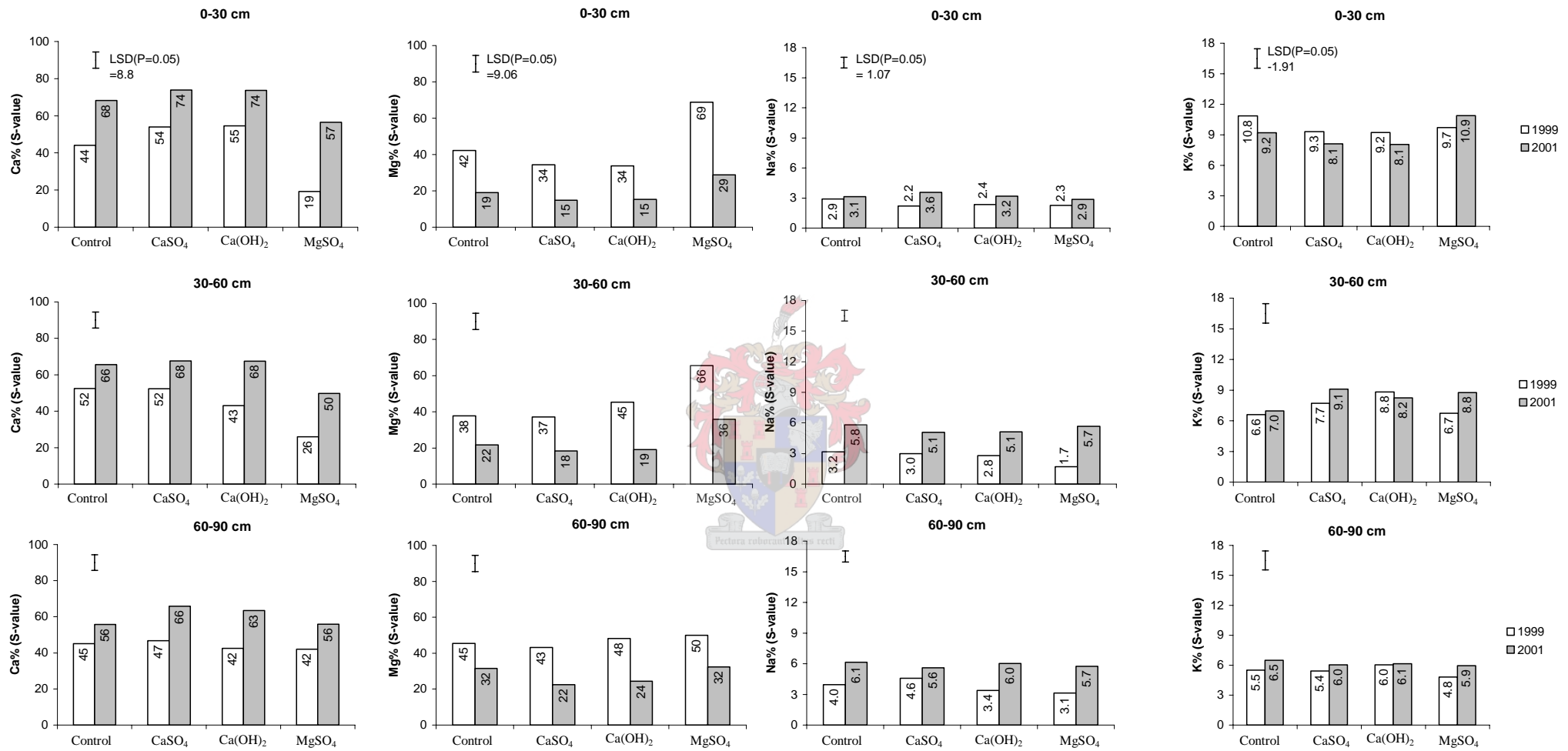


Fig. A1. Changes in cation content for Kersfontein after fertilizer application in 1998, cation changes expressed as a percentage of the S-value (LSD values valid for treatment effects across years and depths for a cation specie)

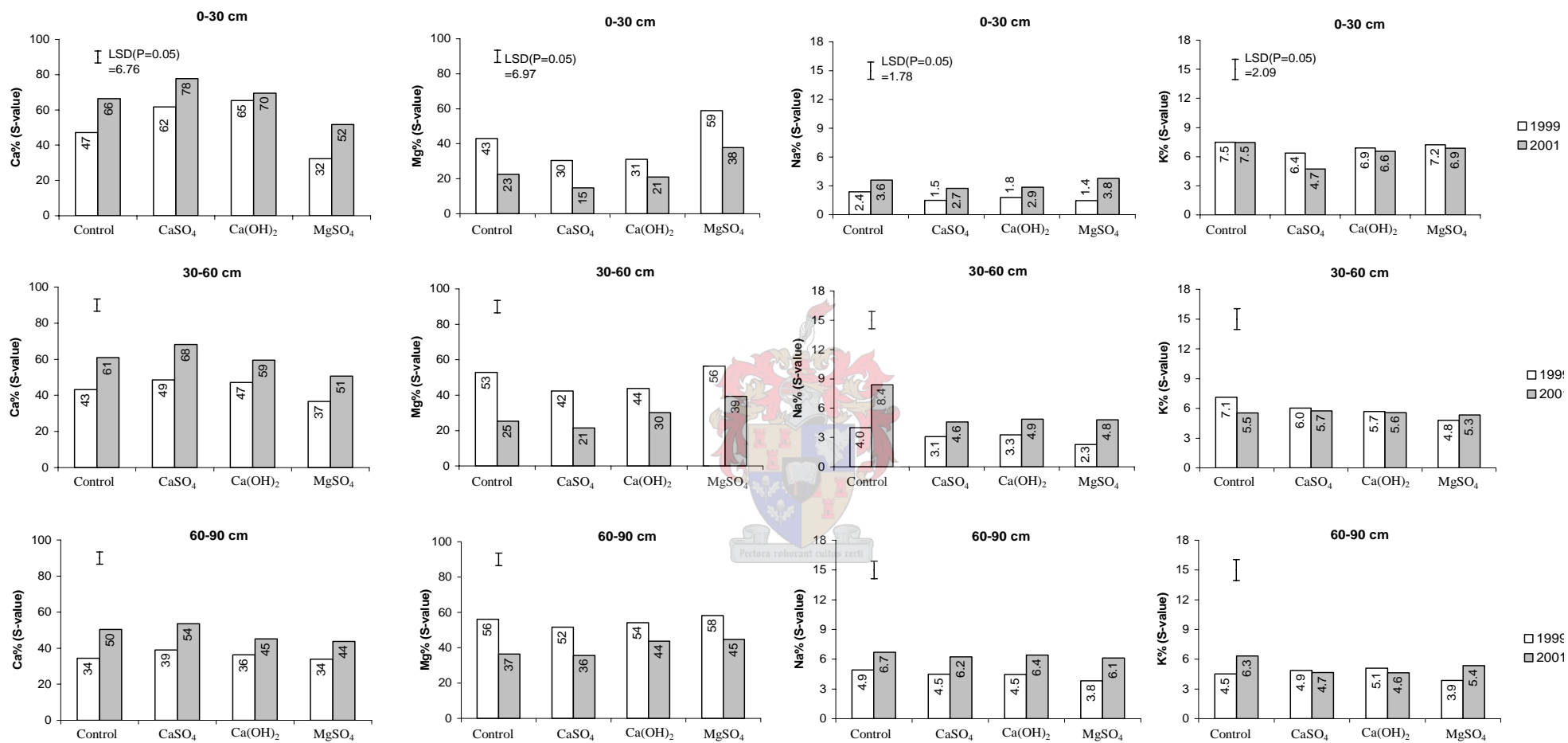


Fig. A2. Changes in cation content for Meerlus after fertilizer application in 1998, cation changes expressed as a percentage of the S-value (LSD values valid for treatment effects across years and depths for a cation specie)

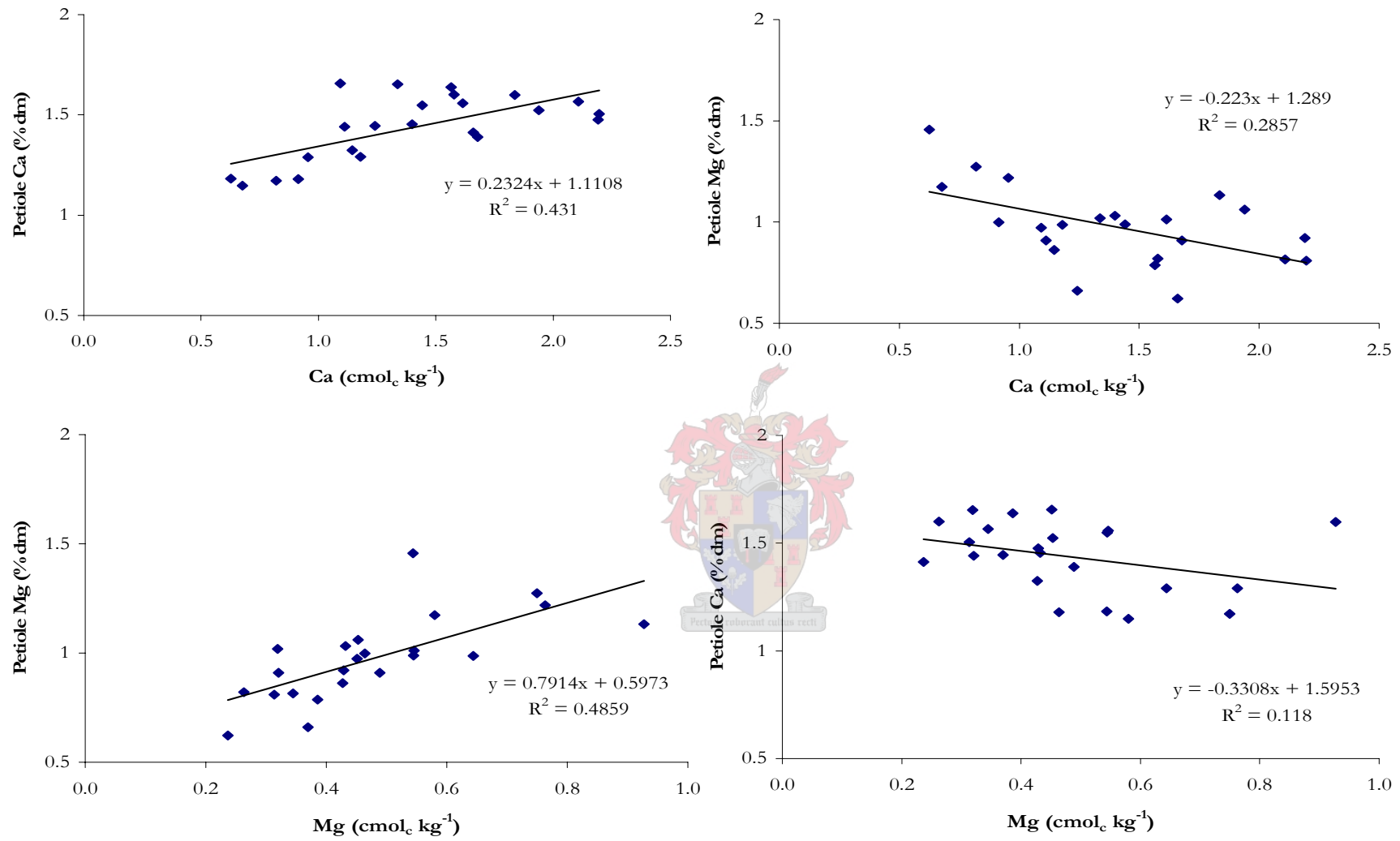


Fig A3 (a). The influence of soil Ca and Mg content on the Ca and Mg composition of Cabernet franc/99R petioles samples at pea-size, 2000/01, Meerlus, Paardeberg

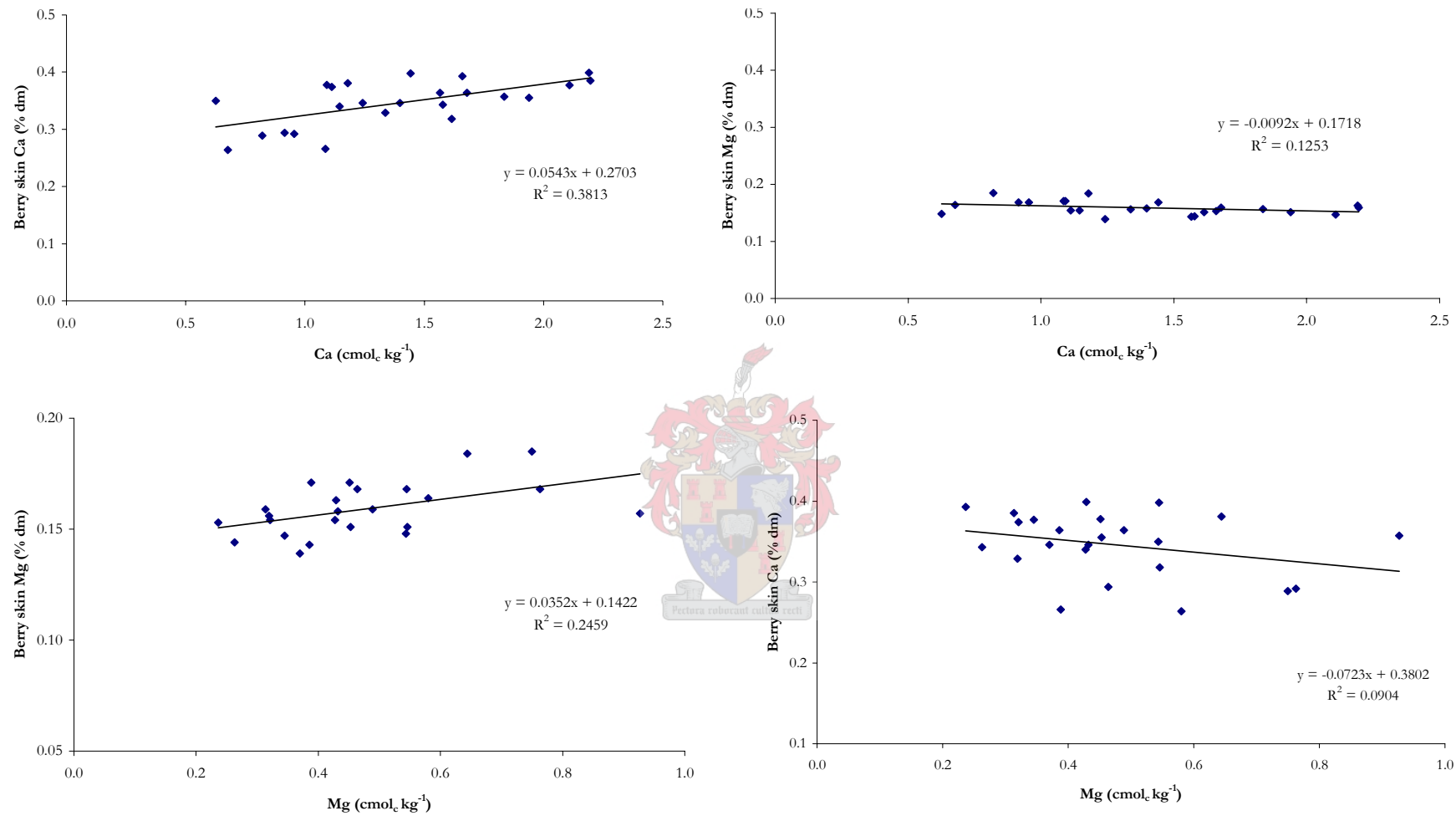


Fig A3 (b). The influence of soil Ca and Mg content on the Ca and Mg composition of Cabernet franc/99R berry skin samples at pea-size, 2000/01, Meerlus, Paardeberg





