

Grapevine cation and anion transfer: a perspective from the soil to wine chemical and sensory properties

by

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Declaration

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Summary

Soil salinity and sodicity occurs mostly in arid and semiarid environments. Saline soils contain high concentrations of soluble salts like sodium chloride (NaCl) in the solum or regolith of the soil. Sodic soils are defined as having a high concentration of sodium ions compared to other cations on the soil particle surface. Grapevines are known to be moderately sensitive to salinity. Both soil salinity and sodicity have an adverse effect on plant growth, whether directly or indirectly. Soil salinity and sodicity have a deleterious effect on the grapevine's physiological responses, including yield reduction, decrease in shoot growth and increase in cation and anion concentrations in the fruit and final wine, and may also affect the biochemical pathways, consequently leading to toxicities, deficiencies and mineral imbalances in the grapevine. The most important cations associated with salinity are Na^+ , Ca^{2+} and Mg^{2+} , whereas the most important anions are Cl^- , SO_4^{2-} and HCO_3^- . These ions may occur naturally in the soil, however they are more commonly added to the soil through irrigation or may be exacerbated through persistent droughts. Cation and anion analysis in the leaves, the petioles and grape components is essential for the prevention of the negating effects these cations and anions have on grapevine physiology, the grape juice, the final wine product and the export feasibility. The OIV (Oeno 6/91) resolution in regard to sodium states that "When wine contains excess sodium (excess sodium is equal to the content of sodium ions less the content of chloride ions expressed as sodium), it is generally less than 60 mg/L, a limit which may be exceeded in exceptional cases...". The limit in South Africa is 100 mg/L Na content. As a result of these restrictions, some wines are rejected from the export market. High concentrations NaCl also has an effect on the sensorial quality of wine, and may as a result be described as flat, dull, soap, seawater-like and saline.

In this study, soil salinity and sodicity occurrences were investigated on two farms, Farm A Chenin blanc and Farm B Chenin blanc and Pinotage in the Paardeberg area. These plots were divided into 'high' and 'low vigour' according to salinity and sodicity levels. Soil analysis was conducted at three depths to confirm the presence of high cation and anion concentrations in the soil. Meso-climate loggers were installed on both farms in order to analyse the climatic effects on the grapevine. Vegetative and reproductive measurements were conducted including trunk circumference measurements, shoot measurements, destructive leaf area measurements, berry sampling and harvest measurements. Investigations were also conducted on the effects of high cation and anion concentrations in the soil, different grapevine parts (leaves, petioles and canes), grape berry parts (juice, homogenised, skin and sediment) and in the subsequent wines. In addition to this, the effects of these cation and anion concentrations on grapevine growth, wine composition and the sensorial

profile of the wines were also determined. The study aimed to provide insight into the positive and negative aspects of possible soil cation and anion transfer to the grapevine, grape juice and wine.

Soil samples confirmed the presence of salinity/sodicity in the plots. This had an adverse effect on the growth as well as yield per vine. Shoot, petiole and leaf analysis showed high concentrations of sodium, reaching values greater than 1500 mg/kg. The juice cation and anion analysis showed high levels of sodium for some plots, however chloride levels in the leaves, petioles, grape juice and wines were found to be below harmful limits. There were differences between juice, sediment, skin and homogenised sample analysis, confirming that the sediment contained the highest cation and anion content. Descriptive sensory analysis showed no significant differences in terms of their saltiness, however some wines exhibited significant differences between aroma and taste descriptors. The high salt content in the wine may have had a positive effect on the taste of the wine. At low salt concentrations wines may appear to be sweeter, or less bitter.

This study showed that high saline or sodic soils had an effect on the grapevine growth, specifically the trunk circumference, shoot growth and leaf area. The different cation and anion concentrations found in the shoots, leaves and petioles showed that some cations and anions were translocated from the soil to the grapevine parts. The grape juice obtained from the grapes also showed high levels of certain cations, however the juice sediment analysis exhibited the highest concentrations of cations compared to the skins, the homogenised and juice samples. The sensory analysis showed that at certain concentrations, wine aroma and taste could be affected positively or negatively, however this was dependent on the concentrations of the cation and anions.

Opsomming

Grond met hoë vlakke wit- of swartbrak kom hoofsaaklik in droë en halfdor omgewings voor. Brak gronde bevat hoë konsentrasies oplosbare soute soos natriumchloried (NaCl) in die solum of regoliet van die grond. Gronde met swartbrak is gronde met 'n hoë konsentrasie natriumione in vergelyking met ander katione op die oppervlak van die grondpartikels. Wingerde is daarvoor bekend dat hulle matig gevoelig is vir brak. Beide wit- of swartbrak het 'n nadelige effek op plantegroei, hetsy direk of indirek. Brak grond het ook 'n skadelike effek op die wingerdstok se fisiologiese response, insluitend 'n afname in opbrengs, 'n afname in lootgroei en 'n toename in kation- en anioonkonsentrasies in die vrugte en die finale wyn, en kan ook die biochemiese paaie affekteer en gevolglik lei tot oormaat, tekorte en mineraal wanbalanse in die wingerdstok. Die belangrikste katione wat verband hou met brak is Na^+ , Ca^{2+} en Mg^{2+} , terwyl die belangrikste anione Cl^- , SO_4^{2-} en HCO_3^- is. Hierdie ione kan natuurlik in die grond voorkom, hoewel hulle meer algemeen by die grond gevoeg word deur besproeiing of vererger kan word deur aanhoudende droogte. Kation- en anioon-analises van die blare, die blaarstele en die druifkomponente is noodsaaklik vir die voorkoming van die negatiewe effekte van hierdie katione en anione op wingerdstokfisiologie, die druiwesap, die finale wynproduk en die moontlikheid vir uitvoer. Die OIV (Oeno 6/91) resoluie met betrekking tot natrium sê dat wanneer wyn 'n oormaat natrium bevat ('n oormaat is gelyk aan die inhoud van natrium-ione minus die inhoud van chloried-ione uitgedruk as natrium), dit gewoonlik minder is as 60 mg/L, 'n perk wat in buitengewone omstandige oorskry mag word. Die perk in Suid-Afrika is 100 mg/L Na^+ inhoud. As gevolg van hierdie perke word sekere wyne op die uitvoermark afgekeur. Hoë NaCl konsentrasies het 'n effek op die sensoriese kwaliteit van wyn en kan veroorsaak dat die wyn as pap, eentonig, seepagtig, seewateragtig en sout beskryf word.

In hierdie studie is voorvalle van wit- en swartbrak in die grond op twee plase in die Paardeberg-omgewing ondersoek – Plaas A se Chenin blanc en Plaas B se Chenin blanc en Pinotage. Hierdie liggings is verdeel in 'hoë' en 'lae groeikrag' op grond van die vlakke van brak waargeneem. Grondanalises is op drie dieptes gedoen om die teenwoordigheid van hoë konsentrasies van katione en anione in die grond te bevestig. Meso-klimaat sensors is op albei plase geïnstalleer om die klimaatseffekte op die wingerdstokke te analiseer. Vegetatiewe en reprodktiewe metings is geneem, insluitend stam-omtrek, lootmetings, destruktiewe blaaroppervlakmetings, monsters van korrels en oesmetings. Ondersoeke is ook gedoen na die effekte van hoë kation- en anioonkonsentrasies in die grond, in verskillende dele van die stok (blare, blaarstele en winterlote), in dele van die druiwekorrel (sap, gehomogeniseer, dop en afsaksel) en in die gevolglike wyne. Daarbenewens is die effekte van hierdie kation- en anioonkonsentrasies op wingerdgroei, wysamestelling en die sensoriese profiel van die wyne bepaal. Die doel van die studie was om

insig te verskaf in die positiewe en negatiewe aspekte van die moontlike oordrag van katione en anione vanuit die grond na die wingerdstok, druiwesap en wyn.

Grondmonsters het die teenwoordigheid van sout/natrium in die persele bevestig. Dit het 'n nadelige effek op die groei sowel as opbrengs per stok gehad. Loot-, blaarsteel- en blaar-analises het hoë konsentrasies natrium aangedui, met vlakke van tot hoër as 1 500 mg/kg. Die analise van katione en anione in die sap het hoë vlakke natrium vir sommige persele getoon, hoewel die vlakke in die blare, blaarstele, druiwesap en wyne gevind is om onder skadelike perke te wees. Daar was verskille tussen die analises van die sap, sediment, dop en gehomogeniseerde monsters, wat bevestig het dat die sediment die hoogste inhoud van katione en anione bevat het. Beskrywende sensoriese analise het egter geen noemenswaardige verskille in terme van hulle southeid getoon nie, hoewel sommige wyne aansienlike verskille tussen aroma- en smaakbeskrywers vertoon het. Die hoë soutgehalte van die wyn het moontlik 'n positiewe effek op die smaak daarvan gehad. Teen lae soutkonsentrasies kan wyn soeter, of ten minste minder bitter, voorkom.

Hierdie studie het getoon dat gronde met hoë vlakke van sout of sout-natrium brakheid 'n effek het op wingerdgroei, veral op stamontrek, lootgroei en blaaroppervlak. Die verskillende kation- en anioonkonsentrasies in die lote, blare en blaarstele het gewys dat sommige katione en anione vanaf die grond na die wingerddele vervoer is. Die sap afkomstig van die druive het ook hoë vlakke van sekere katione getoon, hoewel die afsaksel-analises die hoogste konsentrasies van katione in vergelyking met die doppe, en die gehomogeniseerde en sapmonsters vertoon het. Die sensoriese analises het getoon dat, by sekere konsentrasies, wynaroma en -smaak positief of negatief beïnvloed kon word, maar dit was afhanklik van die konsentrasies katione en anione.

This thesis is dedicated to my dad, Stefan Muller, my mom, Liza Muller, and my sister Stephani Muller for all their guidance, support and love.

Biographical sketch

Katharina Muller was born in Welkom, Free State on 16 January 1991, and lived in various countries thereafter. By moving from Germany to Windhoek, Johannesburg and then Western Australia, Katharina developed, through an interest in travel, a varied and nuanced palate in wine and food. As a result she determined to pursue this interest by completing her first vintage at Groot Constantia, which solidified a creative passion and strong pursuit in winemaking. Finally, she settled in Stellenbosch to begin her formal graduate studies. As part of her degree she worked at Almenkerk Wine Estate, to pursue an interest in cool climate viticultural practices and winemaking. Katharina completed her BScAgric in Viticulture and Oenology in 2014 at the University of Stellenbosch and forthwith began her MScAgric in Viticulture in 2015.

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Preface

This thesis is presented as a compilation of four chapters. Each chapter is introduced separately and is written according to the style of the journal South African Journal of Oenology and Viticulture.

Chapter 1 **General Introduction and project aims**

Chapter 2 **Literature review**

Impact of soil degradation on grapevine functioning, grape and wine composition and quality perception of the final wine.

Chapter 3 **Research results**

An assessment of selected cations and anions from the soil to the wine, including wine sensory effects.

Chapter 4 **General discussion and conclusions**

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List of abbreviations

ABA	Abscisic acid
ADP	Adenosine diphosphate
ATP	Adenosine-5'- triphosphate
CEC	Cation exchange capacity
DAB	Days after budburst
EC _e	Electrical conductivity of the saturated extract
EM38	Proximal sensor for electromagnetic induction measurements
ESP	Exchangeable sodium percentage
GDD	Growing degree days
GLASOD	Global Assessment of Soil Deterioration
GST	Growing season temperature
HI	Heliothermic index
MFT	Mean February temperature
MLF	Malolactic fermentation
NDVI	Normalized Differences Vegetation Index
OC	Organic carbon
OIV	L'Organisation Internationale de la Vigne et du Vin
PCA	Principle Component Analysis
ppm	Parts per million
RuBP	Ribulose-1,5-biphosphate
ROS	Reactive oxygen
SASEV	South African Society for Enology and Viticulture
SAR	Sodium adsorption ratio
TA	Titrateable acidity
TSS	Total soluble solids
UNCED	United Nations Conference on Environment & Development
VA	Volatile acidity
VSP	Vertical shoot positioning

Chapter 1

Introduction and project aims

CHAPTER I: INTRODUCTION AND PROJECT AIMS

1.1 Introduction

Land degradation, which includes occurrences of soil salinity, sodicity, acidity and erosion, has decreased land viability and quality. These occurrences are caused by a number of natural processes. However, human activity has accelerated these developments. Salinity occurs due to high amounts of salt in the soil, and may occur naturally, which is usually referred to as primary salinity. It may also be induced through human activities, which is then termed secondary salinity. High salinity may dehydrate the plant cells of the grapevine and the dissolved salts decrease the osmotic potential of the soil water. This leads to the grapevine not being able to extract water from the soil, which could potentially decrease plant growth and cause death. Sodic soils contain high amounts of sodium (Na) ions, rather than Na salts, as in the case of salinity. These soils usually have poor structure and water permeability (Fitzpatrick, 2002). Conditions such as these have been found to negatively impact the grapevine's physiological responses and biochemical pathways, which result in toxicities, deficiencies and various changes in the mineral balances of a vine (Shani *et al.*, 2005). Grapevines are known to be moderately tolerant to salt stress, however scion and rootstock cultivars play an important role in the different resistance thresholds (Garcia & Charbaji, 1993). In South Africa, problems with salinity and sodicity are often found in semi-arid regions (Myburgh & Howell, 2014). Occurrences of salinity and sodicity have increased in South Africa mainly due to persistent droughts and the use of contaminated irrigation water on crops (Van Rensburg *et al.*, 2011).

Reasons for decreasing salinity in soils are not only linked to the grapevine itself but also to subsequent wine made from these vines grown on the saline soil. Firstly, it has unfavourable consequences on fermentation due to the sensitive nature of yeasts to osmotic stress (Logothetis *et al.*, 2010). Furthermore, there are a number of negative effects associated with excessive Na intake including high blood pressure leading to cardiovascular disease, gastric cancer, decreased bone density and some reports suggest that it may even lead to obesity (Liem *et al.*, 2011). Due to these negative effects on human health (Martínez-Ballesta *et al.*, 2010), Na concentrations in South African wines are not allowed to exceed 100 mg/L (Department of Water Affairs & Forestry, 1996). The L'Organisation Internationale de la Vigne et du Vin (OIV) recommends that wine excess Na should be less than 60 mg/L. However, limitations such as these may have adverse effects in terms of competitive export markets. In Australia, for example, the Na content in wine may not exceed 1000 mg/L as the country has a high occurrence of saline and sodic soils. Consequently, export markets such as South Africa may be negatively affected by these restrictions, particularly for oncoming years, as droughts are reportedly increasing in length and severity (Ngaka, 2012).

High salt concentrations in food and wine could have important sensorial implications, both negative and positive. Low salt concentrations may have a positive influence on the sensorial properties of wine. Salts such as sodium chloride (NaCl) reportedly increase saltiness, but also curb bitterness and increase the perception of sweetness at certain concentrations (Liem *et al.*, 2011). De Loryn *et al.* (2014) noted that red wine made from grapevines grown in saline conditions showed positive sensory characteristics compared to the less salty control wines. However, high concentrations ranging from 0.5 g/L to 1.0 g/L NaCl, have shown that soapy, salty and less fruit expression were common attributes associated with the increased NaCl concentrations.

1.2 Background to the project

According to the South African wine industry, problems experienced with high salt concentration wines are seen as not being too extensive and serious. Of greater concern is the number of incidences where disparities have occurred between analyses done at different laboratories in the industry as well as at the university. In some cases, the results reported the various laboratories differed by as much as 8%, which has had an impact on the quality of wines being exported. The OIV resolution (Oeno 6/91) states: "When wine contains excess sodium (excess sodium is equal to the content of sodium ions less the content of chloride ions expressed as sodium), it is generally less than 60 mg/L, a limit which may be exceeded in exceptional cases. The laboratories and official control agencies, confronted with elevated levels of chloride (Cl) and/or Na, must take the above conclusions into account and possibly make inquiries to the official agencies of the country of origin before expelling these wines."

Recent analysis of small scale wines made from saline sections of a particular farm confirmed Na levels five times the OIV recommended limit, and three times the recommended levels according to the South African guidelines. Previous analysis of commercially available wines also showed levels ranging between 30 mg/L and 60 mg/L sodium. The analysis of both Na and Cl is not seen as general practice in order to determine the free Na, both locally and internationally. Another important aspect is that when cation and anion analysis is done, using the best analytical practices, the measurement errors have been recorded to be from 0.2% to 10%, which still falls within acceptable error norms. This however can lead to some wines being rejected in the export and import markets. Therefore, when wines are analysed for export or import purposes, these measurement errors, methods used in analysis, laboratory accreditation, etc. should be taken into account when legal limits are set.

This project will not only deal with the negative aspects of high salt contents, with regards to the grapevine growth and yield, but also the problems occurring during winemaking, such as delayed fermentations. However, the positive contributions that the elevated salt levels may have on wine

itself, with regards to flavour, mouth feel and subsequent aftertaste of the wine will also be dealt with. The following aims have been proposed:

1.3 Project Aims

The aims of this study were:

1.3.1 Main viticultural aim

To determine if the cations and anions are translocated into the grapevine, and subsequent concentrations in the leaves and bunches will also be determined, as well as examining the effects of the different saline or sodic concentrations on grapevine growth and vigour

Objectives:

1. Choose specific sites that have problems with salinity and sodicity;
2. Locations of translocated anions and cations taken up by the grapevines (*i.e.* the leaves, petioles bunches *etc.*) and
3. The effect of the cation and anion content on the vine itself, *i.e.* vine growth, yield *etc.*

Hypothesis:

H_0 = Different saline or sodic levels in the soil will affect the translocation of cations and anions into the grapevine and subsequent concentrations in the plant parts.

H_1 = The translocation of cations and anions in the grapevine grown under saline or sodic soils will not show significant differences compared to vines grown on non- saline or non- sodic soils.

1.3.2 Main oenological aim:

To determine if the cations and anions found in the berries translates into the final wine product.

Objectives:

1. Identify the differences in ionic concentrations in juice and subsequent wine made from this juice and
2. Identify where the Highest concentration of cations and anions are in berry itself (*i.e.* juice, skin, combination).

Hypothesis:

H_0 = The cation and anion concentrations found in berries (juice, skins, etc.) translate into the final wine product.

H_1 = The cation and anion concentrations in the berries (juice, skins, etc.) do not translate into the final wine product.

1.3.3 Main sensory aim:

To determine if these cations and anions have an effect on the sensorial profile of the wine and if a trained tasting panel can detect differences between the increasing saline concentrations.

Objectives:

1. Identifying the sensorial difference between wine with high ionic content versus low ion concentration and
2. Determine if the elevated Na and Cl levels are advantageous or disadvantageous at different concentrations.

Hypothesis:

H_0 = the high ionic content wines show different sensorial attributes compared to the low ionic content wine, and are advantageous to the wine, dependent on concentrations.

H_1 = the high ionic content wines show no difference in sensorial attributes compared to the low ionic content wine, and are disadvantageous to the wine, dependent on concentrations.

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Chapter 2

Literature review

Impact of soil degradation on grapevine functioning, grape and wine composition and quality perception of the final wine

CHAPTER II: IMPACT OF SOIL DEGRADATION ON GRAPEVINE FUNCTIONING, GRAPE AND WINE COMPOSITION AND QUALITY PERCEPTION OF THE FINAL WINE

2.1 Introduction

The impact of viticultural and environmental parameters on wine quality is a widely discussed topic (Jackson & Lombard, 1993). Soil, climate and the grapevine cultivar fall under the concept of *terroir*, where it was described by Carey (2001), as “a complex of natural environmental factors, which cannot easily be modified by the producer. These complex factors will be expressed in the final product, with the aid of various management decisions, resulting in distinctive wines with an identifiable origin. Therefore the *terroir* cannot be viewed in isolation from management and cultivation practices, although such practices do not form part of the intrinsic definition”. Maintaining and managing important environmental factors such as soil and climate, are critical for sustainable wine grape production (Van Leeuwen & Seguin, 2006).

Land degradation is the systematic decline in land and soil quality which leads to temporary or permanent decline in the land's productivity. It includes occurrences of salinity, sodicity, acidity and erosion in the soil that may lead to desertification (Fitzpatrick, 2002). Although these occurrences are caused by a number of natural processes, human activity has accelerated it. Soil salinity is caused by high amounts of salts such as sodium and chloride present in the soil, which may occur naturally in which case it is referred to as primary salinity, or it may be induced through human activities and then termed secondary salinity (Mullins *et al.*, 1992; Fitzpatrick, 2002; Podmore, 2009). Dissolved salts increase the osmotic potential of the soil water, therefore high salinity may induce dehydration of the grapevine's plant cells. The increase in osmotic potential in the soil water leads to the grapevine not being able to extract water from the soil, which potentially decreases plant growth and may cause vine death (Chaves *et al.*, 2009). Sodic soils contain high amounts of sodium ions, rather than sodium salts, and these soils usually have poor structure and water permeability (Fitzpatrick, 2002). Conditions such as these have been found to negatively impact the grapevine's physiological responses and biochemical pathways, which result in toxicities, deficiencies and various changes in the mineral balances of a vine (Fisarakis *et al.*, 2001; Shani & Ben-Gal, 2005). Grapevines are known to be moderately tolerant to salt stress, however scion and rootstock cultivars play an important role in the different resistance thresholds (Mullins *et al.*, 1992; Garcia & Charbaji, 1993). In South Africa, problems with salinity and sodicity are often found in semi-arid regions (Myburgh & Howell, 2014). Its occurrence have increased in South Africa mainly due to persistent droughts and the use of contaminated irrigation water on crops (Kirchner *et al.*, 1997; de Clercq *et al.*, 2011; Van Rensburg *et al.*, 2011).

The rationale behind aiming for decreased salinity in soils are not only linked to the grapevine itself but also to subsequent wine made from the grapevines grown on saline soil (Leske *et al.*, 1997). Firstly, it has unfavourable consequences on fermentation due to the sensitive nature of yeast with regards to osmotic stress (Logothetis *et al.*, 2010). Furthermore, there are a number of negative effects associated with excessive human sodium intake, including high blood pressure leading to cardiovascular disease, gastric cancer, decreased bone density and some reports suggest that it may even lead to obesity (Liem *et al.*, 2011). Due to these negative effects on human health (Martínez-Ballesta *et al.*, 2010), wine sodium (Na) concentrations in South Africa are not allowed to exceed 100 mg/L according to the Department of Water Affairs and Forestry (1996) (Gong *et al.*, 2010). The L'Organisation Internationale de la Vigne et du Vin (OIV) recommends that the free wine Na should be less than 60 mg/L. However, limitations such as these may have adverse effects in terms of competitive export markets. In Australia, for example, the sodium content may not exceed 1000 mg/L in wine as the country has a high occurrence of saline and sodic soils (Leske *et al.*, 1997). Consequently, export markets such as South Africa may be negatively affected by these restrictions, particularly in oncoming years, as droughts are reportedly increasing in length and severity (Ngaka, 2012).

High salt concentrations in food and wine could have important wine sensory implications, both negative and positive, *i.e.* low salt concentrations may have a positive effect on the sensorial properties of wine (Liem *et al.*, 2011; de Loryn *et al.*, 2014). Salts such as sodium chloride reportedly increase saltiness, but also curb bitterness and increase the perception of sweetness at certain concentrations (Liem *et al.*, 2011). De Loryn *et al.* (2014) noted that red wine made from grapevines grown in saline conditions showed positive sensory characteristics compared to the less salty control wines. However, high concentrations ranging from 500 mg/L to 1000 mg/L NaCl have shown that soapy, salty and less fruit expression were common attributes associated with increased NaCl concentrations.

2.2 The concept of terroir

2.2.1 Definition

Whilst the French term, terroir, has many varying definitions, Barham (2003) referred to terroir as being “an area or terrain, usually rather small, whose soil and microclimate impart distinctive qualities to food products”. According to the OIV/VITI 333/2010 “Vitivicultural “terroir” is a concept which refers to an area in which collective knowledge of the interactions between the identifiable physical and biological environment and applied vitivicultural practices develops, providing distinctive characteristics for the products originating from this area. “Terroir” includes specific soil, topography, climate, landscape characteristics and biodiversity features”. Viticulture terroir has been described by Morlat (as cited in Carey, 2005), as being divided into two distinct groups; natural factors such as

climate (rainfall, temperature, relative humidity, etc.), geology, soil (structure, texture, chemical and physical attributes), and human factors, such as viticultural and oenological practices. Therefore, as a viticulturist, it is integral to understand the effect of natural and human terroir factors on the subsequent wine, in order to optimise and maintain wine quality.

2.2.2 Geology

Factors such as climate, vegetation and time through geological processes have shaped the landscape and raw materials to form soil (Gladstone, 1992). Soil formation or pedology is as a result of changes that have occurred over time to the soil parent material through different climatic and environmental changes (Wilson, 1998; White, 2003). Wilson (1998) noted that the nature and formation of soils are affected by certain factors including: rock weathering (consolidated rocks such as granite or basalt, or unconsolidated material that has been transported), water from rain, snow or water from underground sources as well as plants and animal effects. White (2003) showed that parent material, environment, organisms and duration play a key role in soil formation. Soil formation can, however, also be affected by human activity, such as old settlements (White, 2003). Weathering of rock can occur physically, where factors such as water, ice, heat, roots or gravity can cause cracks to form, which results in multiple surfaces being presented for another type of weathering to occur; chemical. Chemical weathering is very slow process and occurs due to organic acids being secreted by plants growing on the new rock surfaces, as a result of adequate air and moisture (Wilson, 1998).

Perold (1927) stated that the agricultural suitability of soils is not only dependent on the weathering rock, but the mother rock *i.e.* parent material as well as the conditions in which formation took place, play a large role in soil formation. Soil can rest on the mother rock, *in situ* or residual, or it can be moved by forces such as wind or water (aeolian or alluvial). There are different rock types, including consolidated rocks which are of igneous, sedimentary or metamorphic in origin. Igneous rocks can be subdivided into two broad groups based on their mineral composition: acidic rocks, which comprise of granite and rhyolite, and basic rocks, which include basalt and gabbro (White, 2003).

In South African arid regions soils formed from granite are usually coarse sand, which in humid regions for example in the Western Cape give rise to good agricultural soils with soils being fairly coarse and gravelly in texture, still in contact with the mother rock, *i. e.* decomposed granite. Granite mainly comprises of three minerals including quartz, feldspar and mica. Mica minerals reportedly are the first to decompose and are the origin of iron compounds which give some decomposed granite soils their yellow or red colour. Clay material gives the decomposed granite soils their blue-black colour. Feldspars are the following minerals to decompose and include potash feldspar, orthoclase and microcline. These are gradually decomposed into clay and potassium salts which are then absorbed into the soil. These soils are rich in potash but have a low lime content, therefore lime additions are required for vineyard establishment. Basalt weathers fairly quickly, and do not contain

quartz, but do contain iron, calcium, sodium, potassium, magnesium, aluminium, silica, etc. These soils are usually red, brown or dark in colour, and are quite rich in lime. Other geological formations in South Africa include Malmesbury shale, Table Mountain sandstone and the Bokkeveld beds (Perold, 1927).

According to Conradie *et al.* (2002), geology can indirectly determine wine typicity, as well as wine quality. Pomerol (1989) noted that wines made in Chablis on the Kimmeridgian limestone and marl were recognised as making better and more famous wines than the wines made from vineyards grown on the Portlandian limestone. Another example, seen in Van Leeuwen & Seguin (2007) showed a different side, where some of the best wines are produced on Oligocene Asteries limestone in Saint-Emilion. However, wines produced from grapevines grown on the same rock type in Entre-Deux-Mers region were of inferior wine quality, which implies a dominant effect of climate over soil.

2.2.3 Soil

Soil and climate are difficult to separate as they affect one another, however soil plays a vital role in the grapevine development and subsequent wine quality (Gladstone, 1992; Lanyon *et al.*, 2004; Witbooi, 2008). The effect of soil on grapevine physiology, grape composition and wine quality is complex because, as Mouton (2006) suggests, certain soil characteristics such as soil depth, soil texture and structure, soil water status, soil colour, soil temperature, as well as soil chemistry and soil pH are vital for root growth, water uptake and nutrient absorption by the vine.

Grapevines are known to grow in a wide range of soils, however Winkler *et al.* (1962) reported that heavy clays, very shallow soils, poorly drained soils, and soil containing high levels of salt from the alkali metals, boron or any other toxic substances should be avoided for vineyard establishment. High salt concentrations in the soil solution will decrease available water, thereby having a negative effect on the plant as a whole (Warrence *et al.*, 2002). Wang *et al.* (2015) suggested that grapevines grown on soils showing high permeability with large diurnal temperature differences, under the same environmental conditions, tend to have faster photosynthetic rates, increased berry sugar concentration and improved colour and sensory profiles. They also suggested that nutrients are easily absorbed in slightly alkaline to neutral pH soils, thereby also improving vegetative vine growth and grape quality (Xu *et al.*, 2009; Li *et al.*, 2012).

2.2.3.1 Soil physical characteristics

Soil physical properties important for all plants include soil texture, structure, depth and strength (White, 2010). According to Perold (1927), the physical characteristics, including the structure of a soil, determines the suitability to grow grapevines and the subsequent wine quality. The percentage of clay, silt and fine and coarse sand can be described as soil texture. Soil weathering or the chemical and physical breakdown of soil gives rise to a soil's texture. The soil compositional and structural

differences has an effect on the rate of weathering, therefore soil texture remains quite constant and usually does not change through vineyard management practices (McCauley *et al.*, 2005).

Soil that mostly contain clay can be described as having a heavy texture, loamy soils that have an equal amount of clay, silt and sand are considered medium textured, whereas sandy soils are light in texture, being very loose and containing low clay amounts. Clays are considered the smallest soil particles size fraction, with particles usually less than 0.002 mm in diameter. Clay particles have a large surface area compared to their size and volume, which gives them a higher capacity to combine with plant water and nutrients (Robinson, 1994). When clay is suspended in water, the clay particles can remain in colloidal suspension, especially if the exchangeable sodium is higher than 6% of the cation exchange capacity (CEC). Silt particle sizes usually vary between 0.002 and 0.02 mm in diameter. The small size of the silt particles makes it possible for the particles to be carried long distances by wind and water sources in their colloidal form, which makes them prominent in alluvial soil. Sand particles can be divided into fine or coarse sand particles depending on their size, 0.02 to 0.2 mm for fine sand and 0.2 to 2 mm in diameter for coarse sand. In contrast to clay particles, the sand particle surface area is small, making the combination with water and nutrients lower in probability (Robinson, 1994). However sandy soils can withstand higher salinity irrigation water compared to clay soils, as the salts in sandy soils will be leached beneath the root zone (Warrence *et al.*, 2002). According to Warrence *et al.* (2002) clays are also more prone to dispersion than silt and sandy soils. As a result, more salt, including Na, will accumulate in the clay soils compared to silt or sandy soils. Soil texture and -porosity also affect water and air movement, subsequently affecting the grapevine's ability to take up water, as well as its growth. The percentage of pores filled with water and air fluctuates as the soil wets and dries (White, 2010). This makes soil texture one of the most important factors in plant growth and the soil's physical state.

White (2010) defined soil structure as "the aggregation of primary soil particles to form a physical framework, or in terms of the spaces between and inside the aggregates (the pore space or porosity)". Soil aggregation plays an important role in enhancing stability against soil erosion, maintaining soil porosity and water movement, as well as increasing soil fertility and soil carbon sequestration (McCauley, 2005). High Na concentrations in the soil solution will promote clay particle aggregation as well cause soil dispersion. This dispersion of clay particles causes the soil pores to be plugged and as a result the soil will reform and solidify into an almost cement-like soil when repeatedly dried and wetted. The loss of structure as a result of elevated Na concentrations leads to a reduced hydraulic conductivity and water movement in the soil (Warrence *et al.*, 2002).

Soil structure plays a vital role on soil water infiltration, water retention, drainage, aeration and plant root penetration, where the effects are due to the stability of the aggregates as well as the pore space properties (Gardner *et al.*, 1999). Maintaining topsoil structure is important for water infiltration and to

lessen the possibility of erosion occurring. Reportedly where cover crops, mulches and compost are implemented in between the rows, the topsoil structure improves. Subsoil structure is less dependent on the organic matter and more dependent on the soil texture, clay type, as well as iron and aluminium oxides. Poorly structured subsoils will hamper root growth, and due to the decrease in the rate of drainage, may also lead to waterlogged conditions. Concerns have been raised about the negative effects of the increased levels of salts in the topsoil and subsoils, leading to saline or sodic soils (White, 2005), this will be discussed later.

Soil depth is also an important physical soil parameter, as it affects grapevine root penetration and water uptake abilities. Poor nutrient availability makes lateral and vertical root penetration very important for vine health. The soil type can also have an effect on the relative root growth of the vine. 'Duplex' soils have clear textural divisions between the topsoil and the subsoil, where the sudden change in texture can have an adverse effect on vine root growth. Duplex soil forms not only have a negative impact on root growth but also water storage and -availability. Water storage and -availability is dependent on the soil physical characteristics, however there are factors that may inhibit water uptake by the vine, such as surface crusting, which is caused by elevated Na concentrations in the soil, compaction, and the sudden change in the soil texture in the subsoil, *i.e.* in duplex soil forms (Ball *et al.*, 1997). Root distribution is strongly affected by the distribution of water in the soil. Other factors also affected by water uptake and availability include yield, grape quality, both directly and indirectly. Indirectly these effects are seen via vegetative growth, whereas the direct effects include leaf water potential, turgor, translocation of organic and inorganic substances as well as photosynthesis (Lanyon, 2004).

Other important soil physical parameters include soil temperature, which is vital as it regulates the activity of most soil organisms, which are not able to regulate their own body temperature. A change in the soil temperature may have an impact on the soil ecosystem. Soil strength is another physical parameter which is the ability of the soil to resist loss of structure through compaction, slaking which is induced by rainfall and irrigation, as well as to resist plant root penetration and burrowing soil fauna. According to Oliver *et al.* (2013), a soil with good physical properties should be strong enough to maintain soil structure and keep plants upright, but weak enough to allow for root penetration. Soil strength is dependent on the soil water content as well as soil physical attributes.

Infiltration and water availability in the soil are other soil physical parameters that are vital to soil health and quality. Clogged soil pores can be caused by dispersed clay particles in the soil solution when they settle out of solution, as a result of high Na concentrations. As these particles settle, a nearly structureless cement-like soil may form, making establishment and growth for plants difficult. This disruption of the hydraulic properties of the soil may impede water infiltration, *i.e.* less plant available

water especially in the deeper soil depths. Other consequences such as runoff and soil erosion may be exacerbated (Warrence *et al.*, 2002).

2.2.3.2 Soil chemical characteristics

Soil organic carbon status, nutrient availability and the soil pH play a vital role in the chemical status of the soil (McCauley, 2009). The primary function of soil in regards to its chemical characteristics is to provide nutrients for crop growth. The organic matter content of the soil is important because of the association with nutrients like nitrogen, phosphorous and sulphur, as well the beneficial contributions it makes to the physical, chemical and biological state of the soil. Nutrients are released into the soil in the plant available forms by the decomposition of organic materials by microorganisms, and the proportion of nutrients is dependent on the composition of the compounds being decomposed (Bot & Benites, 2005). The soil carbon content also affects the CEC, soil structure maintenance, as well as decreasing the content of readily dispersible clay (Dexter, 2002; White, 2010; Oliver *et al.*, 2013). The levels of organic carbon matter in soil and their subsequent effects on the soil are shown in Table 1.

Table 1: Concentrations of soil organic carbon for soil quality assessment (Oliver *et al.*, 2013).

Level of organic matter (% or g/100 g)	Rating	Interpretation
<0.40	Extremely low	Subsoils or severely eroded, highly degraded surface soils
0.40–0.59	Moderately low	Very poor structural condition, very low structural stability
0.60–0.99	Low	Poor-to-moderate structural condition, low-to-moderate structural stability
1.00–1.59	Moderate	Increasing soil OC level results in improved structural stability, increased pH buffering capacity, increased soil nutrient level (especially N), increased water-holding capacity
1.60–1.99	High	Good structural condition, high structural stability, high pH buffering capacity, high soil nutrient level (especially N), high water-holding capacity
2.00–2.99	Very high	Very good structural condition, high structural stability, high pH buffering capacity, high soil nutrient levels (especially N), high water-holding capacity
3.00–8.70	Extremely high	Soils often dark coloured and greasy to touch with large amounts of organic material, soils usually associated with undisturbed woodlands and forested areas
>8.70	Organic soil material	Highly organic soil including peat

Organic acids, which are part of the soil organic carbon content, play an integral role in making minerals available to plants. The soil is also buffered from large pH changes. The FAO (2016) reported that not only is the soil organic carbon important for general soil health and is part of the carbon cycle, it is also vital for the moderation of climate change effects.

According to Osman (2013) soils contain more than 100 chemical elements, however only a few are considered important. Soils contain 16 nutrients that play a key role in plant growth and living organisms. These can be divided into macro- and micronutrients, where the macronutrients include carbon (C), oxygen (O) hydrogen (H), nitrogen (N), phosphorous (P), potassium (K), calcium (Ca),

magnesium (Mg), sulphur (S) (FAO, 2016). These macronutrients make up the bulk mass, making them essential for plant development. Soil nitrogen is seen as the most important element obtained by plants from the soil, and if not readily available it can impede plant growth. Nitrogen is used by plants in the cation ammonium for (NH_4^+) or the anion nitrate (NO_3^-) forms. Micronutrients are still needed, however in smaller amounts, and include nutrients such as iron (Fe), zinc (Zn), manganese (Mn), boron, (B), copper (Cu), molybdenum (Mo) and chlorine (Cl) (Osman, 2013). Soil nutrition can be modified using fertilizer, however the effectiveness at which these fertilizers function is determined by timing, placement, vine rooting pattern, irrigation and rainfall, as well the soil physical, chemical and biological properties (Lanyon, 2004; Oliver *et al.*, 2013). Table 2 shows the suggested soil nutrient and chemical levels for grape production.

Table 2: Suggested soil nutrient and chemical (in mg/kg) levels for wine grape production (Lanyon, 2004; Raath, 2016).

Nutrient	Deficient	Marginal	Adequate	High	Toxic
$\text{NO}_3\text{-N}$	<1	1-2	2-10	>10	-
K	<50	50-100	100-250	>250	-
Ca				360-500	
Mg				40-120	
P	<25	25-35	35-80	>70	-
Cu	<0.1	0.1-0.2	0.2-0.4	>0.4	>2
Zn	<0.5	0.5-1	1-2	2-20	>20
Mn	-	<2	2-4	-	-
Fe	-	-	>4.5	-	-
Al	-	-	-	-	>100
B	<0.1	-	0.2-1.0	-	>3.0
S	<10	-	-	-	-

B K, P – Colwell bicarbonate extractable, Cu, Zn, Mn, Fe - DPTA extractable, Al – ammonium chloride extract, B - hot water extract

Soil pH, another important chemical property, is key to making each nutrient available for plant uptake. However Seguin (1986) reported that quality wines can also be produced on acidic, neutral or alkaline soil. The soil pH refers to soil's alkalinity or acidity, and is determined by the amount of hydrogen ions (H^+) ions present in the soil solution. If there are high amounts of H^+ present in the soil solution, the soil pH will be low, whereas if there are low amounts, the pH of the soil will be higher (McCauley, 2005). FAO (2016) reports that the soil pH can range from 3.5 (very acidic) to 9.5 (very alkaline). Soils with higher acidity (pH less than 5) will lead to stunted shoot and root growth, which is due to the toxic amounts of Al and Mn (Lanyon, 2004). A soil pH of more than 8 can impede the availability of N, Ca, Mg, Fe, Mn, Cu and Zn, and can sometimes also be associated with B toxicity. High pH soils can also occur on soil with exchange complexes saturated with Ca, Mg and Na (Warrence *et al.*, 2002). Figure 1 shows the relationship between soil pH and plant available nutrients.

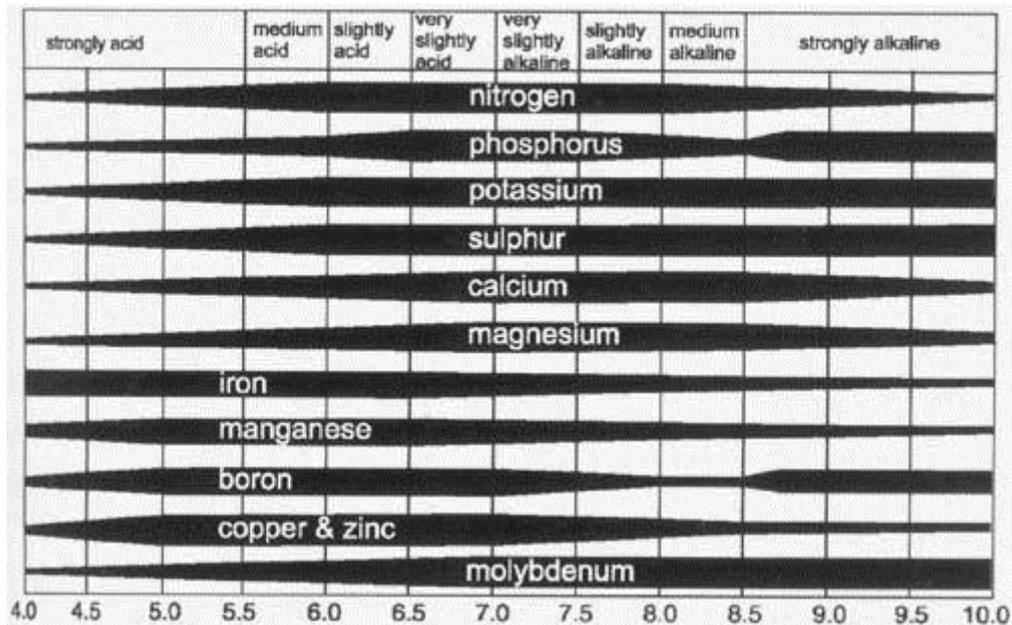


Figure 1: The effect of soil pH on the availability of nutrients in the soil (FAO, 2005).

2.3 Soil degradation: the environmental consequences

2.3.1 Definition of soil degradation

Soil degradation has become one of the most important environmental factors facing the modern world to date. Not only is the human race dependent on it for food production, it also plays an essential role in producing feed, fibre as well as renewable energy. Alongside the world's complex terrestrial ecosystem, climate is highly dependent on soil and the condition thereof (Jie *et al.*, 2002). Rengasamy (2006) reported that global food production will need to be increased by 38% and 57% by 2025 and by 2050, respectively. This means that more land needs to be cultivated in order to meet the demand for food. However due to soil degradation the quality of soil is declining rapidly. The FAO (1998) reported that only 11% of the world's soils can be farmed without practices such as irrigation, drainage, as well improvement of the soil before cultivation (Table 3).

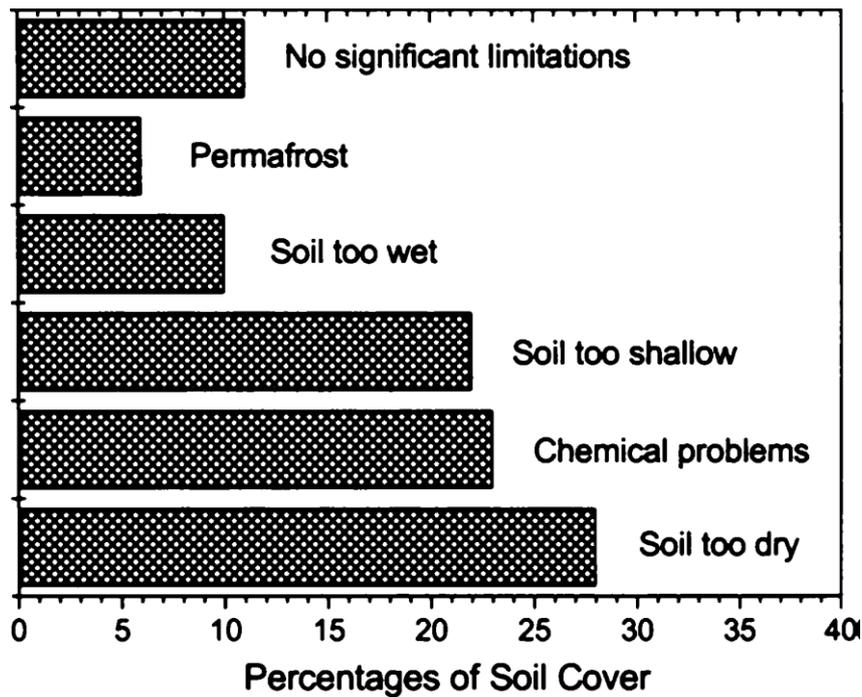


Figure 2: Percentage of soil conditions covering the world's surface.

2.3.2 Causes of soil degradation

The driving force of soil degradation can be divided into three facets, namely soil vulnerability to degradation, physical environmental changes and human activity. The initial state of the soil is an aspect that determines the vulnerability of the soil. This includes factors such as pedogenetic characteristics, the influxes of soil material and the relative age of the soil. Factors such as the chemical, physical mineralogical and biological changes determine the soils' vulnerability. Environmental changes that bring about soil and land degradation include processes such as global warming, drought, sea-level variation, earth processes like geomorphological evolution, volcanic activity and the natural leaching of soils (Jie *et al.*, 2002). Figure 3 shows the different soil degradation types and the regions where they occur.

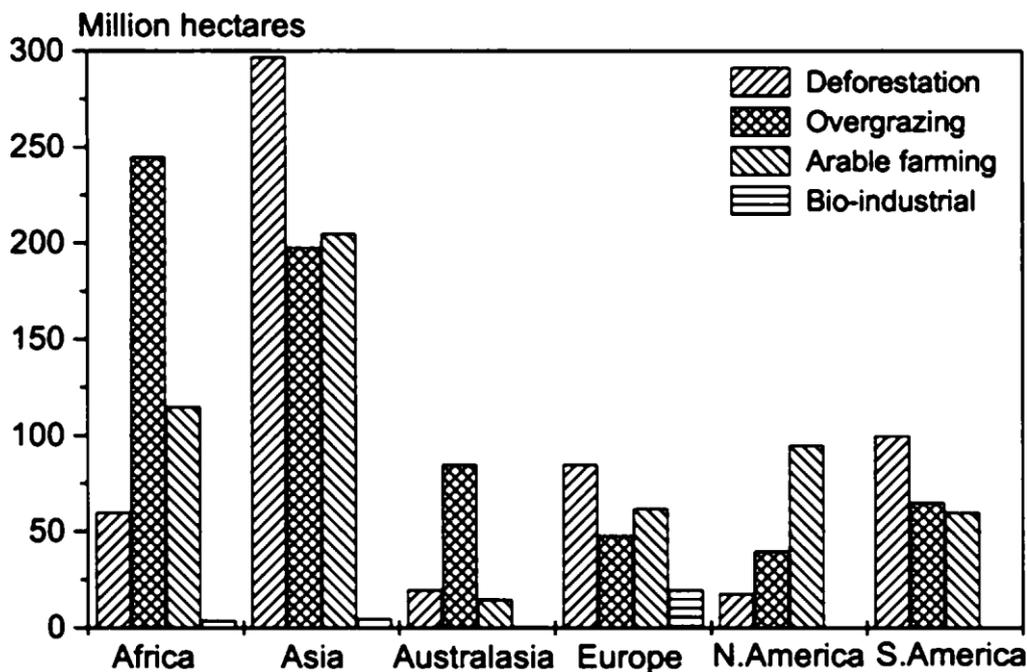


Figure 3: The main causes of soil and land degradation divided into regions (FAO, 1997).

Although soil degradation is considered a natural process, human activity has worsened the problem throughout the years. There are three phases that have been linked to land degradation; namely natural degradation, induced degradation and desertification. Natural degradation is usually slower because soil formation and soil degradation generally occur in a steady state. Induced degradation occurs when human activities such as responsible land use and management are neglected. This type of degradation occurs faster than natural degradation, and even though soil quality declines, production of land is still viable if correct soil management is implemented. Desertification occurs when the degree of soil degradation is such, that the productivity of the land is permanently impaired. This usually leads to the abandonment of the land as it becomes economically unsustainable (Fitzpatrick, 2002).

2.3.3 Soil degradation types

Land degradation can be divided into processes such as acidification, decrease in soil organic matter, decline in soil fertility, erosion with emphasis on compaction and hard setting of the soil, biological factors such as changes in the quality and quantity of biomass and biota, and soil pollution (Jie *et al.*, 2002). Table 3 shows the different types of soil degradation with subtypes included.

Table 3: Soil degradation types according to GLASOD (Global Assessment of Soil Deterioration) (Jie *et al.*, 2002).

Type	Subtype
Water erosion	<ul style="list-style-type: none"> • Loss of topsoil • Terrain deformation/mass movement • Off-site effects: <ul style="list-style-type: none"> ○ Reservoir sedimentation ○ Flooding ○ Coral reef and seaweed destruction
Wind erosion	<ul style="list-style-type: none"> • Loss of topsoil • Terrain deformation • Over-blowing
Chemical deterioration	<ul style="list-style-type: none"> • Loss of nutrients or organic matter • Salinization • Acidification • Pollution • Acid sulphate soils • Eutrophication
Physical deterioration	<ul style="list-style-type: none"> • Compaction, sealing and crusting • Water-logging • Lowering of water table • Subsidence of organic soils • Other physical activities such as mining and urbanisation
Degradation of biological activity	

The most important types of soil degradation that will be discussed in this literature review are: salinity, sodicity, erosion, acidification and desertification of soils.

2.3.3.1 Salinity

Saline soils usually contain high amounts of soluble salts such as sodium chloride (NaCl) in soil solum or regolith that may have adverse effect on plant production (Rengasamy, 2006). Occasionally these soils occur naturally, then referred to as primary salinity. However, human activities such as irrigation and land clearing may also cause salinisation of the soil and this form of salinity is referred to as secondary salinity (de Clercq *et al.*, 2011; Fitzpatrick, 2002). Primary and secondary salinity are known to impede plant growth by causing dehydration of the plant.

The salts in saline soils come from a variety of sources in the landscape including cyclic salt from ocean spray, aeolian and wind-borne salt from ocean spray and sedimentary deposits, which include dune sand and clay particles deposited into rivers or dams, as well as connate or fossil salt in marine sediments where water may have been at an earlier time.

Saline soils form under various conditions and therefore have miscellaneous morphological, chemical, physical and biological properties. According to Fitzpatrick (2002), 'there is no universally accepted definition of soil salinity', however the diverse scientific factions have their own definition and type of measurement necessary for their work. Hydrologists distinguish between primary and secondary salinity, however plant and soil scientists use the soil electrical conductivity and the plant tolerance to saline conditions in order to classify between slightly, moderately or severely affected soils or plants.

Other scientific disciplines may use measurements of the pH, exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR) and the electrical conductivity of the saturated extract (EC_e) to classify saline soils (Fitzpatrick, 2002).

Soils are accepted as being saline when the EC_e is more than 4 dS/m, however the negative impact it may have on plant production is dependent on several factors which include plant type, soil water management, environmental and climatic conditions (Rengasamy, 2006).

There are various forms of salinity which occur in soil and they can be subdivided into three major groups:

Primary salinity

Primary (or inherent) salinity occurs when salts leach from the soil through natural processes such as aeolian or rainfall deposition, which usually leads to an accumulation of salts in the groundwater (Fitzpatrick, 2002; Bagan *et al.*, 2015). This form of salinity is known as groundwater salinity, and occurs when water comes up from the groundwater and the salt accumulates on the topsoil. The reason for the upward movement of the salt-rich water is due to evaporation from the soil surface as well as from the plant transpiring (Rengasamy, 2006). The groundwater often has very high saline conditions, with EC_e ranging from 15 to 150 dS/m. As long as the water table remains 4 to 5 m below the soil surface, this saline water does not affect the natural vegetation (Fitzpatrick, 2002; Rengasamy, 2002). Surface salt deposits usually occur where the water table is close to the soil surface, mainly due to the rising groundwater. The water evaporates from the soil surface, leaving a thin salt deposit layer. The formation of the salt deposit layer is dependent on rainfall, the rate of evaporation from the soil surface, as well as the vegetation cover (Podmore, 2009). An illustration of a groundwater system with various topographic conditions can be seen in Figure 4.

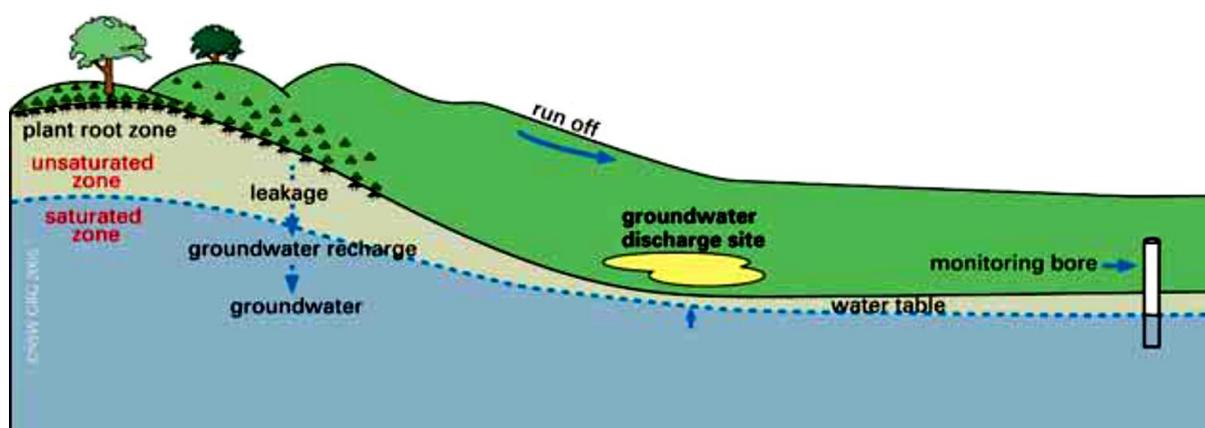


Figure 4: The groundwater system with differing topography (Podmore, 2009).

Salts that are stored in the regolith may have accumulated from the natural deposition by rainfall and oceanic wind near coastal regions. Additionally, the weathering of rocks when soil formation occurred

and the leaching of salts trapped in the natural sediments of the rock may also have led to a build-up of subsoil saline conditions (Fitzpatrick, 2002). The accumulation of salts is dependent on geology, landscape, climate (temperature, precipitation, rate of evaporation, and the spatial and temporal variability) and vegetation (Bullock & Houérou, 1996).

Secondary salinity

Secondary salinisation of the soil is mostly due to human activity such as urbanisation and agriculture (Podmore, 2009; Bugar *et al.*, 2015). Secondary salinisation occurs when agricultural crops replace natural vegetation, and the drainage of the soil is improved causing the groundwater to rise (Fitzpatrick, 2002). Consequently, the saline groundwater infiltrates the topsoil, and in low-lying areas or near riverbeds may cause salinisation of the river. Due to modern day agriculture, irrigation has become a necessity especially in regions where rainfall does not occur in abundance. In South Africa, the average rainfall is 480 mm, which makes it necessary for most agricultural production areas to irrigate. However, Stander (1987) reported that between the 1960s and 1980s, the quality of the water used for irrigation dropped. It was also reported that during the 1970s and 1980s, elevated salinity levels were attributed to irrigation water. The development of irrigation schemes by the government has improved the problem of irrigation with saline water, however mismanagement occurring on farms still occurs (Van Rensburg *et al.*, 2011).

Seepage salinity

Seepage salinity may occur in deeper saline groundwater tables through capillary rise on silt loam soils. This process of capillary rise allows groundwater to be drawn into the dry soil above the water table, resulting in a net mass flow of salt in solution to the upper soil layers, thereby making it available for plants to take up (Fitzpatrick 2002; Podmore, 2009).

The EC_e is normally used as it is the fastest method to assess the salinity of the soil. The method is based on electrical currents that are transmitted between two electrodes change when they come into contact with soluble salts. Both Siemens per meter (S/m) and deciSiemens (dS/m) are used as basic SI units for electrical conductivity (Tavakkoli, 2011). Various instruments are used in field to measure soil salinity including non-invasive electromagnetic induction instruments like the EM38 scanner and data logger, and Invasive Electromagnetic Induction instruments (Rhoades *et al.*, 1999).

2.3.3.2 Sodic soils

Sodic soils contain large amounts of sodium ions relative to the other cations in the soil solution. A soil is considered sodic when the concentration of sodium ions affects the structure of the soil (Fitzpatrick, 2002). Clay dispersion can occur because sodium is known to separate clay layers when it comes into contact with water. Soils in South Africa are considered sodic when the exchangeable

sodium percentage (ESP) is 15% or more, EC_e is less than 4 dS/m and the pH is more than 8.5 (De Villiers *et al.*, 2003).

Sodic soils usually have poor structure and low water permeability, due to various factors including hard surface setting or crusting, formation of hard and impenetrable sub-soils, which restricts water infiltration and air flow, and may cause waterlogging, eventually leading to serious gully and tunnel erosion (Slinger & Tennison, 2005; Rowling & Slinger, 2007). Hard sodic soils restrict root growth to the cracks when clay swelling and dispersion occurs and the above topsoil as movement of important nutrients, water and gases is restricted. The overall effect on plant growth is similar to salinity or drought conditions (Fitzpatrick, 2002). A high pH may occur if calcium carbonate accumulated during pedogenesis, because as Na accumulates in the soil layer, sodium bicarbonate and -carbonate are generated. This high pH may also lead to iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and phosphorous (P) deficiencies, which will also then subsequently affect plant growth (Rengasamy, 2002). Table 4 indicates properties of sodic soil compared to those of an ideal soil.

Table 4: Properties of sodic soils versus ideal soils (Rengasamy, 1997).

Properties	Sodic subsoil	Ideal soil
pH _{1:5} (water)	9.2	6.0-8.0
EC _{1:5} (dS/m)	0.2	<0.4
Organic carbon (%)	0.3	>1.0
SAR _{1:5}	9.9	<3.0
Spontaneously dispersed clay (%)	8.7	0
Hydraulic conductivity at saturation (mm/day)	4.0	>80.0
Penetrometer resistance (MPa) at 100 kPa suction	3.8	<2.0
Aeration porosity (%)	5.6	>15
Bulk density (Mg/m ³)	2.2	<1.5
Non-limiting water range (mm ³ /mm ³)	0.38-0.42	0.1-0.5

Figure 5 shows the different effects various saline, saline-sodic and sodic soils in different soil pH conditions have on the plant.

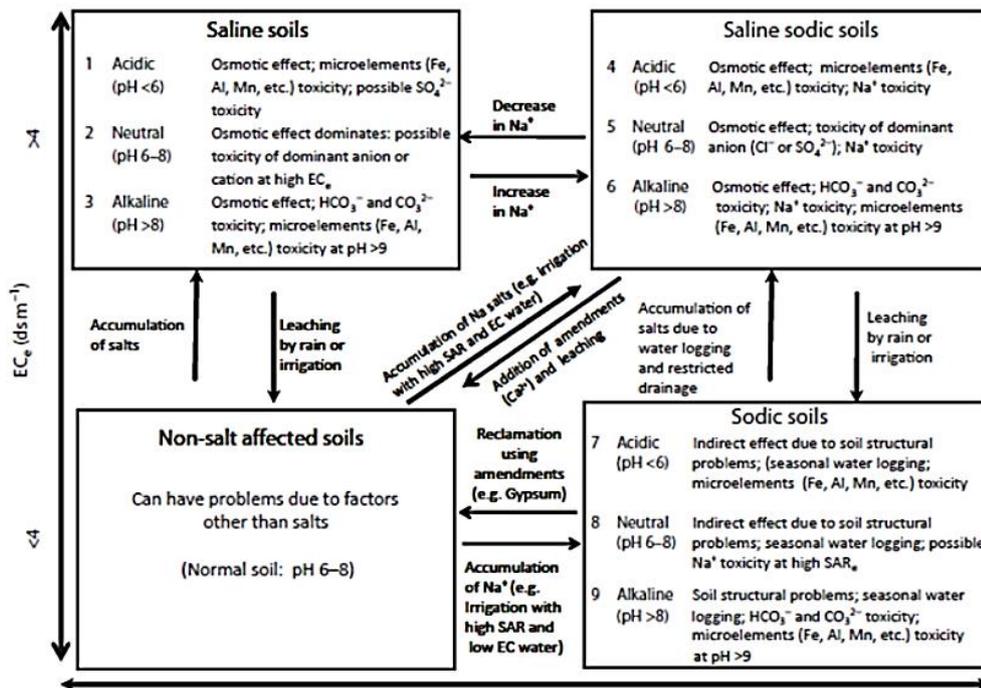


Figure 5: Salt affected soil categories that are based on the SAR and the EC measured in soil saturation extract, pH measured in soil water suspension and the effects on plants (Tavakkoli, 2011).

2.3.3.3 Soil erosion

Soil erosion is a process of detachment and transportation of soil particles by various agents such as wind or water that leads to a loss of soil (Bullock & Houérou, 1996). Soil surface losses by wind and water erosion occur globally and have negative effects of land productivity. Although soil erosion is a natural process, human activity has accelerated the process. The reduction of soil quality due to erosion has led to the decline of the natural, agricultural and forest ecosystems, but has damaged the diversity of plant, animals and microbes (Fitzpatrick, 2002).

Wind and water energy are the main causative agents of soil erosion, however, in South Africa, water erosion is the dominant causative agent. When water hits the bare soil surface in an unconcentrated flow (sheet erosion) and concentrated flow (gully or rill erosion), it can easily dislodge soil particles from the soil surface and remove a thin soil layer (Le Roux *et al.*, 2008). This type of erosion occurs the most frequently and is one of the main forms of soil degradation in South Africa (Pimentel, 2006). Wind erosion occurs when wind transports soil particles by suspension, surface creep or saltation over varying distances, from a few centimetres to kilometres (Bullock & Houérou, 1996).

Factors that affect soil erosion include:

- I. Rainfall [the amount, frequency, duration and intensity determine the degree of erosion (Bullock & Houérou, 1996)].
- II. Wind speed [the direction, strength and frequency of the wind determine the intensity of erosion (Bullock & Houérou, 1996)].

- III. Topography (the slope of the land determines the severity of erosion, as well slope length).
- IV. Vegetative cover [when a soil is covered with dead or alive plant material, the probability of soil erosion relatively minimised, as the rain and wind energy comes into contact with the plant material before the soil surface, thereby nullifying the effect (Pimentel, 2006)].
- V. Soil structure [the soil structure determines the vulnerability of the soil to erosion. Bajracharya and Lal (1992) reported that soils with medium to fine texture, in conjunction with low organic material content and weak structure were more easily erodible than soils with stronger structure and higher organic matter content. These soils usually have low infiltration rates, thereby making them very susceptible to water erosion. Porous sandy soils, are also very susceptible to water erosion, and without the protection of vegetation and the soil stabilisation by the roots, thus susceptibility increases (Fitzpatrick, 2002)].

2.3.3.4 Soil acidification

Soil acidity impedes plant growth, which makes it an important issue in crop production in general (Schroeder *et al.*, 1994). Acidification of soils occur naturally due to the leaching with slightly acidic CO₂ rich rainfall, but it can also occur by the over application of some fertilisers, as well as in coastal areas where the drainage or oxidation of pyrite-containing soils tend to occur (Oldeman *et al.*, 1992). Fey (2001) stated that 'the hydrolytic displacement of base cations and the provision of additional acids from oxidative reactions' are the primary methods by which a soil is acidified. He also reports that sandy soils that are base-deficient, occurring in high rainfall areas with good drainage tend to acidify faster, whereas clay base-rich soils in low rainfall areas with weaker drainage acidify slower.

There are various soil properties and processes that are altered in response to acidification. Processes such as the microbial transformation of organic matter and nitrogen are inhibited. The presence of toxic elements and compounds, such as aluminium (Al), iron (Fe), manganese (Mn), nitrites and toxic organic acids, also have negative effects on plant growth and may decrease the uptake of essential macronutrients such as calcium (Ca), magnesium (Mg) and potassium (K) as well as trace elements such as boron (B) and zinc (Zn) (Fey, 2001; Jakovljević *et al.*, 2005). Fey (2001) also noted that acidification of the soil leads to the contraction of cation exchange capacity, as well as the expansion of anion exchange capacity.

2.3.3.5 Desertification

Desertification occurs when economically important agricultural land becomes less productive due to soil degradation. In extreme cases this degradation develops into a desert-like environment incapable of any agricultural production necessary for the sustainability of a community. The United Nations Conference on Environment and Development (UNCED) described desertification as: "...land degradation in arid, semiarid, and dry sub-humid areas resulting from various factors including climatic variations and human activities" (UNEP, 1992). The incidence of desertification is amplified in areas

where low rainfall, drought seasons, mobile surface deposits, skeletal soils and soil with low vegetative covering occur (Bullock & Houérou, 1996). Drought, in conjunction with land mismanagement, is the main factors in the process of desertification. Human activities such as deforestation, over cultivation of soils and overstocking have also been linked to the process of desertification. Occurrences in South Africa have been reported by Hoffman and Cowling (1990a) and Dean and McDonald (1994). Table 5 shows the extent of desertification in different world regions.

Table 5: Worldwide occurrence and extent of desertification (Bullock & Houérou, 1996).

Region	Light		Moderate		Strong		Severe	
	Area ⁽¹⁾	% ^{*(2)}	Area	%*	Area	%*	Area	%
Africa	1180	9	1272	10	707	5.0	35	0.2
Asia	1567	9	1701	10	430	3.0	5	0.1
Australasia	836	13	24	4	11	0.2	4	0.1
North America	134	2	588	8	73	0.1	0	0
South America	418	8	311	6	62	1.2	0	0
Total	4273	8	4703	9	1301	2.5	75	0.1

(1) Area is in 10 000 km

(2) 2 % of area desertified in total drylands

2.4 Grapevine growth and mineral composition

2.4.1 Mineral nutrient uptake by the grapevine

Grapevines require an adequate supply of certain nutrients; macro- and micronutrients, in order to complete certain physiological and biochemical functions (Brataševac, 2013) (Table 6). All plant-available nutrients enter the vine roots from the soil and need to be dissolved in the soil solution, which is the interface between the soil matrix and the water in the soil. The nutrient uptake is therefore dependent on water flow that occurs through the soil-root-shoot pathway, as well as the nutrient concentration of the soil solution (Brataševac, 2013). Epidermal cells and root hairs of the absorption zone of the roots are the primary entry point for nutrient uptake. Mineral nutrients can be absorbed into the vine via two mechanisms: passive and active transport. Passive transport entails the absorption of nutrients by diffusion and absorption into the root endodermis (Winkler *et al.*, 1962). According to Hylmo (1953) this mode of transport is dependent on the water absorption and transpiration rates of the vine. Hoagland (1948) however stated that the rate of ion absorption is closely correlated to the rate of respiration. The active transport of nutrients uses energy in the form of adenosine-5'-triphosphate (ATP), which is dependent on respiration and can only take place in aerobic conditions, as well as when sugars or other carbohydrates can be utilised (Winkler *et al.*, 1962; Brataševac, 2013). This mode of absorption involves ions attached to carrier molecules, where the subsequent movement results in carrier-ion complexes being moved through the root cell barriers. These complexes are then discharged into the xylem cells of the root. Ions and ion groups are selectively transported via these complexes into the root (Winkler *et al.*, 1962).

Table 6: Plant nutrients absorbed by plant, their absorption forms, the optimal pH for absorption, as well as their plant (phloem) mobility (in Brataševac, 2013).

Nutrient	Absorption form of nutrients	Optimal soil pH for assimilation	Plant (phloem) mobility
Nitrogen	NH ⁴⁺ , NO ³⁻	6.0-8.0	High
Phosphorous	HPO ₄ ²⁻ , H ₂ PO ₄ ⁻	6.5-7.5	High
Potassium	K ⁺	6.0-8.0	High
Calcium	Ca ²⁺	7.0-9.0	Low
Magnesium	Mg ²⁺	6.0-8.5	High
Sulphur	SO ₄ ²⁻	5.5-9.0	High
Iron	Fe ²⁺ , (Fe ³⁺)	3.0-6.5	Intermediate
Zinc	Zn ²⁺	3.5-7.0	Intermediate
Copper	Cu ²⁺	5.0-7.5	Intermediate
Manganese	Mn ²⁺	3.0-6.5	Low
Boron	B(OH) ₃	5.0-7.2	Intermediate
Molybdenum	MoO ₄ ⁻	6.5-9.0	Intermediate

Mineral nutrients are mostly moved into the grapevine root against the concentration gradient, where the ion's concentration is higher in the soil solution compared to in the root cells. The translocation of minerals to various plant parts therefore is also against the concentration gradient (Winkler *et al.*, 1962).

Water, mineral nutrients, carbohydrates and other materials move through the vascular system via translocation. Mineral nutrients and water are translocated to the upper parts of the plant through the roots via the xylem. The phloem is used to transport the carbohydrates, as well as their derivatives throughout the vine (Hellman, 2003).

Various environmental factors can affect the translocation of nutrients throughout the grapevine. Some of the factors include nutrients, temperature, water, light, carbon dioxide, photoperiod, as well as diurnal and seasonal changes that occur in the vineyard specifically. These factors can indirectly or directly affect the grapevine's translocational capabilities, however hormones also have an important role in regulating plant nutrient translocation through the vine (Winkler *et al.*, 1962).

2.4.2 Grapevine response to soil degradation

2.4.2.1 Soil salinity effects on grapevine

Grapevines are known to be moderately sensitive to salinity. This was defined by the Maas and Hoffman's yield response model, using the 'bent stick' model which is where the yield does not decrease unless a certain concentration threshold is reached (Prior *et al.*, 1992a; Walker *et al.*, 1997). Grapevine response to salinity, however, is dependent on several factors such as climate, soil type, rootstock-scion combination as well as irrigation system (de Clercq *et al.*, 2001; Baneh *et al.*, 2013).

The grapevine has a general response to salinity, which can be divided into two phases. Phase one is the reduction of grapevine growth by osmotic stress, whereas phase two is the reduction of growth by ionic toxicities (Munns & Termatt, 1986; Munns *et al.*, 1995; Munns & Tester, 2008; Tavakkoli, 2011). The salt concentrations, environmental conditions as well as the grapevine state play an important role in determining the transition time between phases, as well as the subsequent severity of the stress.

In phase one, the reduction in plant growth is mainly due to the osmotic effect of the salt experienced by the plant. A high soil salinity results in the loss of water from the leaf cells, however the loss is brief, due to the plants' ability to adjust the osmotic condition of the cell. Cell elongation rates are, however, reduced, which in turn has an effect on the expansion of new young leaves. Although there is a reduction in the rate of cell division and the size of the cells, the amount of the cells remains unaffected. In the ionic toxicity phase there is an accumulation of Na and Cl ions in the shoot tissue, which usually leads to early leaf fall (Tavakkoli, 2011). The effect on growth in the plant affected by high salt concentrations is determined by the rate of salt accumulation in the specific tissue as well as the tolerance of the plant itself to salt stress. In the case of the grapevine, which is moderately affected by salt stress, lateral shoot development is inhibited. Symptoms of salt stress are usually characterised by chlorosis of the older leaves, eventually leading to leaf senescence and reduced growth and lower new leaf production rate (Munns & Tester, 2008). Urdanoz and Aragüés (2009) reported that the osmotic effect on vine growth is proportional to the decrease in the osmotic potential of the soil solution.

Prior *et al.* (1992b) showed that the large yield decreases were due to the high levels of Na and Cl which had accumulated in the plant tissue. Sodium and Cl petiole analysis indicated the best relationship to yield reduction in grapevines. She also states that the maximum for chloride and sodium levels should be no more than 420 mmol.kg⁻¹ dry weight for chloride and 191 mmol.kg⁻¹ dry weight for petiole sodium concentrations. Robinson and McCarthy (1985) recommended that the petiole Na and Cl content should not exceed 217mmol.kg⁻¹ sodium dry weight and 423 mmol.kg⁻¹ chloride dry weight. Growth parameters such as pruning mass, shoot length, cane number, leaf and petiole mass were reportedly decreased by high saline conditions in the soil (Prior *et al.*, 1997b). Table 7 shows the different salinity levels according to EC_{SE} and soil texture effects on the grapevines.

The abiotic stress in the grapevine can affect various physiological processes including reduction in grape yield, shoot growth, number of bunches per vine, berries per bunch, as well as increase the Na and Cl concentrations in the fruit (Lanyon *et al.*, 2004). Sudhir and Murphy (2004) reported that salt stress leads to an increase in the rate of respiration and ion toxicities, where an excessive accumulation of Na and Cl ions leads to a decrease in the uptake of other minerals such as Ca, K and Mn. Plant growth, mineral distribution, membrane instability resulting from the displacement of

Ca by Na ions, membrane permeability and decrease in photosynthesis are also linked to salinity stressed grapevines.

Table 7: Various concentrations of salinity in the grapevine and the effects thereof (Lanyon *et al.*, 2004).

Salinity hazard	*EC _{SE} dS/m	Effects on grapevine growth	1:5 soil/water extract (dS/m)				
			<i>Loamy sand</i>	<i>Loam</i>	<i>Sandy clay loam</i>	<i>Light clay</i>	<i>Heavy clay</i>
Non-saline	< 2	Negligible effect on vine	< 0.15	< 0.17	< 0.25	< 0.30	< 0.40
Slightly saline	2 – 4	Own-rooted vines begin to be affected	0.16 – 0.30	0.18 – 0.35	0.26 – 0.45	0.31 – 0.60	0.41 – 0.80
Saline	4 – 8	Own-rooted vines severely affected but some rootstocks unaffected	0.31 – 0.60	0.36 – 0.75	0.46 – 0.90	0.61 – 1.15	0.81 – 1.60
Very saline	8 – 16	Grapevines cannot be grown successfully	0.61 – 1.20	0.76 – 1.45	0.91 – 1.75	1.16 – 2.30	1.60 - 3.20
Highly saline	> 18	All grapevines will die	> 1.20	> 1.45	> 1.75	> 2.30	> 3.20

* EC_{SE} is saturated paste electrical conductivity

A reduction in biomass caused by salinity has also been linked to reductions in transpiration. A reduction in transpiration can be attributed to salinity-induced stomatal closure, which in turn have negative effects on photosynthesis and shoot growth in the grapevine (Shani & Ben-al, 2005). Grapevines grown in saline soils tend to show significant decreases in stomatal conductance, which are as a result of osmotic stress, chloride and sodium ion toxicities. Abscisic acid accumulation in the leaves of salt stressed grapevines has been linked to reduced stomatal conductance (Pessarakli, 1996). The photosynthetic CO₂-fixation rate is also reduced by soil salinity, and is dependent on the concentration of the salts accumulated and the duration of the salt exposure. This leads to stomatal closure and a decrease in intercellular CO₂ content in the leaves. Prior *et al.* (1997b) concluded that the primary reason for yield reduction was due to the decline in photosynthesis per unit leaf area and the subsequent drop in stomatal conductance. The accumulation of toxic ions in the leaves also had a noticeable effect on the leaf area and shoot growth, which affected carbon fixation thereby having a detrimental effect on the grapevines' following seasons' photosynthetic capacity (Prior *et al.*, 1997b).

The increased formation of reactive oxygen species (ROS), as well as the activity of the enzymes responsible for the detoxification of these species, is mainly due to the reduction of photosynthesis (Munns & Tester, 2008). As photosynthesis is inhibited by high salt concentrations in the plant tissue, the absorption of light energy may be in excess, which results in ROS production and accumulation. Antioxidants are able to reduce the production of ROS, without undergoing conversions themselves, thereby slowing the rate of uncontrolled oxidation. Antioxidants include ascorbic acid, glutathione, and carotenoid pigments. Enzymes responsible for ROS signalling or the degradation pathways include superoxide dismutase, catalase, peroxiredoxins, ascorbate peroxidase and glutathione reductase (Carvalho *et al.*, 2015).

Although salt stress in the grapevine can be considered on a whole plant level, tolerance can also occur on a cellular level. The most common tolerance response in a plant is the overproduction of some various compatible organic solutes, such as carbohydrates, for instance sugars, amino acids and proteins, which act as osmolytes. Tolerance to salt stress is also dependent on the genetic variation that may occur in various grapevine genotypes. Different grapevine genotypes can tolerate salt stress by altering the internal root tissues' osmotic potential towards the outside environment. This method of salt exclusion is termed osmoregulation where the vine adjusts the water potential in its own root tissue to be at a lower level than the surrounding root substrate (Owais, 2015). Proline accumulates in large quantities in response to stress (Baneh *et al.*, 2013). Fozouni *et al.* (2012) demonstrated that proline accumulation increased significantly with increasing salinity on four hydroponically grown own-rooted table grape varieties at different salt concentrations.

2.4.2.2 Soil sodicity effects on grapevine

Sodic soils contain large amounts of Na salts, where the effect on the grapevines' physiological processes is mainly due to the adverse effects that high Na concentrations have on the soil structure (Lanyon *et al.*, 2004). Consequently, there is an adverse indirect effect on vine performance due to this poor soil structure however the direct effects on vine performance have not been fully investigated according to Lanyon *et al.* (2004).

The poor soil structure and the low permeability of sodic soils, have a negative effect on plant growth. A healthy soil allows for easy permeability of water, gases (oxygen and carbon dioxide) and solutes to and from the plant roots. Hard sodic soils occurring on the soil surface or close to the soil surface it can act as a root development barrier. This does not allow for water, gas and solute penetration into the deeper subsoil layers. This effect on plant growth is similar to symptoms caused by drought or saline conditions (Fitzpatrick, 2002). Soil structure plays an important role in determining the amount of salts percolating downward into the subsoil layers. In coarse textured soils, water will move downward faster, taking with it the salts that have accumulated on the soil surface.

Although the effects of soil structure on grapevine physiological processes is well recognised, the actual direct effects of soil sodicity on grapevine performance have not yet fully been studied, however Khanduja *et al.* (1980) and Samra (1985;1986) showed the relative response on grapevine shoot growth with increased ESP for low soil electrical conductivity.

2.4.2.3 Soil acidification effects on grapevine

Although grapevines are moderately tolerant to acid soil conditions, low pH soils are known to affect nutrient availability as well as root development (Bates *et al.*, 2002). Soil acidification occurs beneath irrigation drippers in vineyards that use urea or ammonium-based fertilisers in their irrigation systems (White, 2015). Soil fertility is affected by a low soil pH, due to it influencing the solubility of metal ions, such as aluminium (Al), manganese (Mn), Fe, copper (Cu), zinc (Zn) and molybdenum (Mo). Other effects include the supply of important nutrient cations and anions, as well as changes occurring in the microbe environment surrounding the grapevine roots (Oliver *et al.*, 2013).

Nutrient deficiencies of the base cations such as calcium (Ca), magnesium (Mg) and K, as well as phosphorous deficiencies occur due to acidic soils. According to Oliver *et al.* (2013), at pH_{Ca} less than 5, Al and Mn become more soluble, where Al^{3+} and $AlOH^{2+}$ become phytotoxic to the grapevine. When pH_w levels are below 5, vine shoot and root growth are detrimentally affected, and at a pH_w of below 4.5, root and shoot growth cease (Oliver *et al.*, 2013; Robinson *et al.*, 2013). This is due to the inhibition of cell division in the root apical meristem. Excessive hydrogen ions in the soil solution affects the root cell membrane potential, however the pH itself does not affect root growth. As the pH decreases from 5 to 3.5, Al solubility increases, which has an effect on nutrient availability and root

growth. This 'free' Al, precipitates phosphorous (P), making P, as well as Ca and Mg unavailable to the grapevine (Bates *et al.*, 2002).

2.4.3 Effect of land degradation on mineral nutrients in the grapevine

2.4.3.1 Sodium

Sodium is not considered an essential element in vine nutrition, however it may play an important role in grape production (Winkler *et al.*, 1962; Galet, 2000). Some beneficial effects of Na in the grapevine, may include lowering of high acidity, however this method is not used often because other elements usually meet these needs more aptly (Winkler *et al.*, 1962). Galet (2000) describes that under normal conditions the grapevine contains relatively small amounts of Na, however if the Na concentrations in the soil solution increase, it may lead to wines with high Na concentrations, as well as having a negative effect on the grapevine as a whole. High Na concentrations may cause leaf burn, where the leaf scorch begins at the margin of the leaves and slowly progresses inwards. This may produce symptoms that can easily be mistaken as K deficiencies (Winkler *et al.*, 1962). Amiri & Eshghi (2015) found that as the Na content in the soil solution increased, the leaf and root concentration also increased. They also noted that Na is initially retained in the roots and then transported to the aerial parts of the woody plants.

The similarity between Na and K according to their hydrated ionic radii, make it difficult for the cell membrane transport system to differentiate between these two ions. This could be the foundation of Na toxicity levels under saline conditions (Amiri & Eshghi, 2015). Another factor which increases the Na toxicity, may be as a result of the fact that Na ions can be transported into cells by the K transporters (Parida & Das, 2005). Na also interferes with K uptake and disturbs stomatal regulation which ultimately leads to water loss. Other effects of high Na, include the decreased uptake of essential nutrients such as P, K, N, Ca and Mg and the reduction of photosynthesis, by reducing stomatal conductance (Parihar *et al.*, 2005).

2.4.3.2 Chloride

Cl is considered an essential micronutrient for higher plants with a minimal requirement for crop growth. This minimal Cl requirement can generally be supplied by rainwater, fertilizer applications (KCl), irrigation, sea spray, dust and air pollution, with Cl deficiencies occurring rarely in plants. Cl is involved in turgor- and osmoregulation, and is a major osmotically active solute in the vacuole. It also regulates enzyme activities in the cytoplasm and acts as a counter anion. Cl ion fluxes are responsible for the stabilisation of the membrane potential and pH gradient regulation (White & Broadley, 2001). Irrigation with saline water, however, increases the Cl concentration in the leaves and may cause leaf damage (Kafkafi *et al.*, 2001). This high concentration of Cl in the leaves shows the poor capacity of *Vitis Vinifera* L. vines for Cl exclusion (Amiri & Eshghi, 2005). The control of Cl transport and Cl

exclusion from shoots can be linked to salt tolerance in many plant species. Cl toxicity may also cause a reduction in growth and a decrease in the photosynthetic capacity of the plant as a result of the non-stomatal effects and chlorophyll degradation (Parihar *et al.*, 2015).

2.4.3.3 Potassium

Potassium is considered the most abundant cation in plants and can be found in large amounts in plant tissue. In grapevines the concentration of K can vary between 1 % and 4 % on a dry weight basis but this is dependent on the plant tissue type (Peacock, 2007). Wang *et al.* (2013) noted that concentrations of 100 to 200 mM of K ions can be found in the cytoplasm, whereas the apoplastic concentrations vary anywhere from 10 mM to as much 500 mM. The plant availability of K can be evaluated by leaf analysis at full bloom and véraison. However, this does not always accurately determine the K content, as K is present in its free form which can be rapidly distributed to growing organs of the grapevine or stored in the reserve organs such as the shoots, trunk and cordon arms. As much as 50% of the K taken up by the grapevine accumulates in the berries. Functions in the berries include synthesis reactions, enzymatic activation, which directly contributes to fruit maturation, sugar synthesis, as well as cell turgor maintenance. Potassium also plays an important role in the transport of solutes, the barrier of assimilates and polyphenol synthesis, which is responsible for berry colour and aroma (Brunetto *et al.*, 2015).

Deficiencies in K can result in marginal leaf burn in white grape cultivars and marginal red discolouration in red varieties. Marginal leaf burn, leaf curling, as well as defoliation in extreme cases have also been reported. There are also less common symptoms associated with K deficiency, such as reduced bunch mass, uneven berry ripening, and the black discolouration of leaves (Ashley, 2011). As the plant grows due to the mobility of K, symptoms move from basal leaves to the younger leaves. Reasons for deficiencies include over cropping, K application maintenance, salt stress, as well as drought stress. Both drought and salt stress can limit K uptake in the plant, therefore making it essential to apply sufficient K fertiliser (Wang *et al.*, 2013). Cakmak (2005) suggested that plants suffering from environmental conditions such as drought and salt stress require larger amounts of K.

In arid and semi-arid regions the most limiting factor in crop production is the availability of water. Reactive oxygen species may be formed when drought occurs continuously, which leads to leaf damage and a subsequent decrease in crop yield and quality. The K ion diffusion rates in the soil towards the roots and root growth are restricted, which is linked to a lower K ion uptake by the plant. Salinity in soil is an important abiotic stress, not only restricting root growth by osmotic and toxic effects, but also affects the uptake and transportation of essential nutrients such as K in plants (Wang *et al.*, 2013; Shabala & Pottosin, 2014). High concentrations of Na ions in the soil reduce the activity of K ions, making it less available for plant uptake, but a significant decline in K ions is also as a result of the direct competition between Na and K ions for uptake sites at the plasma membrane, which

include low- and high-affinity transporters (Shabala & Pottosin, 2014). Amiri & Eshghi (2015) also noted that leaf and root K/Na ratio reduced progressively with increasing salinity. In both salt and drought stressed affected plants with K deficiency, there is a reduction in photosynthetic CO₂ fixation and molecular O₂ is activated, which leads to extensive ROS generation, as well as the oxidative degradation of chlorophyll and membranes. Cakmak (2005) shows several examples where improvement of K-nutritional status of plants greatly minimised the negative effects of drought and salinity,

2.4.3.4 *Phosphorus*

Phosphorus is of vital importance to every plant, in terms of plant growth. It is known to be involved in several important functions including energy transfer in regards to adenosine triphosphate (ATP) and adenosine diphosphate (ADP), in photosynthesis as an energy source, transformation of sugars and carbohydrates, nutrient movement in plant and the transfer of genetic material in the plant to the next generation (Armstrong, 1999). Phosphorus in the grapevine is involved in the transfer of ADP and ATP energy within plant cells to facilitate metabolism. As well as assimilating and metabolising carbohydrates, it also forms part of the fatty portion of cell membranes (Ashley, 2011).

Deficiencies may occur due to a low soil pH, where Al toxicity reduces the ability for the grapevine to take up P. Salinity also reduces P concentrations in the plant tissue not only because of the ionic strength effects that have an influence on the activity of phosphate, but also due to phosphate concentrations in soil solution are tightly controlled by sorption processes, as well as by the low solubility of Ca-P minerals (Grattan & Grieve, 1999). A deficiency in phosphorus leads to reduced vine growth; in particular the reduction of leaf expansion and leaf surface area, as well as a decrease in shoot and root growth. Carbohydrates are also utilised more slowly, consequently leading to a build-up of carbohydrates and in turn influences the colour of the plants leaves. Ashley (2011) reported that a yellow discolouration on the interveinal basal leaves can be seen when a deficiency of phosphorus occurs, however in extreme cases this may lead a red discolouration. This eventually leads to early leaf fall, and may lead to poor bud initiation and fruit set later on in the physiological cycle of the vine. There are various other effects in regards to P deficiency, including a reduction in crop quality, decrease in disease resistance and a delay in ripening of fruit (Armstrong, 1999).

2.4.3.5 *Calcium*

Plants use networks of sensors, second messengers, kinases and transcription factors in order regulate gene expression as well as adapt to new conditions. Ca is the most well-known second messenger, however it is also important in maintaining proper cell wall structure and membrane integrity (Ashley, 2011; Robertson, 2013). Ca is present in relatively high concentrations between 0.1 and 80 mM in cell walls and organelles, however, cytoplasmic levels are maintained around 100 nM.

The very low Ca concentration in the cytoplasm makes it an ideal second messenger, where a number of stimuli have shown the rapid changes in cytosolic Ca in response to various abiotic and biotic stress (Maathuis, 2009). The concentration is also kept low, as Ca readily forms insoluble salts with sulphates and phosphates.

Calcium forms complexes with negative groups of organic compounds like proteins, sugars, phosphates and carboxyls of phospholipids. This is shown in plant cell walls where microfibrils are cross-linked by glycans and pectins (Maathuis, 2009). Ca plays a similar role in cell membranes, as in the cell walls, where the rigidity in the cell wall is determined by the carboxyl groups from opposing pectins which are electrostatically coordinated by Ca. In the cell membrane Ca coordinates with phosphate groups. This complex occurs in the outer part of the plasma membrane, where the removal of membrane Ca will compromise the integrity of the cell membrane and wall. Salt stress as well as heavy metals may have detrimental effects on the cell wall and membrane. Mahajan *et al.* (2008) noted that extracellular stress signals are first observed by membrane receptors, this activates large and complex intercellular signals, including the Ca second messenger signals. This signal initiates stress signalling pathways for stress tolerance. In saline soils, Na readily displaces Ca from its extracellular binding site, thereby seriously reducing Ca availability, especially at high Na/Ca ratios (Hu & Schmidhalter, 2005; Amiri & Eshghi, 2015).

Ca deficiency usually occurs in acid soils, where transpiration is poor and waterlogged conditions are prevalent for long periods at a time. Deficiency symptoms include stunting of grapevine growth, localised tissue necrosis, as well as marginal leaf necrosis. Due to the immobility of Ca, symptoms are mainly visible on the younger growing tissue, rather than the older leaves. Deficiencies also lead to an increase in disease susceptibility (Kennelly *et al.*, 2012). Ca deficiency can also impair the cell membrane's selectivity and integrity, but can also permit the passive accumulation of Na in the plant tissue (Amiri & Eshghi, 2015).

2.4.3.6 Magnesium

Magnesium is an important component of chlorophyll, therefore it contributes carbohydrate production in leaves through photosynthesis (Ashley, 2011). A vital Mg^{2+} -activated enzyme is ribulose-1,5-biphosphate (RuBP) carboxylase, which an important enzyme photosynthesis and is the most prevalent enzyme in the world. Other functions include photophosphorylation, photosynthetic CO_2 fixation, protein synthesis, phloem loading, partitioning and utilisation of photoassimilates, the photo oxidation in leaf tissues and the generation of ROS (Cakmak & Yazici, 2010). Magnesium is therefore very important in a number of physiological and biochemical processes, consequently when Mg^{2+} deficiency does occur, plant growth and yield are negatively affected. A symptom of Mg^{2+} deficiency is leaf yellowing in the form of interveinal chlorosis. Early leaf fall may occur, particularly in older leaves.

Although deficiencies occur mainly in strongly acidic, sandy soils, deficiencies have also occurred in alkaline soil. Strongly acidic soils are of vital importance, due to magnesium's potential for leaching in highly weathered soils, as well as its potential to interact with Al. Plants have adapted to acid soils, by releasing organic acid anions from roots. These acids will chelate the toxic Al ions, subsequently forming Al-organic acid complexes making them less phytotoxic (Cakmak & Yazici, 2010). Guo *et al.* (2016) reported that many toxic heavy ions such as Al have been reduced by the addition of Mg. According to Amiri & Eshghi (2015) Mg content in roots and shoots decreased with increasing salt concentrations in the soil.

2.4.3.7 Sulphur

Organic and inorganic forms of S can be found in soils. Saline and sodic soils contain mainly the inorganic forms of S, the predominant form taken up by plants being sulphates (SO_4^{2-}) in aerobic conditions. When conditions become anaerobic, such as in waterlogged conditions, sulphides become prevalent. In plants S is mainly taken up as SO_4^{2-} via sulphate transporters. This form is highly mobile and is rapidly transported through the xylem and shoots, where it is then reduced to SO_3^{2-} and subsequently to S^{2-} , consequently it is incorporated into the amino acid cysteine and methionine. Roots however obtain most reduced S via the phloem, in the form of tripeptide glutathione (Maathuis, 2009). Sulphur plays an important role in energy metabolism and is also present in proteins and chlorophyll (Ashley, 2011).

Sulphur deficiency symptoms are very similar to nitrogen deficiencies, and can often be misidentified, unless proper analysis is carried out. Sulphur deficiencies are however quite rare given that sulphur-based sprays for fungicide management and S containing fertilisers are widely used worldwide (Ashely, 2011). Sulphur toxicity is also rare, however it does occur in saline soils, where high levels of SO_4^{2-} salts are found. Toxicities can also be formed when soils are in an undisturbed waterlogged state and are exposed to oxygen, where sulphuric acid is formed from these acid sulphate soils.

2.4.3.8 Micronutrients (B, Cu, Mn, Fe, Zn, Mo)

Micronutrient availability is dependent on the pH and pE of the soil solution and the nature of their binding sites or inorganic and organic particle surfaces. Deficiencies of the micronutrients occur in saline and sodic soils, due to their low solubility (Grattan & Grieve, 1999). This is however dependent on crop species and the salinity concentrations (Hu & Schmidhalter, 2005). Corso and Bonghi (2014), however, confirm that high salinity in grapevine (*Vitis vinifera*) cause severe problems in water uptake as well as the availability of micronutrients. In the complex relationship between salinity and micronutrients, salinity may increase, decrease or may have no effect on the micronutrient content of the plant tissue (Grattan & Grieve, 1999). It has been reported that studies done on most horticultural crops, indicate that saline conditions decrease Mn concentrations in shoot tissue (Pandya *et al.*,

2004). Zinc applications, on the other hand, have been found to improve growth in salt-stressed plants, however better results were obtained in sodic soils than in saline or saline-sodic soils (Grattan & Grieve, 1999; Tavallali *et al.*, 2009).

2.5 Grape berry development and -composition in relation to cation and anion content

After berry set the grape berries enlarge very rapidly, however the level and character of growth is determined by the berry set mechanisms (Winkler *et al.*, 1962). There are three distinct stages followed in grape berry development and enlargement, which represents a sigmoidal curve seen in Figure 6:

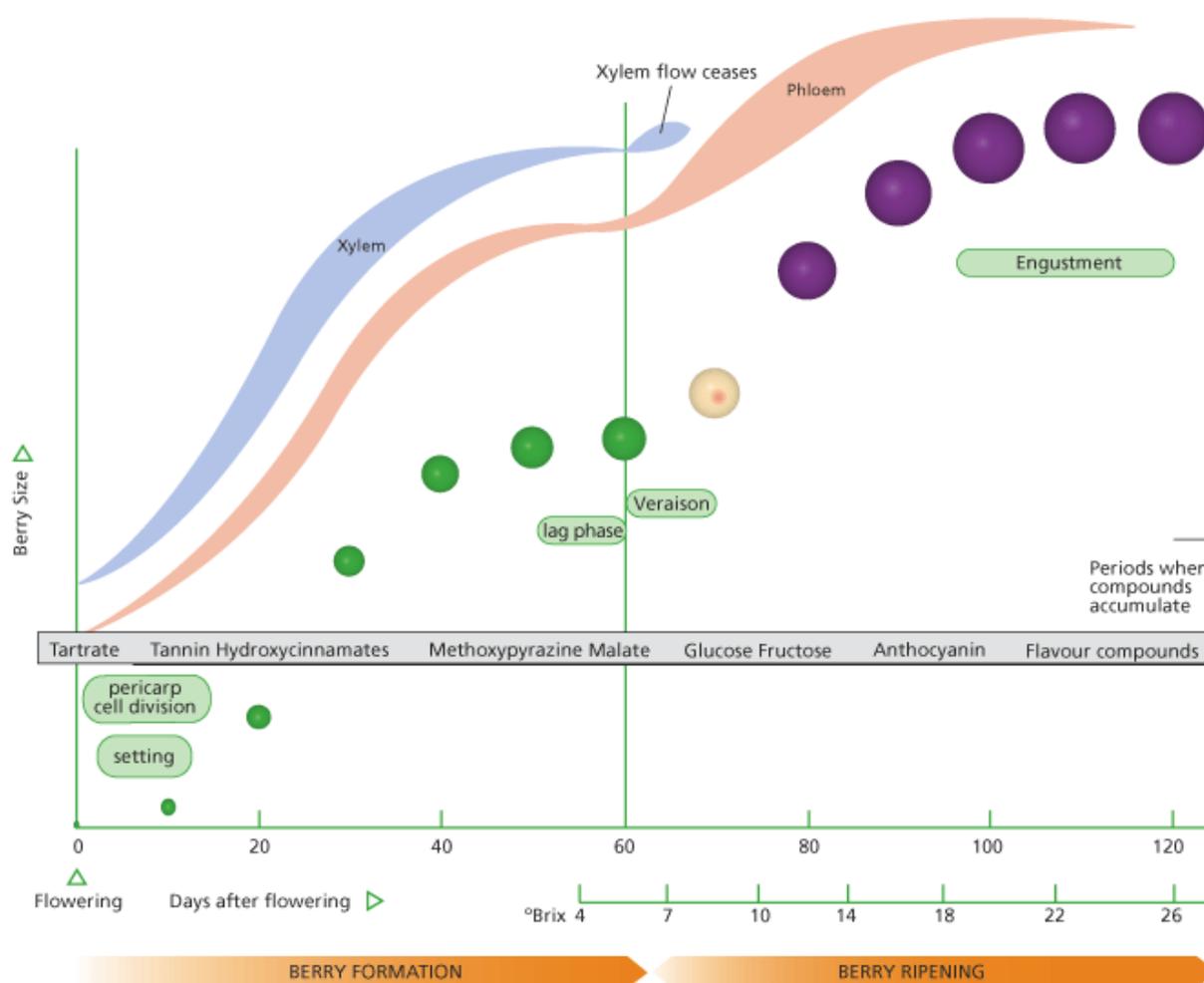


Figure 6: The sigmoidal curve depicting grape berry development (Kennedy, 2002).

In Stage I the seed and the pericarp grow, however the embryo remains small. The pericarp has a period of rapid cell division which ceases within three weeks of anthesis. This is then followed by rapid cell enlargement (Winkler *et al.*, 1962; Mullins *et al.*, 1992). The grape berries are green, firm and

hard, and acid accumulation takes place quite rapidly. Stage I usually lasts between 40 and 60 days (Mullins *et al.*, 1992). In Stage II the pericarp and seed maturation slows down markedly. The hardening of the endocarp occurs and the embryo starts developing rapidly. During this stage the embryo usually reaches its maximum level (Winkler *et al.*, 1962). According to Mullins *et al.* (1992) the chlorophyll content, photosynthesis and respiration rates decrease, however the titratable acidity reaches its maximum level. Sugar also starts to accumulate, however the berries remain hard and green until the end of Stage II. This phase lasts between 7 and 40 days dependent on whether the cultivar is early- or late maturing. During the third stage the berry starts to rapidly grow again, as well begins to soften considerably. The growth in the berry is due to cell enlargement. Colour and sugar accumulate, the acid decreases and aroma characteristics start to develop. Stage III lasts approximately 35 to 55 days (Mullins *et al.*, 1992).

2.5.1 Chemical berry composition

2.5.1.1 Sugars

As the grape berry ripens it becomes a strong sink for dry matter transported from photosynthesis and wood reserves (Agasse *et al.*, 2009). The main source for nutrition for the grape berries until they have almost reached maturity, are the leaves of the grapevine. The produced sugars are moved via the phloem to locations responsible for growth, production of other carbohydrates, or they accumulate as carbohydrate reserves for the grapevine (Davies & Robinson, 1996). Dokoozlian (2000) also noted that sugars provide the foundation for compounds such as organic and amino acids, which are synthesised and located in the fruit. The main sugar derived from leaf photosynthesis is sucrose, which is transported to the berries through the phloem. Other sugars include raffinose and stachyose, however in much smaller amounts. When the sucrose is translocated to the berry, it is hydrolysed into glucose and fructose (Winkler *et al.*, 1962). Glucose and fructose are approximately in equal amounts in the grape berries at harvest (Dokoozlian, 2000). Water deficits as a result of saline or sodic soils, increase the sugar concentrations in the grape berry as a result of berry shrinkage and a lower competition for carbon between berry ripening and shoot growth (Van Leeuwen *et al.*, 2009).

2.5.1.2 Acids

The main acids in berries are dominated by D-tartaric and L-malic acid, which account for over 90% of the total titratable acidity (Mullins *et al.*, 1992). Other acids include succinic and citric acid, which only contributes approximately 0.02% to 0.03% of the acid in the grape berry, inorganic acids are also present in the berry, but in very small amounts (Winkler *et al.*, 1962; Muñoz-Robredo *et al.*, 2011). As the berry ripens there are rapid changes occurring in the acid/sugar balance. In order to make a good, balanced and stable wine, the presence of adequate levels of organic acids is vital (Conde *et al.*, 2007). When the berry starts to grow, malic and tartaric acid increase gradually up until midway

through the lag phase of berry growth and just before the berry starts to ripen. As the berries ripen, the malic and tartaric acids in the berry start to decrease, where malic acid decreases more than tartaric acid. The faster degradation of malic acid, is due to it being more readily respired, but also due to several enzymes capable of metabolising it (Winkler *et al.*, 1962). The decrease of malic and tartaric acid is due to a few factors, including dilution by the increase of berry volume, activation of acid breakdown, inhibition of acid synthesis, as well as the transformation of acid into sugars (Mullins *et al.*, 1992).

2.5.1.3 *Phenolic composition*

Wine phenolic compounds are molecules that are naturally derived from plants and microbes (Conde *et al.*, 2007). They comprise derivatives of hydroxycinnamic acids, which include caffeic and coumaric acid, flavonoids, which include anthocyanins, flavonols and tannins. Unmodified grape juice contains major phenolic compounds such as caffeic and coumaric acid (Mullins *et al.*, 1992). Phenolics are synthesised in the berry and concentrated in the berry skins as well as the seeds. These components play a vital role in determining fruit colour and astringency (Dokoozlian, 2000). Tannins, the most abundant class of soluble polyphenols, which are complex esters of phenolic acids and sugars, occur mainly in the skins, stems, and the skins of grapes (Adams, 2006). As the grape berries ripen, the tannin content increases at the same rate as the colour. Tannins can be classified as hydrolysable and condensed (Winkler *et al.*, 1962). Hydrolysable tannins are made up of gallic and ellagic acids, which are mainly extracted from oak wood. The condensed tannins are composed of flavan-3-ols, such as catechin and epicatechin, and are usually found in the grape (Keller, 2015).

The green colour of the berries can be attributed to chlorophyll, which fades as the berry starts to ripen (Winkler *et al.*, 1962). In white cultivars, the colour changes usually to a translucent straw colour, whereas the red cultivars turn either red or black in colour (Waterhouse, 2002). Pigments of colour can usually be found in the skins, however the colour intensity is dependent on the cultivar, maturity, environmental and seasonal conditions and crop level (Winkler *et al.*, 1962). The pigment compounds of grapes are anthocyanidins, which include cyanidin, delphinidin, petunidin, peonidin and malvidin. The compounds are modified into anthocyanins by the attachment of a glucose moiety. Mullins *et al.* (1992) suggested that the accumulation of sugars and anthocyanins in the berry are closely associated.

2.5.1.4 *Nitrogenous compounds*

In immature grape berries, nitrogen compounds are found as ammonium cations and as organic nitrogen compounds such as amino acids and proteins. During the initial stages of berry ripening, the ammonium cations constitute to more than half the total nitrogen in the berry. As the fruit matures, the amino acid synthesis and proteins increases rapidly, and the ammonium concentrations decrease.

Amino acids such as arginine and proline are the main amino acids present in most cultivars at harvest (Winkler *et al.*, 1962; Mullins *et al.*, 1992; Dokoozlian, 2000).

2.5.1.5 Minerals

Minerals in the soil are taken up by the grapevine roots and are translocated directly into the fruit or remobilized from permanent organs through the xylem or the phloem. According to Dokoozlian (2000), the main minerals found are the cations K, Ca and Na. Winkler *et al.* (1962) on the other hand, also found Fe, P, S, Cl and trace amounts of bromide, iodine and fluoride. Rogiers *et al.* (2006) found that minerals occurring during berry ripening, can be divided into two broad categories according to their accumulation patterns. Some minerals continued to accumulate throughout berry growth and ripening and some minerals accumulated mostly before ripening *véraison*. Minerals that accumulate throughout berry growth include K, P, S and Mg. Winkler *et al.* (1962) noted that as the grapes started to mature, the concentrations of K, Ca, Mg and Na increase 2 to 3 times in the skin, 1.2 to 1.9 times in the pulp and 1.5 to 2.5 times in the peduncle. The anions such as phosphates also increase particularly in the seeds. They also reported that the calcium and magnesium levels decreased during ripening.

Grape berries are known to be rich in K, which is an essential mineral for grapevine and grape berry growth and development. It not only deals with enzyme activation, but also determines the uptake of other cations and anion, as well as sugars. Additionally it regulates the osmotic potential, therefore it also controls the plant water relations, turgor maintenance and growth. During early season vine growth, K is mainly accumulated in the leaves, however after *véraison* berry K increases rapidly as a result of K redistribution from leaves to berries. Ca, Mg and Na minerals are also present in the grape berry. Ca and Mg can be found at similar concentrations in the berries and must. Ca content is at its maximum at *véraison*, and remains stable or lowers as the berry matures (Conde *et al.*, 2007). The Ca flesh and pericarp concentrations increases up to *véraison* but then decrease as the berry ripen. Increases of Ca in the berry may be due to Ca accumulation in seeds during ripening as a result of Ca translocation from the berry flesh to the seeds and skins (Cabanne & Donèche, 2003).

2.6 Other factors increasing cation and anion content in wine

Factors other than soil mineral availability, soil types, climate, types and the rate of fertilisation, grape cultivars, harvest practices and processing conditions affect the cation and anion content in wine, in particularly concentrations of Na, Cl, K, Ca and Mg. Na concentrations in wine may be increased by certain winery practices. Practices such as ion exchange treatment, in order to stabilise the wine from K bitartrate precipitation, the use of Na metabisulphite and Na bentonite fining, may have an effect on the Na content of a wine (Cox *et al.*, 1977; Catarino *et al.*, 2008). Chloride concentrations, expressed

as NaCl, may increase in wine as a result of vines grown in close proximity to the sea or in white wines that undergo fining with egg whites (Moreno & Peinado, 2012).

K concentrations in red wine are usually higher than in white wine as a result of the inhibition of K bitartrate precipitation by red wine phenols and also because most red grapes undergo skin contact pre-, during or post-fermentation. Rakonczás *et al.* (2015) reported an increase in K concentrations as a result of skin contact and high temperatures during skin contact. Noble rot and raisin grapes are also known to contain the highest K concentrations (Moreno & Peinado, 2012). Ion exchange resins also have an effect on the K content of wine (Karataş *et al.*, 2015).

White wine contains higher Ca concentrations than red wine, and Ca may be added to wine as a result of certain fining agents such as bentonite, DE and filter pads (Margalit, 2014). Ca can also be added to wine as CaCO₃ or CaSO₄ in order to deacidify must and wine or enhance acidity of grape juices, respectively (Woldemariam & Chandravanshi, 2011; Rakonczás *et al.*, 2015). Mg concentrations are also dependent on storage temperature and the rate of pressing (Karataş *et al.*, 2015).

2.7 The effect of salinity on grape juice and wine composition

2.7.1 Juice composition

Rogiers *et al.* (2006) reported that the mineral nutrition status of the grape berries was not only important for viticulturists but also for winemakers, as there is a direct impact of berry nutrition on juice and must composition. Differences in juice mineral concentrations are as a result of cultivation aspects such as the wine-growing area, soil, climate, variety, rootstock and fertilisation (Coli *et al.*, 2015). Other factors such as the concentration of minerals in the soil solution play an important role in the uptake of minerals. Salinity and sodicity levels, rootstock and scion type affect the Na and Cl concentrations in the grape berry and subsequently the grape juice. The Na and Cl concentrations increase slowly initially, however as the berry ripens, the concentrations increase more rapidly (Walker, 2010).

Some factors are affected by pH in grape juice is dependent on various factors such the total acidity (organic acid concentrations), the proportion of stronger acids (tartaric acid) to weaker acids such as malic acid, as well as the proton exchange involved in the monovalent metal cations uptake by the berry tissue. Increases in Na and K ions will therefore increase the pH of the juice (Stevens *et al.*, 2011). Holland *et al.* (2015) also noted an increase in pH and Na content in grape juice which is affected by salinity.

2.7.2 Wine composition

2.7.2.1 Alcoholic fermentation

In modern winemaking, product consistency and quality are always demanded, which shows the importance of yeast genetics and physiology. This importance impacts directly on stress tolerance, alcohol production, yeast growth, utilising of sugar, volatile compound production as well as off-flavour development. Desired yeast qualities in winemaking include osmotolerance, high acid and changing temperature tolerance as well as low oxygen tolerance (Logothetis *et al.*, 2010; Logothetis *et al.*, 2014). However, differences between yeast species have been reported concerning osmotolerance. Logothetis *et al.* (2010) showed that non-*Sacchormyces* strains displayed higher salt tolerance.

Osmotic stress during primary fermentation due to salt stress, has a negative impact on yeast viability, and initiates a series of biological responses to maintain yeast cell viability and cell cycle progress. Logothetis (2010) noted that a gradual increase in sodium chloride (NaCl) concentration in a growth medium containing yeast cells, may cause cell growth arrest, however this was dependent on the NaCl concentrations. Donkin *et al.* (2010) also found that NaCl also indirectly affected yeast development and viability with the production of acetic acid and acetaldehyde. Yeasts produce glycerol when coming into contact with osmotic pressure, where it is a compatible solute aimed at avoiding cell dehydration and cell death. The production of acetic acid is a mechanism by which the redox potential is maintained during glycerol formation by acetaldehyde oxidising to acetic acid. Both acetic acid and acetaldehyde are also toxic to yeast development and viability, where acetic acid has also been linked to causing stuck or sluggish fermentations

2.7.2.2 Malolactic fermentation (MLF)

The concentration of Na and Cl ions in wine is determined by grape concentrations and winemaking practices, and may not only affect alcoholic fermentation but also malolactic fermentation (MLF) and wine composition (Donkin *et al.*, 2010). In MLF, the impact of NaCl on the malic acid catabolism was shown to be variable, in some cases increasing it and in others reducing it.

2.7.2.3 Post-fermentation

Winemaking practices that may affect the Na content are tartrate stabilisation methods using sodium carboxymethyl cellulose (CMC) and bentonite fining products containing Na. Another method for tartrate stabilisation includes the stabilisation by ion exchange. This treatment consists of wine passing through a column which contains a resin in cationic or anionic form. In the cationic form, the resin used is charged with Na ions or hydrogen (H) ions, as well as a combination of both Na and H ions. As the wine is treated with the Na resin, it is exchanged with K ions, as well as other cations, like Ca and Mg, forming a more soluble compound sodium bitartrate. A slight reduction in acidity and an increase in the Na content in the wine may occur (Dharmadhikari, 1994).

2.8 Effect of salt content on the sensorial profile of the wine

Wine containing high NaCl concentrations is not considered favourably, and has been described as salty, flat, dull, soapy, seawater-like and brackish by Walker *et al.* (2010b) and De Loryn *et al.* (2014). De Loryn *et al.* (2014) reported that a strong linear relationship between mean salty taste score and Na, Cl and K ion concentrations in the wine, where the tasters described the wines as having a soapy character, relatively low perceived acidity, low fruit flavour as well as astringency. There are five accepted taste qualities, sweet, sour, bitter, salty and umami, that have been accepted and received by humans, where salty tastes are believed to play an important role in the maintenance of ion and water homeostasis (Sugita, 2006; De Loryn *et al.*, 2014). Taste buds are distributed across different papillae of the tongue, palate epithelium, upper gastrointestinal and respiratory tracts. These taste receptor cells are the basic anatomical units of taste detection and perception, where Na and Cl ions are required to activate these salt receptor cells (De Loryn *et al.*, 2014).

The human gustatory system is known to be capable of responding and processing solitary compounds in water, this solitary taste system rarely occurs outside of a laboratory. Salty, bitter and sour interactions constitute a significant amount (between 30 to 50%) of the possible binary taste interactions. At moderate concentrations salts and acids can enhance each other, but at higher concentrations they can also suppress one another. When sodium and bitterness interact, the bitter compounds are usually suppressed to some extent, whilst the salty compounds remain unaffected. These interactions are dependent on various factors such as concentrations, the individual taste subjects' sensitivities to various taste compounds, as well as the type of compound (*i.e.* malic versus tartaric acid) (Breslin, 1996).

2.9 Summary

Wine quality is dependent on various viticultural and environmental parameters. Therefore, the need to maintain and manage important environmental factors, such as soil and climate, is highly important in maintaining a sustainable wine grape production. Soil degradation is defined as the systematic decline, where the lack of soil maintenance and management, as well as natural processes have exacerbated the problem. Soil degradation may include salinity, sodicity, acidity and erosion. Occurrences of soil degradation may have a negative impact on grapevine production and the quality of the wine. Therefore, a greater understanding of elements involved in soil degradation, the grapevines responses to these elements and the effect these elements may have on wine composition and quality, are required. Not only is this important for wine quality, but also for the subsequent sales to overseas markets. International export of wine requires a farm to abide by strict laws regarding certain elements in wine, particularly free Na in wine. Free Na in wine may occur due to various environmental, viticultural and winemaking practices.

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Chapter 3

Research results

An assessment of selected cations and anions from the soil to the wine, including wine sensory effects.

CHAPTER III: AN ASSESSMENT ON THE EFFECTS OF CERTAIN CATIONS AND ANION ON THE GRAPEVINE

3.1 Introduction

Soil degradation is defined as the systematic decline and loss of soil quality as a result of natural processes, but accelerated by human activity (Fitzpatrick, 2002; Jie *et al.*, 2002). Soil salinity and sodicity occur mainly in arid and semiarid regions. Saline soils usually contain high concentrations of soluble salts like NaCl in the soil solum or regolith, which have an adverse effect on plant growth (Rengasamy, 2006). Sodic soils contain large quantities of Na ions compared to other cations on the soil particle surfaces, and have an indirect effect on plant growth. Soils are considered sodic when the Na concentrations affect the soil structure. Consequently sodic soils affect the soil water availability to the plant through factors such as hard surface setting or crusting and hard and impenetrable subsoil formation. Both factors reduce water infiltration and air flow, which has a negative effect on the plant (Slinger & Tennison, 2005; Rowling & Slinger, 2007).

Grapevines are known to be moderately sensitive to salinity (Maas & Hoffman, 1977). Saline and sodic soils have an adverse effect on the grapevine's physiological responses and biochemical pathways, as a result, toxicities, deficiencies and mineral imbalances occur in the grapevine (Fisarakis *et al.*, 2001; Shani & Ben-Gal, 2005). The most important cations associated with salinity are Na⁺, Ca²⁺ and Mg²⁺, whereas the most important anions are Cl⁻, SO₄²⁻ and HCO₃⁻ (Yadav *et al.*, 2011). These ions are quite variable in concentrations and may be indigenous, however they are more commonly added to the soil by irrigation water and may be as a result of persistent droughts (Bernstein, 1975). Salinity and sodicity in soils affect various grapevine physiological processes including yield reduction, shoot growth as well as an increase in cation and anion concentrations in the fruit and the subsequent wine (Lanyon *et al.*, 2004).

The analysis of cations and anions not only in the leaves and the petioles, but also the different grape components is of vital importance, as it may help prevent the negative effects these cations and anions may have on grapevine growth and physiology, as well as the subsequent wine quality and export feasibility. Some export wines are rejected based on their cation and anion content. Recent analysis of small scale wines made from saline sections of a particular farm confirmed high Na levels, and three times the recommended levels according to the South African guidelines (100 mg/L free Na). Cation and anion analysis in the wine is not seen as a general practice both locally and internationally, which has had a negative impact on some export wines.

In this study farms were chosen based on the varying degree of soil salinity and sodicity found as well as the grapevines vigour. The aims of this study were to i) determine if cations and anions were translocated into grapevine parts and their subsequent concentration, ii) determine the cation and

anion concentrations in the wine, and finally iii) determine if these cations and anion concentrations had an impact on the wine sensorially.

3.2 Materials and Methods

3.2.1 Experiment layout

3.2.1.1 Farm A

The farm is located near Paarl off the R44, and is approximately 26.9 ha. The vines are all bush vine (“goblet”) Chenin blanc under rain-fed conditions. The areas were initially chosen according to vigour using NDVI (Normalized Differences Vegetation Index) imaging, Google Earth Images, as well as visual inspection, which was confirmed by soil, leaf and petiole analyses and plant growth. The goal with this was to try and select designated areas with more salinity issues, similar to the study by Strever (2003). Figure 1 below shows the plot layout for Farm A Chenin blanc, where the red depicts the low vigour sites, and the yellow plots are the high vigour blocks.

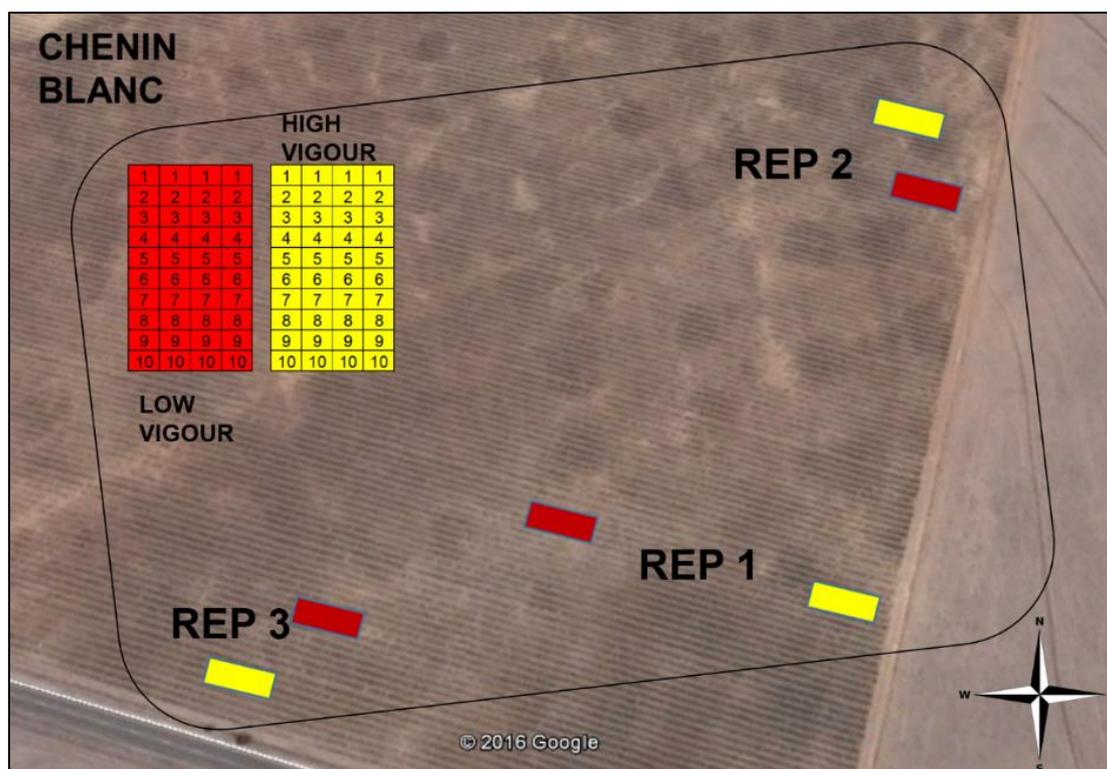


Figure 1: A map showing Farm A with all the replicates.

3.2.1.2 Farm B

The second farm has two different cultivars, namely Chenin blanc and Pinotage. The Pinotage block is 6.07 ha, whilst the Chenin blanc block is 8.6 ha. The vines are trained according to the 5-wire-Perold System. Figure 2 shows the plot layout for Farm B Chenin blanc and Pinotage. The characteristics of the different vineyards are displayed in Table 1. Farm B was irrigated every 11 days at 2.7 mm per hour for approximately 12 hours.

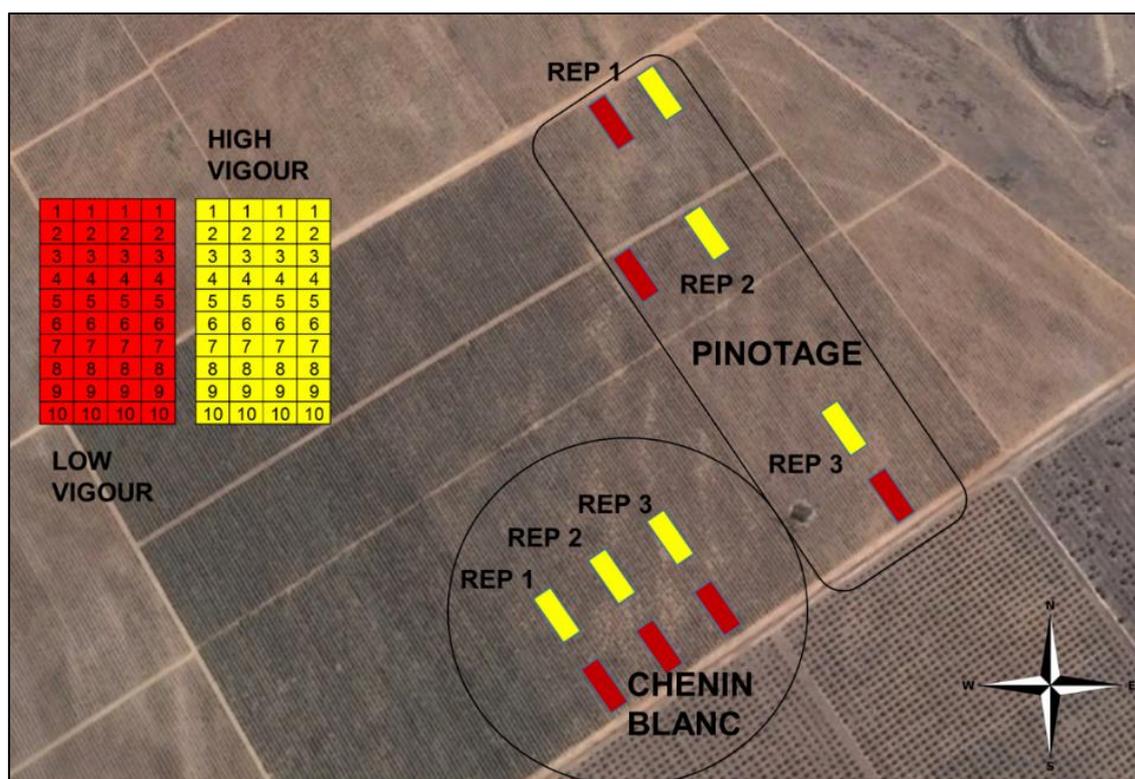


Figure 2: A map showing Farm B with all the replicates and cultivars.

Table 1: Characteristics of Farm A and Farm B.

Descriptor	Farm A	Farm B	
Cultivar	Chenin blanc	Chenin blanc	Pinotage
Rootstock	Richter 110	Richter 99	Richter 99
Year established	2002	1997	1997
Row orientation	North-West	East-West	East-West
Lat/Long/elevation	Lat 33°39'54.63"S Long 18°51'43.00"E 142-162m elevation	33°41'35.86"S 18°51'40.54"E 140-147m elevation	33°41'47.31"S 18°51'42.12"E 142-146 m elevation
Grapevine spacing	3 m x 1.2 m	3 m x 1.2 m	3 m x 1.2 m
Trellis/training system	Bushvine	Vertical shoot position (VSP)	Vertical shoot position (VSP)
Irrigation system	Dryland	Drip	Drip
Pruning system	Spur	Spur	Spur
Climate	Semi-arid/ arid	Semi-arid/ arid	Semi-arid/ arid

3.2.2 Soil sampling

Collection of soil samples was according to low and high vigour, as well as at the different replicates. The idea was to get abroad overview of the chemical and physical soil conditions that may affect vigour and cation/anion content in the grapevines and wines. Soil samples were taken at three different depth levels, namely 0-30 cm, 30-60 cm and 60-90 cm, using a soil auger. These samples were collected at 18 different locations (nine low vigour, nine high vigour). Figure 4 shows the soil sampling layout for the different positions. The samples were taken c. 50 cm from the vine trunk, and were collected in the centre of each replicate. Thereafter, the soil samples were photographed and

taken to an independent laboratory (Elsenburg Institute for Plant Production: Laboratory Services: Soil, water and plant tissue laboratory) for the standard soil analysis (soil pH, resistance, Ca, Mg, K, Na, P, Cu, Zn, Mn, S and total cations).



Figure 3: A soil sample being taken with an auger.

1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9
10	10	10	10

1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9
10	10	10	10

Figure 4: Locations of where the soil samples were taken in the low and high vigour (low vigour on the left, high vigour on right).

3.2.3 Climate measurements

During 2015/2016 each site had one mesoclimate logger (Tinytag® model TGP-4500, Gemini Data Loggers, West Sussex, United Kingdom) housed in a radiation shield, *i. e.* a gill screen (Tinytag® model LS-1, Gemini Data Loggers, West Sussex, United Kingdom) installed at canopy height. Data

was logged at 30 minute intervals. The sensor's temperature measurement range is between -25°C and +85°C, with a relative humidity measurement range of between 0% and 100%. The loggers measure minimum and maximum temperature in degrees Celsius (°C), and minimum and maximum relative humidity in percentage (%). Data was downloaded using the TinyTag program every 2 months (Davel, 2015). When all the data was collected for the growing season, the growing degree days (GDD) (Table 2), Heliothermic Index (HI) (Table 3) (Huglin, 1978) and the mean minimum January, February and March temperatures was calculated (Table 4). The HI was calculated using the mean and maximum monthly temperatures from October to March. The following equations (equation 1 & 2) were used to calculate the GDD from the 1st September to the 30th March:

Equation 1: Growing degree days (GDD) are calculated using a summation of the daily mean temperature above 10 °C, from 1st September to 30th March (Le Roux, 1974).

$$GDD = \sum_{i=1}^n \frac{(T_{max,i} + T_{min,i})}{2} - 10$$

where,

GDD = Growing degree days

$T_{max, i}$ = Maximum Temperature

$T_{min, i}$ = Minimum Temperature

Equation 2: The heliothermic index for the Southern Hemisphere (Huglin, 1978).

$$HI = \sum_{31.03}^{01.10} \frac{((T - 10) + (Tx - 10))}{2} d$$

where,

HI = Heliothermic Index

T = Mean air temperature (°C)

Tx = Maximum air temperature (°C)

d = Length of day coefficient (a coefficient of 1 is used in the south Western Cape)

Table 2: The Amerine & Winkler (1944) indices adapted to the Western Cape criteria for viticulture (Le Roux, 1974).

Degree days (°C)	Region	Viticulture potential
<1389	I	Quality red and white wine
1390-1666	II	Good quality red and white table wine
1667-1943	III	Red and white table wine and port
1944-2220	IV	Dessert wine, sherry and standard quality table wine
>2220	V	Dessert wine and brandy

Table 3: Heliothermic indices, the climate associated with them and their subsequent viticulture potential (Huglin, 1978).

Huglin Index	Climate	Viticulture potential
IH1: 1400-1500	Very cool	Only very early cultivars can ripen
IH2: 1500-1800	Cool	A large scale of cultivars can ripen
IH3: 1800-2100	Temperate	Late cultivars can reach maturity
IH4: 2100-2400	Warm temperate	No further heliothermic constraints for ripening
IH5: 2400-3000	Hot	Exceeds heliothermic requirements, high temperature stress
IH6: >3000	Very hot	Possibility of two harvests per year, high temperature stress

Table 4: Mean February temperature (MFT) index in different climates, with cultivation potential (de Villiers *et al.*, 1996).

MFT (°C)	Climate	Cultivation potential
17-18.9	Cold	High quality white table wine
19-20.9	Cool	High quality white and red table wine
21-22.9	Moderate	High quality red table wines
23-24.9	Hot	Low acid, high pH
>25	Very hot	Low acid, pH

3.2.4 Vegetative measurements

3.2.4.1 Trunk circumference

The trunk circumference of each grapevine in every replicate was measured using a standard measuring tape. The first measurement was done 10 cm above the graft union, the second approximately in the middle of the trunk and the last measurement was done 10 cm below the cordon (Strever, 2003).

3.2.4.2 Shoot measurements

From budburst until shoot growth cessation shoot lengths were measured with a standard tape measure. The modified EL-System was used to identify the major and the intermediary grapevine growth stages (Eichhorn & Lorenz, 1997).

3.2.4.3 Destructive leaf area measurements

Destructive leaf area measurements were done shortly after harvest on five shoots per treatment. The shoots were randomly removed from a spur position close the centre of the vine. After the shoot was removed, the main and lateral leaves were counted separately and placed into different plastic bags. The main and lateral shoot lengths were measured with a standard tape measure. The nodes on the main and lateral shoots were also counted. The total leaf area was determined using a leaf area meter (Li-Cor 3000) for the lateral and main shoots. The average leaf area could then be determined (Strever, 2003; Davel, 2015).

3.2.4.4 *Pruning mass*

The measurement of pruning mass per treatment did not occur as a result of pre-pruning done on both Farm A Chenin blanc and Farm B Chenin blanc and Pinotage.

3.2.4.5 *Leaf and petiole sampling*

In total, 18 sites, *i.e.* nine low vigour, nine high vigour, were sampled on the two farms. During bloom and véraison, 30 mature, unscathed leaves opposite a bunch were randomly sampled from the shoots in accordance with the protocol of Conradie (1994). Petioles were immediately separated from the leaf blade and they were placed into separate paper bags and sealed. All of the samples were dried in a fan oven at 60°C for 24 hours. The dried leaf blade and shoot contents were determined by a commercial laboratory (BEMLAB, Strand). Leaf and shoot nitrogen (N) was measured by means of a nitrogen analyser using the methods described by Horneck and Miller (1998). Samples were prepared for analysis of P, K⁺, Ca²⁺, Mg²⁺, Na⁺, Mn²⁺, iron (Fe²⁺), copper (Cu²⁺), zinc (Zn²⁺), Cl⁻ (only leaf samples) and B³⁺ and analysed by means of an ICP-OES spectrometer (PerkinElmer Optima 7300 DV, Waltham, Massachusetts, U.S.A.) using methods described by Isaac and Johnson (1998).

3.2.4.6 *Cane sampling*

Cane sampling took place post-harvest, where five canes were removed from every treatment and immediately cut into smaller pieces and placed into separate paper bags. Thereafter, the 18 samples were sent to Bemlab (Pty) Ltd. an independent laboratory for standard analysis (N, P, K, Ca, Mg, Na, Mn Fe, Zn, Cu and B).

3.2.5 **Harvest Measurements**

3.2.5.1 *Berry sampling*

Berry sampling commenced from véraison until harvest. Fifty berries were randomly sampled from all the plots, and placed into plastic bags for further analysis at the Paul van der Bijl Laboratory. All samples were analysed for sugar concentration (°B), titratable acidity (TA), pH, volume (mL) and weight (g) (Strever, 2003; Davel, 2015).

3.2.5.2 *Harvest*

Grapes were harvested on 29/01/2015 and 19/01/2016, on all sites and according to vigour. Yield per vine was recorded and the harvested grapes were put into crates and transported to the JH Neethling Experimental Cellar for small-scale winemaking. All bunches harvested were counted and weighed on a laboratory scale, and the average bunch mass was calculated (Strever, 2003; Davel, 2015).

3.2.5.3 *Juice sampling for cation and anion analysis*

A 500 mL representative sample was taken just after crushing and before the sulphur adjustment, making it a total of 18 samples.

3.2.1 Sample preparation

3.2.1.1 Skins

After collection, the skins were dried in an oven at 70°C for two weeks, until they had lost all their moisture (until stable mass). The dried skins were then ground for one minute using a grinder. The fine powder was put into a fresh container for analysis at two different laboratories.

3.2.1.2 Juice

The grape juice was put through a 2 mm sieve in order to remove large particles. Juice was centrifuged using the Sorvall RC6 Plus (Thermo Electron Corporation) for 30 minutes at 10 000 revolutions per minute (rpm). This juice was then deposited into a fresh container for analysis.

3.2.1.3 Sediment

The sediment was separated from the juice using a centrifuge (Sorvall RC6 Plus, Thermo Electron Corporation), at a speed of 10 000 rpm for 30 minutes and a temperature of 4°C. The sediment was then placed into a new container for analysis.

3.2.1.4 Homogenising

The must samples were also homogenised together for a representative sample. The homogeniser (IKA T18 Basic, Ultra-Turax) was used to homogenise the samples for 4 minutes. This homogenised sample was then put into the oven at 70°C for two weeks, until all the moisture had evaporated. The samples were also ground in the same way the skins were ground (refer to 3.2.1.1).

3.2.2 Winemaking procedure

Standard winemaking procedures were used at the University experimental cellar. The replicates were processed separately, however the same procedure was used for all. The Chenin blanc grapes from both farms were pressed on the day of harvest. These grapes were inoculated with VIN13 yeast and left to ferment dry. Pinotage grapes were inoculated with D21 yeast, were left to ferment dry, and allowed to proceed through malolactic fermentation (MLF). No acidity adjustments and barrel ageing were done. Both the Chenin blanc and Pinotage wines were SO₂ (free) adjusted to 50 ppm (parts per million), and the Chenin blanc also received a Ca bentonite fining at 80 ppm. All wines were cold stabilised at -4°C for approximately a month, and bottled standard in 750 mL bottles. These bottles were stored at 15°C until all sampling, analysis and sensory evaluations were completed.

3.2.3 Grape juice and wine cation and anion analysis

3.2.3.1 Lab A

Sample Digestion

Sample digestion was performed with a MARS microwave digester, using ultra-pure HNO₃, or HNO₃ + HCl, at elevated temperature and pressure. This was done in order to solubilise the acid extractable elemental content of the sample. After a cooling period, the extractant was made up to 50 mL volume with deionised water and, analysed by ICP-AES and/or ICP-MS for the selected analyses.

Major element analysis

Major elements were analysed on a Thermo ICap 6200 ICP-AES. The instrument was calibrated using NIST (National Institute of Standards and Technology, Gaithersburg MD, USA) traceable standards purchased from Inorganic Ventures (INORGANIC VENTURES · 300 Technology Drive · Christiansburg, VA 24073) to quantify selected elements. A NIST-traceable quality control standard from De Bruyn Spectroscopic Solutions, Bryanston, South Africa, were analysed to verify the accuracy of the calibration before sample analysis, as well as throughout the analysis to monitor drift.

3.2.3.2 Lab B

Juice and wine:

For elements other than Cl, 50 mL wine was digested in 5 mL HNO₃ and 1 mL HClO₄, which was then made up in a 50 mL volumetric flask. Analysis was carried on a Varian 725ES ICP, and if needed a 1:10 dilution was made if the samples were found to lie outside of the standards. For Cl analysis, 20 mL wine with 1 mL HNO₃ was subjected to potentiometric titration with 0.01 N AgNO₃.

Solids:

Solids were all dried at 100°C, afterwards a representative 1 g sample was turned to ash at 600°C for four hours. Ten mL of 6N HNO₃ and 10 mL 6 N HCl acid solution was added to the ashed sample for the determination of all the elements with the exception of Cl. This was then filtered and analysed on the Varian 725ES ICP. For the Cl samples, 1 g sample had 10 mL 0.01N HNO₃ added to it, stirred and left to stand for two hours. Thereafter, the samples were subjected to potentiometric titration with 0.01N AgNO₃.

3.2.4 Red wine colour and total phenolic content determination

A representative 75 mL sample was taken from three bottles of wine from each treatment from the 2015 and 2016 vintages. The pH was determined using a pH meter, where a separate portion of the representative wine sample was adjusted to a pH of 3.5 either with 1N HCl to decrease the pH or with NaOH to raise the pH. Consequently a 25 mL pH adjusted representative sample and a 50 mL

unadjusted wine sample was used for the experiment. Six test tubes were clearly marked, with three replicates for each experiment as shown in Figure 5 (Illand *et al.*, 2000).

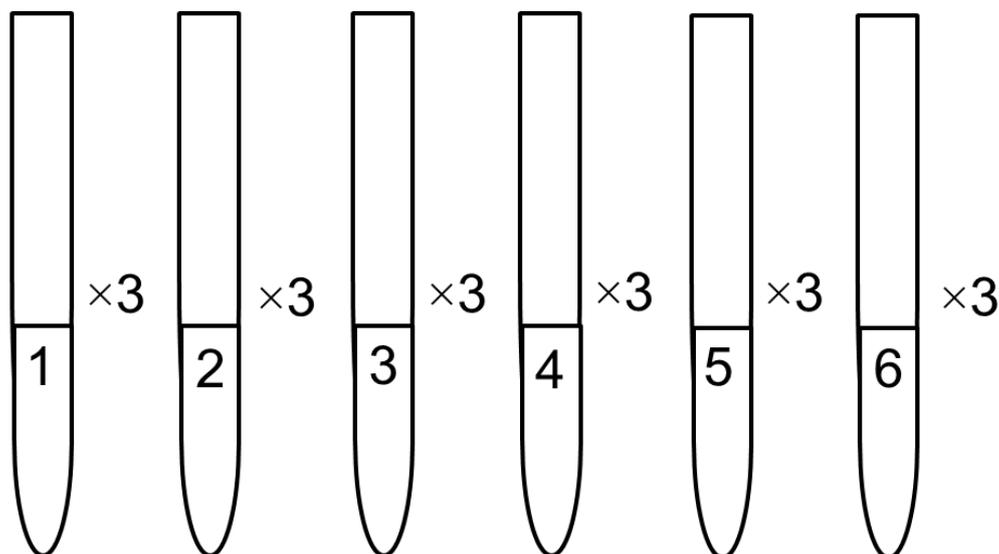


Figure 5: The layout of the experiment showing test tubes 1 to 6 and the triplicated thereof. Captions are: 1. Wine, 2. Wine adjusted to pH 3.5, 3. Wine + SO₂, 4. Wine adjusted to pH 3.5 + SO₂, 5. Wine adjusted to pH 3.5 + CH₃CHO, 6. Wine + HCl (SASEV/ SAWWV, 2003).

Using a micro pipettor 2 mL wine was accurately added to test tubes one and three, and 2 mL pH 3.5 adjusted wine was added to test tubes two, four and five. In test tubes three and four, 30 μ L of a 25% Na₂SO₅ solution was added and thoroughly mixed using a Heidolph REAX vortex. Subsequently 20 μ L of a 10% CH₃CHO solution was added to test tube 5 and thoroughly mixed using the vortex. Samples were left to stand for 45 minutes before spectral measurements were taken. During this time, test tube six was prepared by adding 10 mL 1N HCl to the test tube. A 100 μ L sample of wine was micro pipetted into test tube six. This test tube was then left to stand for three hours before spectral measurements were done. Before the samples were measured in the UV/Visible Spectrophotometer SPECORD 40, all samples were centrifuged in the Digicen 21R (OrtoAlresa) at 13000 rpm for 10 minutes at 15°C. A representative wine sample was used to inspect the instruments reliability, as well as the sample consistency. These absorbance readings were done in triplicate. Test tubes one to five were measured in a 1 mm glass cuvette at 420 nm and 520 nm, whereas test tube six was measured in a 10 mm quartz cuvette at 280 nm and 520 nm. The absorbance readings of test tubes one to five were multiplied by a factor 10, and divided by the width of the cell, *i.e.* 1 mm, in order to calculate what the absorbance would have been if it was measured in 10 mm cuvettes. The absorbance readings of test tube six were also converted to what it would have been undiluted, *i.e.* multiplied by the dilution factor of 101. The above-mentioned procedure was done for all 12 red wines in triplicate, and the spectral measures were calculated using the formulae in Table 5.

Table 5: Formulae used to calculate the various spectral measures by applying the appropriate values. (SASEV/SAWWV, 2003).

Wine colour density = $A_{520} + A_{420}$	Modified wine colour density = ($A_{CH_3CHO_{520}} + A_{CH_3CHO_{420}}$) pH 3.5
Wine colour hue = A_{420} / A_{520}	Modified wine colour hue = ($A_{CH_3CHO_{420}} / A_{CH_3CHO_{520}}$) pH 3.5
SO ₂ resistant pigments = $A_{SO_2_{520}}$	Modified SO ₂ resistant pigments = ($A_{SO_2_{520}}$) pH 3.5
Total red pigment colour = $A_{HCl_{520}}$	
Degree of red pigment colouration = ($A_{520} / A_{HCl_{520}}$) x 100%	Modified degree of red pigment colouration = ($A_{CH_3CHO_{520}} / A_{HCl_{520}}$) pH 3.5 x 100%
Total phenolics = $A_{HCl_{280}} - 4$	

3.2.5 Standard analytical parameters

During 2016 clear samples (50 mL) were sent to the CAF Laboratory at Stellenbosch University in the for a Standard analytical parameters (FOSS GrapeScan 2000, FT 120) measuring volatile acidity (g of acetic acid/L), total acidity (g of tartaric acid/L), malic acid (g/L), lactic acid (g/L), glucose and fructose (g/L), ethanol (% vol) and glycerol (g/L) concentrations. The WineScan could not be completed on the 2015 wines, as a result of most of the wines were completed used for the sensory analysis (Davel, 2015).

3.2.6 Sensory analysis

Descriptive Analysis (DA) sensory evaluation was used in order to evaluate all wines according to the different salt concentrations, both in 2015 and 2016. In 2015, twelve judges were trained for eight 2-hour session for the white wines, and six 2-hour sessions for the red wine. These panellists were trained according to the consensus method (Lawless & Heymann, 2010). Different sensory characteristics were developed in these training sessions for both the Pinotage and Chenin blanc wines, and then used for the actual testing of the wines at the end of the training sessions. In 2016, the same procedure was used, however new attributes were chosen for the different wines. The analysis was done on the aroma, and taste of the wine as well as mouth feel, length and if saltiness was picked up by the panel. The various panel members were asked to measure the intensity of the chosen attributes, as well as their presence or absence when appropriate.

3.2.7 Statistical analysis

Statistical analysis was conducted using StatSoft STATISTICA 13®. Principle component analysis (PCA) biplots were obtained using mean values which were scaled.

3.3 Results and discussion

3.3.1 Soil samples

According to Fitzpatrick *et al.* (1994) there are three properties common in classifying salt-affected soils: soil profile morphology, soil physical properties and soil chemistry. Soil chemistry properties such as salt content, composition, distribution in whole profile as well as in the groundwater, ESP and SAR, the soil pH and the presence of Na carbonates in the soil profile. Soil samples taken from Farm A and B Chenin blanc and Pinotage (Figure 6, 7, 8) showed considerable variation between the low and high vigour levels and depths, especially Farm A Chenin blanc (Figure 6) and Farm B Pinotage (Figure 8). Soil electrical resistance demonstrates that high vigour showed higher resistance than low vigour, whereas the soil Na content is higher in the low vigour plots. This confirms larger amounts of salts present in the soil, as they conduct electricity and lower the soil electrical resistance (Van Schoor *et al.*, 2000), confirming the antagonistic relationship between the resistance and salt levels of the soils on Farm A Chenin blanc (Figure 6) and Farm B Pinotage (Figure 8). An increase in SAR and ESP values are noted in deeper soil horizons of the low vigour plots, showing a synergistic relationship with the soils' Na content.

Some of the ESP values in the low vigour plots are higher than 15%, with some surpassing 35% and some resistance values were lower than 300 Ohm. When the resistance is lower than 300 Ohm and the ESP is higher than 15%, the soil can be classified as being saline (Van Schoor *et al.*, 2000). According to Flynn & Ulery (2011) when the ESP is above 15% and pH is more than 8.5, the soil can be classified as sodic.

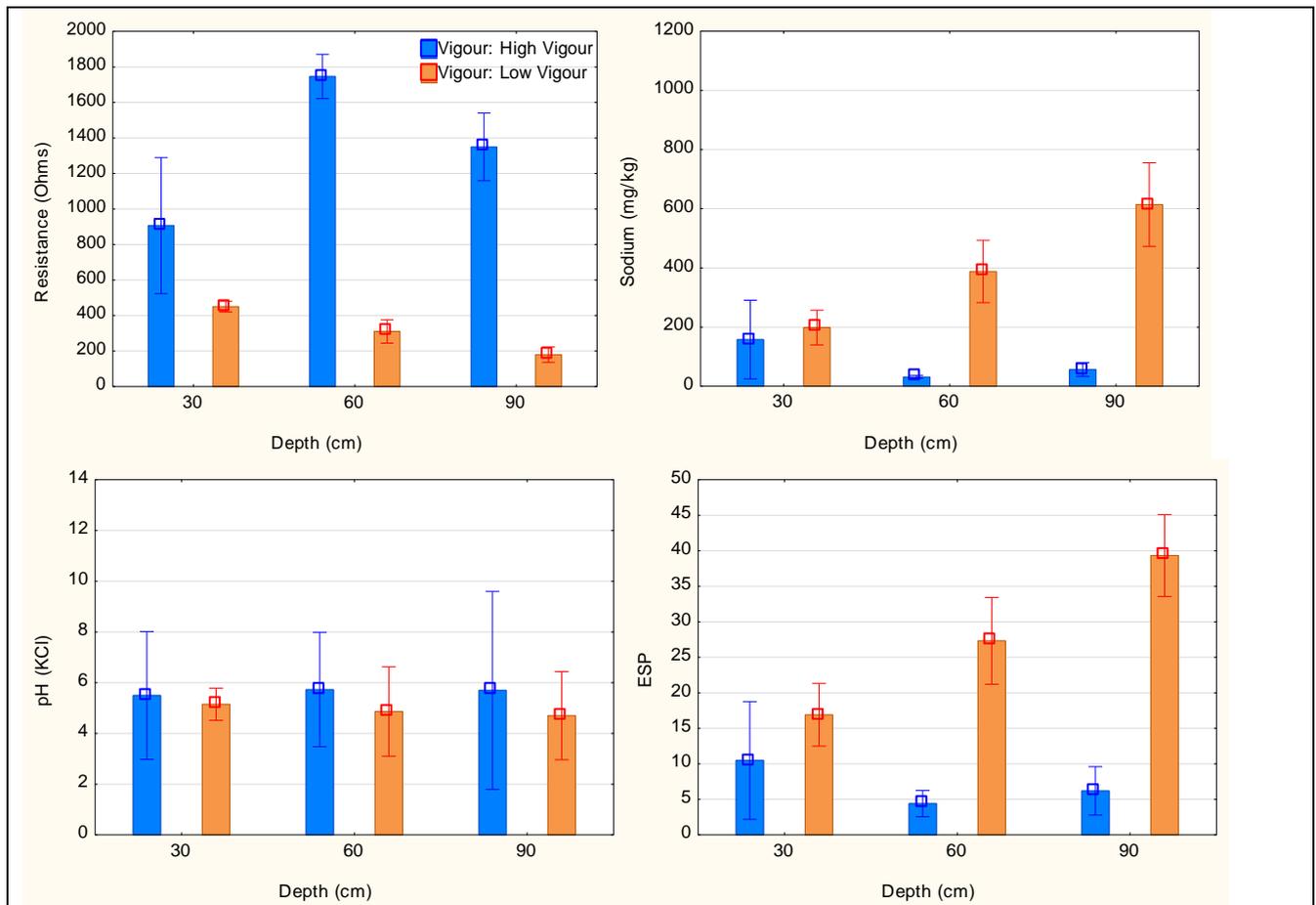


Figure 6: Soil resistance (Ohms), sodium content (mg/kg), SAR and ESP (%) of Farm A Chenin blanc grouped by depth and categorised according to vigour, vertical bars denote standard errors (for each parameter, depth and vigour, bars represent mean values of 3 replicates).

The pH values from Figure 6, 7 and 8 showed no significant trend towards being classified as being sodic from a pH point of view. This could indicate a high amount of Na salts present in the soil without the soil being sodic.

Figure 7 illustrates the soil resistance measurements being fairly similar, whereas the soil Na content is higher in the low vigour plots compared to the high vigour plots. However this soil cannot be classified as brackish according to Van Schoor *et al.* (2000), as the soil's resistance for low and high vigour are higher than 300 Ohm and there are only a few ESP values that have values above 15%. Due to this it can be concluded that the Farm A Chenin blanc (Figure 6) and Farm B Pinotage (Figure 8) plots are salt-affected. Addendum A shows a full soil sample analysis for Farm A Chenin blanc, Farm B Chenin blanc and Farm B Pinotage.

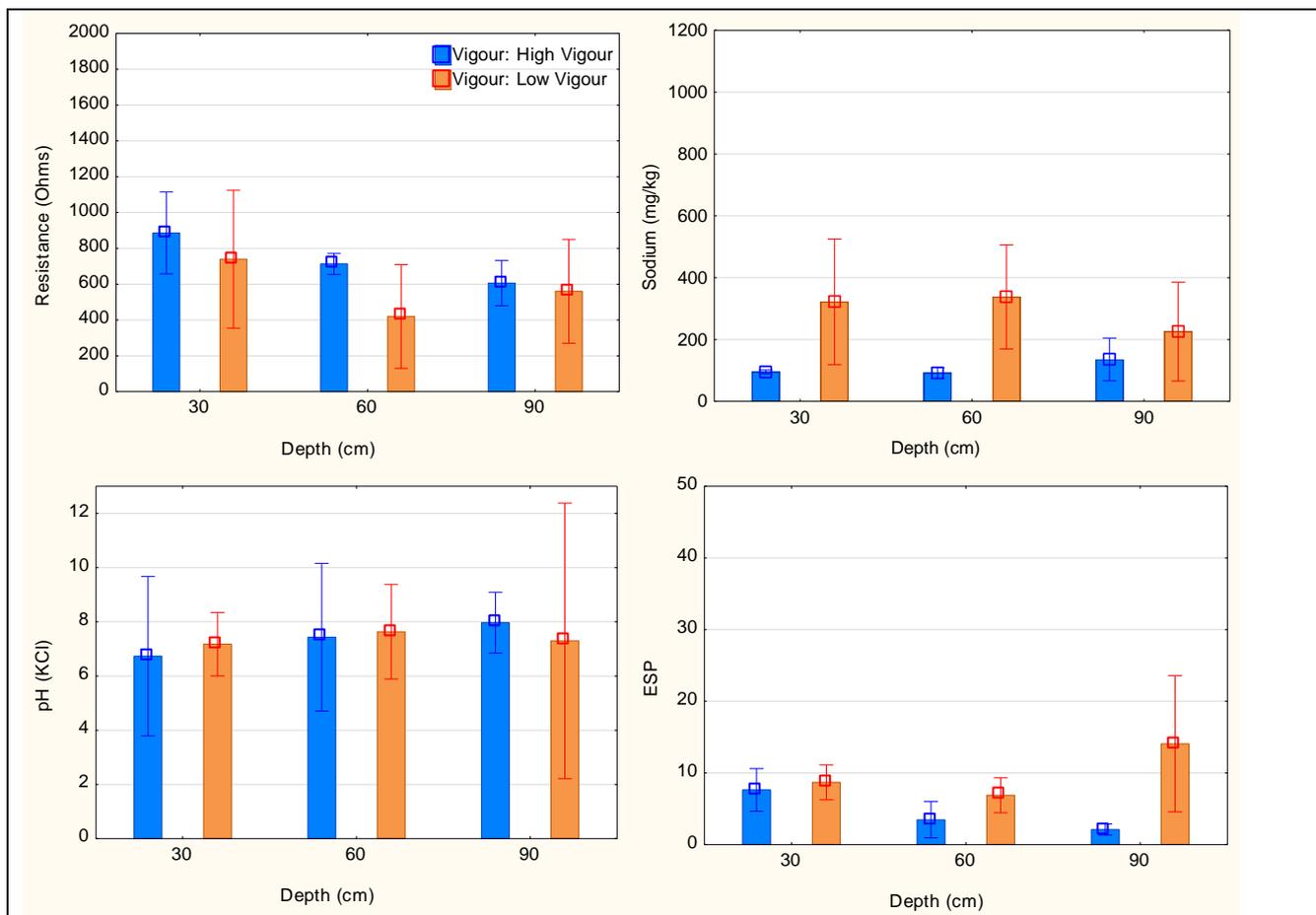


Figure 7: Soil resistance (Ohms), sodium content (mg/kg), SAR and ESP (%) of Farm B Chenin blanc grouped by depth and categorised according to vigour, vertical bars denote standard errors (for each parameter, depth and vigour, bars represent mean values of 3 replicates).

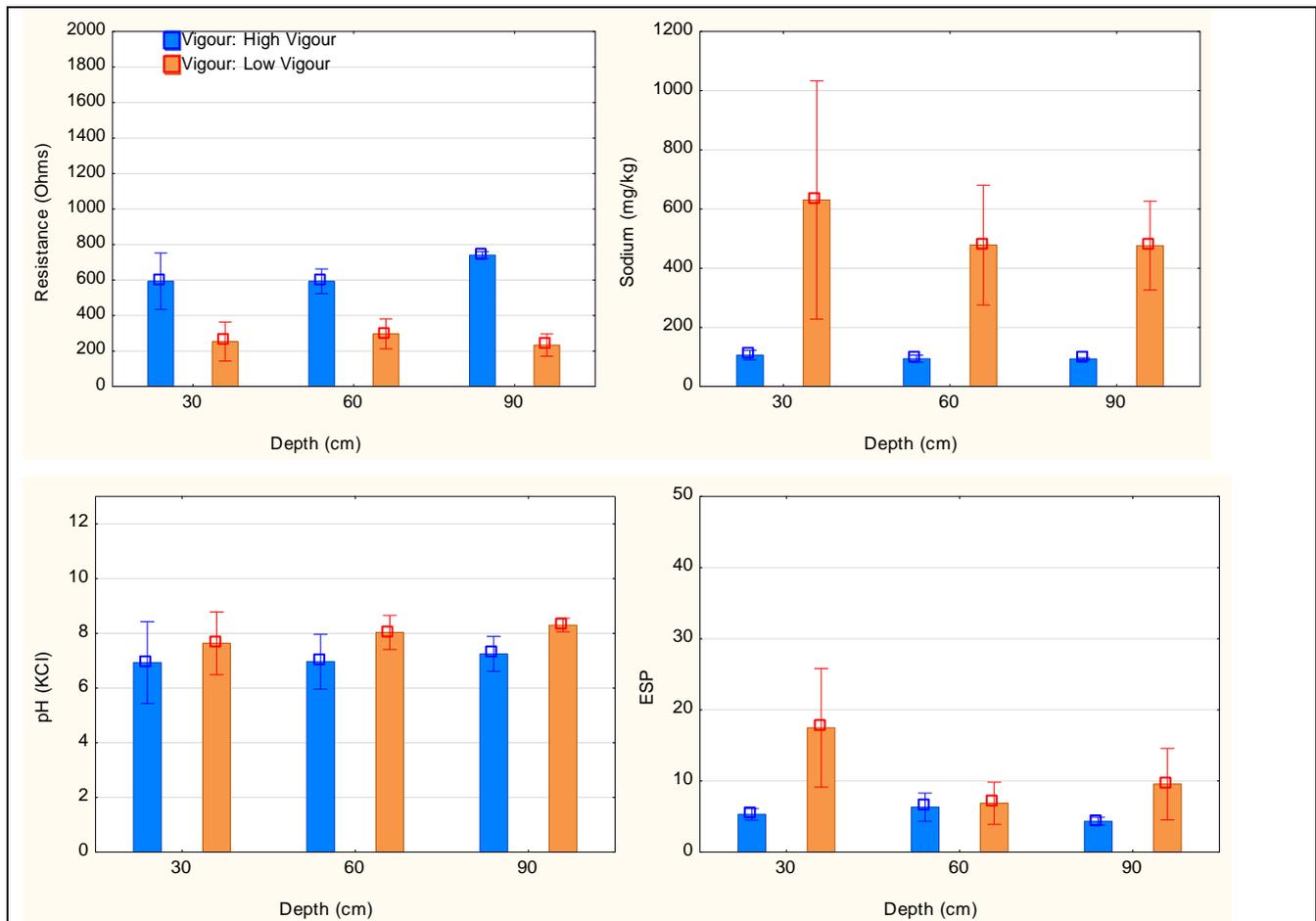


Figure 8: Soil resistance (Ohms), sodium content (mg/kg), SAR and ESP (%) of Farm B Pinotage grouped by depth and categorised according to vigour, vertical bars denote standard errors (for each parameter, depth and vigour, bars represent mean values of 3 replicates).

3.3.2 Climate measurements

Climate plays a crucial part in wine grape production, and can affect wine quality and wine typicity throughout the world (Tonietto & Carbonneau, 2004; Mouton, 2006). According to Anderson *et al.* (2008) temperature has the largest effect on the grapevine, specifically on the phenology, photosynthesis, respiration and translocation of assimilated carbon, as well as the biochemistry and translocation of flavour compounds and berry precursors. In South Africa the climate in the Western Cape Province can be described as warm, temperate Mediterranean climate, with winter rainfall (Kendrew, 1961; Schulze, 1972 as cited in Conradie *et al.* 2002).

During the 2015 season in the Paarl region decreases in production were reported due to dry conditions and wind which led to weaker growth and smaller berries. In the 2016 season, much smaller crops were harvested in the Paarl region at an earlier stage. The small berries may have been as a result of the low rainfall, limited water supply and very high temperatures (Van Schalkwyk, 2015 & 2016). Figure 9 shows the temperature differences between the two farms throughout the growing season. In Figure 9A Farm A, the maximum, minimum and mean temperatures follow a parabolic

trend. January being the warmest month and July reaching the coldest minimum temperature. Figure 9B, Farm B, shows a similar parabolic trend however a sudden temperature decrease can be seen around May. The slight difference in temperature between the two farms could be attributed to the difference in elevation of the sites.

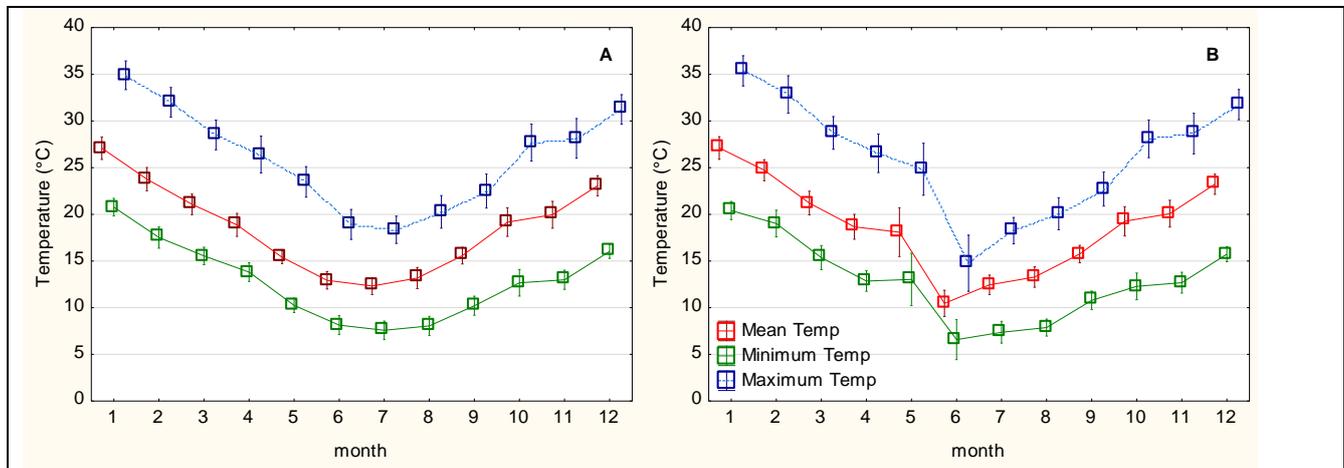


Figure 9: A distance-weighted least squares plot of daily mean, minimum and maximum temperatures (°C) from meso-climate logger (Tinytag® model TGP-4500, Gemini Data Loggers, West Sussex, United Kingdom) on Farm A and B (A and B respectively), with the vertical bars denoting a 0.95 confidence interval.

Grape composition and quality is influenced by temperature. According to Van Schalkwyk (2015) the 2015 vintage was early in Paarl, with smaller crop but of exceptional quality. The 2016 season however produced small crops as a result of a dry and warm season (Van Schalkwyk, 2016). Climatic indices can quantify the viticultural regions in terms of quality using temperature (Tonietto & Carbonneau, 2004). Using Le Roux's (1974) adaption of Amerine and Winkler (1944) indices, Equation 1 calculates the growing degree days (GDD) for a specific region, using the daily summation of the minimum and maximum temperature between the beginning of September and the end of March. Five climatic regions are shown in Table 2 where both Farm A and Farm B were categorised as being in region V, which is considered desert wine and brandy climatic conditions. A weather station close to the farms was also used to calculate the different indices. The temperature at the weather station is also classified as region V, however the GDD is far less than for Farm A and B.

Another index, the Huglin Index (1978), is calculated using the mean and maximum monthly temperatures from the beginning of October to the end of March, but taking the day length coefficient into consideration, which is 1 in the Western Cape.

Table 3 shows the six Huglin climatic indices, where Farm A and the weather station climate can be considered hot, which exceed heliothermic requirements and can cause high temperature stress for the grapevine. Farm B is considered to be very hot, and according to this index a possibility of implementing two harvests in a year may be possible (Table 3).

In the Western Cape, the mean February temperature is also used as an index, as it is considered to be the warmest month of the year. De Villiers *et al.* (1996) adapted the mean February temperature from Smart & Dry (1980), which was done for Australian vineyards, for the Western Cape. According to Table 6 the mean temperature for February was lower than the mean temperature for January, which made January the warmest month during 2015/2016 ripening season. Using the mean February temperature the climate can be described as hot, where low acids and high pH may occur in the final wine. If the mean January temperature is used, the climate can be described as hot, which may result in wines with low acidity and high pH, thereby negatively affecting the wine quality.

Table 6: Climate indices showing Farm A and B, and a nearby weather station. (GDD = Growing degree days; HI = Huglin Index; GST = Growing season temperature and mean January, February and March temperature Indices).

		GDD	HI	GST	Mean Jan. Temp. (°C)	Mean Feb. Temp. (°C)	Mean March Temp. (°C)
2015/2016	Farm A	2644.3	2967.1	22.4	27.1	23.8	21.1
2015/2016	Farm B	2641.0	3038.7	22.6	27.1	24.7	21.2
2015/2016	Weather Station	2281.1	2710.9	20.9	25.5	23.8	21.1

3.3.3 Vegetative measurements

3.3.3.1 Trunk circumference

The grapevine trunk circumference can be used as a measure for variation in vigour on a site-specific level (Bramley *et al.*, 2011; Imre *et al.*, 2013; Strever, 2003). De Clercq & Van Meirvenne (2006) noted trunk circumference can be used as an index of growth. They reported a negative correlation between trunk circumference and EC_e, and a positive relationship with soil pH. Trunk circumference on Farm A Chenin blanc varied from 20 to 40 cm in size, whereas Farm B Chenin blanc varied from 15 to 20 cm in size. Farm B Pinotage showed far less variation between low and high vigour, where values ranged from around 15 to just below 20 cm respectively. The trunk circumference for both Figure 10A and B show considerable differences in vigour, the low vigour areas seeming to have smaller trunk circumferences. Farm A Chenin blanc showed the most variation in both the low and high vigour plots, which may be due to the bush vine training system used. Both Pinotage and Chenin blanc on Farm B showed little variation in grapevine trunk size. Variations in trunk circumference could be due to various soil and vegetative characteristics of the plots (Imre *et al.*, 2013; Strever, 2003). Soil characteristics such as soil electrical resistance and texture could contribute to the variation in trunk size occurring on both plots.

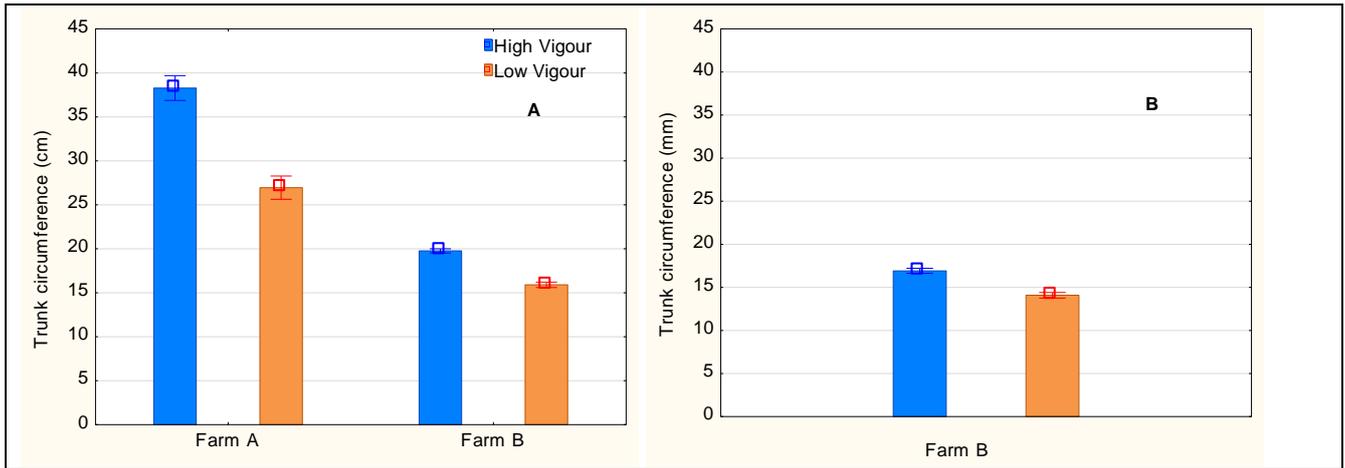


Figure 10: Trunk circumference (cm) on Farm A and B (A) Chenin blanc and Farm B Pinotage (B) grouped by depth and categorised according to vigour, vertical bars denote 0.95 confidence interval (for vigour, bars represent mean values of 3 replicates).

Figure 11 shows a logarithmic relationship between trunk circumference and soil resistance, where the higher the soil resistance is, the larger the trunk circumference would be. According to Strever (2003) relationships between soil conditions and trunk circumference should be logarithmic, because of certain environmental and vine genetic limitations, but also due to the fact that soil resistance levels theoretically will not reach zero.

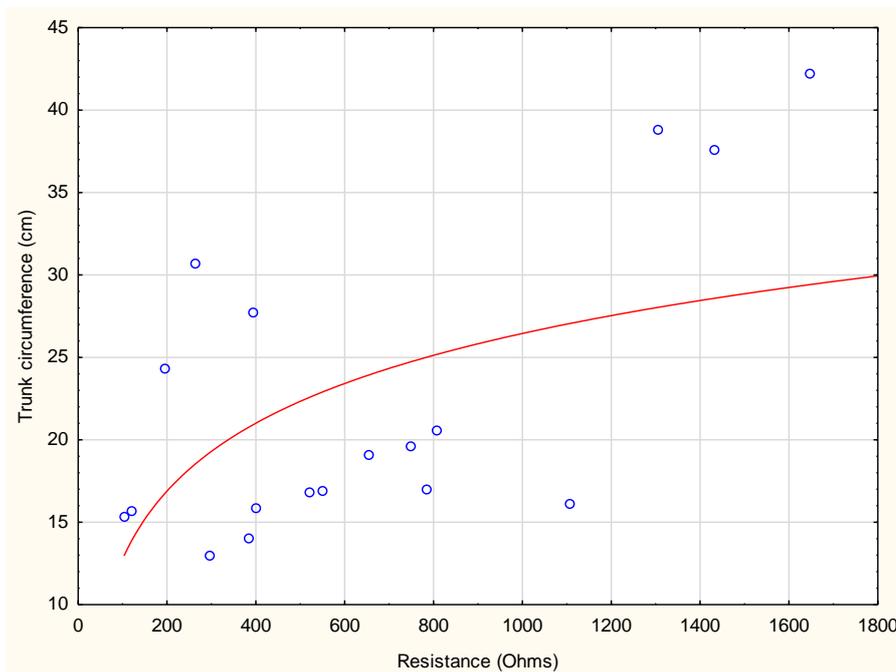


Figure 11: Relationship between the mean trunk circumference and the mean resistance of a saturated soil paste for Farm A and B Chenin blanc and Farm B Pinotage ($p = 0,002$; $r = 0,68$).

3.3.3.2 Shoot growth

High quality wine grape production is dependent on a balance between grapevine vegetative and reproductive growth (Winkler *et al.*, 1962; Bowen & Kliewer, 1990). According to Williams & Matthews (1990) vegetative growth can be described as exponential at the start of budburst, where the shoot

elongation is highest early in the grapevine's growing season, and slowly decreases as the season progresses, thereby becoming sigmoidal in shape. This growth pattern can clearly be seen in Figure 12B and to a lesser degree in Figure 12C. However, Figure 12A shows a steady linear increase in shoot growth with an abrupt stop in growth due to topping action completed just before véraison by the farm. A distinct difference in shoot vigour can be observed in Figure 12A and B, where the low vigour vines appear to have less shoot elongation than the high vigour vines throughout the vegetative growing season. Less variation in vigour can be noted on Farm B Pinotage (Figure 12C), the low vigour still somewhat slower in rate of shoot growth. However since shoot growth data was not collected the previous season (2014/15) no accurate assumptions can be made.

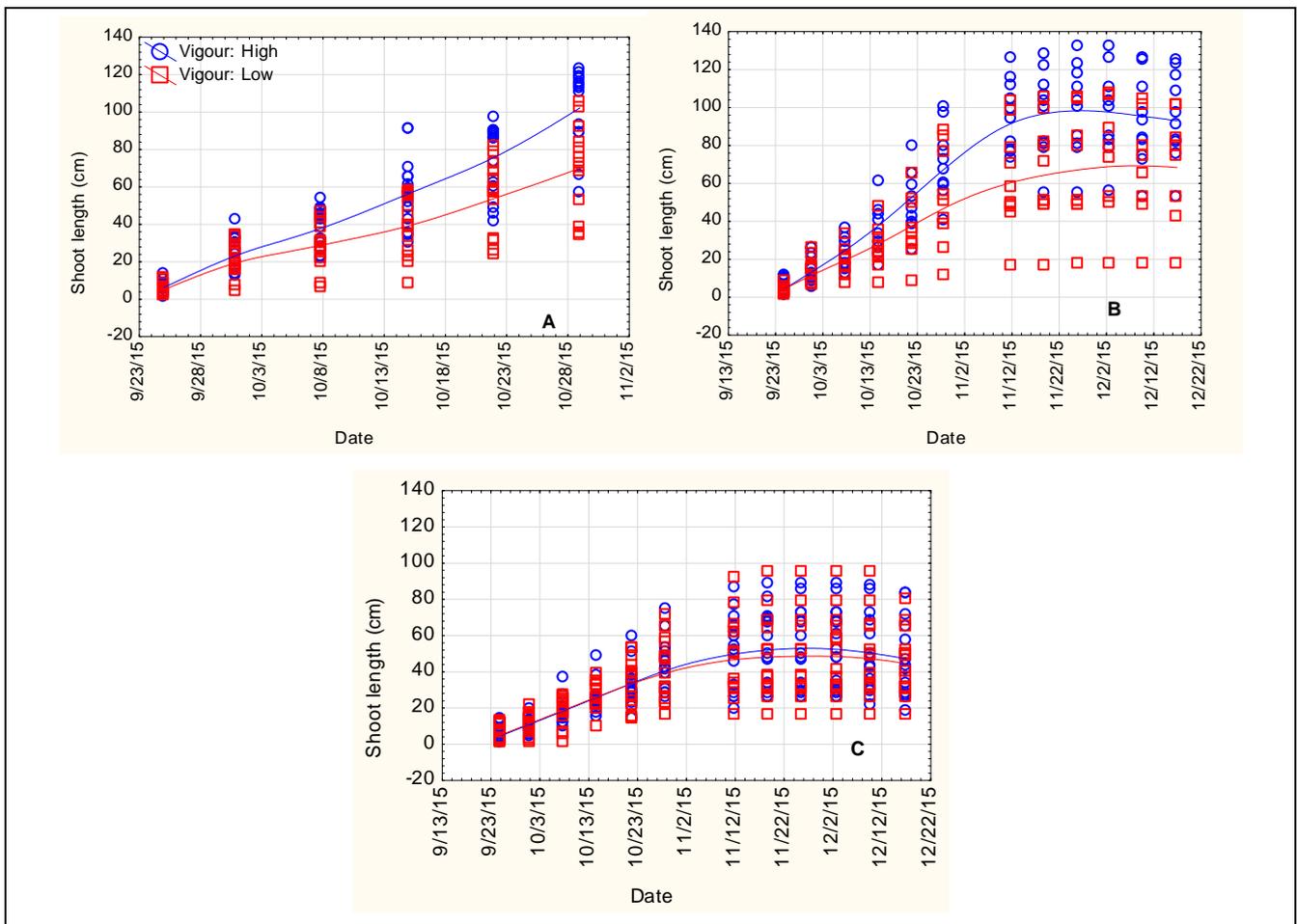


Figure 12: Distance weighted least squares fit shoot growth graphs from measurements conducted over a course of 12 weeks, grouped by date and categorised by vigour on Farm A Chenin blanc (A), Farm B Chenin blanc (B) and Farm B Pinotage (C) (for each parameter, bars represent mean values of 3 replicates).

3.3.3.1 Destructive shoot analysis

Differences in vigour can be seen in Table 7, where the typical characteristics of high vigour vines can be seen to have longer shoots, larger leaves and more lateral shoots compared to the low vigour plots (Smart *et al.*, 1985). The high vigour vines produced larger leaves for the Farm A Chenin blanc and Farm B Pinotage, whereas the Farm B Chenin blanc showed no significant differences (Figure 13 & Table 7). Furthermore, the high vigour vines also produced higher main and lateral leaf areas for

all plots. Farm B Chenin blanc showed the highest total leaf area per shoot for the high vigour plots, but also for the low vigour plots. Smart (1992) attributed high lateral growth to more vigorous growth.

Table 7: Destructive shoot analysis for Farm A and B Chenin blanc, and Farm B Pinotage, grouped according to vigour; showing standard deviations and coefficients of variation (all variables between vigour levels are significantly different at the $p \leq 0.05$ level) (for each parameter, bars represent mean values of 3 replicates).

	Farm A Chenin blanc		Farm B Chenin blanc		Farm B Pinotage	
	Low Vigour	High Vigour	Low Vigour	High Vigour	Low Vigour	High Vigour
Area per leaf on main shoots (cm ²)	55,3 ± 21,1* (38,2**)	83,3 ± 17,2 (20,7)	66,6 ± 16,8 (25,2)	62,5 ± 8,7 (14,0)	60,9 ± 11,8 (19,4)	82,8 ± 10,90 (13,2)
Main leaf area (cm ²)	543,3 ± 204,8 (37,7)	1139,7 ± 388,4 (34,1)	935,1 ± 242,8 (26,0)	1293,4 ± 459,3 (35,5)	801,5 ± 224,4 (28,0)	1280,6 ± 201,4 (15,7)
Lateral leaf area (cm ²)	223,3 ± 237,6 (106,4)	514,5 ± 394,5 (76,7)	336,3 ± 368,3 (109,5)	550,5 ± 431,7 (78,4)	71,9 ± 83,5 (116,1)	348,8 ± 204,5 (58,6)
Total leaf area per shoot (cm ²)	766,6 ± 250,5 (32,7)	1654,3 ± 680,0 (41,1)	1271,4 ± 570,3 (44,9)	1843,9 ± 854,5 (46,3)	873,4 ± 299,4 (34,3)	1629,4 ± 344,3 (21,1)
Ratio lateral: main leaf area	0,41	0,45	0,36	0,43	0,09	0,27

* Standard deviation of mean

** Coefficient of variance (%)

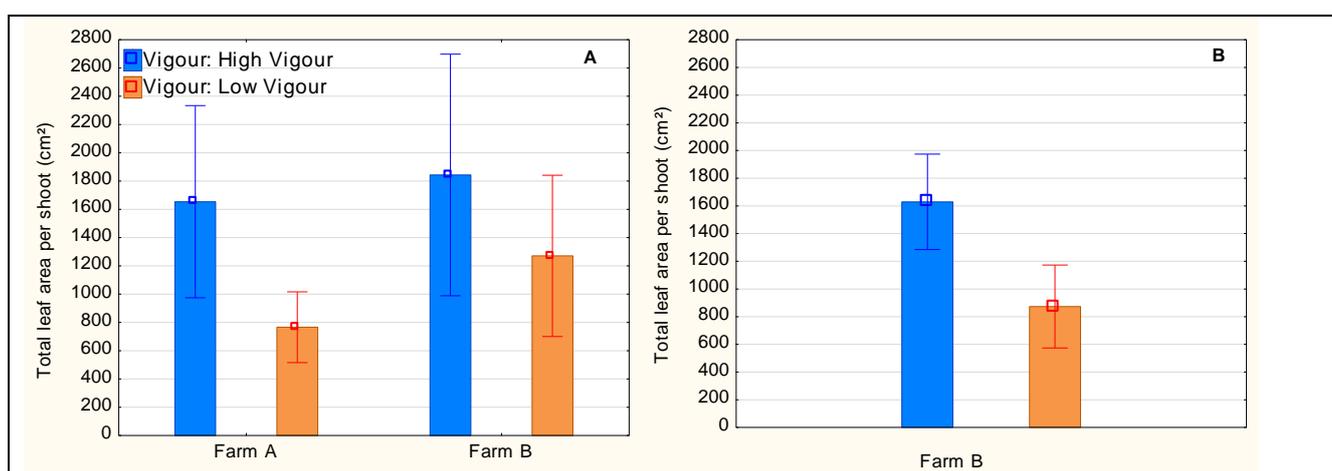


Figure 13: Total leaf area per shoot (cm²) for Farm A and B Chenin blanc (A) and Farm B Pinotage (B) grouped by cultivar and categorised according to vigour, vertical bars denote 0.95 confidence intervals (for each vigour, bars represent mean values of 3 replicates).

The density and distribution of leaves in a canopy are vital parameters for grapevine growth and canopy composition. Factors including light penetration, grapevine responses to the environment, training systems and canopy management practices play an important role in determining canopy characteristics (Lopes & Pinto, 2005). Factors such as salt stress in the grapevine may also have an

impact on the vigour differences. According to Sinclair & Hoffman (2003) salt stress reduces photosynthetic rates by lowering leaf expansion rates, decreasing root and shoot growth, but also cause leaf burn and leaf death in extreme cases. Figure 14 shows a relatively strong correlation between the soil resistance and the total leaf area per shoot. It indicates that as soil resistance increases, the total leaf area will also rise.

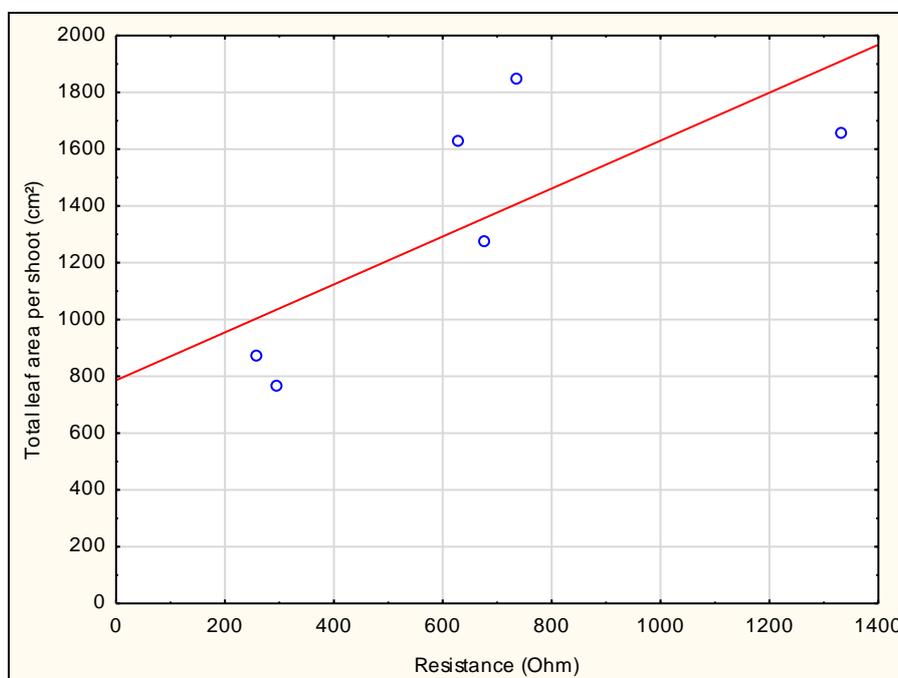


Figure 14: Relationship between soil resistance and total leaf area per shoot ($p = 0,095$; $r^2 = 0,54$).

3.3.3.2 Leaf and petiole mineral nutrient measurements

Grapevine mineral nutrients can be divided into two broad groups, based on their uptake patterns. Nutrients such as N, K, Mg and P are taken up by the grapevine throughout berry growth, however Ca is taken up before véraison (Raath, 2012) Mineral nutrient content may change depending on the plant part sampled, as well as the time of sampling (Romero *et al.*, 2010). According to Prior *et al.* (1992) saline conditions had an effect on the mineral contents of the different vine parts in their study, specifically the leaf laminae and petioles. However poor consistency between years and between the laminae and petiole samples was also reported. Differing nutrient levels could be attributed to indirect effects, particularly as a result of growth reductions, as well as alterations of physiological processes (Downton, 1985).

The Na concentrations in the leaves and petioles during véraison and bloom are shown in Figure 15A, C and E. A clear difference between the Na leaf and petiole sample content can be distinguished, showing the petiole samples as being higher than the leaf samples. Prior *et al.* (1992) concurred this; he noted that Cl and Na levels in the petiole were always higher than the concentrations found in the laminae. Christensen (2005) also confirmed this, stating that if Na and/or Cl toxicity is suspected, only the petioles should be analysed, as these elements accumulate mainly in the petioles, however the

leaves may show the symptom. He also noted that levels of more than 0.5% (>5000 mg/kg) at bloom in the petioles may suggest toxic Na levels. Both Figure 15B and C, show levels just below 5000 mg/kg in the petiole samples during bloom. The high petiole Na concentrations may be due to the high Na levels in the soils found on Farm B Pinotage (Figure 8). A strong correlation between leaf Na content and petiole Na content is shown in Figure 19A ($r^2 = 0.79$; $p < 0.001$; $r = 0.89$).

K is seen as the most important mineral nutrient cation, as it plays a number of vital roles in the metabolic functions in the grapevine. An antagonistic relationship between Na and K leads to lower K concentrations in all plant parts if saline conditions are present in the soil (Fisarakis *et al.*, 2007). This is due to the chemical similarities between Na and K, where both are alkali metals containing one single valence electron, as well as being very good reducing agents (Peacock, 1999). Even though this antagonism exists, the K content on Farm B Chenin blanc is still high, even though high Na levels were also found. This may have been due to an addition of K fertiliser, such as K chloride, K nitrate, K sulphate, liquid K carbonate and liquid K thiosulphate, however as problems with salinity have occurred on this farm, K chloride was most probably not used (Peacock, 1999). The K leaf and petiole sample concentrations during bloom and véraison are displayed in Figure 15B, D and F. A slight difference can be seen between the leaf and petiole sample contents, where the leaf concentration is slightly less than the petiole K content. According to Weir & Cresswell (1993) leaf K concentrations of less than 0.62% for samples taken during flowering show a K deficiency, whereas K levels of less than 0.52% during véraison are seen as deficient. Normal leaf K levels during flowering are between 1.0 and 1.8%, whereas for véraison 0.8 and 1.6%. Figure 15B, D and F all show K leaf levels to be below the 'normal' ranges. The petiole K concentration levels differ slightly compared to the leaf K content levels. A deficiency in K in the petioles occurs if the K levels are below 1.0%, whereas the K levels are considered normal between 1.8 and 3.0%. Figure 15D and F show K levels in petioles as being adequate both during bloom and véraison. Figure 15B, on the other hand, indicate 'marginal' K levels in the petiole. The amount K in the leaves and petioles Figure 15D and F is slightly less during véraison, due to the translocation of K into the grapevine berries. The reason for the movement of K ions into the berries, may be due to high demand of K during rapid cell expansion (Mpelasoka *et al.*, 2003). Figure 19B also shows a strong correlation between leaf and petiole K uptake in the grapevine ($r^2 = 0.61$; $p < 0.001$; $r = 0.78$). Correlations between all minerals analysed in the leaves and petioles are displayed in Addendum B.

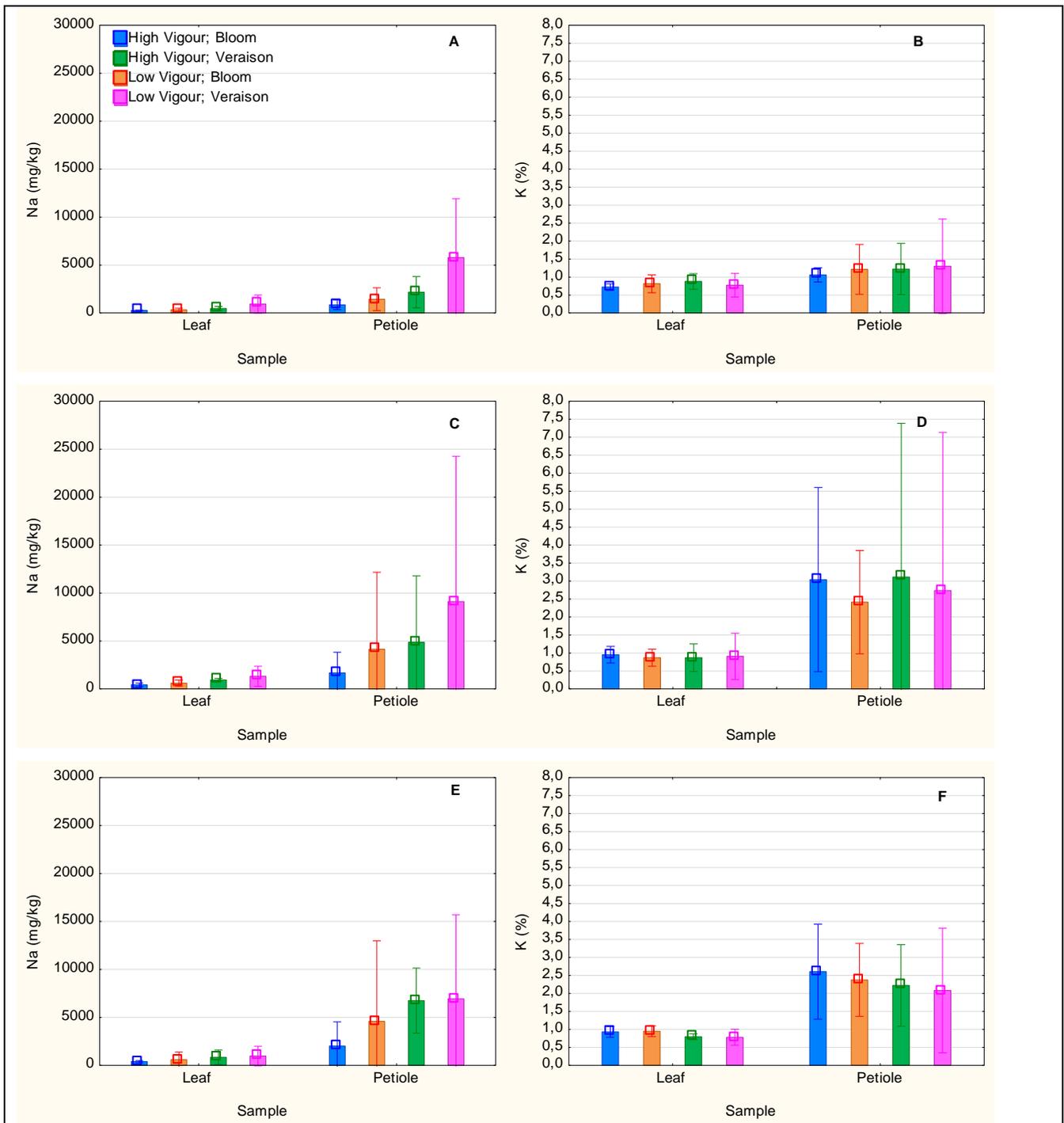


Figure 15: Leaf and petiole Na (mg/kg) and K (%) concentrations of Farm A Chenin blanc (A & B), Farm B Chenin blanc (C & D) and Farm B Pinotage (E & F) grouped according to sample (leaf/petiole), categorised by vigour and phenological stage; vertical bars denote 0.95 confidence intervals (for each parameter, sample type, sample time and vigour's, bars represent mean values of 3 replicates).

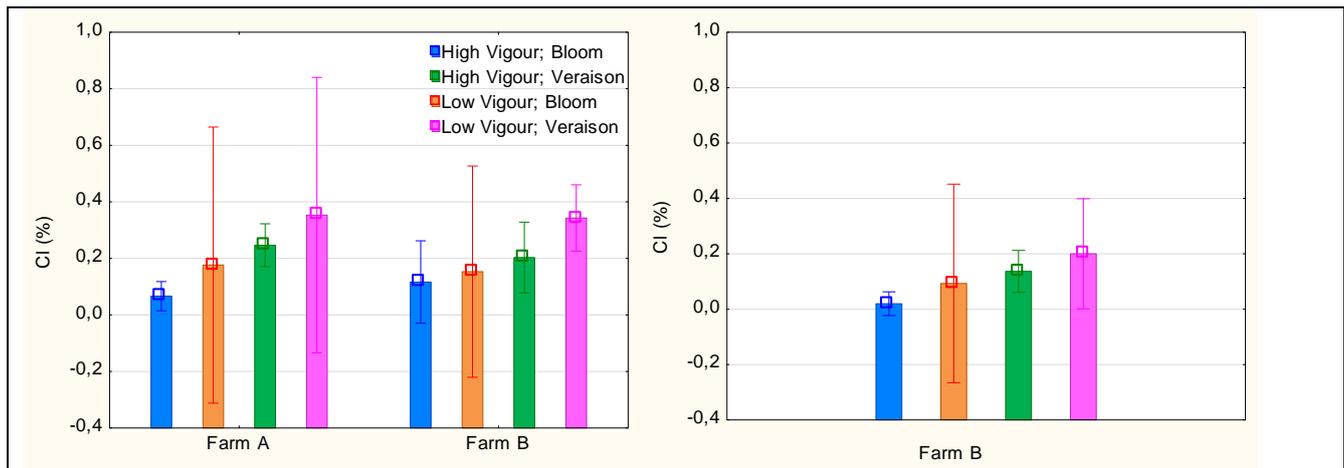


Figure 16: Leaf Cl (%) grouped according to farm, categorised by vigour and phenological stage; vertical bars denote 0.95 confidence intervals (for each parameter, sample time and vigour's, bars represent mean values of 3 replicates).

Cl plays an essential role in biochemical and physiological processes including photosynthesis (Storey *et al.*, 2003). However if Cl toxicity occurs, marginal chlorosis and leaf burn may occur. Excessive Cl accumulation particularly in the leaves is reportedly the reason for salt damage in the grapevine. Grapevines accumulate significant amounts of Cl in the shoots and leaves, particularly the older leaves (Abbaspour, 2008). Cl concentrations in the leaf showed variability between vigour levels, sample time and sites. For the low vigour sites, leaf Cl concentrations exhibited the highest Cl levels, which concurred with higher salt content in the soil as a result of salinity (Kafkafi *et al.*, 2001). The highest Cl content was shown to be from leaves obtained during véraison. The Na concentration in the leaves during véraison was also shown to be the highest. Figure 17 displays a strong correlation between the Cl and Na leaf concentrations ($r^2 = 0.50$; $p < 0.001$, $r = 0.70$). According to Weir & Cresswell (1993) the Cl concentrations in the leaves during véraison are considered normal when below 1.3%, high when between 1.3 and 1.8%, and toxic when above 1.82%. Figure 16, however indicates that levels occurring in this trial are much lower than the toxic levels, which indicates that Cl concentrations in the grapevine leaves are low.

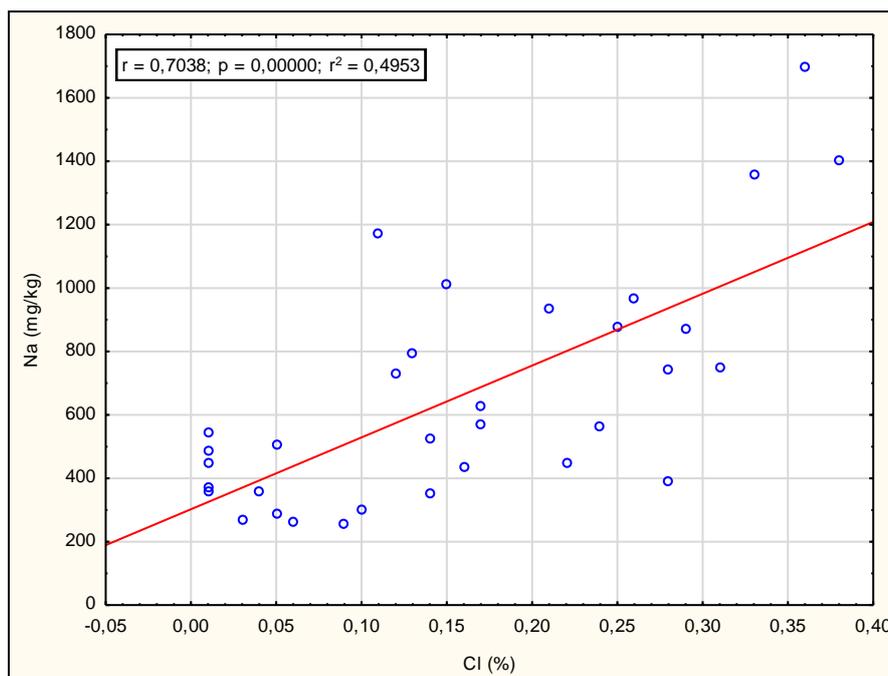


Figure 17: Correlation between leaf Na and leaf Cl concentrations.

Ca is a non-mobile plant nutrient, which means that remobilisation of Ca does not occur, therefore older leaves would have the highest Ca content. According to Romero *et al.* (2010), the Ca content should be analysed using leaves rather than petioles. Benito *et al.* (2013) also reported that Ca levels were highest in the leaves, rather than the petioles. Christensen (2005), however showed petiole Ca levels to be more when K and Mg levels are low. Figure 18A, C and E all show Ca levels in leaf blades being more than in the petiole Ca samples. According to Weir & Cresswell (1993) adequate leaf Ca levels during flowering are 1.2 to 2.8%, whereas for véraison levels between 1.8 to 3.2% seem to be normal. Figure 19C shows a strong correlation between leaf and petiole Ca levels ($r^2 = 0.79$; $p < 0.001$, $r = 0.89$). The low vigour véraison leaf Ca levels, however are slightly lower than the normal levels.

As salinity increases, Ca content of plant parts do not increase, whereas Mg levels rise (Downton, 1985). Petiole and leaf Ca concentrations decreased under increasing Na concentrations (Figure 8), which could be attributed to antagonistic effects between Na and Ca (Figure 18E). Both low and high vigour Ca leaf and petiole levels during bloom and véraison were lower than the high vigour Ca levels, which may have been due to the antagonism between Na or Mg and Ca (Christensen, 2005). Fisarakis *et al.* (2007) reported that the presence of Ca and Mg in leaves increased salinity damages.

Mg is a vital component of chlorophyll, thereby making it essential for photosynthesis (Saayman, 1981). Mg is a mobile mineral in the grapevine, therefore it may remobilise from old to new leaves (Romero *et al.*, 2010). Romero *et al.* (2010) and Benito *et al.* (2013) reported that Mg levels were higher in the petioles compared to the leaf blades, which corresponds with Figure 18D, E and F, which shows petiole Mg concentrations are higher compared to the leaf levels. Pradubsuk & Davenport (2010) also showed Mg levels in the petiole, shoot tips and clusters to be higher and more dynamic,

compared to other plant parts. According to Christensen (2005) and Benito *et al.* (2013) Mg content in leaves and petioles increased throughout the season, which can also be seen in Figure 18B and F. Figure 18D shows a slight increase from bloom to véraison, however not as high as Figure 18B and F. Figure 19D shows the strong correlation between leaf and petiole Mg levels ($r^2 = 0.74$; $p < 0.001$; $r = 0.86$). Weir & Cresswell (1993) noted that leaf Mg levels below 0.2% at flowering can be seen as deficient, whereas levels between 0.3 and 0.6% were seen to be normal. The petiole Mg sample levels of below 0.3% are seen as deficient and above 0.4% as adequate, where no visible signs of toxicity are visible. All petiole Mg levels during véraison are normal according to Weir & Cresswell (1993).

Downton (1985) and Prior *et al.* (1992) reported that increasing salt concentrations in the soil, increased the Mg content of the leaves and petioles. This could be due to the increasing Mg concentrations in the soil salt solution. Both the leaf and petiole analysis for the low vigour plots in Figure 18B, D and F indicate a higher Mg content than in the high vigour plots, which could be linked to salt problems in the soil.

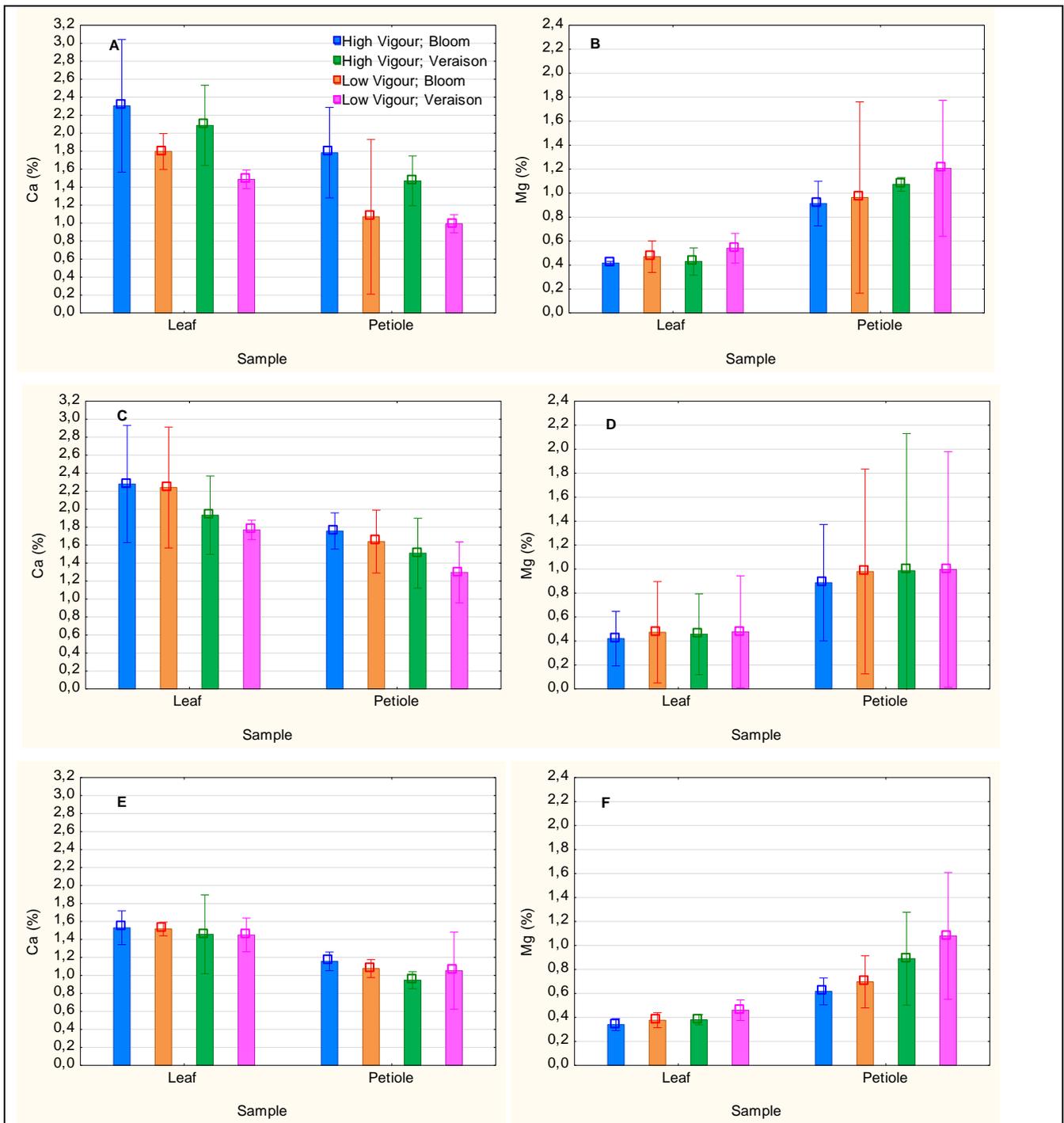


Figure 18: Leaf and petiole Ca (%) and Mg (%) concentrations of Farm A Chenin blanc (A & B), Farm B Chenin blanc (C & D) and Farm B Pinotage (E & F) grouped according to sample (leaf/petiole), categorised by vigour and phenological stage; vertical bars denote 0.95 confidence intervals (for each parameter, sample type, sample time and vigour's, bars represent mean values of 3 replicates).

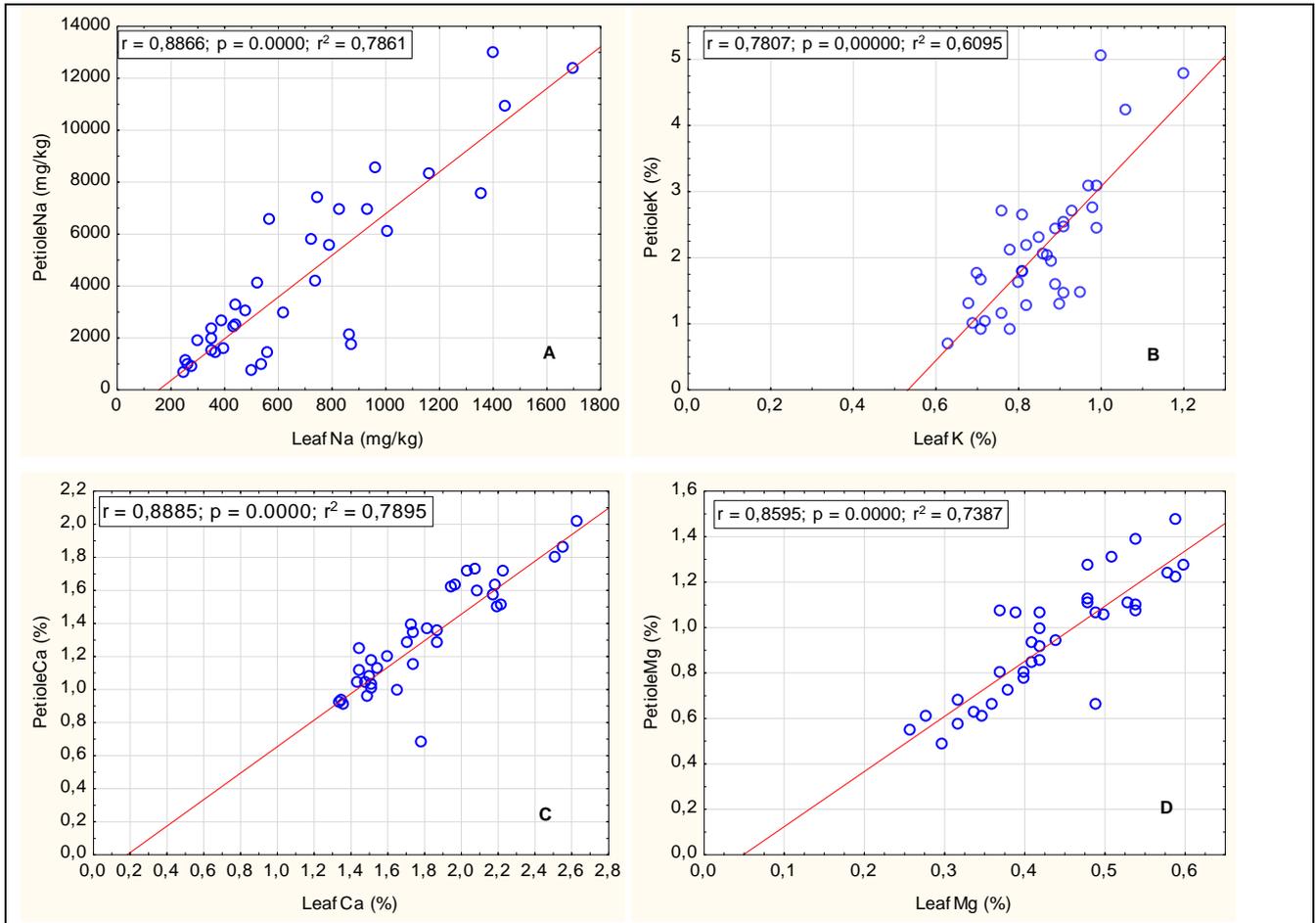


Figure 19: Scatterplot correlating petiole and leaf mineral content (Na (A), K (B), Ca (C) and Mg (D)).

3.3.3.3 Cane analysis

Post-harvest cane sample analysis showed some vigour differences occurring with cane Na content, where the low vigour plots tended to have higher Na levels than the high vigour for both sites and cultivars (Figure 20A). The highest levels of Na in the canes were found in the Chenin blanc on Farm B, whereas the lowest was seen in the Chenin blanc from Farm A. Some leaf and petiole Na concentrations (Figure 15) were far higher than the cane Na levels. Figure 21 shows a strong correlation and relationship between Na and Mg content in the canes, as the Na increases in concentration, the cane Mg levels also increase. Downton (1985) and Prior *et al.* (1992) reported higher Mg contents in the leaves and petioles with increased salt concentrations in the soil.

K levels in the canes showed less significant results in terms of vigour differences. Farm B Chenin blanc and Pinotage showed lower K concentrations in the low vigour plots, whereas Farm A Chenin blanc showed no significant vigour variation. The lower K levels in the canes could be attributed to the prior K mobilisations to support the growth of new roots, stems, leaves and clusters, the berries being the largest sink for K. This may have had an exhausting effect on the K levels in the canes samples after harvest (Raath, 2012). Other reason could be due to antagonisms between Ca, Mg or Na. No significant differences were found in the cane Ca levels, however leaf and petiole Ca concentrations are higher. The low vigour cane Mg levels are slightly more than the high vigour plots, which could be due to the cane Na content in the low vigour plots (Figure 21).

The cane Na, K, Ca and Mg concentrations were much lower than the leaf and petiole analysis. This may have been as a result of the time of sampling (post-harvest), as most minerals are remobilised into the berries after véraison, especially Na, K and Mg as they are highly mobile in the grapevine, or the minerals are used for specific grapevine functions. Accurate K concentrations determination in the petioles, leaves and shoots is sometimes not possible, as K is rapidly translocated into growing organs, *i.e.* berries, or may be stored in the roots (Brunetto *et al.*, 2015). Ca is a non-mobile nutrient, therefore the plant has little control over its uptake, therefore the plant sequesters Ca as Ca-oxalate crystals in specialised cells (roots, leaves and petiole and leaves) in order to minimise toxicity. Mg is a structural component of chlorophyll, it may also be involved in the manufacturing of proteins and is also an important cofactor for enzyme activation (Keller, 2015).

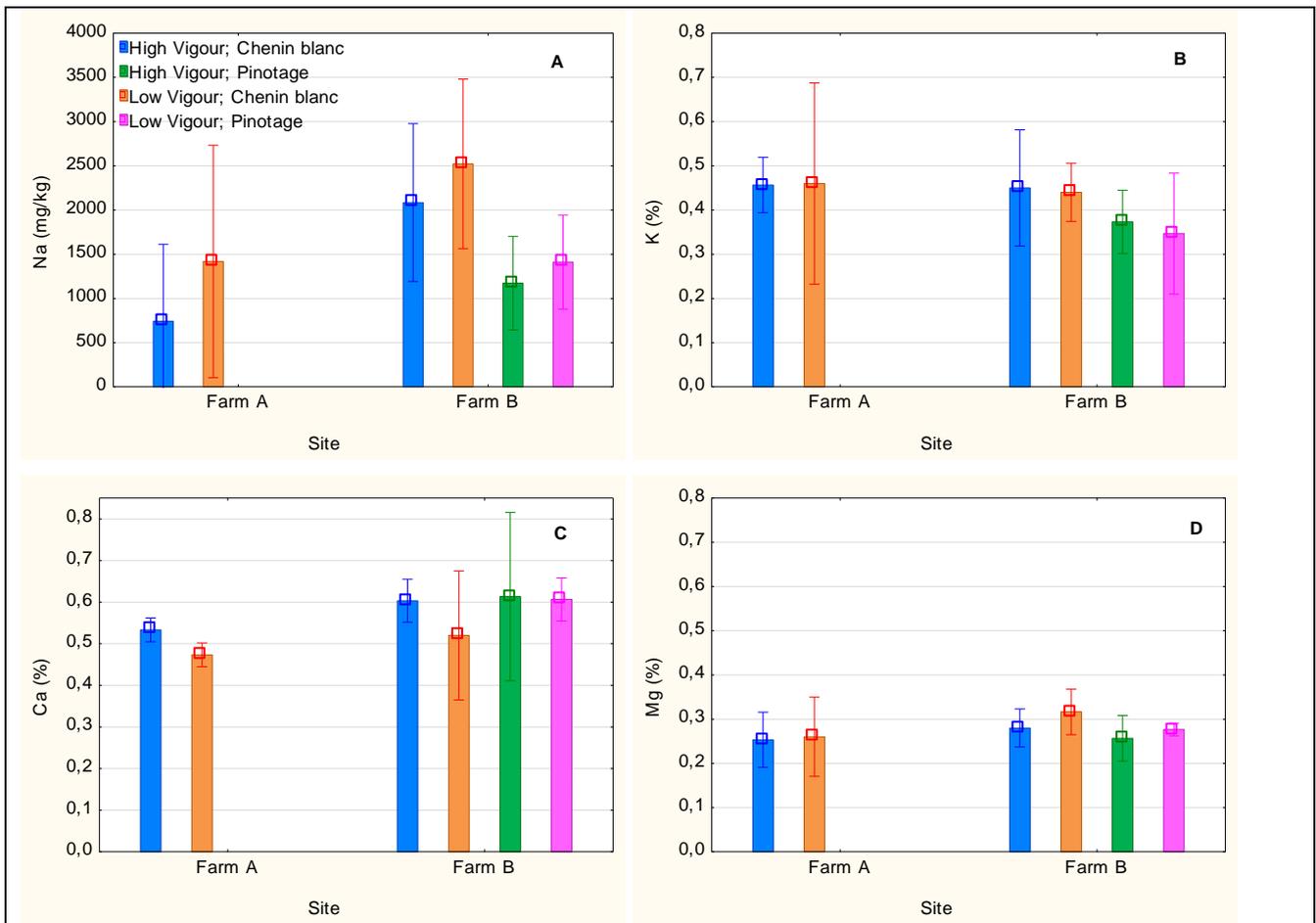


Figure 20: Shoot Na (A), K (B), Ca (C) and Mg (D) concentrations for Farm A Chenin blanc, Farm B Chenin blanc and Farm B Pinotage, categorised by vigour and cultivar; the vertical bars denote 0.95 confidence intervals (for each vigour's, bars represent mean values of 3 replicates).

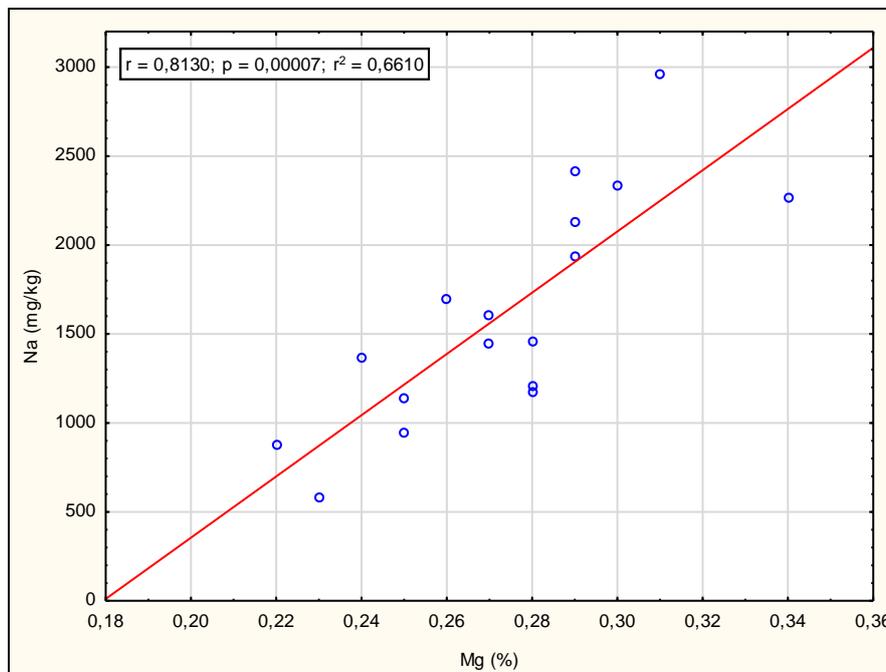


Figure 21: Correlation between cane Na (mg/kg) and Mg (%) concentrations.

3.3.4 Harvest measurements

3.3.4.1 Berry sampling

Grape berry sugar accumulation occurs between Stage II and III of ripening, where according to Coombe (1992) during Stage II and III the berry starts to soften, the grape berry acid decreases and sugar accumulation increases, berry growth and colour development resumes. Ferrer *et al.* (2014) reported that various environmental conditions affected the resultant grape berry size and composition. Ojeda *et al.* (2001) showed that grapevine water status, amongst other factors, had the largest effect on the grape quality *via* the ratio between skin area and juice volume. Physiologically, the effects of water stress and grapevines grown in salt affected soils are very similar (Sinclair & Hoffman, 2003; Meggio *et al.*, 2014).

Figure 22A, B and C indicate differences between the plots of different vigour levels, showing a slower total soluble solids (TSS) accumulation in the low vigour plots compared to the high vigour plots. Farm A Chenin blanc shows a steady increase in both high and low vigour plots, however as the low vigour plots reach just over 109 days after budburst (DAB), a lowering of TSS accumulation occurred. Rain-fed conditions at Farm A could have caused soil water deficits during the first and later stages of berry development, which may have caused increases in abscisic acid (ABA), thereby inhibiting cell division and expansion (Ferrer *et al.*, 2014). Unfortunately soil water measurements were not conducted, making correct assumptions difficult. According to Rienth *et al.* (2016), extremely high temperatures may impede sugar accumulation in grape berries, where the mean temperature during mid-January was between 19 and 20.5°C, and the maximum temperature was around 35°C (Table 6 & Figure 9). This could have also lead to the decreased TSS accumulation on the low vigour plots on Farm A Chenin blanc. The TSS accumulation in Farm A Chenin blanc was the slowest compared to Farm B Chenin blanc and Pinotage. This could be attributed to the bush vine training system, where Van Zyl & Van Huyssteen (1980) showed that sugar concentrations in grapes from the bush vine training system showed a slower increase in TSS than any other trellising system.

Figure 22B and C depict the TSS accumulation per berry from Farm B Chenin blanc and Pinotage respectively. The Chenin blanc on Farm B showed an increase in both low and high vigour plots, however both vigour levels show slower TSS accumulation as the berry ripens. The early harvest of the vines on Farm B Chenin blanc could have occurred before optimal ripeness was reached. Figure 22C also shows differences in the vigour levels according to their TSS accumulation, however the high vigour plots TSS accumulation reached a plateau before the low vigour plots. This could have been due to the temperature or early season water deficits.

During the early stages of grape berry growth, the organic acids, particularly tartaric and malic acid, increase in the berry (Dharmadhikari, 1994). Titratable acidity (TA) is an important parameter used by most winemakers to determine the acidity of grapes. Various conditions may affect the organic

acid composition during ripening, including cultivar, soil and environmental conditions (temperature, light and humidity) (Haggerty, 2013). As berry ripening commences, the acid concentration decreases (Mullins *et al.*, 1992). Malic acid degradation is determined by temperature, where higher temperatures decrease malic acid at a faster rate, due to the activation of the malic acid enzyme responsible for catalysing the conversion of malate to pyruvate (Haggerty, 2013). Other factors that contribute to the loss of acid in the grape berry include the dilution effect as the berry increases in size and volume, the inhibition of acid synthesis and the transformation from acid to sugar (Mullins *et al.*, 1992).

The TA decrease in Figure 22D and E shows a slower rate of acid breakdown in the low vigour plots compared to the high vigour plots. High soil K could affect the acid balance in the grape juice, by increasing the pH, thereby lowering the acidity (Conradie *et al.*, 2002). Other factors described by Conradie *et al.* (2002) such as high water stress could also contribute to low acidity and high pH.

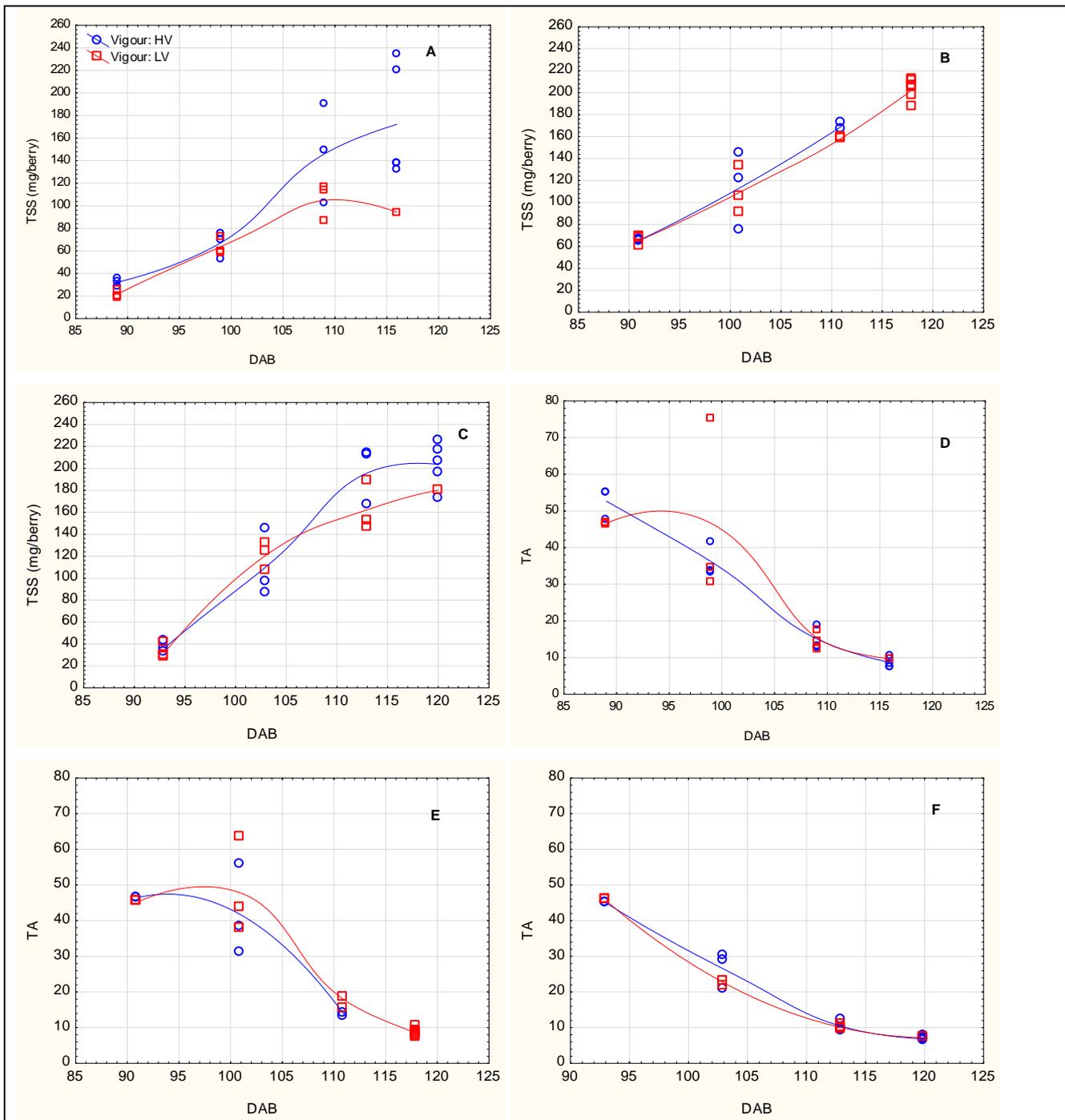


Figure 22: Mean plot of total soluble solid accumulation per berry (TSS) (mg/berry) and mean total acidity (TA) for Farm A Chenin blanc (A & D) and Farm B Chenin blanc (B & E) and Pinotage (C & F) grouped by date after budburst (DAB); categorised by vigour and cultivar, a least-squares mean fit is drawn (for each parameter, bars represent mean values of 3 replicates)..

3.3.4.2 *Harvest measurements*

Berry mass and size are largely determined during the developmental stages of berry growth. Factors that may affect berry and bunch mass and size include the number of berries in a bunch, as well the number of bunches per grapevine (crop load). Irrigation, degree of ripeness, pip numbers in the grape berry, genetics and bunch position may also have an effect on the size and mass of the berries (De Villiers, 1987; Davel, 2015). According to Goussard (2008) Chenin blanc bunches are medium in size with small berries. Pinotage however has small bunches with small berries.

Table 8 depicts differences between the vigour levels throughout 2015 and 2016 for Farm A Chenin blanc and Farm B Pinotage. Berry mass for the low vigour plots on Farm A Chenin blanc was lower than berry mass found in Strever (2003). Vigour variation on the Farm A Chenin blanc bunches could be attributed to the dryland conditions. Barbagallo *et al.* (2010) reported that environmental and cultivation techniques, such as irrigation, pruning, canopy management, row orientation, *etc.*, may have influenced grape berry and bunch mass. As mentioned before, physiologically, the effects of water stress and vines grown in salt affected soils are very similar (Sinclair & Hoffman, 2003; Meggio *et al.*, 2014). This means that the soil at the low vigour plots may have problems with salt toxicity, which may have affected the mass of the grape bunches and berries on Farm A Chenin blanc and Farm B Pinotage. Farm B Chenin blanc shows very little variation between vigour levels in bunch and berry mass at harvest. Both vigour plots may have had similar environmental and cultivation practices, which may have led to the low variation between the vigour levels. The bunches and berries from Farm A Chenin blanc also have the lowest mass compared to Farm B Chenin blanc and Farm B Pinotage. According to Loubser (2008) yields of bush vines were shown to be lower compared to other training systems, due to the smaller effective canopy. The high variation between low and high vigour plots of Farm A, could be due to the main and lateral leaf area differences seen in

Table 7 7 between the low and high vigour plots. The low vigour plots from Farm A also indicated that at the time of harvest the berry sugar accumulation followed a decreasing trend seen in Figure 22A. According to Perold (1927) this stage is known as the over-ripe stage, where evaporation of water from berry leads to concentration of contents of the berry and berry shrinkage.

Bunch size variability on Farm B Pinotage and Chenin blanc could have been due to cultural practices followed by the farm, as well as environmental factors during flower differentiation and the green berry stage (Barbagallo *et al.*, 2011).

Table 8: Harvest measurements conducted over the 2015 and 2016 time period (for each vigour, sample type, sample time and vigour's, bars represent mean values of 3 replicates).

			Average bunch mass (g)	Average berry mass (g)
Farm A Chenin blanc	2015	Low Vigour	74,9 ± 27,2* (36,4**)	0,7 ± 0,2 (25,4)
		High Vigour	182,3 ± 46,3 (25,4)	1,3 ± 0,3 (19,2)
	2016	Low Vigour	47,9 ± 28,7 (59,9)	0,5 ± 0,1 (24,5)
		High Vigour	131,2 ± 66,7 (50,8)	0,9 ± 0,3 (30,2)
Farm B Chenin blanc	2016	Low Vigour	133,1 ± 45,5 (34,1)	0,9 ± 0,04 (4,4)
		High Vigour	125,4 ± 37,3 (29,7)	0,9 ± 0,09 (10,5)
Farm B Pinotage	2015	Low Vigour	105,1 ± 33,6 (32,0)	1,1 ± 0,2 (14,4)
		High Vigour	147,9 ± 38,6 (26,1)	1,4 ± 0,08 (5,6)
	2016	Low Vigour	104,0 ± 29,6 (28,5)	0,9 ± 0,04 (4,3)
		High Vigour	120,4 ± 26,6 (22,1)	1,0 ± 0,2 (18,3)

* Standard deviation of mean

** Coefficient of variance (%)

3.3.5 Cation and anion analysis in the grape berry

Principle component analysis (PCA) was done looking at the different grape components (grape skins, homogenised, juice and sediment) and the cations and anions associated with them (Figure 23). Differences between the cation and anion concentrations in the grape components can clearly be seen. The grape skins and homogenised samples seem to be closely related, with Ca, Mg, B, Zn and P showing the highest concentrations in these grape components. A close relationship can be seen between Ca and Mg, and can further be confirmed when looking at Figure 24C and D. Figure 24C and D illustrate the highest concentrations of Ca and Mg were found in the grape skins, with slightly less in the homogenised samples. Etchebarne *et al.* (2009a) also confirmed Ca concentrations in the grape berry skins to be highest, because it is linked to the grapes' resistance to pathogenic bio-aggressors. The high Ca content in the skins could also be attributed to calcium's important function in providing cell structure (Doerr, 2014). The concentrations of K, Ca, Mg and Na increase 2 to 3 times in the skin, 1.2 to 1.9 times in the pulp and 1.5 to 2.5 times in the peduncle as the grape berries mature (Winkler *et al.*, 1962). According to Rogiers *et al.* (2006) the highest concentration of Ca, Mg, B, Zn and P was found to be in the grape berry seeds. This may show a link to the homogenised samples, which indicate the highest concentrations of some minerals, because the homogenised sample is made up of all berry components, including the grape berry seeds. Abdrabba & Hussein (2015) however showed that the concentrations of Ca, Mg and P were highest in the grape skins.

The grape berry sediment contained the highest concentrations of K, Fe, Al, Mn, barium (Ba) and silicon (S). Grape berries are rich in K and is vital for grape berry growth and development (Mpelasoka *et al.*, 2003; Etchebarne *et al.*, 2009a; Doerr, 2014). K is also involved in enzyme activation, cellular membrane transport processes and translocation of assimilates, anion neutralisation, osmotic

potential regulations, turgor maintenance and growth (Martins *et al.*, 2012). According to Rogiers *et al.* (2006) and Martins *et al.* (2012), the highest K concentrations were found in the skins, this concurs with findings shown in Figure 23 and Figure 24B, which depicts the grape berry sediment, mostly comprised of pulp and skin solids, contained the highest K content. Figure 24B indicates a large difference between K concentrations in the grape berry skin and sediment, where sediment contains almost six times more K than the skins. Reasons for this contradiction could include the use of sediment as a sample type for cation and anions as it is not generally used. Usually the skin, juice and pips, and occasionally the brush and the pedicel are used for sample analysis. As with K, Fe concentrations in the berry was predominantly high in the sediment, however Rogiers *et al.* (2006) also reported that Fe was mostly deposited in the pulp and the skin. The highest concentrations of Fe was found in the brush of the berry. Conde *et al.* (2007) noted that grapes have a low concentrations of Fe, usually approximately 10 mg/L. These levels may increase depending on winemaking or viticultural practices.

According to Figure 23 and Figure 24 the grape berry juice contained lowest concentrations of all minerals with no association with any cations and anions. According to Etchebarne *et al.* (2009b) there are 17 mineral nutrients essential for plant growth and development, of these K, Ca, Mg and Na are vital for plant life. Figure 23 shows the highest concentrations of Ca and Mg are in the grape skins, with lower concentrations in the homogenised samples. The grape berry sediment contained the largest quantity of K. Na showed very little variation in concentrations in the grape berry samples, with variable amount occurring in all parts, the highest concentrations being in the homogenised sample (Figure 24A). This corresponds to what Etchebarne *et al.* (2009b) also found; Na accumulation in the grape berry was limited and quite variable, with similar dynamics to K accumulation. Walker (2010) noted that both Na and Cl accumulated in the pulp and grape skin, where the highest concentrations were found in the skin. Cl concentrations were shown to be highest in the homogenised sample, which is also where the highest Na levels were found.

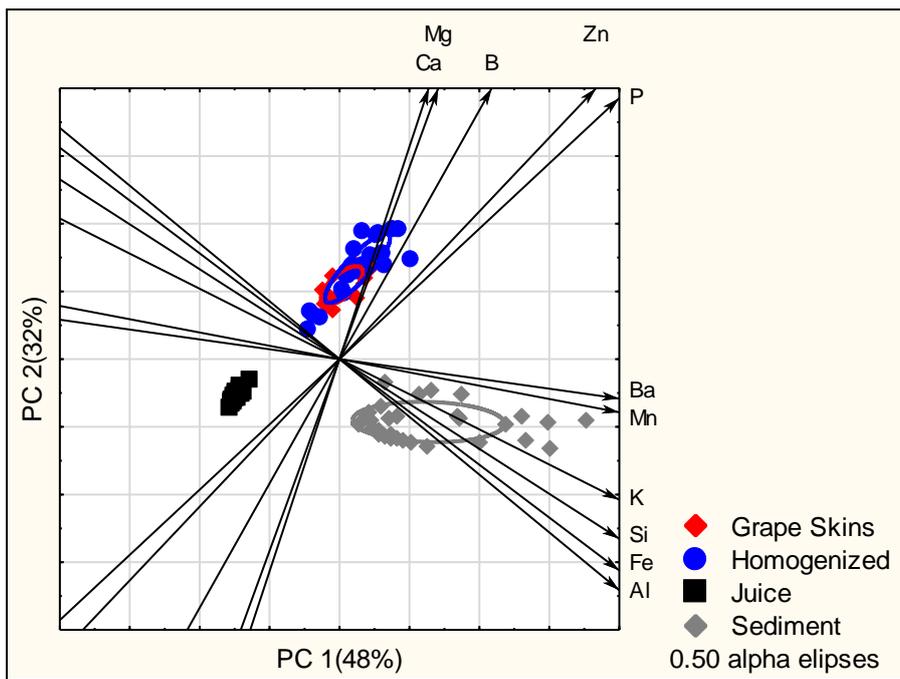


Figure 23: Mineral content of the grape skins, homogenized, juice and sediment samples depicted in a PCA Biplot (all variables $r^2 > 0.50$).

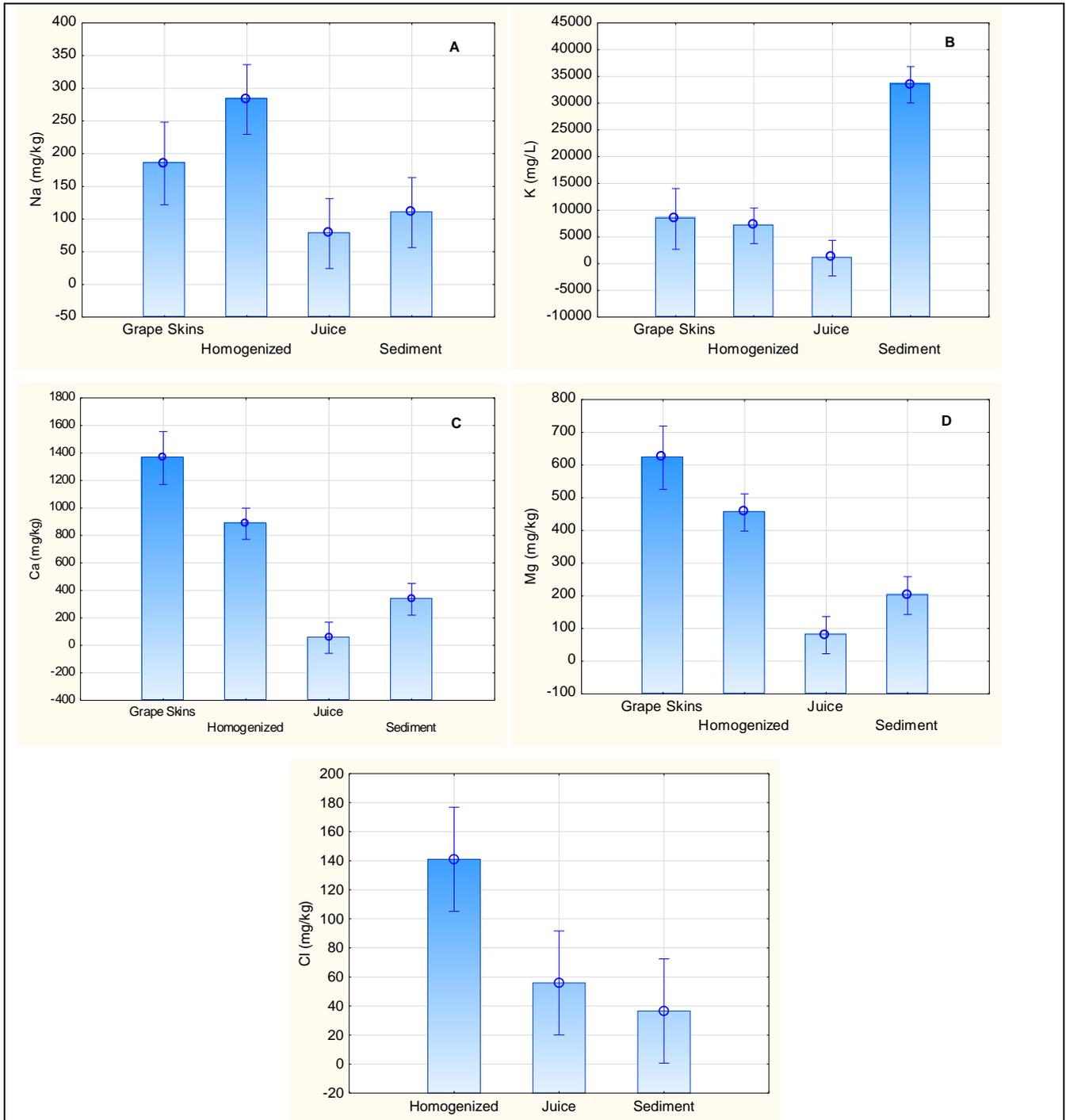


Figure 24: Na (A), K (B), Ca (C), Mg (D) and Cl (E) concentrations differences in the grape skins, homogenised, juice and sediment samples, vertical bars denote 0.95 confidence intervals.

3.3.6 Soil, grapevine, juice and wine mineral interactions

3.3.6.1 Grape juice to wine mineral interactions

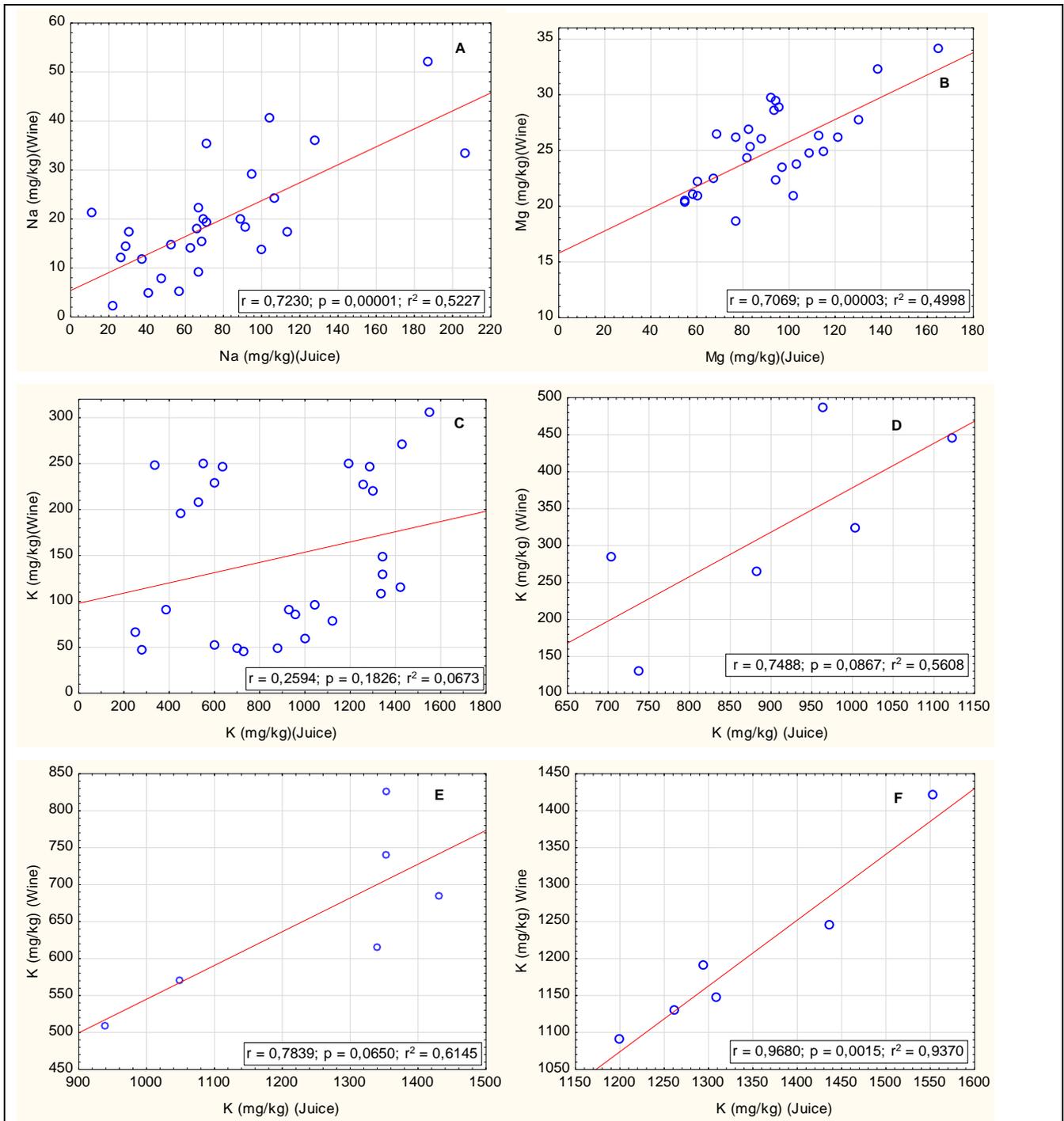
Rogiers *et al.* (2006) reported that the mineral nutrition status of the grape berries was not only important for viticulturists but also for winemakers, as there is a direct impact of berry nutrition on juice and must composition. Figure 25 depicts correlations between grape juice mineral concentrations and wine mineral concentrations, specifically looking at Na (A), Mg (B), K (C-F), Ca (G & H) and Cl (I) K

and Ca correlations were done according to farm, as no correlations were found between the K and Ca concentrations in the grape juice and the wine from all farms. Therefore a more in depth investigation was done and the concentrations were grouped according to farms. According to Schoeman (2012) minerals like Na, K, Ca and Mg usually are present at much higher concentrations in the berry skins than the pulp, which during alcoholic fermentation would enhance the extraction due to higher temperatures and alcohol production. This may result in increased concentrations of these minerals in the wine. The grape juice Na content (Figure 25A) showed a strong correlation to the wine Na concentrations, with a strong relationship ($p < 0.005$; $r^2 > 0.5$). This indicates that as grape juice Na increases, the wine Na concentrations also increase. Winemaking practices such as the use of sodium caseinate as a fining agent for wine clarification, sodium bentonite, sodium bisulphite in dilute sulphuric acid, which is used to keep barrels and tanks in good condition, sodium carbonate as an acid reducing agent, sodium metabisulphite and sodium salt of ascorbic acid as a sterilizing and preserving agent for wine, but can also be used to inhibit secondary fermentation and mould growth (Galani-Nikolakaki & Kallithrakas, 2006). Cl concentrations in the grape juice and wine showed a strong correlation (Figure 25I). Walker (2010) noted that Cl concentrations in wine were similar to the Cl concentrations found in the grape juice.

K and Ca concentrations in grape juice and wine show no correlation and relationship between all farms (Figure 25C & G). However when looked at more closely, K and Ca showed strong correlation on some farms. K showed strong correlations on Farm A Chenin blanc ($r = 0.75$; $p = 0.0867$; $r^2 = 0.56$), Farm B Chenin blanc ($r = 0.78$; $p = 0.065$; $r^2 = 0.61$) and Farm B Pinotage ($r = 0.97$; $p = 0.0015$; $r^2 = 0.594$) (Figure 25D, E, F). This was also noted for Ca grape juice and wine correlations from Farm A Chenin blanc ($r = -0.67$; $p = 0.141$; $r^2 = 0.46$) (Figure 25H). The skewed correlations could have been due to the high concentration differences between farms, but also due to the fact that some minerals, particularly K, are found in higher concentrations in red wine compared to white wine. Both K and Ca concentrations in the wine are lower than in the juice. K content in wine is dependent on pressing, K caseinate addition for fining and K metabisulphite or carbonates additions to crushed grapes (Galani-Nikolakaki & Kallithrakas, 2006). High concentrations of K in grape berries lowers the free tartaric acid content, by exchanging tartaric acid protons with K, which cause precipitation of K bitartrate thereby also increasing the pH (Martins *et al.*, (2012). The Ca content in grape juice is dependent on grape cultivar and rootstock, environmental conditions and Ca soil availability. Like K, Ca can also combine with tartaric acid, which forms Ca tartaric crystals, which precipitate during fermentation, thereby reducing the Ca content in the wine (Martins *et al.*, (2012).

Mg levels in the juice show a moderate correlation and a strong relationship to the Mg content in wine (Figure 25B). As the juice Mg concentrations increased, the Mg levels in the wine also increased. The concentrations of Mg in wine are lower compared to the juice. The Mg concentrations in wine are dependent on several factors including grape cultivar, the rate of pressing, pH, as well as the time

and temperature of maceration. Other factors such as the addition of carbonates to deacidify wine, concrete tank storage, relative concentrations of alcohols and the use of ion-exchange resins (Galani-Nikolakaki & Kallithrakas, 2006).



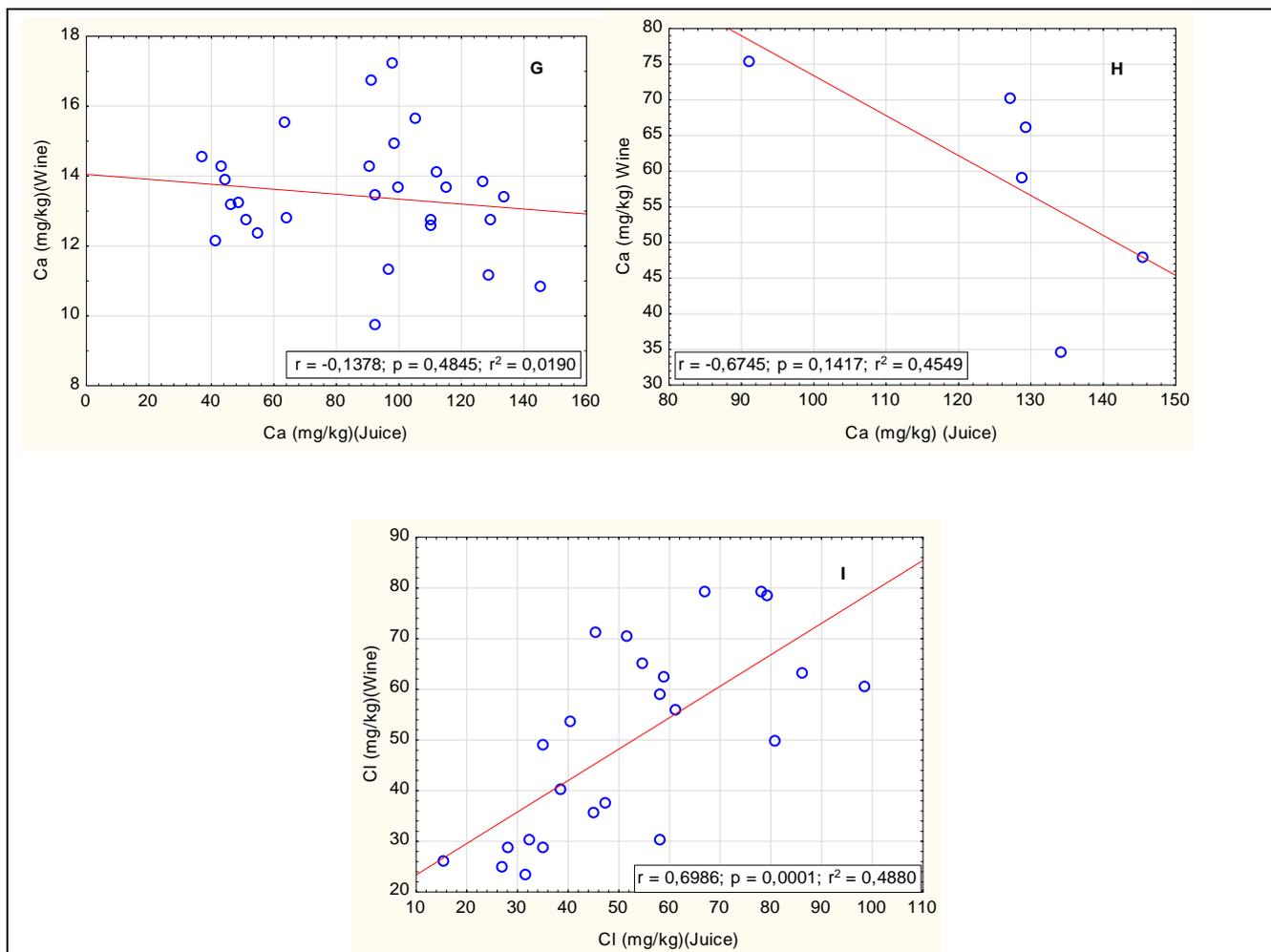


Figure 25: Correlations of Na (A), Mg (B), K (C) on all farms, K(D) Farm A Chenin blanc, K(E) Farm B Chenin blanc, K(F) Farm B Pinotage), Ca (G) on all farms, Ca (H) Farm A Chenin blanc, and Cl (I) translocation from grape juice to wine.

3.3.6.2 Soil to grape juice and wine mineral interaction

The uptake of minerals from soil to the vine, grape juice and subsequently the wine shows large variation between the different minerals. Minerals such as Na, Mg and Ca in the wine (data not shown) and juice samples (Addendum C) showed no relationships with regards to the Na, Mg and Ca concentrations in the different soil depths. This could possibly be attributed to the antagonistic relationship between cations such as K, Mg and Ca, where the interaction between ions of similar size and valence can cause binding sites not being able to distinguish the differences between these ions. In soil, the ion concentration levels may affect the rate of absorption by the plant, where the ion with the greater availability to the plant will have a greater chance for absorption than the other competing ions (Marschner, 1995; Hannan, 2011). This antagonistic effect can be seen between Ca in the different soil depths with Mg uptake by the grapevine into the grape juice (Figure 26). As the Ca levels increase, the Mg uptake into the grape juice decreases, thereby altering correlations between ion levels in the soil and ions occurring in the grape. K was the only mineral nutrient that showed a good correlation between soil K and wine K as seen in Figure 27.

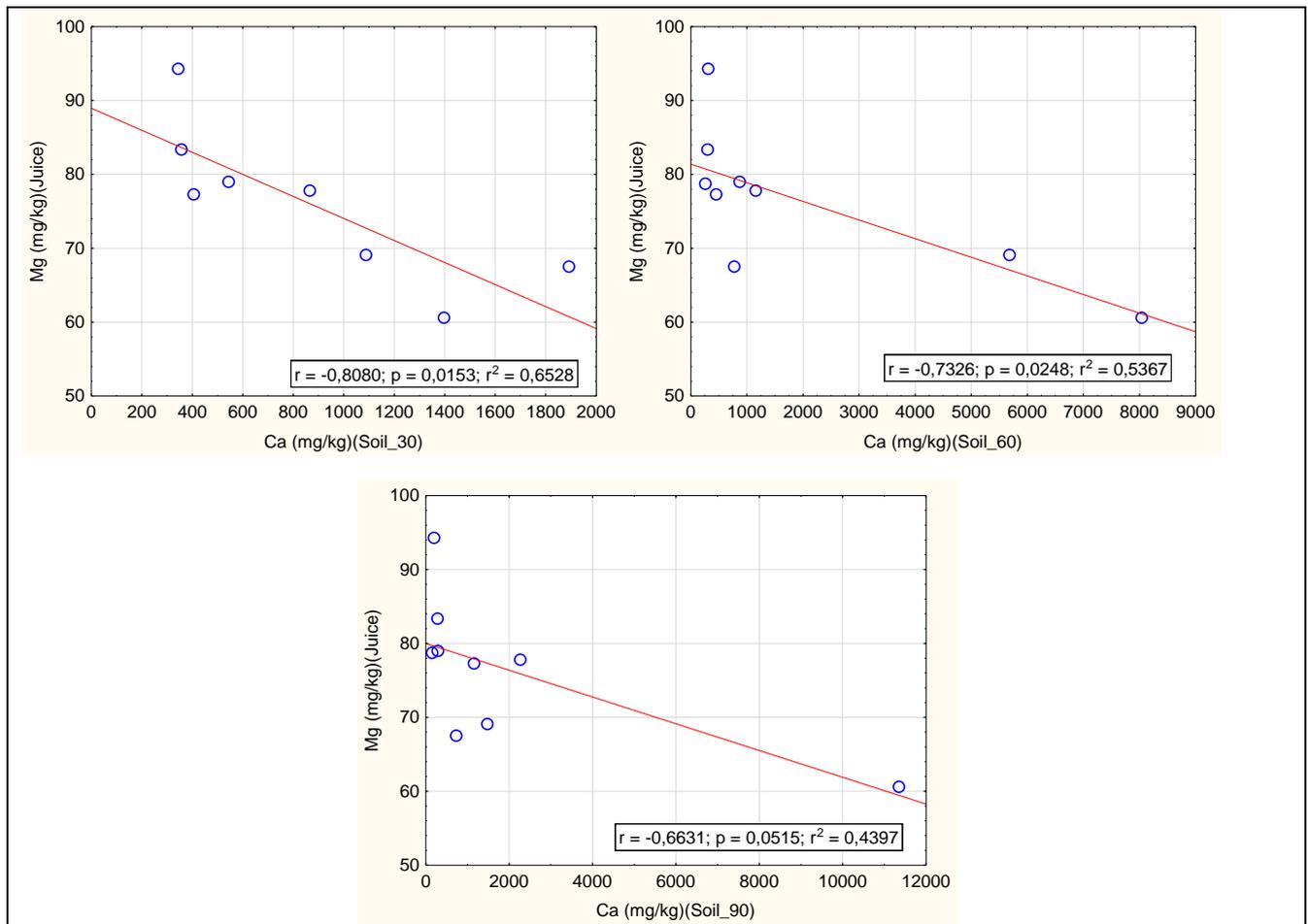


Figure 26: The antagonistic effect that high Ca concentration in the soil at different depths has on the Mg content of the grape juice.

The K concentration in the wine showed a good correlation and strong relationship particularly with the K content at soil depths of 30 to 60 cm and 60 to 90 cm (Figure 27). Figure 27 also shows the K concentrations in the soil are lower than, but related to the K concentrations in the wine. This could be due to the fact that the soil samples were taken during winter, which may have been before any fertiliser was applied or supplemented. The differences between the soil depth K concentrations, may be as a result of the K content in the soil solution, the size, health and age of the roots, the rootstock/scion combination, rootstock and scion type (Agenbach, 2006). Whereas the K content of the grapevine is determined by plant and soil factors. Soil factors including soil texture, clay mineralogy, CEC, soil pH, soil moisture, soil aeration, soil temperature, amount of exchangeable K in soil and subsoil and rooting depth (Sipiora, *et al.*, 2005). Figure 27A shows a lower correlation and relationship between the K in the 0 to 30 cm depth and the K content in the wine, however the upper soil layer contained the highest K content in the soil. Pradubsuk (2008) also found that the highest K content in the soil was found in the upper layers of the soil, compared to the subsoil.

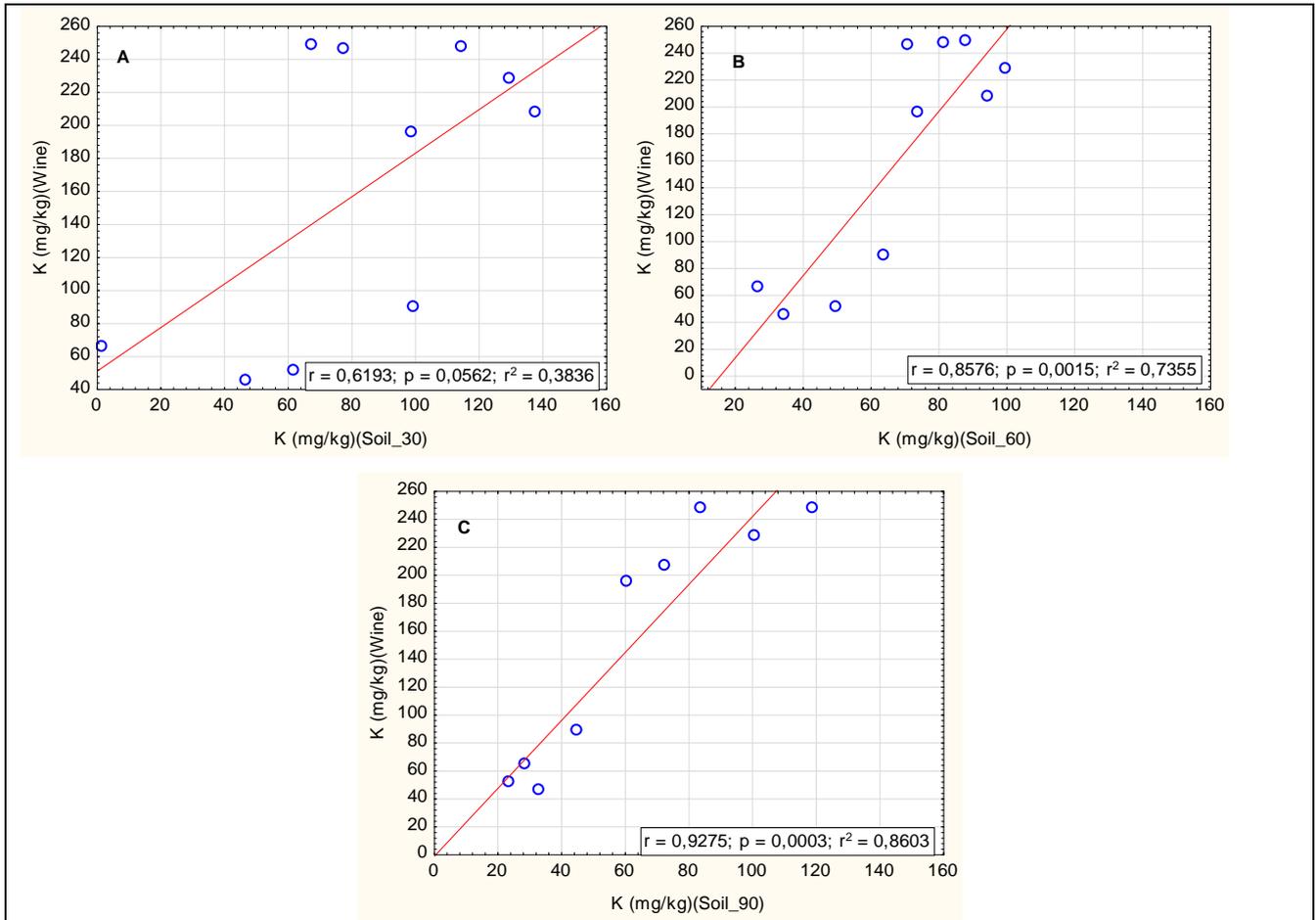


Figure 27: Correlations between K concentrations at different soil depths and wine K content.

The high K concentrations in some of the wines may have an adverse effect on pH, titratable acidity and may modify the tartaric acid to malic acid ratio, due to K salts and tartrate formation (Moss, 2016). This can clearly be seen in Figure 28 as the K contents increase the pH values are higher and the TA values decrease. The decrease in free tartaric acid is due to the increase of the K content and the formation of K bitartaric acid. As the K concentration rises in the berry, malic acid degradation is inhibited in the berry. This shifts the tartaric acid to malic acid ratio towards malic acid, making wines taste more 'sour', therefore having a negative impact on the sensorial profile of the wine (Conde *et al.*, 2007).

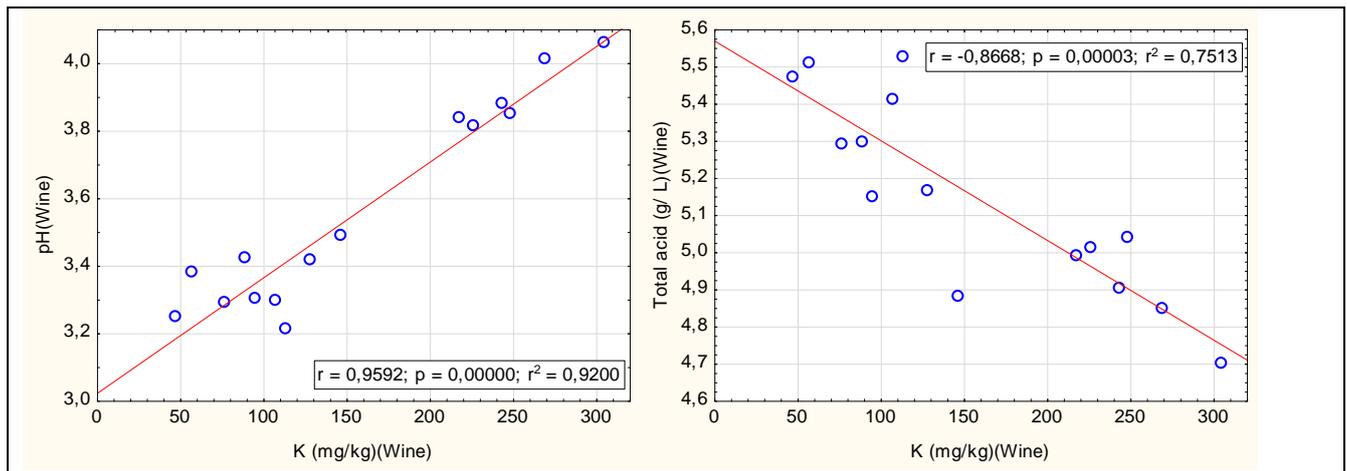


Figure 28: Correlation between K concentration in wine with pH and total acidity (g/L) of wine.

3.3.6.3 Grape juice mineral composition

The Na content of grape juice obtained from Chenin blanc vines grown on Farm A depicts lower Na concentrations than both the Chenin blanc and Pinotage from Farm B (Figure 29A and B). Differences between the 2015 and 2016 seasons can also clearly be seen in grape juice from plots, which may have been due to climate. The 2015 season in the Paarl showed decreases in production due to dry conditions and wind leading to weaker growth and smaller berries. In the 2016 season, much smaller crops were harvested in the Paarl region at an earlier stage. The small berries may have been as a result of the low rainfall, limited water supply and very high temperatures (Van Schalkwyk, 2015 & 2016). The Chenin blanc on Farm A showed marked differences between the Na content in wines made in 2015 and wines made in 2016, where the 2015 wine showed less Na in the wine. The Pinotage on Farm B also exhibited noticeable differences between 2015 and 2016, where 2015 had higher wine Na concentrations. The highest wine Na content was the low vigour plots from the 2016 Farm B Chenin blanc. The differences in grape juice Na concentrations could be attributed to the soil, climate, variety, rootstock and fertilisation procedures (Coli *et al.*, 2015). The differences between 2015 and 2016 may be as a result of higher Na concentrations in the soil as well as the climate.

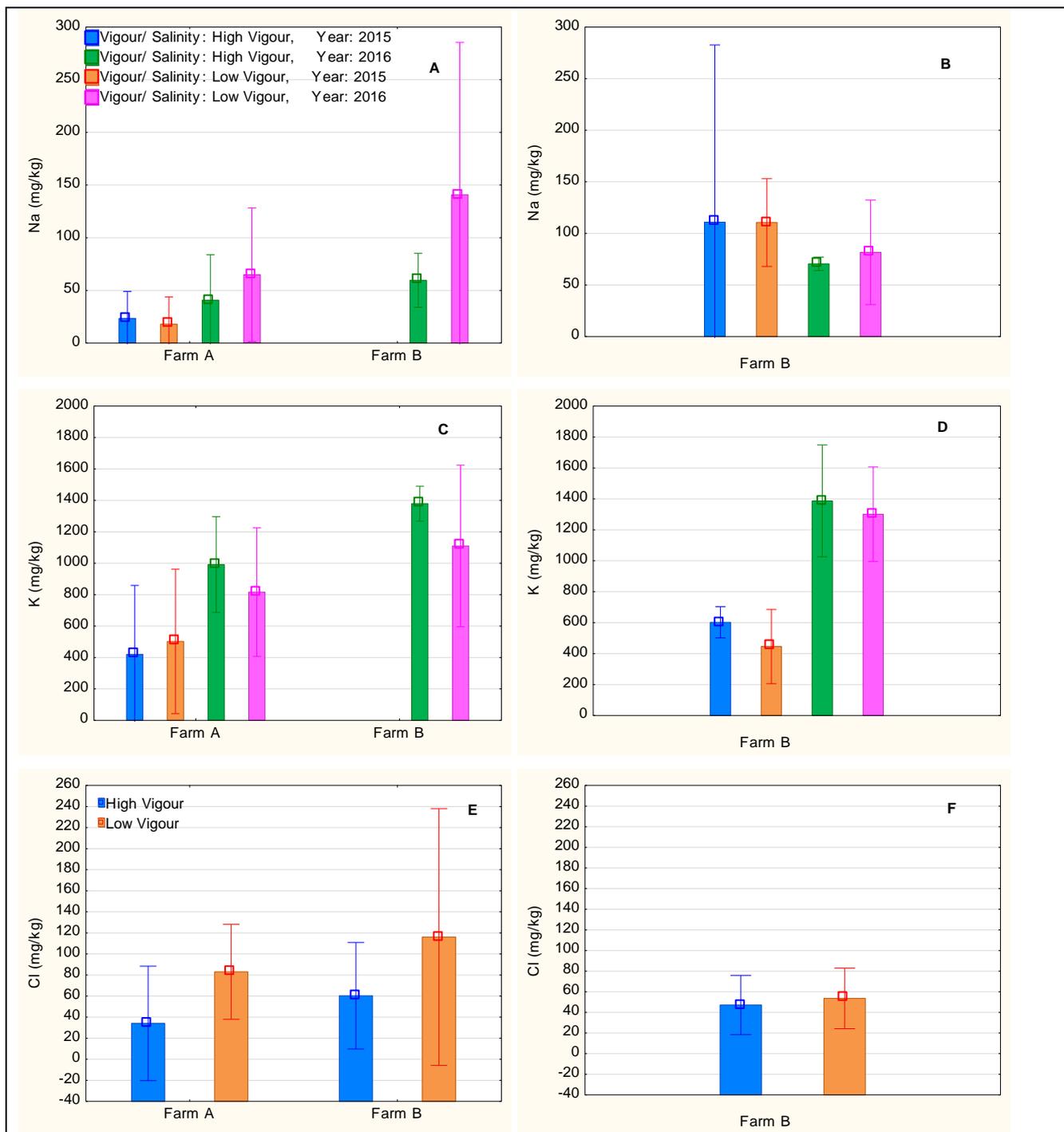
The K concentrations in the grape juice also showed high variability between the vigour levels and years (Figure 29C and D). The 2016 season exhibited higher juice K concentrations, which could be as a result of canopy vigour differences between 2015 and 2016. Higher density canopies lead to higher juice K concentrations and pH (Agenbach, 2006). Other factors that may have led to differences between the 2015 and 2016 vintage may include K fertilisation and Ca/Mg antagonism, where the supplementation of Mg or Ca to the soil, may have led to a decrease in K uptake by the plant (Hannan, 2011). The soil pH also plays a vital role in determining the K uptake by the vine, where liming will increase the soil K fixation in very acidic soil by releasing hydrogen ions from colloidal surfaces, thereby increasing the probability of K release into the soil solution (Agenbach, 2006;

Hannan, 2011). According to Moss (2016) lower soil pH increases the K availability for plant uptake and decreases the Ca and Mg availability for uptake. Liming will also increase the Ca and Mg content in the soil, which will lead to the before mentioned antagonism. Water availability, soil temperature and root surface area also has a large effect on K uptake by the grapevine. If there is low water available, K will not readily diffuse into the plant roots, higher temperatures also increase K uptake, and a greater root surface area will also have a positive effect on plant K uptake (Moss, 2016).

Cl levels in the juice had some variation occurring between vigour levels and sites. The highest Cl concentrations were shown to be in the grapes obtained from the low vigour sites of Farm A and B Chenin blanc. The Pinotage did not exhibit much variation between the vigour levels, and tended to be lower in Cl content than the other sites. Cl juice concentrations are mainly affected by Cl uptake by the vine roots, which is partially dependent on the Cl levels in the soil, and largely dependent on the severity of soil saline conditions. Higher Cl levels in the low vigour site grapes, indicates that the soil had amounts of salts present in the soil solution (Leske *et al.*, 1997; Walker *et al.*, 2009). Rootstock and scion type also play an important role in Cl uptake by the grapevine. According to Walker (2010) the increase of Cl and Na in the grape berry is initially slow, however it starts to accelerate as the berry develops.

Ca concentrations in the grape juice was quite variable between the different sites, years and vigour levels as seen in Figure 30A and D. The largest difference occurred between 2015 and 2016, with the 2016 vintage showing the highest concentrations of Ca in the grape juice. The uptake of Ca by the grapevine is influenced by various factors including soil pH, where at low pH, Al is the dominant cation at the soil cation exchange sites, thereby interfering and reducing Ca binding to cell walls of root cells. Other factors include the Ca concentration in the soil solution, antagonism with other cations, such as K and Mg, and ultimately the rate of transpiration as Ca moves with water (Raath, 2012).

Mg concentrations in the grape juice showed a steady increase throughout the years, where 2016 had a higher Mg content compared to 2015. The difference could be ascribed to increased Ca in the soil, as a result of fertilisation. This may cause Ca/Mg antagonism, where a high Ca content in the soil may negatively impact the Mg content in the grape juice (Figure 26). Differences between the high and low vigour plots on both farms can also be seen in Figure 30. This could also be attributed to an antagonism between other cations, specifically K. High K concentrations in the soil solution may limit the uptake of both Mg and Ca (Ashley, 2011).



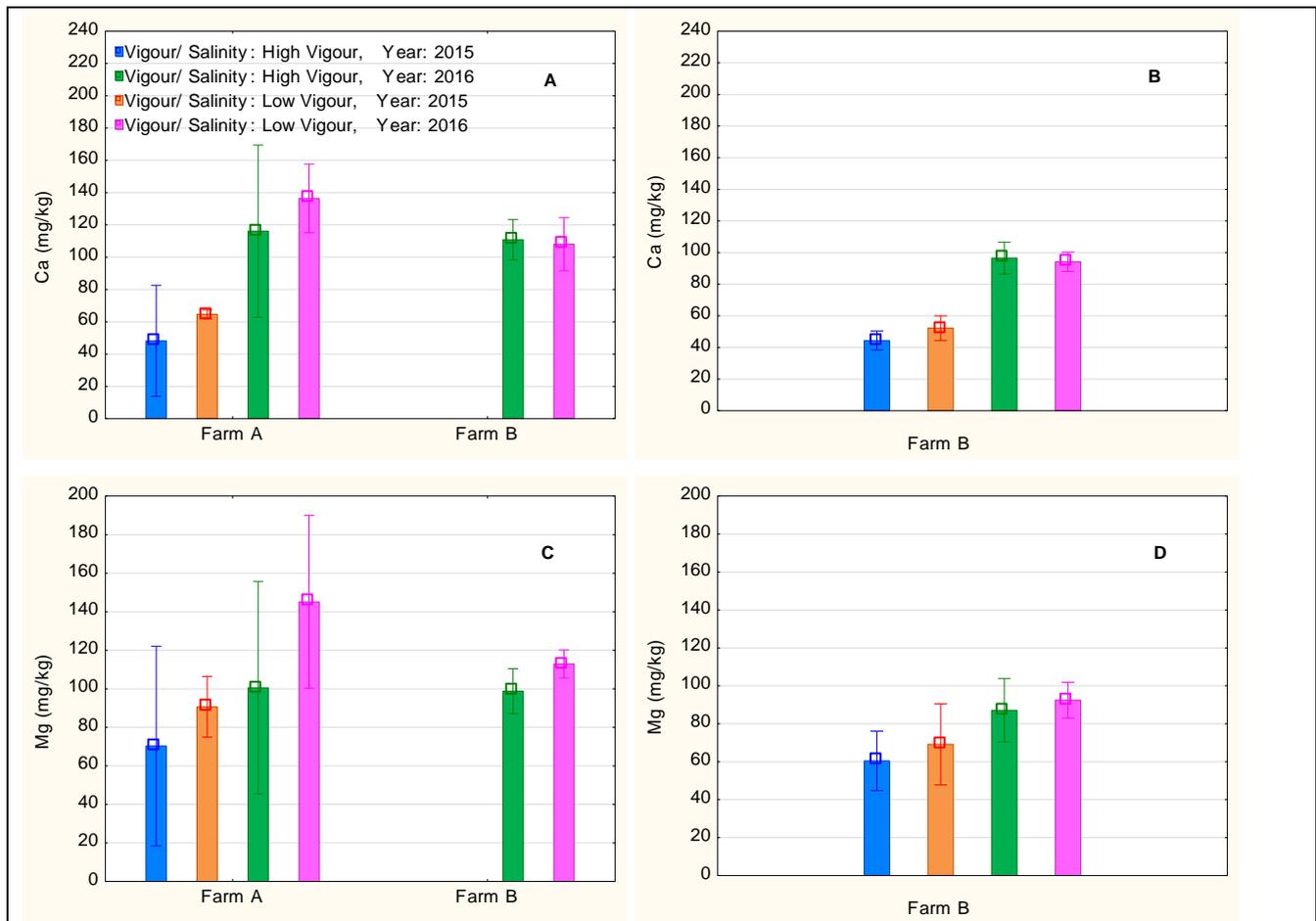


Figure 30: Grape juice Ca and Mg concentrations from Farm A Chenin blanc and Farm B Chenin blanc (A & C) and Farm B Pinotage (B & D), categorised according to vigour, vertical bars denote 0.95 confidence intervals.

3.3.6.4 Wine mineral composition

The mineral content for all sites shows great variability especially for the Na and K concentrations in the wines (Figure 31). Year variability is also present, which could be due to the difference in climate observed between 2015 and 2016. The Na content in wines for Farm A and B Chenin blanc in Figure 31A were different between the vigour levels, where the low vigour sites were higher than the high vigour sites in Na content. This also can be seen on the Farm B Pinotage in Figure 31B, however with slightly less variation. The OIV resolution Oeno 6/91 which states (i.e. with respect to sodium): “When wine contains excess sodium (excess sodium is equal to the content of sodium ions less the content of chloride ions expressed as sodium), it is generally less than 60 mg/L, a limit which may be exceeded in exceptional cases. The laboratories and official control agencies, confronted with elevated levels of Cl and/or Na⁺, must take the above conclusions into account and possibly make inquiries to the official agencies of the country of origin before expelling these wines.” The limit for South Africa is 100 mg/L free Na content, where the chlorides make up about 60.7% of NaCl. Some wines seen in Figure 31A and B exhibit high Na concentrations, which makes it imperative to control free Na levels in the wines. The moderate to high Na contents may not only come from the soil, but also some winemaking procedures, such as using Na based bentonite and ion exchange (Leske *et al.*, 1997; Donkin *et al.*,

2010). The Cl content in the wine showed variability between vigour levels, years and sites. The highest Cl concentrations were found in the low vigour sites for all farms. The highest concentrations of Cl throughout all the sites, was found on Farm A Chenin blanc, with some levels exceeding 100 mg/kg. Walker (2010) reported that Cl concentrations in wine were similar to the Cl concentrations found in the grape juice. Na and Cl content in wine may have certain effects on the sensorial profile of the wine as well, either negative or positive, depending on the concentrations. According to de Loryn *et al.* (2014) high salt content in wine is generally seen as unfavourable, often being described as salt, flat, dull, soapy, seawater-like and brackish.

The K contents shown in Figure 31C and D have variable concentrations throughout all the plots. The highest K concentrations were found in wines made from the high vigour vines, which corresponds to findings found by Mpelasoka *et al.* 2003. Canopies with more shaded conditions, *i.e.* higher vigour, transport K into grape berries in order to compensate for the lack of sugar accumulation. By doing this, the vine is able to maintain cellular turgor and avoid berry growth reductions (Mpelasoka *et al.*, 2003). The highest K content was also found to be from Chenin blanc and Pinotage on Farm B, which could be due to the plots being irrigated. Irrigation has been found to increase the K uptake in the plant, thereby increasing the berry, must and wine K concentrations (Moss, 2016). Not only does increased soil water content increase the K supply to the roots, it also increases grapevine growth, thereby leading to a denser canopy (Kodur *et al.*, 2009). The high K content also affects pH and TA, as seen in Figure 28, which may have adverse effects on the wine quality and sensorial profile (Agenbach, 2006; Kodur, 2011). Throughout all the sites Farm B Pinotage had the highest K content in the wine, which can be ascribed to the fact that red cultivars tend to have higher K content compared to white cultivars, and may be as a result of skin contact (Cabello-Pasini *et al.*, 2013; Aleixandre-Tudo *et al.*, 2015). Figure 24B depicts the highest K concentration in the grape berry was found in the sediment, with less K found in the skin.

The Ca content in wines made from all plots, showed very little variability between years and vigour levels (Figure 32A and B). The differences in Ca concentrations of the wines may have been due to Ca fertilisation and winemaking practices that include Ca bentonite fining and clarification for the removal of suspended solids after fermentation as well as to decrease turbidity and the use of CaCO₃ and CaSO₄ for must and wine deacidification and grape juice acid enhancement respectively (Woldemariam & Chandravanshi, 2011). Differences between the Ca concentrations could also be as a result of Mg and Ca antagonism, seen in Figure 26 (Birch *et al.*, 2003). The Mg concentrations between the different farms, showed a linear increasing trend between 2015 and 2016. Differences in Mg wine content could be attributed to Mg fertilisation and K/Ca/Na and Mg antagonism (Birch *et al.*, 2003; Peacock & Christensen, 2007). Mg functions essential for yeast physiology, including cell division and growth, mitochondrial structure and function, respiration and metabolism and environmental stress responses (Birch & Walker, 2000; Birch *et al.*, 2003).

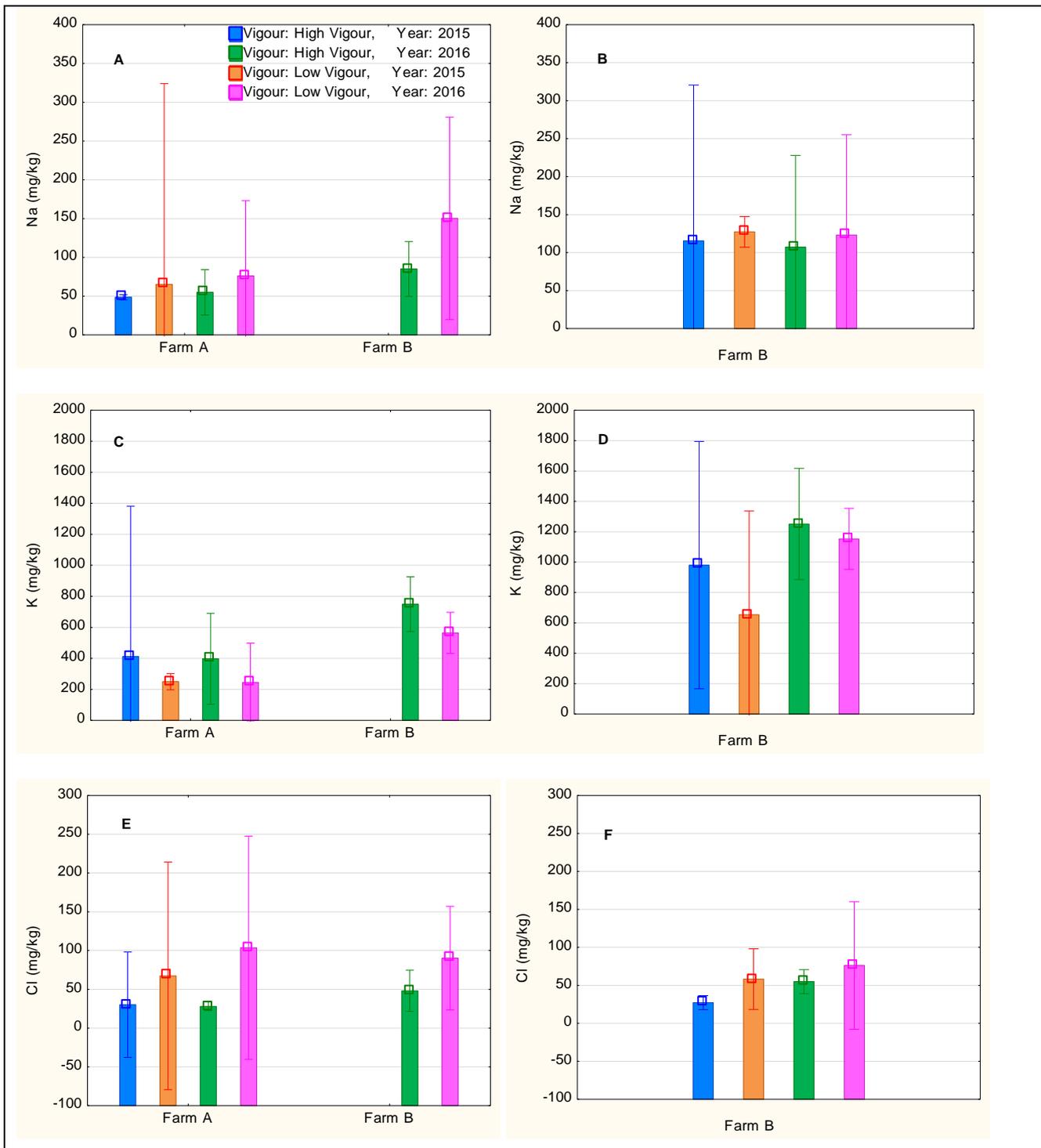


Figure 31: Wine Na, K and Cl concentrations from Farm A Chenin blanc and Farm B Chenin blanc (A, C and E) and Farm B Pinotage (B, D and F), categorised according to vigour, vertical bars denote 0.95 confidence intervals (for each parameter, vintage and vigour's, bars represent mean values of 3 replicates).

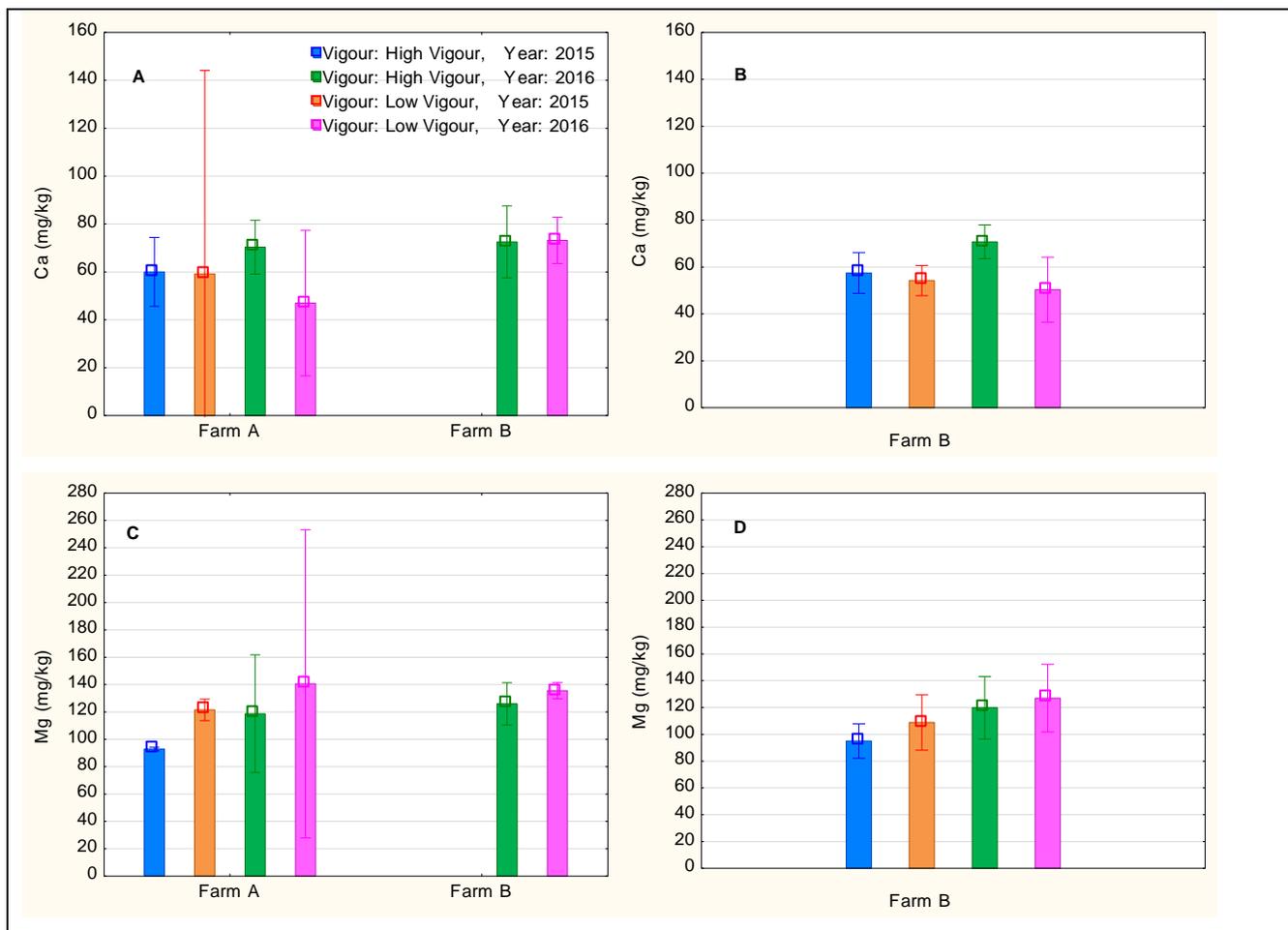


Figure 32: Wine Ca and Mg concentrations from Farm A Chenin blanc and Farm B Chenin blanc (A & C) and Farm B Pinotage (B & D), categorised according to vigour, vertical bars denote 0.95 confidence intervals (for each parameter, vintage and vigour's, bars represent mean values of 3 replicates).

3.3.7 Red wine colour and total phenolic content

Wine colour is an important factor for the initial judgement of wine quality (Lawless & Heymann, 1998). Wine colour shows quantitative and qualitative factors that may be affected by grape variety, the viticultural practices followed by the farm, winemaking style, as well as the age of the wine (Birse, 2007). Phenol composition in red wine also contribute to the quality of wine, by having an effect on the astringency and bitterness of a wine, and it plays a vital role in red wine colour stability (Fisher & Noble, 1994; Cliff *et al.*, 2007). The phenolic composition of wine is also affected by cultivation and environmental factors (Fisher & Noble, 1994).

Wine colour density measurements determine the density at the actual wine pH as well as with the bleaching effect of SO₂ (Du Toit, 2008). Wine colour density ($A_{420\text{nm}} + A_{520\text{nm}}$) variation between years for Farm A Pinotage, as well as between the vigour levels, was large in this study. According to Somers (1998) wine colour density may range from 3 absorbance units for old wines and 25 absorbance units for young wines. However this was not the case for the Pinotage made in 2015 compared to the Pinotage made in 2016. Du Toit (2008) noted that values ranging from 0 to 6 OD for colour density indicated a light coloured wine, values between 6 and 10 OD as medium coloured and

more than 10 OD as a deep red. The low vigour plots in 2015 produced wines with the highest colour density and could be termed medium coloured, whereas all the other plots would be termed light coloured. The main contributory factor that may have resulted in a lower colour density for 2016, could have been due to harvest taking place before phenological ripeness was achieved. It may have also been due to differing environmental factors and cultivation practices. Some factors such as pH and sulphur dioxide have an effect on the colour of the wine (Somers & Evans, 1974). Modified wine colour density is when the measurement of wine colour density is done in the absence of added SO₂ as well as wine pH modified to 3.5. The same trend followed by the unmodified wine colour density was seen with the modified wine colour density. For both unmodified and modified colour density, the low vigour plots in 2015 showed the highest wine colour density.

Wine colour hue was calculated using the ratio between 420 nm and 520 nm, where the 420 nm are for the brown polyphenols and the 520 nm, for the red anthocyanins (Balga *et al.*, 2014). Wine colour hue was relatively similar between the vigour levels, however some seasonal variation could be seen between 2015 and 2016. Somers & Verette (1988) showed that young wines had a hue of between 0.4 and 0.5, whereas in older wines the hue values were between 0.8 and 0.9. Du Toit (2008) reported Pinot noir wines having a higher hue value than other cultivars used in the trial, which he attributed to lower red colour (520 nm) compared to the 420 nm measurements. He also noted that young wines usually had a colour hue of 0.5 and 0.7, whereas older wines between 1.2 and 1.3. Table 9 shows the wine colour hue values for both low and high vigour levels during the 2015 and 2016 seasons. The values exceed the thresholds set by Somers & Verette (1988) for both old and young wines, however Du Toit (2008) showed that the threshold value for older wines to be slightly more. Reasons for the high hue values could be attributed to the high pH values (pH>3.5) for both 2015 (data not shown) and 2016 (Table 10). The 2016 vintage showed the highest pH values (3.89 for the low vigour plots and 3.93 for high vigour plots). Other factors however could have also played a role in the high wine hue values, such as production areas, grape variety, maturity, viticultural and oenological practices (Balga *et al.*, 2014). The modified wine colour hue showed almost no differences between treatments, which could indicate that pH and SO₂ may have played a role in the differences occurring with the wine colour hue measured in wine pH and additional SO₂ additions.

Measurement of the SO₂-resistant pigments shows the percentage of red coloured pigments which are resistant to SO₂ bleaching. The values shown in Table 9 for the SO₂-resistant pigments follow the same trend as the wine colour density. As the wine colour density increases, the SO₂-resistant pigments also increase. The 2015 low vigour wine showed the highest amount of SO₂-resistant pigments, which is a sign of colour pigment polymerisation (Du Toit, 2008). The modified SO₂-resistant pigments indicated a slight increase in the 2015 wines, however very little to no increase was noted in the 2016 wines. The total red pigments in wine can be described as being an estimate of the total pigments in wine. The total red pigments were also highest in the 2015 low vigour wines.

The highest amounts of total anthocyanins could be seen in the 2015 low vigour wines, however the highest variation also occurred in these wines. High variation between vigour levels can also be seen in Table 9, however 2015 and 2016 vigour trends are different. In 2015 the low vigour wines show the highest total anthocyanin content compared to the high vigour wine, whereas 2016 the opposite occurred. This could be attributed water stress, differences in canopy management and environment. Skin contact, fermentation temperature, use bentonite and gelatine as clarifying agents, as well as the skin to must ratio play important roles in determining the amount of anthocyanins extracted (Heyns, 2003). Wine colour and anthocyanin content are also negatively affected by the interaction between K and pH. A low pH in wine, indicates a higher concentration of anthocyanins in the red form (Mehmel, 2010).

The phenolic content of a wine plays an important role in contributing to wine quality, by altering determining the bitterness and astringency, as well as the colour, flavour, stability and ageing potential of the wine (Vinci *et al.*, 2008; Burin *et al.*, 2010). The total phenol content of the low vigour wine from 2015 was highest compared to all treatments, with the lowest total phenol content being the 2016 low vigour wine. The low phenolic content of the 2016 low vigour wine could be attributed to the early harvest, which may have been before phenolic ripeness had occurred.

All colour and phenolic measurements that were conducted, showed that the 2015 low vigour wine contained the highest amount of colour and phenolic compounds. The lower colour and phenol content of the 2015 high vigour plots, could be attributed to various viticultural factors, such as, canopy characteristics, irrigation, water stress, *etc.* and oenological practices, such as skin contact, fermentation temperature, fining and clarification, SO₂ additions, *etc.* Climate may have had an effect on the colour differences. The 2015 season showed decreases in production due to dry conditions and wind. This led to weaker growth and smaller berries. In the 2016 season, much smaller crops were harvested in the Paarl region at an earlier stage. The small berries may have been as a result of the low rainfall, limited water supply and very high temperatures (Van Schalkwyk, 2015 & 2016). Smaller berries have a higher skin to pulp ratio, which increases colour extraction. An increase in flavonols, skin-derived proanthocyanidins and anthocyanins have been reported in wines made from grapes grown under decreased vine water status (Teixera *et al.*, 2013).

Table 9: Average and standard deviation of colour and phenolic compounds for the Pinotage on Farm B during the 2015/2016 vintages (for each parameter, vintage and vigour's, bars represent mean values of 3 replicates).

Wine parameters	2015		2016	
	Low Vigour	High Vigour	Low Vigour	High Vigour
Wine colour density (OD)	6,35 ± 2,71* (42,7**)	5,00 ± 2,18 (43,6)	3,91 ± 1,88 (48,1)	4,08 ± 1,90 (46,6)
Wine colour hue	0,93 ± 0,33 (35,5)	0,92 ± 0,32 (34,8)	1,08 ± 0,5 (46,3)	1,09 ± 0,51 (46,8)
SO ₂ - resistant pigments (OD)	1,34 ± 0,09 (6,7)	1,09 ± 0,17 (15,6)	0,67 ± 0,06 (9,0)	0,75 ± 0,06 (8,0)
Total red pigment colour (OD)	20,23 ± 3,90 (19,3)	18,39 ± 2,90 (15,8)	16,09 ± 2,12 (13,2)	17,61 ± 1,71 (9,7)
Total anthocyanins (mg/L)	325,63 ± 176,84 (54,3)	258,47 ± 140,72 (54,4)	201,19 ± 120,93 (60,1)	209,80 ± 123,09 (58,7)
Total Phenols (OD)	47,02 ± 3,89 (8,3)	43,63 ± 5,90 (13,5)	39,76 ± 3,11 (7,8)	43,41 ± 2,59 (6,0)
Modified wine colour density (OD)	9,46 ± 0,65 (6,9)	7,52 ± 0,70 (9,3)	6,17 ± 0,64 (10,4)	6,58 ± 0,52 (7,9)
Modified wine colour hue	0,61 ± 0,02 (3,3)	0,60 ± 0,003 (0,5)	0,61 ± 0,006 (0,9)	0,61 ± 0,02 (3,3)
Modified SO ₂ - resistant pigments	1,45 ± 0,11 (7,6)	1,15 ± 0,18 (15,7)	0,69 ± 0,08 (11,6)	0,77 ± 0,08 (10,4)
Modified degree of red pigment colouration (%)	27,69 ± 1,76 (6,4)	24,66 ± 0,13 (0,5)	24,11 ± 0,11 (0,4)	23,87 ± 0,44 (1,8)

* Standard deviation of means

* Coefficient of variation (CV%)

3.3.8 Basic physical-chemical characteristics

Differences were found between all treatments for wine pH, volatile acidity (VA), total acid, malic acid, glucose, fructose, ethanol and glycerol content, however with less differences between the vigour levels (Table 10). One of the most important factors affecting juice and wine quality is pH. The pH of juice and wine influences the perception of acidity, the sugar and acid balance, as well as the expression of fruit flavour. It also affects protein stability and K bitartaric and Ca tartrate acid precipitation during winemaking. Red wine colour stability, MLF and microbial stability are also influenced by juice and wine pH (Boulton, 1980; Kodur, 2011). Farm A Chenin blanc showed the lowest pH compared to both Farm B Chenin blanc and Pinotage. The Pinotage on Farm B had the highest pH, reaching a pH of 3.93 in the high vigour plots. Factors that may have caused the high pH in wines made from Farm B Pinotage, may include temperature, rainfall, soil type, viticultural practices and vine cultivars. Table 10 also indicates differences between white and red cultivars, which can be attributed to white wines generally having lower K concentrations compared to red wines (Robinson, 1994). K is extracted from the grape skins during skin contact, which may have led to the high pH in the Pinotage. According to Figure 23B, which shows the concentrations of K in the different grape berry parts including grape skins, juice, homogenised and sediment, the highest K concentration was found in the sediment. High sediment and skin K content (>1500 mg/kg) may have led to the increased

pH in the Pinotage (Boulton, 1980). The Pinotage went through MLF, which would have raised the pH as well.

Volatile acidity measurements are routinely used as indicators of wine spoilage, where the EU limit for VA which is expressed as acetic acid, is 1.08 g/L for white and rosé wines and 1.2 g/L for red wines. Acetic acid is the most common volatile acid in wine, however other volatile acids such as succinic, lactic, formic and propionic acids can also be found in trace amounts in wine (Robinson, 1994). The oxidation of acetaldehyde during yeast fermentation may lead to increased acetic acid content in the wine, but other factors such the presence of acetic and lactic acid bacteria may also cause high levels of acetic acid in wine (Villamor, 2012). Farm B Pinotage had the highest VA concentrations, however all treatments were below the EU limits, as well as the sensory threshold (Table 10). The higher VA content in the Pinotage may be as a result of fermentation temperature, MLF, pH, sugar and N levels, levels of acetyl-CoA synthetase enzyme and other microorganisms present (Du Toit & Pretorius, 2000). The high pH of the Pinotage may also contributed to the higher VA levels. During MLF, high pH may be favourable, however it may also increase microbial instability and decrease SO₂ effectiveness in wine (Muñoz *et al.*, 2014).

Wine acidity can come from two sources: organic acids extracted from wine grapes, which include L-tartaric, L-malic and citric acids and the metabolism of yeasts and bacteria during fermentation (Volschenk *et al.*, 2006). The definition given by the OIV-MA-AS313-01 states that “the total acidity of the wine is the sum of its titratable acidities when it is titrated to pH 7 against a standard alkaline solution. Carbon dioxide is not included in the total acidity”. The total acid content was highest for wines made from Farm A Chenin blanc, and lowest from Farm B Pinotage. The main reason for this could be that the wine underwent MLF, which deacidifies the wine by converting L-malic acid into L-lactic acid by means of a malolactic enzyme and in the presence of cofactors NAD⁺ AND Mg²⁺. The lactic acid bacteria (LAB) utilise the remaining hexose and pentose sugars (Volschenck *et al.*, 2006). Kodur (2011) notes that high concentrations of K may lead to a decrease in the free acids concentrations, especially concerning tartaric acid. This may have also been a reason for the lower total acid in wine made from the Pinotage on Farm B. The malic acid concentrations are mostly consistent between the Chenin blanc on Farm A and B, however the low vigour Chenin blanc on Farm A is slightly lower in malic acid compared to the other Chenin blanc treatments. Malic acid degrades faster than tartaric acid in high temperatures as it is more readily respired and some enzymes capable of metabolising it (Winkler *et al.*, 1974). The Pinotage on Farm B has the lowest malic acid concentration as it underwent MLF.

The glucose and fructose concentrations were quite variable for all wines made from all farms. Higher glucose concentrations were seen compared to fructose levels for Farm A and B Chenin blanc. This could indicate the wine did not complete alcoholic fermentation, and the Chenin blanc wine from Farm A would not be considered dry (<5 g/L). Glucose and fructose concentrations should be below 1 g/L,

to be considered dry according to Butzke (2010). Low glucose was found in wines made from the Pinotage Farm B as a result of MLF, which utilises sugars to convert L-malic acid into L-lactic acid (Volschenk *et al.*, 2006).

The highest ethanol content was seen in wines made from the Chenin blanc on Farm A, whilst the lowest from Farm B Pinotage. The high ethanol levels could be due to the high sugar concentrations of the Chenin blanc grapes from Farm A (Table 11) and lower ethanol levels in the Pinotage wines could be due to lower sugar concentrations in the grapes shown in Table 11.

Glycerol in wine is the most abundant constituent produced during alcoholic fermentation except for carbon dioxide and ethanol, and is formed in wine as by-product of glycolysis during alcohol fermentation in wine (Csutorás *et al.*, 2014). Prescott & Dunn (1949) showed that Pasteur in early studies noted that up to 3.6% of sugar in wine was fermented into glycerol. However according to Csutorás *et al.* (2014), the glycerol levels in grape juice is low, however during fermentation 4 to 10% of the sugar content is converted into glycerol (Scanes *et al.*, 1998). Remize *et al.* (2003) indicated that in wine glycerol levels can vary from 2 to 11 g/L, dependent on yeast strain, grape must composition and fermentation conditions. The glycerol levels in all treatments are quite high, with all of them exceeding 8,0g/L, which could be ascribed to yeast used (VIN13), a medium to high glycerol producing yeast. The highest glycerol levels can be found in the Pinotage wine from Farm B, which could be attributed to the fact that red wines tend to have higher glycerol concentrations than white wines (Csutorás *et al.*, 2014). The low vigour Farm A Chenin blanc also has a relatively high glycerol content, which could be due to the condition of the grape juice when fermentation started, or the high sugar content (Table 11). According to Logothetis *et al.* (2010) the salt-preconditioned yeasts (VIN13) influenced the stress-tolerance of the yeast by the production of glycerol and trehalose. This may have also had an influence on the high concentration of glycerol in the wine. Table 11 depicts the sugar concentrations of 2015 and 2016. The low vigour plots tended to have higher sugar concentrations compared to the high vigour plots.

Table 10: WineScan analysis for Farm A Chenin blanc, Farm B Chenin blanc and Pinotage in 2016 (for each vigour, bars represent mean values of 3 replicates).

	Farm A Chenin blanc		Farm B Chenin blanc		Farm B Pinotage	
	Low Vigour	High Vigour	Low Vigour	High Vigour	Low Vigour	High Vigour
pH	3,26 ± 0,10* (3,1**)	3,23 ± 0,18 (5,6)	3,39 ± 0,07 (2,1)	3,45 ± 0,04 (1,2)	3,89 ± 0,09 (2,3)	3,93 ± 0,11 (25,4)
Volatile Acid (g/L)	0,46 ± 0,04 (8,7)	0,33 ± 0,07 (21,2)	0,32 ± 0,05 (15,6)	0,33 ± 0,04 (12,1)	0,60 ± 0,04 (6,7)	0,62 ± 0,01 (1,6)
Total Acid (g/L)	5,59 ± 0,15 (2,7)	5,40 ± 0,30 (5,6)	5,16 ± 0,11 (2,1)	5,12 ± 0,19 (3,7)	4,96 ± 0,09 (1,8)	4,86 ± 0,13 (2,7)
Malic Acid (g/L)	1,63 ± 0,15 (9,2)	2,22 ± 0,33 (14,9)	2,80 ± 0,19 (6,8)	2,94 ± 0,18 (6,1)	0,79 ± 0,07 (8,9)	0,76 ± 0,05 (6,6)
Lactic acid (g/L)	N/A	N/A	N/A	N/A	1,21 ± 0,14 (11,6)	1,20 ± 0,25 (20,8)
Glucose (g/L)	5,85 ± 1,53 (26,1)	6,90 ± 3,66 (53,0)	3,84 ± 3,07 (79,9)	3,42 ± 2,00 (58,5)	N/A	N/A
Fructose (g/L)	2,98 ± 1,87 (62,8)	1,32 ± 0,56 (42,4)	0,78 ± 0,45 (57,7)	0,59 ± 0,08 (13,6)	0,57 ± 0,16 (28,1)	0,63 ± 0,12 (19,0)
Ethanol (%)	14,71 ± 0,81 (5,5)	13,76 ± 0,05 (0,3)	12,96 ± 0,42 (3,2)	13,03 ± 0,32 (2,5)	11,45 ± 0,60 (5,2)	12,02 ± 0,35 (2,9)
Glycerol (g/L)	9,90 ± 0,31 (3,1)	9,67 ± 1,38 (14,3)	8,20 ± 1,24 (15,1)	8,37 ± 0,65 (7,8)	9,84 ± 0,37 (3,7)	9,99 ± 0,34 (3,4)

Table 11: Sugar concentrations in balling (°B) for Farm A Chenin blanc, Farm B Chenin blanc and Farm B Pinotage during 2015 and 2016 (for each parameter, vintage and vigour's, bars represent mean values of 3 replicates).

Year	Farm A Chenin blanc		Farm B Chenin blanc		Farm B Pinotage	
	Low Vigour	High Vigour	Low Vigour	High Vigour	Low Vigour	High Vigour
2015	26,3 ± 0,6* (2,4**)	22,9 ± 1,4 (6,2)	24,2	23,9	24,7 ± 1,2 (5,0)	24,4 ± 1,2 (5,1)
2016	25,9 ± 1,4 (5,4)	24,0 ± 0,9 (3,8)	21,8 ± 0,3 (1,5)	21,9 ± 0,6 (2,6)	22,7 ± 1,1 (5,0)	21,4 ± 0,7 (3,3)

* Standard deviation of means

* Coefficient of variation (CV%)

3.3.9 Sensory analysis

Wines containing high (500 mg/L to 1000 mg/L) NaCl concentrations are not considered favourably, and has been described as salty, flat, dull, soapy, seawater-like and brackish by Walker et al. (2010) and De Loryn *et al.* (2014). De Loryn *et al.* (2014) reported a strong linear relationship between mean salty taste score and Na, Cl and K ion concentrations in the wine was found, where the tasters described the wines as having a soapy character, relatively low perceived acidity, low fruit flavour as

well as astringency. High NaCl concentrations in wine could have important wine sensory implications, both negative and positive, *i.e.* low salt concentrations may have a positive effect on the sensorial properties of wine (Liem *et al.*, 2011; de Loryn *et al.*, 2014). NaCl increases saltiness in wine, but also reportedly lowers bitterness and it may also increase the perception of sweetness (De Loryn *et al.*, 2014).

3.3.9.1 2015

Principal component analysis (PCA) was done on Chenin blanc wine made from Farm A and Farm B in 2015 using important aroma and taste descriptors (Figure 33). A total variability explanation of 79% was observed for this set, where PC1 and PC2 explained 52% and 27% of the variance respectively (Figure 33). High variation can be seen between the two farms, the vigour levels and the replicates. The Chenin blanc wines made from the high and low vigour plots on Farm A, replicate 1 (Rep1), were closely related to one another in terms of the descriptors used to define the wines. Cooked vegetable, paw paw and herbaceous were positively correlated between these two wines. As these wines were from the same site, but different vigour levels, the similarities between them could be site-, soil-climate related.

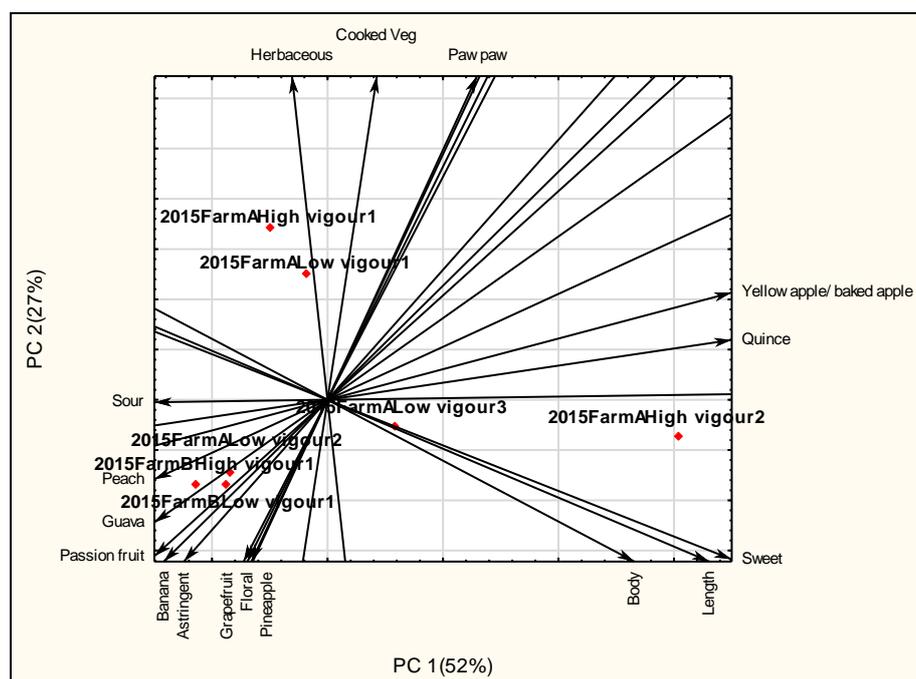


Figure 33: Principal component analysis (PCA) scatterplot of 2015 Farm A and B Chenin blanc wines according to important aroma and taste descriptors.

The high vigour Chenin blanc made from Farm A (Rep2) exhibited the highest amount of yellow/baked apples, quince, and was seen to have the most length and body, but was also the sweetest out of all the wines in Figure 33. Descriptors such as peach, guava, passion fruit, banana, grapefruit, floral and pineapple were associated with more of the wines. The Chenin blanc made from the low vigour plot on Farm A (Rep2), and the wines made from the low and high vigour plots on Farm B corresponded

closely in terms of descriptors. These wines were also seen as the most sour and astringent out of all the wines made.

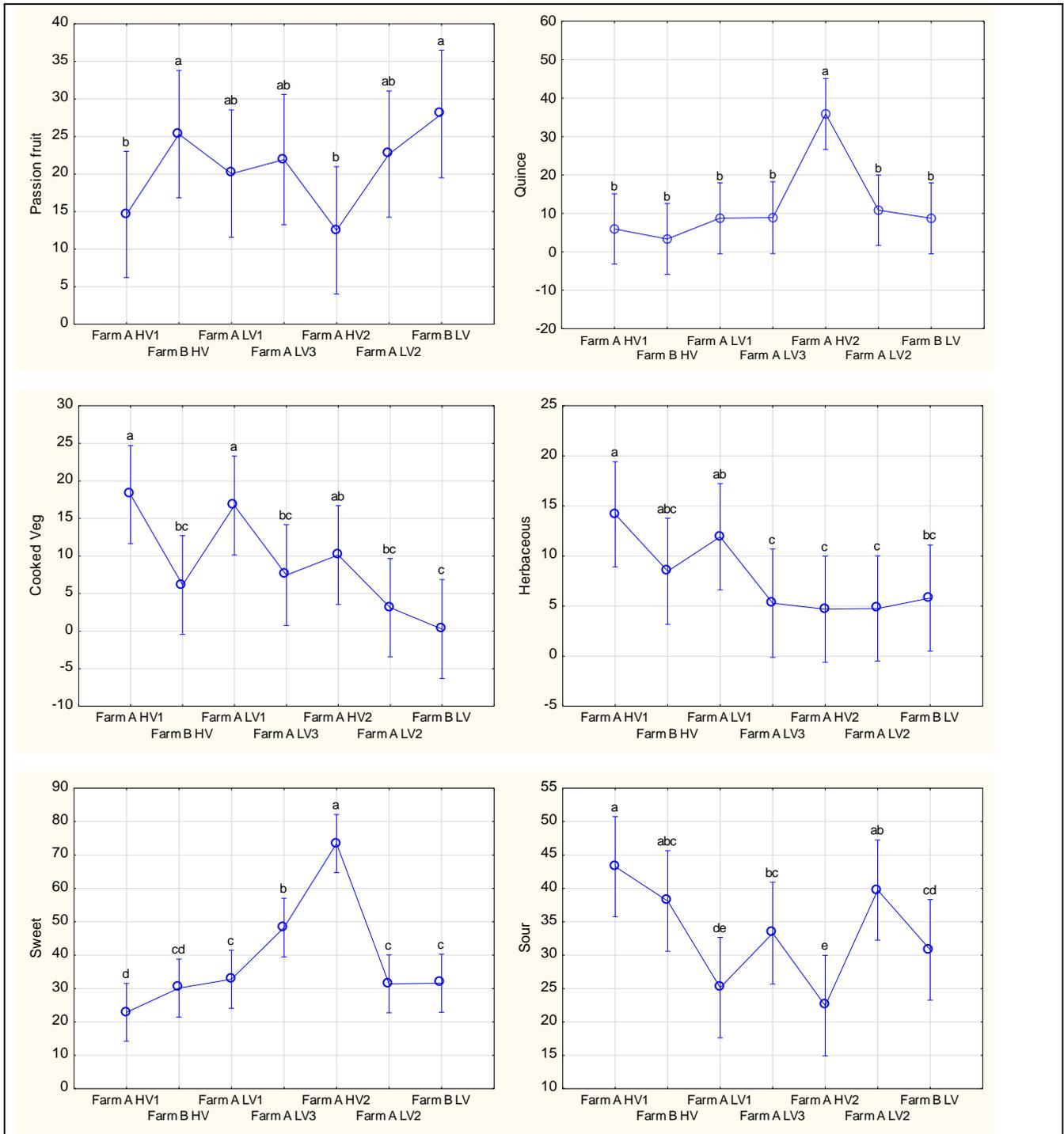


Figure 34: The LS Mean (LSM) plots for the significant taste and aroma descriptors for descriptive analysis completed in 2015 for Farm A and B Chenin blanc, low and high vigour (LV/HV). Different alphabetical letters in the plot indicate significant differences ($p < 0.05$). Vertical bars denote 0.95 confidence intervals.

Significant differences between the aroma and taste attributes according to the vigour levels and replicates of Farm A and B Chenin blanc wines are depicted in Figure 34. Passion fruit aroma descriptor was shown to be perceived as significantly higher in wines made from the low and high

vigour plots on Farm B, whereas wines made from Farm A high vigour plots (Rep2) were perceived as having the lowest rating for the passion fruit aroma. The quince aroma descriptor was shown to be significantly higher on the wines made from the high vigour plots (Rep2) on Farm A. The highest cooked veg aroma was found to be from wines made from the low and high vigour plots (Rep1) from Farm A. The herbaceous aroma descriptor showed significantly higher perception from wines made from Farm A low vigour plots (Rep1). The sweetest perceived wine was made from grapes obtained from the high vigour plots (Rep2) on Farm A, whereas the sourest perceived wine, was shown to be from the high vigour plots (Rep1) from Farm A.

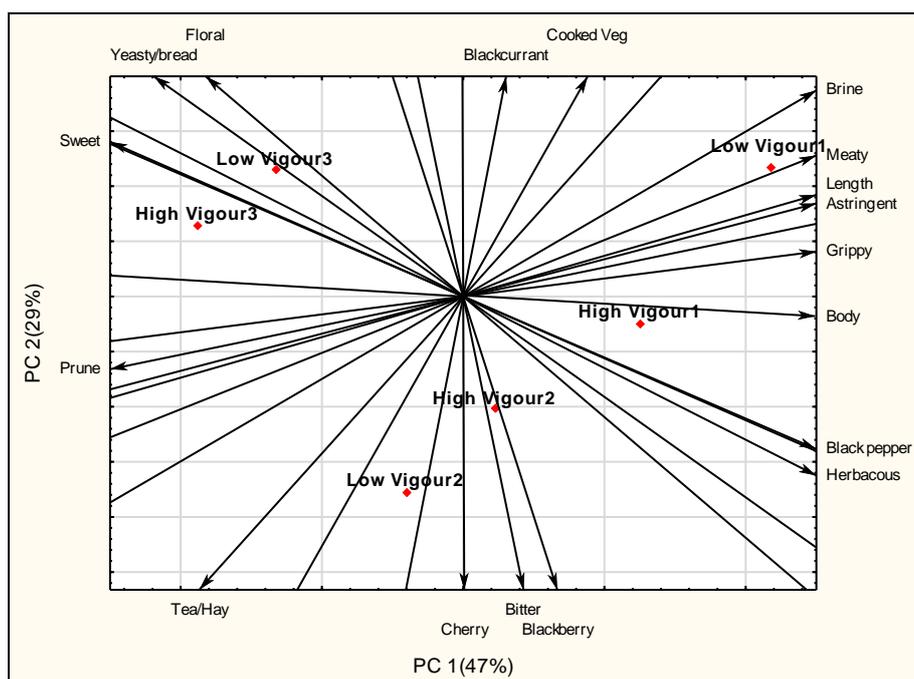


Figure 35: Principal component analysis (PCA) scatterplot of 2015 Farm B Pinotage wines according to significant aroma and taste descriptors.

A PCA plot was done on wines made from Farm B Pinotage using the most important aroma and taste descriptors (Figure 35). PC1 and PC2 explained 47% and 29% of the variance respectively and the total variance observed was 76%. A high amount of variation can be seen between the different replicates, however some positive correlations can be seen between the vigour levels of the replicates. Wines made from low vigour plots (Rep1) were described as meaty and brine on the aroma profiles, and astringent and grippy on the taste profiles. These two wines also were noted as having the longest length and highest body. Wines made from the high and low vigour plots (Rep2) were also positively correlated and regarded as bitter, with notes of cherry and blackberry. The Pinotage wines made from low and high vigour (Rep3) were described as the sweetest in taste, and a yeasty/bread and floral attributes were correlated to these two wines. All wines made from the Pinotage block, showed more variance between sites than vigour levels, which suggests the site difference played

the biggest role in determining the taste and aroma profile of the wine. No significant differences were found between the vigour levels and the replicates (data not shown).

3.3.9.2 2016

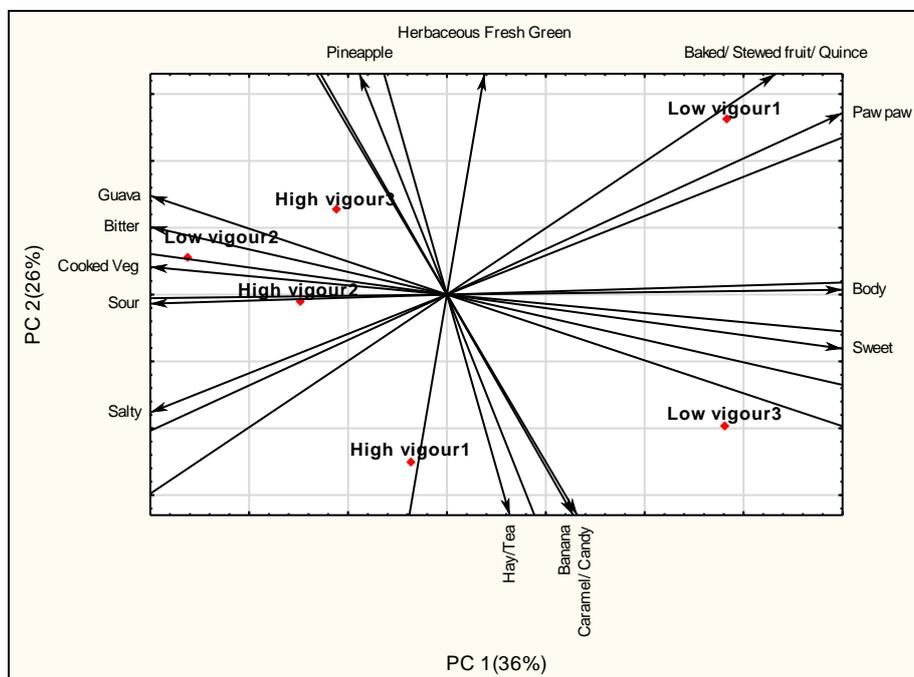


Figure 36: Principal component analysis (PCA) scatterplot of 2016 Farm A Chenin blanc wines according to significant aroma and taste descriptors.

Figure 36 depicts a PCA plot describing the aroma and taste profile of wines made from Chenin blanc grown on Farm A. PC1 and PC2 explain 36% and 26% of the variance respectively, and the total variance is shown to be 62%. Wines made from the bush vine Chenin blanc on Farm A showed high variation between all vigour levels, replicates and sites. The Chenin blanc made from the low vigour plot (Rep1) showed no similarity to other wines. Baked/stewed fruit/quince and paw paw aromas were associated with this wine. Wines made from the low vigour plot (Rep3) were considered sweetest and also had the highest body. Chenin blanc wines made from the high vigour sites (Rep1) were described as having hay/tea, banana and caramel/candy aromas. All the wines made from the low vigour site (Rep2), high vigour (Rep2) and high vigour (Rep3) were grouped together according to their descriptors. Guava and cooked veg were the aromas used to describe these wines, whereas these wines were also considered salty, bitter and sour. The vigour differences, rather than the site differences, between all wines made from the Chenin blanc on Farm A showed the highest variation. No significant differences in aroma and taste descriptors between vigour levels and replicates were found (data not shown).

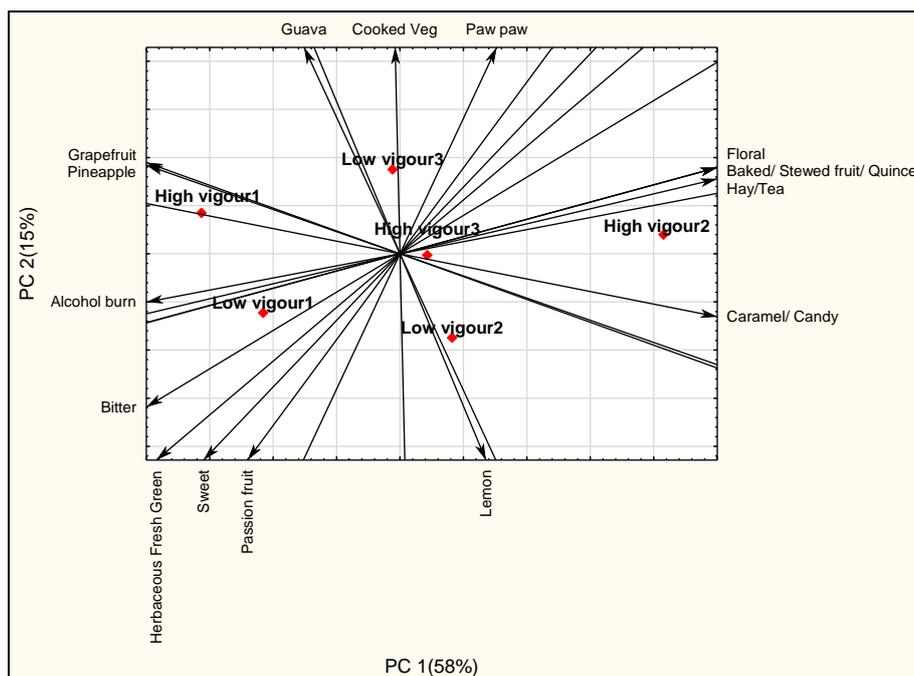


Figure 37: Principal component analysis (PCA) scatterplot of 2016 Farm B Chenin blanc wines according to significant aroma and taste descriptors.

A PCA plot of the Chenin blanc wines made from Farm B was constructed using aroma and taste descriptors used the panel (Figure 37). The total variance observed was 73%, with the PC1 and PC2 plots making up 58% and 15% of the variance respectively. None of the wines show correlations between one another. All the wines made from the different replicates and vigour levels show different aroma and taste descriptors. Wines made from the low vigour plots (Rep1) had the highest alcohol burn, whereas wines made from the high vigour plots (Rep1), aroma descriptors such as grapefruit and pineapple were used. Chenin blanc made from the low vigour plots (R2) showed dominant lemon aromas, and the wines made from the different vigour plots (Rep2) rather had floral, baked/stewed fruit/quince and hay/tea aromas, with slight notes of caramel/candy aromas. The wines made from the low vigour (Rep3) vines had aroma descriptors such as paw paw, guava and cooked veg, which may be associated to an off-odour. The higher vigour plot wines (Rep3) showed no positive correlation with any of the descriptors.

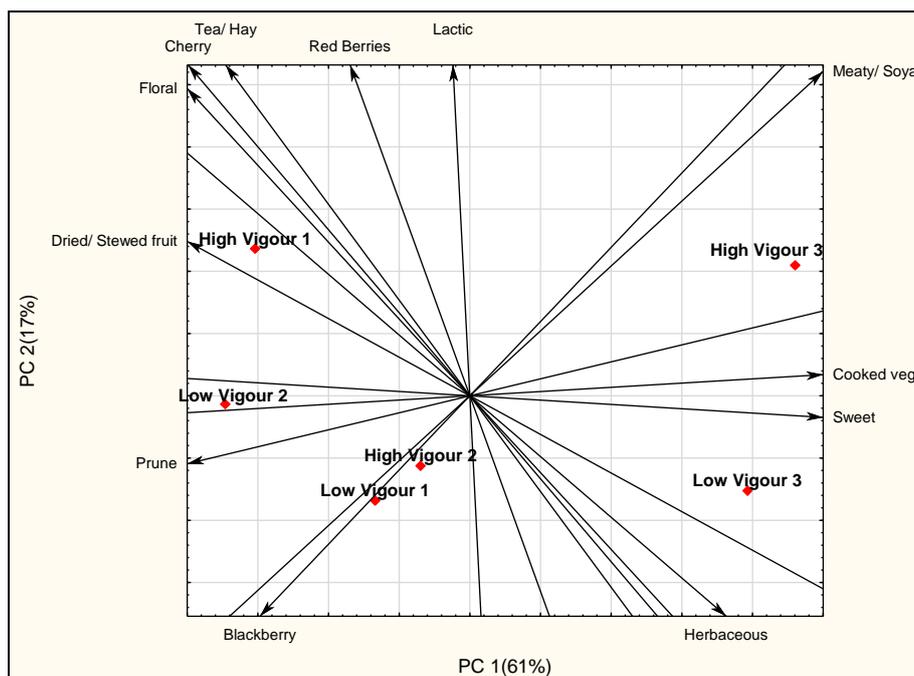


Figure 38: Principal component analysis (PCA) scatterplot of 2016 Farm B Pinotage according to significant aroma and taste descriptors, PC1 vs. PC2.

Figure 38 depicts a PCA plot of descriptors of wines made from Pinotage grown on Farm B during 2016. PC 1 and PC2 explain 61% and 17% of the variance, where the observed total variance was 78%. The Pinotage wine made from the low vigour (Rep1) sites showed positive correlation to the wine made from the high vigour (Rep2) site, with the predominant attribute being blackberry. The high vigour (Rep1) showed more dried/stewed fruit, floral, cherry and tea/hay aroma descriptors. Whereas the low vigour (Rep2) wine, prune was the main aroma descriptor. Both low and high vigour (Rep3) wines showed similar descriptors, however the high vigour wines also had meaty/soya aroma notes, and the low vigour wines were picked up to be more herbaceous.

Figure 39 also depicts the main descriptors of the Pinotage wines from 2016, however PC1 and PC3 are compared, with variance values being 61% and 14% respectively, thereby observing a total variance of 75%, which is weaker than the variance that was explained in the PCA plot shown in Figure 38. The descriptors shown in Figure 39 show a slight variation compared to Figure 38. Wines made from low vigour (Rep1) and low vigour (Rep2) showed a better correlation in Figure 39, with descriptors such as cherry, blackberry, hay/tea and floral linked to the wines. Other stronger correlations were found between wines made from high vigour (Rep1) and high vigour (Rep2), with attributes like prune and dried fruit being the predominant descriptors used. Finally wines made from the low and high vigour plots (Rep3) showed an even stronger association, describing the wines as being the sweetest, with cooked veg and meaty/soya aroma notes.

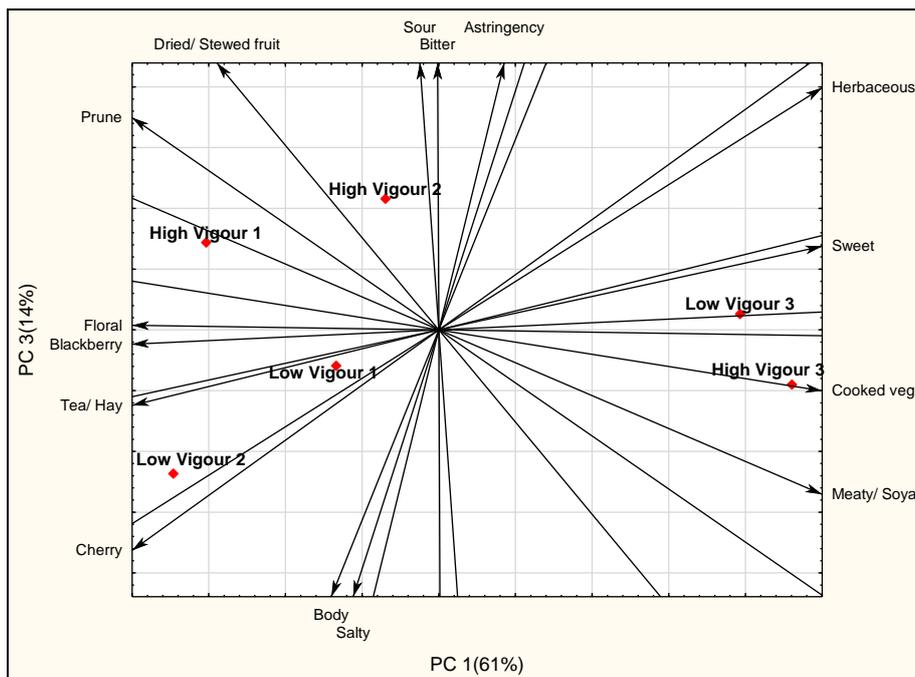


Figure 39: Principal component analysis (PCA) scatterplot of 2016 Farm B Pinotage according to significant aroma and taste descriptors, PC1 vs. PC3.

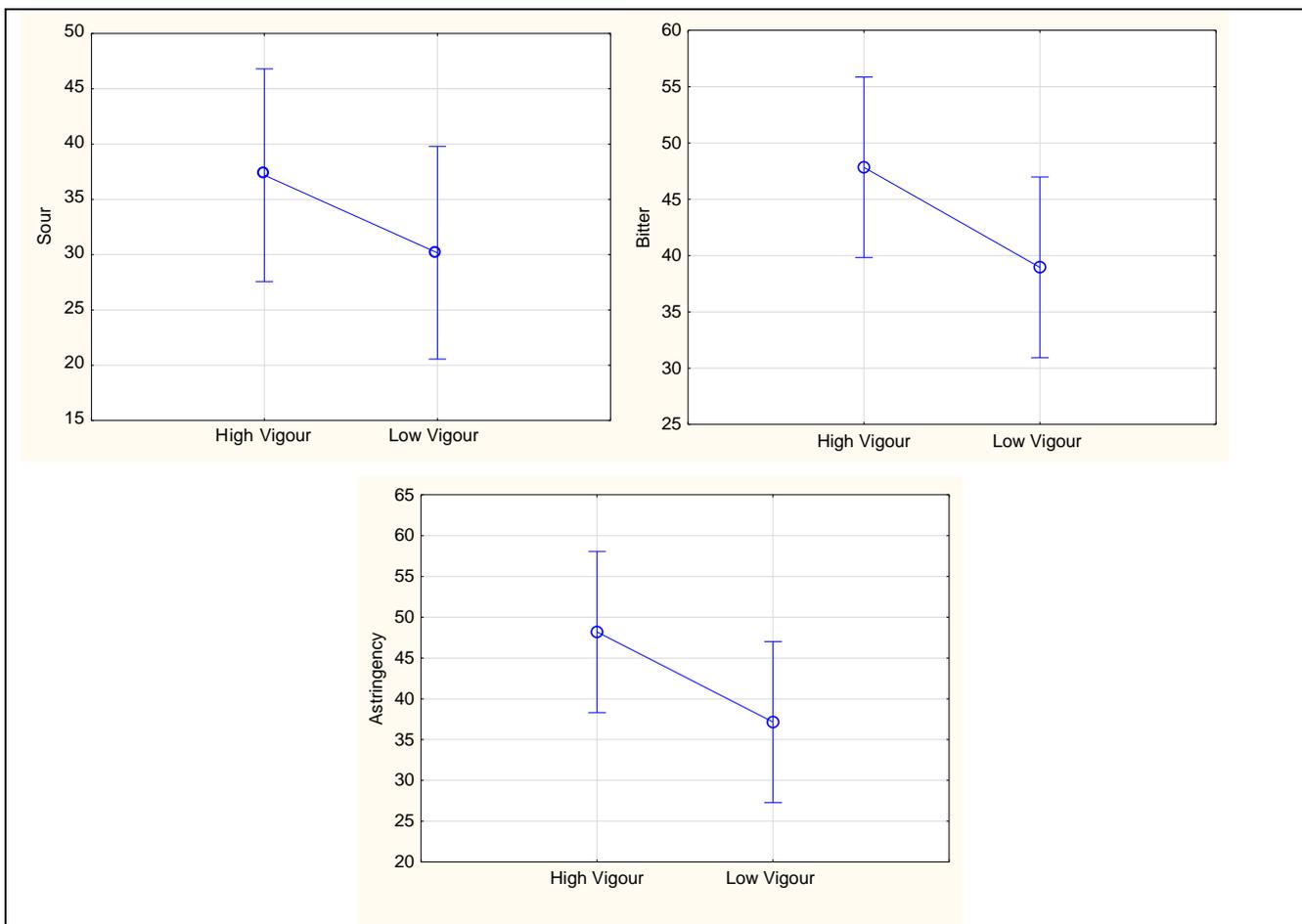


Figure 40: The LS Mean (LSM) plots for the significant taste descriptors differences between vigour levels for descriptive analysis completed in 2016 for Farm B Pinotage ($p < 0.05$), vertical bars denote 0.95 confidence intervals.

Figure 39 displays the significant taste differences between vigour levels. It shows the high vigour plots from Farm B Pinotage are significantly perceived to be the most sour, bitter and astringent from all the Pinotage wines made during the 2016 vintage.

The similarities and differences between some of the wines could be as a result of the similarities and differences between intrinsic factors such as grape genetic specificity and extrinsic factors such as environmental conditions, including soil, climate and location, grapevine management practices and winemaking practices (Santis *et al.*, 2016). Several researchers found that soil has an impact on the overall quality of grapes and the subsequent wine quality (Sabon *et al.*, 2002; Van Leeuwen *et al.*, 2004; Santis *et al.*, 2016). According to Hanekom (2012) at sugar levels exceeding 0.5% the perception of body can be affected by sweetness. Glycerol may also affect the body of a wine when occurring in high concentrations. The high bitterness of the 2016 Pinotage may also be as a result of other salts such as KCl, which increase the bitterness in some wines (De Loryn *et al.*, 2014).

The wines made from Farm A and B Chenin blanc in 2015, showed significant differences between vigour levels and replicates, and wines made from the Pinotage on Farm B showed significant differences between the vigour levels for certain taste descriptors. The other wines showed no significant differences between aroma and taste descriptors, which may be as a result of the unknown tasters' reliability to perceive salt in wines, therefore errors may have occurred (De Loryn *et al.*, 2014). The lack of differences could also be attributed to early harvest of 2016, or it may also be as a result of limited site and climate variability on wine sensory quality. The panel did not find any significant differences in regards to the saltiness of the wines, which may have been as a result of the salt levels being below the panels' detection limits (De Loryn *et al.*, 2014). De Loryn *et al.* (2014) also noted that some factor's mask the saltiness of wine, including sweetness and acidity in excess. Alcohol may also have had a masking effect. The effects of the different salt concentrations in terms of vigour showed negative significant aroma and taste attributes mostly in the high vigour plots. Wines made in 2015 Farm A and B Chenin blanc exhibited 'negative' descriptors in the high vigour wines (cooked veg, herbaceous, sour). The 2016 Pinotage also showed higher occurrences of 'negative' attributes in the high vigour wines (sour, bitter, astringency). This indicates that soil salinity and sodicity had little effect on the sensorial attributes in the wine.

3.4 Conclusions

Results showed a clear difference between the high and low vigour plots from all farms concerning soil analysis. The lowest resistance was found on Farm A Chenin blanc and Farm B Pinotage, where the low vigour sites exhibited resistance levels lower than 300 Ohm, which according to Raath (2016) indicates a large amount of salts are present in the soil, which as the resistance lowers have a growing negative impact on the vineyard. The highest Na concentrations were found for Farm B Pinotage, whereas the soil pH of all farms were quite variable, however Farm B Pinotage showed the highest

pH for both the low and high vigour plots. The highest ESP was discovered to be on Farm A, where some ESP values were greater than the 15%, making those soils Na alkaline rich (Raath, 2016).

The climate variation between Farm A, Farm B and the weather station near the farms showed some differences. Farm A had the highest GDD values, whereas Farm B showed the highest HI and GST. The weather station had the lowest values for all the indices (GDD, GST and HI). Usually the mean February temperature is used as an index as it is the warmest month of the year. However, results showed January mean temperatures were higher than the mean February temperatures during the 2016 vintage.

The vegetative measurements showed high variability between sites and vigour levels. Trunk circumference measurements were different between vigour levels as well as sites. The low vigour plots depicted the smallest trunk circumference. The bush vines on Farm A Chenin blanc had the largest trunk circumference, however the vines also showed the most variability. Both the Chenin blanc and the Pinotage on Farm B displayed the smallest trunk circumference. A positive correlation was found between the soil resistance and trunk circumference, as the soil resistance increases, so did the trunk circumference. Shoot growth on vines from Farm A and B Chenin blanc exhibited differences between vigour levels, whereas the Pinotage showed very little difference between vigour levels. The Pinotage however, had the slowest shoot growth, with the shoots also being the smallest compared to the vines from Farm A and B Chenin blanc. The Chenin blanc on Farm A was topped during the season, so no clear conclusion can be drawn from this plot. Leaf area also showed variability between vigour levels, where the low vigour vines always had the smallest leaf area. The highest total leaf area per shoot was on vines from Farm B Chenin blanc. The high vigour vines on Farm A Chenin blanc had the highest lateral to main leaf area ratios. A positive correlation was also found between soil resistance and total leaf area per shoot.

Leaves and petioles were sampled at bloom and véraison. The analysis of these samples displayed large difference between the stages of sampling, bloom and véraison, but also between sample types, petioles and leaves. The petiole samples usually depicted the highest concentrations of minerals, like Na, K and Mg, however Ca levels were highest in the leaf samples. Sampling done during véraison, showed the highest Na, Cl and Mg concentrations, whereas Ca levels were highest during bloom. K concentrations were quite variable between bloom and véraison. The highest Na levels were in the petioles of the low vigour vines on Farm B Chenin blanc during véraison. The high vigour vines from Farm B Chenin blanc exhibited the highest petiole K concentrations during bloom and véraison. The Ca levels in leaf samples taken during bloom from vines from Farm A and B Chenin blanc were highest in the high vigour vines. Similar Mg levels were found on all farms, samples and vigour levels. Positive correlations were found between the leaf (Na, K, Ca and Mg) and petiole samples (Na, K, Ca and Mg respectively). Cane mineral analysis was done post-harvest. Differences in the concentrations of minerals (Na, K, Ca and Mg) between the vigour levels and the farms were found. The low vigour

canes from Farm B Chenin blanc exhibited the highest Na concentrations. The K levels in the canes were highest from vines on Farm A and B Chenin blanc. The highest Ca levels were found in the canes from Farm B Pinotage, whereas the Mg concentrations from the canes of all farms displayed similarities. A positive correlation was found between Na and Mg concentrations in the canes.

All farms and vigour levels depicted differences in TSS accumulation and TA. Generally the low vigour TSS accumulation was slower and less than the high vigour plots, except for the Farm B Chenin blanc, where both vigour levels showed very similar berry TSS accumulation. The TA of the high vigour plots on Farm A and B Chenin blanc decreased linearly and showed lower TA values than the Pinotage on Farm B. Yield measurements displayed differences between vigour levels and sites, where for the low vigour plots on Farm A Chenin blanc and Farm B Pinotage had a lower average bunch and berry mass. Farm B showed very little differences between the high and low vigour plots.

The grape component mineral analysis exhibited cation and anion concentration differences between the grape skins, homogenate, juice and sediment samples. It was found that Ca, Mg, B, Zn and P were at highest concentrations in the grape skins and homogenised samples, whereas the highest levels of K, Al, Fe, Mn, Ba and Si were found to be in the sediment. The juice samples showed no minerals at high concentrations. This has implications for wines undergoing skin contact. A more detailed look, showed Na and Cl content was highest in the homogenised samples, K was highest in the sediment and Ca and Mg were highest in the grape skins.

The grape juice to wine mineral content interactions, showed that grape juice Na, Cl and Mg concentrations had positive correlations with the Na, Cl and Mg levels in the wine, respectively. No correlations were found between the grape juice K and Ca levels and the K and Ca wine concentrations. However, if the K and Ca correlations were considered separately according to farms, K correlated strongly to all farms separately and Ca grape juice and wine correlations showed strong correlations from Farm A Chenin blanc. The soil to grape juice and wine interactions showed no correlations between minerals found in the different soil depths and the grape juice and wine concentrations, except for K. K levels in the soil at different depths showed moderate to strong correlations with wine K concentrations. Correlations could also be seen between wine K concentrations, pH and the TA of the corresponding wine. As the K levels rose, the pH also increased, whereas as the TA dropped as the K concentrations increased.

The grape juice and wine mineral concentrations were quite variable between sites, years and vigour levels. The Na concentrations in the grape juice was highest from the low vigour plots from Farm B Chenin blanc grape juice. K was highest in grape juice obtained from high vigour plots during the 2016 vintage, whereas Ca concentrations were highest in 2016. Mg levels on the other hand, showed that the grape juice from the low vigour plots during 2016 were the highest. All minerals found in the wines, showed great variability between sites, vigour levels and years. Na and Mg levels were highest

in the low vigour plot grape juice. The K concentrations were higher in the high vigour plots, whereas no clear differences between the vigour levels, years and sites were noted between the Ca levels. The highest Cl concentrations in the grape juice and wine were found in the low vigour plots, which corresponds to the Na grape juice and wine concentrations, and the increased soil salinity.

The red wine colour and phenolics of the Pinotage from Farm B, showed variation in vigour and vintage. The differences in years could be attributed to the time of harvest, especially in 2016, where phenolic ripeness had not occurred before the grapes were harvested. Generally the 2015 low vigour sites wines showed higher anthocyanin and phenolic content, as a result of the smaller berries. The wine colour hue was high, which meant the red: brown colour ratio was lower. The colour hue differences may have been due to the high pH content of the Pinotage wines. The VA was also higher in the Pinotage from Farm B. The total acid was highest from wines made from grapes from Farm A Chenin blanc, where the highest malic acid concentration were found in wines made from Farm B Chenin blanc grapes. Glucose concentrations were quite variable and high, which may have been as a result of high sugar levels, incomplete fermentation or an analytical error.

The descriptive analysis showed only significant differences between attributes generated for the Farm A and B Chenin blanc wines made in 2016. The Pinotage wines made from Farm B also showed significant differences between the vigour levels. Significant aroma descriptors for Farm A and B Chenin blanc wines were passion fruit, quince, cooked veg and herbaceous, with significant taste attributes being sweet and sour. Farm B Pinotage made in 2016, only had significant taste descriptors, such as sour, bitter and astringency. It was also concluded the salt content in the wine did not affect the wine's aroma and taste profile, the differences between the wines were probably site differences, in particular the soil and climate.

3.5 References:

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Chapter 4

General discussion and conclusions

CHAPTER IV: GENERAL DISCUSSION AND CONCLUSIONS

4.1 Brief overview

In this study, the occurrence of soil salinity and sodicity was investigated on two farms, namely Farm A (Chenin blanc) and Farm B (Chenin blanc and Pinotage). Recent analysis of small scale wines made from saline sections of the farm confirmed free Na levels five times the OIV recommended limit (60 mg/L), and three times the recommended Na levels according to the South African guidelines (100 mg/L). The study aimed to provide insight into the positive and negative aspects of possible soil cation and anion transfer to the grapevine, grape juice and wine. The concentrations of these cations and anions were therefore investigated in the soil, different grapevine parts (leaves, petioles & canes), grape berry parts (juice, homogenised, skin & sediment) and in the final wines. In addition to this, the effects of these cation and anion concentrations on grapevine growth, wine composition and the sensory profile of the wines were also determined.

4.2 General discussion of findings according to the original aims

4.2.1 Viticultural: Translocation and concentrations of soil cations and anions in the different grapevine parts and their effects on grapevine growth and yield

The high and low vigour plots on all farms showed large differences between the low and high vigour plots according to the soil analysis. Differences in soil resistance, pH_{KCl} Na concentrations, and the ESP were noted between the farms and vigour levels. The soil resistance tended to be lower in the low vigour plot's soils. The low vigour plots on Farm A Chenin blanc and Farm B Pinotage exhibited the lowest resistance with the soil resistance in some plots being less than 300 Ohm. According to Raath (2016) as the soil resistance lowers, the amount of salts in the soil solution increase, thereby increasing the negative impact on the grapevine. This corresponded with the Na concentrations found in the soil solution on Farm A Chenin blanc and Farm B Pinotage, where some Na levels exceeded 400 mg/kg. The soil pH on both farms showed very little differences, with the soil pH values on Farm B Pinotage exhibiting the highest values of the farms. The soil ESP depicts the amount of Na ions present in the soil compared to the total amount of exchangeable cations. The ESP values of more than 15% in conjunction with the low resistance (< 300 Ohm) can be used to classify the type of soil salinity (Van Schoor *et al.*, 2000; Raath, 2016).

Various types of grapevine measurements were conducted in order to establish the effect of salinity and sodicity on grapevine growth and mineral composition. Grapevines are known to be moderately sensitive to salinity (Maas & Hoffman, 1977). Salinity affects plants in various ways including having osmotic effects, specific-ion toxicities and the potential to cause nutritional disorder (Läuchli & Grattan, 2007). Both soil salinity and sodicity affect various grapevine physiological processes, such

as yield reduction, shoot growth and an increase in cation and anion concentrations in the fruit (Lanyon *et al.*, 2004).

In the study, trunk circumference, shoot growth, leaf area, and the leaf, petiole and cane cation and anion contents were measured according to the low and high vigour plots for the different plots. The trunk circumference was measured on all vines from all sites, and it became apparent that the trunk circumference of vines seemed highly reduced in the lower vigour areas on Farm B. It was also noted that as the soil resistance levels increased, the trunk circumference also exhibited a logarithmic increase. The grapevine trunk circumference does reach a maximum size in practice due to various genetic and vine limitations, which described the logarithmic relationship between soil resistance and trunk circumference, in accordance with a previous study (Strever, 2003).

A reduction in shoot growth can also be attributed to soil salinity and sodicity. This reduction is commonly expressed by a reduction in leaf area and stunted shoots (Läuchli & Grattan, 2007). There were clear differences between vigour levels were reported on Farm A and B Chenin blanc, where the low vigour vines had a much slower and shorter final shoot growth compared to the high vigour vines. This reduction in shoot growth as a result of salt stress can be linked to Cl, Na or a combination of the two (Tavakkoli *et al.*, 2010). Salinity and sodicity also have a negative effect on the leaf area of grapevines. Results showed that the leaf area from vines grown on the low vigour plots was smaller than what?. Gomez-Del-Campo *et al.* (2002) reported that as the salinity in the soil increased, the total leaf area decreased as a result of the decreased number and size of the leaves. A positive linear relationship between the soil resistance and total leaf area was also reported. The decrease in shoot growth and leaf area may also be as a result of the antagonism between K and Na concentrations in the soil solution. An antagonistic relationship between Na and K leads to lower K concentrations in all plant parts if saline conditions are present in the soil (Fisarakis *et al.*, 2007).

The leaf and petiole cation and anion analysis conducted during bloom and véraison, exhibited differences between the sample type (leaf or petiole), sample time (bloom or véraison), the sites and the vigour levels. Grapevine mineral nutrients can be divided into two broad groups, based on their uptake patterns. Firstly, the nutrients taken up throughout berry growth such as N, K, Mg and P and secondly, elements taken up before véraison, which include Ca (Raath, 2012). Mineral nutrient content may change depending on the plant part sampled, as well as the time of sampling (Romero *et al.*, 2010). The Na, K, Ca and Mg concentrations in the leaves and the petioles were analysed during bloom and véraison in this trial. The Na and Mg levels in the both plant parts showed higher concentrations in samples taken at véraison. The highest Ca concentrations were, however, found during bloom. The K levels showed variable results between samples obtained from both bloom and véraison. The Na concentrations were noted to be highest in the petiole samples, concurring with

Prior *et al.* (1992). Christensen (2005) reported that levels of more than 0.5% (>5000 mg/kg) at bloom in the petioles may suggest excess toxic Na levels. Myburgh and Howell (2014) reported that the toxic leaf Na concentrations are 0.25% (2500 mg/kg). During this trial, the Na levels in the leaves showed higher concentrations than these maximum limits. The highest K concentrations were found in the leaf samples, however according to Weir and Cresswell (1993) the K concentrations were adequate. Calcium is a non-mobile plant nutrient, which means that remobilisation of Ca does not occur; therefore older leaves would have the highest Ca content. This trial showed the highest Ca levels in the leaves, which was also reported by Romero *et al.* (2010). As the salinity levels increased, the leaf and petiole Ca concentrations decreased. This could be attributed to the antagonistic effects between Na and Ca (Christensen, 2005; Myburgh & Howell, 2014). Magnesium is an essential component of chlorophyll, thereby making it highly important for photosynthesis (Saayman, 1981). Magnesium is a mobile mineral in the grapevine, therefore it may remobilise from old to new leaves (Romero *et al.*, 2010). Romero *et al.* (2010) and Benito *et al.* (2013) reported that Mg levels were higher in the petioles compared to the leaf blades, which corresponds with what was found in this trial. In this trial, a positive correlation and relationship was shown between the Na, K, Ca and Mg levels in the leaves and the petioles. The cane Na, K, Ca and Mg levels showed lower levels than the leaf and petiole samples.

In this trial, the TSS accumulation and TA decrease throughout ripening was also investigated to see if the soil salinity and sodicity had an impact. Physiologically, the effects of water stress and vines grown in salt affected soils are very similar (Sinclair & Hoffman, 2003; Meggio *et al.*, 2014). Ojeda *et al.* (2001) showed that grapevine water status, amongst other factors, had the largest effect on the grape quality *via* the ratio between skin area and juice volume. This study showed a higher rate of TSS accumulation in the high vigour vines, compared to the low vigour vines, whereas the low vigour vines showed a slower decline in TA. In terms of yield, the bunch and berry mass were reduced in the low vigour vines, which may have been affected by factors such as the number of berries in a bunch. Irrigation, degree of ripeness, pip numbers in the grape berry, genetics and bunch position may also have an effect on the size and mass (De Villiers, 1987; Davel, 2015).

4.2.2 Oenological: Translocation, concentration and effects of cations and anions into the grape components (juice, skin, sediment and homogenised) and the final wine product

Wine colour plays an important role in the initial judgement of wine quality (Lawless & Heymann, 1998). The phenolic composition of red wine is also a contributory factor to wine quality. It may have an effect on the astringency and bitterness of a wine, as well as play a vital role in red wine colour stability (Fisher & Noble, 1994; Cliff *et al.*, 2007). Both wine colour and the phenolic composition of wines are affected by grape variety, the viticultural practices followed by the farm, winemaking style, as well as the age of the wine (Birse, 2007). The largest variation in red wine colour and phenolic composition was noted between vintages (2015 and 2016), with little difference between vigour

levels. The highest wine colour density, colour hue, total red pigment, total anthocyanins and total phenols were found in the 2015 low vigour plot wines. This could have been due to the smaller berries, as a result of water deficits caused by the salt stress.

In this study, the chemical composition of the wines was also investigated in terms of soil salinity and sodicity. Differences were noted between all treatments for wine pH, volatile acidity (VA), total acid, malic acid, glucose, fructose, ethanol and glycerol content, however with less differences between vigour levels. One of the most essential factors affecting grape juice and wine quality is the pH. The pH of juice and wine has an effect on the perception of acidity, the sugar and acid balance, as well as the expression of fruit flavour. It also affects protein stability and K bitartaric acid precipitation during winemaking. Red wine colour stability, malolactic fermentation and microbial stability are also affected by juice and wine pH (Boulton, 1980; Kodur, 2011). The Pinotage made from grapes obtained from Farm B had the highest pH during the 2016 vintage. This may have been caused by various factors including temperature, rainfall, soil type, viticultural practices and vine cultivars. Potassium is extracted from the grape skins during skin contact, which may have also led to the high pH in the Pinotage. The VA on all the wines was below the EU limit of 1.2 g/L and also the detection threshold. This may be an indication that soil salinity and sodicity have no effect on the VA of a wine. The glucose concentrations were unnaturally high, which may have been due to an incomplete alcoholic fermentation. The highest ethanol was wine made from Farm A Chenin blanc, as it also had the highest sugar content. Glycerol in wine is the most abundant constituent in wine except for carbon dioxide and ethanol, and is formed in wine as by-product of glycolysis during alcohol fermentation in wine (Csutorás *et al.*, 2014). Remize *et al.* (2003) indicated that in wine glycerol levels can vary from 2 to 11 g/L, dependent on yeast strain, grape must composition and fermentation conditions. Glycerol levels were high in all the wine, which may be as a result of the condition of the grape juice when fermentation started, or the high sugar content. According to Logothetis *et al.* (2010), the salt-preconditioned yeasts (Vin13) influenced the stress-tolerance of the yeast by the production of glycerol and trehalose. This may have also had an influence on the high concentration of glycerol in the wine.

The cation and anion concentrations of different grape components were determined in this trial. It was shown that Na, Ca, Mg, B, Zn and P concentrations were highest in the grape skin and homogenised samples, whereas K, Fe, Al, Mn, Ba and silicon (Si) concentrations were highest in the sediment. The grape berry juice contained lowest concentrations of all cations and anions. This is of importance if the wines undergo skin contact, which may lead to higher concentrations of cations and anions in the final wine product.

Results also showed that grape juice mineral content does not necessarily translocate into the final wine product. The Na and Mg concentrations in the grape juice showed the only strong positive

correlations to the final wine Na and Mg concentrations, respectively. Other reasons may include by the partial precipitation during and post-fermentation of K and Ca as K bitartrate and Ca tartrate. The soil to grape juice to wine translocation only exhibited strong correlations between K concentrations in the soil and in the wine. The antagonistic relationship between K, Mg and Ca may have had an effect on the absorption of minerals by the vine (Marschner, 1995; Hannan, 2011).

The concentration of Na, K, Ca and Mg in the grape juice showed differences between vigour levels and years. The juice Na, Ca and Mg concentrations were much higher in 2016 than in 2015, whereas the low vigour sites usually displayed the highest levels of Na in both 2015 and 2016. The antagonism between Na and K may have led to the lower K concentrations in the low vigour sites. The K levels were also far higher in 2016 compared to 2015. Factors that may have led to differences between the 2015 and 2016 vintage may include K fertilisation and Ca/Mg antagonism, where the supplementation of Mg or Ca to the soil, may have led to a decrease in K uptake by the plant (Hannan, 2011). Canopies with higher shaded conditions, *i.e.* higher vigour, transport K into grape berries in order to compensate for the lack of sugar accumulation (Mpelasoka *et al.*, 2003). The wine Na, K, Ca and Mg concentrations were also quite variable, however differences occurred between the years and vigour levels. The Na concentrations in 2016 and in the low vigour plots exceeded the OIV limit of 60 mg/L free Na and the South African limit of 100 mg/L with Cl making up approximately 60.7% of NaCl. The moderate to high Na contents may not only come from the soil. The K concentrations were higher in 2016 and the high vigour plots. The differences between the wine Ca and Mg concentration were minimal. The Ca concentration differences in the wine may be as a result of Ca fertilisation and winemaking practices that include Ca bentonite fining and clarification for the removal of suspended solids after fermentation as well as to decrease turbidity and the use of CaCO₃ and CaSO₄ for must and wine deacidification and grape juice acid enhancement respectively (Woldemariam & Chandravanshi, 2011). Differences in Mg wine content could be attributed to Mg fertilisation and K/Ca/Na and Mg antagonism (Birch *et al.*, 2003; Peacock & Christensen, 2007).

4.2.3 Wine sensory results: The effect of cations and anions on the sensorial profile of the wine and if 'saltiness' was perceived

High salt content in wine has important wine sensory implications, both negative and positive, *i.e.* low NaCl concentrations may have a positive effect on the sensorial properties of wine (Liem *et al.*, 2011; de Loryn *et al.*, 2014). NaCl increases saltiness in wine, but also reportedly lowers bitterness and it may also increase the perception of sweetness (De Loryn *et al.*, 2014). Descriptive analysis between wines indicated that the only significant differences were found between attributes generated for the Farm A and B Chenin blanc wines made in 2016. The Pinotage wines made from Farm B also showed significant differences between the vigour levels. Significant aroma descriptors for Farm A and B Chenin blanc wines were passion fruit, quince, cooked veg and herbaceous, with

significant taste attributes being sweet and sour. Lawless and Heymann (2010) reported that at low salt concentrations, sweetness may be enhanced, which could be the reason for increased perception of sweetness in the Chenin blanc wines. Farm B Pinotage made in 2016, only had significant taste descriptors, such as sour, bitter and astringency. Bitterness may have been enhanced by other salts present in the wine, specifically KCl (de Loryn et al., 2014). It was also concluded the salt content in the wine did not significantly affect the wine's aroma and taste profile, the differences between the wines were probably site differences, in particular the soil and climate. This more formal sensory analysis confirms a previous informal NaCl addition trial, with wines from the same farms, and about seven tasters uninformed about the addition. It was found that NaCl addition to about 300 mg/L could not be picked up as salty by any of the tasters, and for Pinotage wines, it was even the preferred wine.

4.3 Recommendations for future studies

Even though the effects of cations and anions were investigated on a broad scale, *i.e.* viticulturally, oenological, and sensory, various research possibilities still exist and arose from this study. These include:

4.3.1 Viticulture

- Root studies including root cation and anion concentrations should be conducted in winter, to quantify the roots reaction to soil salinity and sodicity. The uptake and distribution of the cations and anions should also be measured during the root studies in order to identify the concentration differences between the low and high vigour plots in the fine, medium and large roots.
- Soil and plant water status should be determined throughout the season using a neutron probe and the pre-dawn leaf water potential, respectively. Reasons for this include a better understanding the soil-plant water relationship as a result of soil salinity and sodicity.
- The photosynthetic rates, chlorophyll content of the leaves and the stomatal conductance should also be measured in order to quantify the effects observed in relation to soil salinity and sodicity.
- Cane mass during pruning should be investigated in order to quantify the differences in vigour levels.

4.3.2 Oenology

- Cation and anion concentrations should be measured during fermentation, in order to identify patterns of cation and anion accumulation during fermentation. This should be conducted on wines undergoing skin contact, as well as wines not undergoing skin contact.

- The concentration effects of certain winemaking practices, such as differences between Ca and Na bentonite fining, on resultant wine cation and anion concentrations should be investigated as well as the effects of other winemaking practices on the cation and anion content of the final wine product.

4.3.3 Sensorial

- Descriptive analysis should also be done on wines spiked with NaCl at different concentrations, in order to better evaluate the effect salt both on the wine's aroma and taste profile.
- A consumer preference tasting should be conducted to evaluate the consumer's preferences to increasing salt concentrations.

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4.5 ADDENDUM A

Table 1: Soil sample analysis for Farm A Chenin blanc, Farm B Chenin blanc and Farm B Pinotage according to vigour, with standard deviation (SD).

		pH (KCl)	Resistance (Ohms)	Ca (cmol(+)/kg)	Mg (cmol(+)/kg)	K (mg/kg)	Na (mg/kg)	SAR	P (citric acid)	Total cations (cmol(+)/kg)	ESP	Cu (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	S (mg/kg)
Farm B Chenin blanc High Vigour	Mean	7,4	736,7	17,2	6,0	90,8	107,7	0,2	9,4	23,9	4,4	1,1	18,4	122,1	8,4
	SD	1,0	220,1	14,9	4,8	23,0	65,5	0,1	10,0	19,4	4,3	0,4	7,6	79,1	2,6
Farm B Chenin blanc Low Vigour	Mean	7,4	677,8	8,8	5,3	119,0	306,2	0,5	13,2	15,7	9,3	1,1	15,4	70,5	19,8
	SD	0,6	507,4	12,5	4,6	52,3	302,7	0,4	13,1	17,9	6,6	0,3	9,0	25,9	20,5
Farm A Chenin blanc High Vigour	Mean	5,6	1334,4	2,4	1,4	43,7	82,1	0,3	17,0	4,8	7,0	1,0	1,1	60,6	7,7
	SD	1,0	530,6	1,3	0,6	29,7	130,6	0,5	10,7	1,7	8,4	0,8	0,7	68,1	3,9
Farm A Chenin blanc Low Vigour	Mean	4,9	296,3	1,4	1,9	38,4	425,4	1,5	4,9	6,0	29,2	0,4	0,6	7,1	60,0
	SD	0,6	134,9	0,3	0,3	13,6	241,0	0,8	3,0	1,1	12,4	0,1	0,4	4,8	34,2
Farm B Pinotage High Vigour	Mean	7,0	630,0	4,6	3,4	94,4	98,4	0,2	20,6	8,6	5,5	1,4	96,1	80,8	8,7
	SD	0,4	174,8	2,1	1,4	22,4	19,8	0,1	20,1	3,4	2,2	0,5	180,9	32,4	2,9
Farm B Pinotage Low Vigour	Mean	8,0	261,1	18,5	8,8	91,2	528,4	0,8	12,7	29,9	11,3	0,9	9,5	44,1	27,2
	SD	0,4	134,5	18,9	6,0	23,7	418,7	0,7	14,1	22,7	10,0	0,3	8,3	19,0	13,7

4.6 ADDENDUM B

Table 2: Correlations between petiole and leaf analysis.

	LeafN (%)	LeafP (%)	LeafK (%)	LeafCa (%)	LeafMg (%)	LeafNa (mg/kg)	LeafMn (mg/kg)	LeafFe (mg/kg)	LeafZn (mg/kg)	LeafCu (mg/kg)	LeafB (mg/kg)
PetioleN (%)	0,883326	0,497225	0,129226	0,324209	-0,118209	-0,432744	-0,027061	-0,509123	0,557600	0,183042	-0,242102
PetioleP (%)	0,198698	0,800642	0,207019	0,634328	-0,060114	-0,133545	-0,483542	0,006598	0,125049	0,362224	0,197480
PetioleK (%)	-0,161472	-0,069585	0,774396	-0,097058	-0,616239	0,061768	-0,278501	-0,097743	-0,316066	0,657458	0,029962
PetioleCa (%)	0,245899	0,793550	0,099641	0,882023	-0,011613	-0,277505	-0,175881	-0,004089	0,420700	0,051130	0,355435
PetioleMg (%)	-0,148760	0,149265	-0,727260	0,147547	0,854987	0,299724	-0,023450	0,355475	0,014198	-0,218415	-0,137807
PetioleNa (mg/kg)	-0,415108	-0,226535	-0,424410	-0,363037	0,507900	0,890751	-0,423941	0,324937	-0,579011	0,432188	-0,409470
PetioleMn (mg/kg)	0,239488	-0,165701	0,038239	-0,033039	0,141293	-0,330402	0,963626	-0,157971	0,542009	-0,579502	0,032836
PetioleFe (mg/kg)	-0,576270	-0,252181	-0,153119	-0,360397	0,095246	0,269228	-0,272559	0,534766	-0,513157	-0,002369	-0,102497
PetioleZn (mg/kg)	0,113747	0,361914	-0,353223	0,003327	0,497495	0,332558	-0,525746	0,146419	-0,176177	0,486013	-0,431470
PetioleCu (mg/kg)	-0,232277	-0,081668	0,117653	-0,346403	-0,151808	0,448961	-0,714589	0,150784	-0,669028	0,831431	-0,339464
PetioleB (mg/kg)	0,052592	0,075709	0,378941	0,227856	-0,432198	-0,388404	0,169485	-0,109719	0,172936	-0,191219	0,630937

4.7 ADDENDUM C

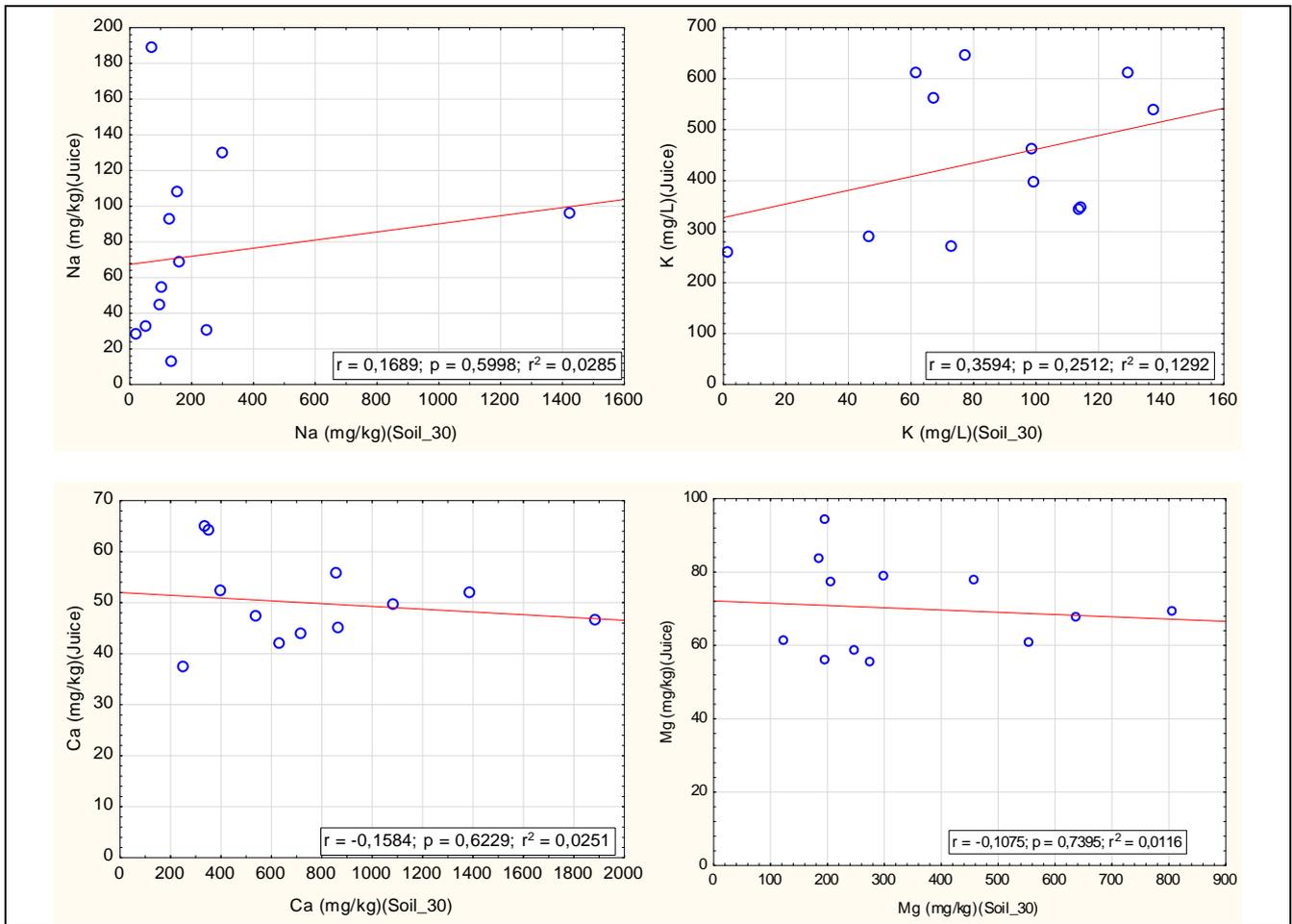


Figure 1: Correlations of Na (A), K (B), Ca (C) and Mg (D) translocation from 30 cm soil depth to grape juice.

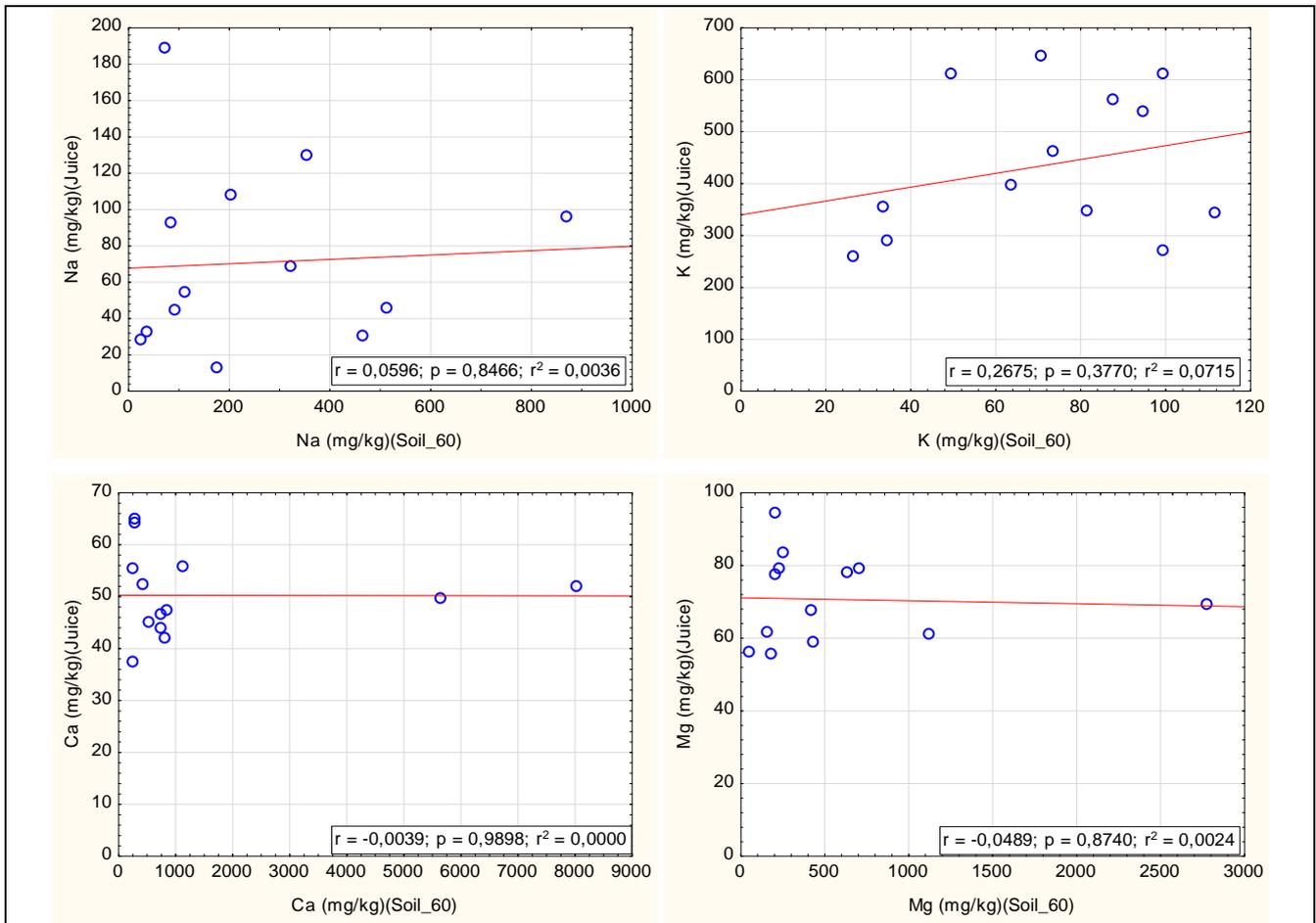


Figure 2: Correlations of Na (A), K (B), Ca (C) and Mg (D) translocation from 60 cm soil depth to grape juice.

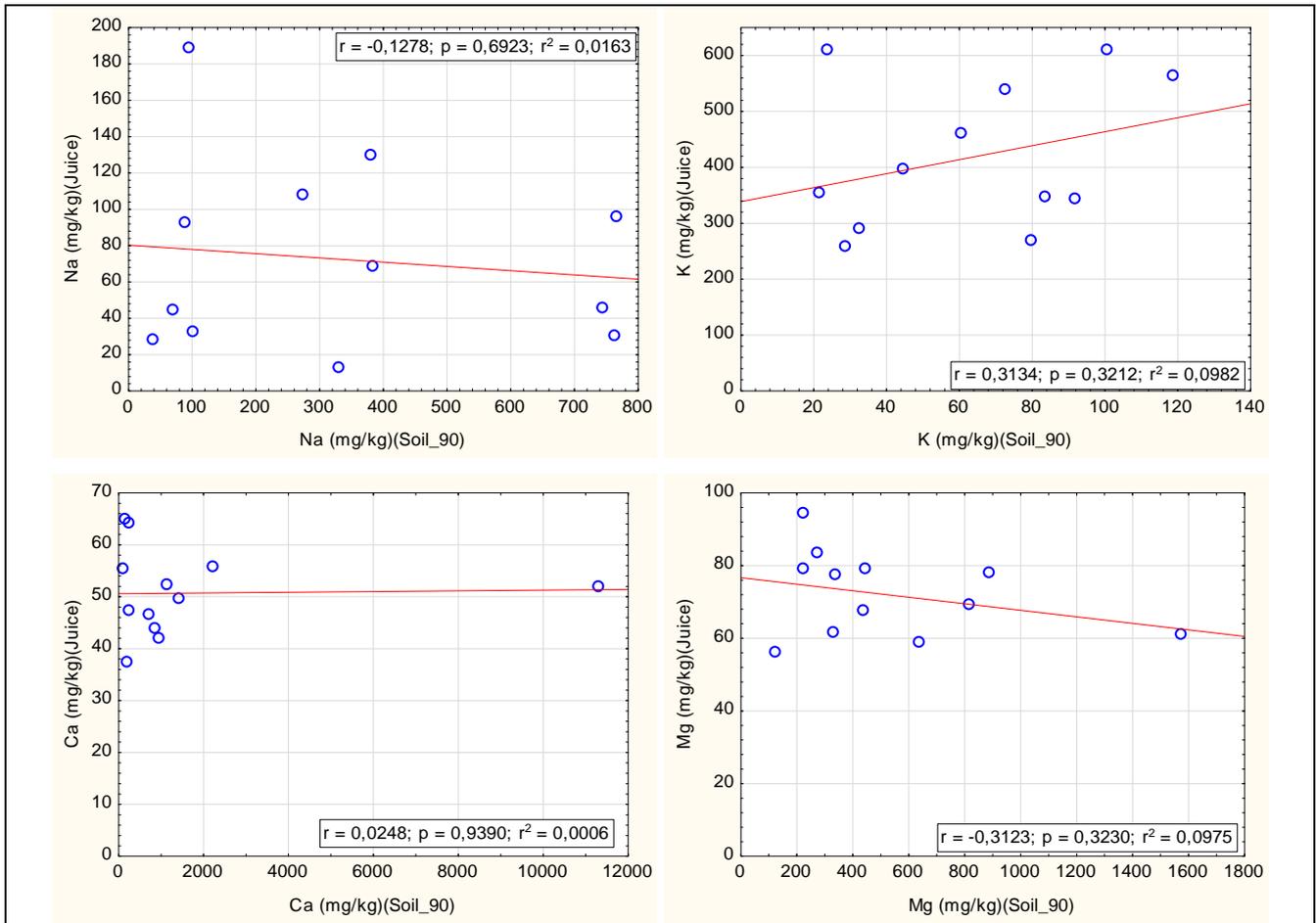


Figure 3: Correlations of Na (A), K (B), Ca (C) and Mg (D) translocation from 90 cm soil depth to grape juice.