Effect of soil parameters and canopy structure on root growth and distribution

by

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Summary

Because of long-term climate changes, apparently associated with higher temperatures and fewer rainfall events, factors such as water-use efficiency and site selection for new cultivars are a matter of increasing importance for viticulture. Within this context, the root system is expected to play a key role. Its relevance to grapevine functioning is due to the numerous functions in which it is involved. In the light of this, the development of the root system is highly relevant to the viticulturist because of the fact that grapevine growth and functioning are dependent on the development of the root system. Differences can, therefore, be expected in terms of berry ripening on single grapevines of the same scion for situations with differing development of root systems, despite being grafted on the same rootstock.

Root growth is influenced by several factors, among the ecological aspects. Soil parameters have a predominant influence on root growth and distribution but also annual root production can be altered by canopy manipulation. Due to the importance of root growth to the aboveground development of the vine, it is critical to gain understanding of the relationship between soil factors and root growth and distribution, and the central role that the subterranean environment plays in the concept of terroir. This study aimed to investigate the effect of selected soil physical and chemical parameters on root growth and distribution and to investigate whether having very different canopies influences root growth. In order to achieve these goals, two experiments were conducted; the first was performed in two commercial Sauvignon blanc vineyards each grafted onto Richter 110, non-irrigated, with two treatments: undisturbed lateral growth and complete lateral removal. The second study included the analysis of eight commercial Sauvignon blanc vineyards grafted onto Richter 99 and Richter 110 located in the Stellenbosch Wine of Origin District. Measurements of physical and chemical soil parameters, root growth and distribution, canopy growth and functioning, vine water status and berry composition were performed.

The edaphic factors appeared to be one of the most important parameters that affected root development by changing soil water availability and possibly causing physical or chemical limitations on root growth. From the results of this study, it is clear that severe water stress and a pH (KCl) lower than 4.5 play a key role in the limitation of root growth. Due to the fact that most of the soils from the Stellenbosch Wine of Origin District, especially the subsoils, are acidic, this is a factor to consider before planting. On the other hand, the combination of favourable edaphic conditions, such as a subsoil pH of higher than 5.0, light- to medium-textured subsoil and moderate water stress, allow increased growth of thin roots.

However, the effect of canopy management on root growth cannot be discounted due to its importance in the variation of carbohydrate demand by competing sinks. This study showed that lateral removal done from when the berries are at pea size results in an increase in the number of thin roots (0.5-2.0 mm). The secondary leaf area represents at least the same leaf area as the primary leaf area in all the vineyards evaluated, which reveals the relative importance of the laterals in the total leaf area of the vine and the potential importance in terms of microclimate and leaf area available for photosynthesis. Studies of root growth should take the vineyard canopy architecture into account.

Opsomming

As gevolg van langtermyn klimaatsveranderinge wat toegeskryf kan word aan die voorkoms van hoër temperature en laer reënval, is faktore soos effektiwiteit van waterverbruik en liggingseleksie vir nuwe kultivars van kardinale belang vir wingerdkunde. Binne hierdie konteks, speel die wortelsisteem ‘n belangrike rol. Die belangrikheid hiervan vir wingerdfunksionering kan toegeskryf word aan die talle funksies waarby dit betrokke is. Die ontwikkeling van die wortelsisteem is dus hoogs relevant vir die wingerdkundige, omdat wingerdgroei en funksionering afhanklik is van die ontwikkeling van die wortelsisteem. Verskille kan daarom dus verwag word in terme van korrelrypwording op ‘n enkele wingerdstok van dieselfde onderstok vir gevalle met verskillende ontwikkeling van die wortelsisteem, ten spyte daarvan dat dit op dieselfde onderstok geënt is.

Wortelgroei word, onder ekologiese aspekte, deur verskillende faktore beïnvloed. Grondfaktore het meerendeels ‘n predominante invloed op wortelgroei en -verspreiding, terwyl jaarlikse wortelproduksie deur lowermanipulasie beïnvloed kan word. Weens die belangrikheid van wortelgroei vir die bogrondse ontwikkeling van die wingerd, is dit krities om kennis op te doen oor die verhouding tussen grondfaktore en wortelgroei en –verspreiding, asook die sentrale rol wat die subterreinomgewing op die terroir-konsep speel. Die studie was daarop gemik om die invloed van geselekteerde fisiese en chemiese parameters van grond op wortelgroei en -verspreiding vas te stel, en ook te ondersoek of verskillende lowers wortelgroei sal beïnvloed. Om laasgenoemde doelwitte te bereik, is twee eksperimente uitgevoer. Die eerste is uitgevoer in ‘n kommersïele Sauvignon blanc-wingerd wat geënt is op Richter 110, sonder besproeïng en met twee behandelings, naamlik onversteurde sêkondere lootgroei en volledige sêkondere lootverwydering. Die tweede studie het die analise van agt kommersïele Sauvignon blanc-wingerde geënt op Richter 99 en Richter 110 in die Stellenbosch Wyn van Oorsprong Distrik. Metings van fisiese en chemiese grondfaktore, wortelgroei en -verspreiding, lowergroei en -funksionering, plantwaterstatus en korrelsamestelling is uitgevoer.

Dit blyk dat edafiese faktore een van die belangrikste parameters is wat wortelontwikkeling beïnvloed deur beskikbaarheid van grondwater te verander, en wat moontlik fisiese en chemiese beperkings op wortelgroei kan veroorsaak. Uit die resultate van die studie is dit duidelik dat intense waterspanning en ‘n pH (KCl) laer as 4.5 ‘n belangrike rol in die beperking van wortelgroei speel. Aangesien die meeste van die grondsoorte in die Stellenbosch Wyn van Oorsprong Distrik, veral al die subgronde, suur is, is dit ‘n faktor wat in oorweging geneem moet word voor aanplantings. Die kombinasie van gunstige edafiese toestande, soos ‘n subgrond met ‘n pH hoër as 5.0, ‘n lig tot medium tekstuur en matige waterspanning, sal dus aanleiding gee tot ‘n toename in die groei van dun wortels.

Die effek van lowerbestuur op wortelgroei kan egter nie buite rekening gelaat word nie weens die belangrikheid daarvan in die variasie van koolhidraataanvraag deur kompeterende vraagpunte. Hierdie studie toon dat, indien sêkondere lootverwydering tydens ertjiekorrelgrootte toegepas is, dit aanleiding gee tot ‘n toename in die dun wortels (0.5 tot 2.0 mm). Die sêkondere blaaroppervlakte verteenwoordig minstens dieselfde blaaroppervlakte as die primêre blaaroppervlakte in al die wingerde wat ondersoek is, wat dui op die belangrikheid van sêkondere lote in die totale blaaroppervlakte van die wingerd en die potensiële belangrikheid

daarvan in terme van mikroklimaat en blaaroppervlakte wat vir fotosintese beskikbaar is. Studies van wortelgroei moet lowerargitektuur in ag neem.

This thesis is dedicated to my parents, Jaime Serra and Magdalena Stepke, my wife Marcela and my son Iñaki

Biographical sketch

Ignacio Serra was born in Santiago, Chile on 20 June 1973. He matriculated at Escuela Laboratorio and Colegio Julio Acosta García at San Ramón, Costa Rica and Colegio Preciosa Sangre at Pichilemu and Colegio Inglés “George Chaytor” at Temuco, Chile. He enrolled at University of La Frontera, Temuco, Chile for an engineering degree in Agronomy and graduated in 2000. Ignacio trained at the Polytechnic University of Madrid, Spain in the course Master in Viticulture and Enology and graduated in 2002. In 2008, he enrolled for the degree MSc Agric (Viticulture) at the Stellenbosch University.

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Preface

This thesis is presented as a compilation of five chapters. Each chapter is introduced separately, with the results presented in chapters three and four and concluded in chapter five, and is written according to the style of the South African Journal of Oenology and Viticulture.

Chapter 1	**Introduction and project aims**
Chapter 2	**Literature review** Soil parameters and canopy management practices that affect root development, with implications for grapevine performance
Chapter 3	**Research results** Root growth, canopy functioning and berry ripening response to lateral removal in Sauvignon blanc/Richter 110 in two soils
Chapter 4	**Research results** Root growth and distribution of Sauvignon blanc/Richter 110 and Sauvignon blanc/Richter 99 under different soil conditions in the Stellenbosch Wine of Origin District
Chapter 5	**General discussion and conclusions**

Contents

Chapter 1

Introduction and project aims

INTRODUCTION AND PROJECT AIMS

1.1 INTRODUCTION

Because of long-term climate changes, apparently associated with higher temperatures and fewer rainfall events, factors such as water-use efficiency and site selection for new cultivars are a matter of increasing importance for viticulture. Within this context, the root system is expected to play a key role. Its relevance to grapevine functioning is due to the numerous functions in which it is involved. These functions include water and nutrient uptake, structural support of the plant, and storage (Fitter, 1987) and synthesis of plant hormones (Dodd, 2005), which are linked to root-to-shoot signalling. This latter aspect mediates the relationship between the root system and the canopy. Signal molecules (other than water and nutrients) are supplied from the root system and these predominantly regulate shoot growth and water use (Dodd, 2005).

In the light of this, the development of the root system is highly relevant to the viticulturist because of the fact that vine growth and functioning are dependent on the development of the root system (Hunter *et al*., 1995). Differences can therefore be expected in terms of berry ripening on single grapevines of the same scion for situations with differing development of root systems, despite being grafted on the same rootstock. Recent studies show that a limitation in the root system influences carbon assimilation by the plant and that the effect is immediate (Smart *et al*., 2006).

Despite the known importance of roots, little is known about root development in comparison to the wide spectrum of literature on the canopy, mainly due to the difficult inherent subterranean studies. In general, it is possible to classify the research done on the roots of woody plants into two main categories: root physiology and root ecology. Root physiology deals mainly with the study of physiological processes in roots, while root ecology investigates the influence of environmental factors on the development of root systems (Young, 1990).

Among the ecological factors, soil parameters have a predominant influence on root growth and distribution. Soil texture influences the rooting depth as well the vertical distribution of roots (Nagarajah, 1987), acidic soil conditions alter the uptake of nutrients by the roots and root development and anatomy (Conradie, 1988; Kirchhof *et al*., 1991), saline conditions affect water transport (Shani *et al*., 1993), and a high soil Cu concentration decreases root growth (Toselli *et al*., 2009). On the other hand, root morphology is plastic and root production, length, longevity and mortality can be enhanced by the availability of soil resources (Pregitzer *et al*., 1993). Annual root production can also be altered by canopy manipulation due to modifications in the carbohydrate demand for competing sinks (Eissenstat, 2007).

Natural terroir units have been defined as a volume of the earth's biosphere that is characterised by a stable group of values relating to the topography, climate, substrate and soil (Laville, 1993). The Stellenbosch Wine of Origin District presents an extremely large number of natural terroir units, due, in part, to the existence of different soil types related to varying geological parent material (Carey *et al*., 2008). This situation can explain, in part, the heterogeneity found between different vineyards and even within a single vineyard. Increased understanding of the main soil-related factors that affect root growth in the Stellenbosch Wine of Origin District might improve the site selection and cultural practices in this wine-producing area.

1.2 SPECIFIC PROJECT AIMS

The main aim of this project was to determine the effect of soil factors on the root growth and distribution in the Stellenbosch Wine of Origin District. In order to achieve these goals, the following primary (i and ii) and secondary (a, b, c) approaches were followed:

i. To characterise the root growth of the same rootstock grafted to the same scion in two different soils under standardised (topping of shoots and removal of laterals) and normal canopy conditions and to investigate the main causes of root growth variation
    a. to determine the effect of canopy size and the presence of laterals on the growth of the root system under field conditions,
    b. to determine the influence of soil on root distribution, and
    c. to investigate the relationship between root growth and select measures of grapevine performance.

ii. To characterise the root distribution of the rootstocks Richter 99 and Richter 110 grafted to Sauvignon blanc on eight selected sites located throughout the Stellenbosch Wine of Origin District
    a. to investigate the relationship between soil parameters and the grapevine root system.

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Chapter 2

Literature review

Soil parameters and canopy management practices that affect root development with implications for grapevine performance

LITERATURE REVIEW

2.1 INTRODUCTION

Grapevine performance is determined by terroir, which is defined as the multiple interactions between climate, the physical and chemical properties of the soil, and the characteristics of the grapevine cultivar, all modified by human activity (Vaudour, 2002). Van Leeuwen *et al*. (2004) simultaneously studied the effect of the main parameters of terroir, namely climate, soil and cultivar, on vine development and grape composition and found that the influence of climate was greatest on most of the vine performance parameters, followed by soil and cultivar. Nevertheless, in a determined area in the same mesoclimate, the effect of soil is highly relevant, exerting a great influence on vine growth (Saayman, 1977). Grapevines are grown in a wide range of soils (Nagarajah, 1987), which set up the existence of several soil-root system interactions. Root growth and functioning are highly influenced by soil parameters, with water-holding capacity (Morlat & Jacquet, 1993; Conradie *et al*., 2002; Van Leeuwen *et al*., 2004) as one of the most important soil factors. Nevertheless, there are other soil-related factors that may have a relative importance in certain situations, such as the limitation of root growth due to soil acidity, as well as factors driven by human activity that are part of the long-term and short-term management strategies for quality grapes, such as scion/rootstock combination and seasonal canopy management respectively.

The aim of this review is to describe and analyse the relevance of soil, particularly its physical and chemical properties, as well the effect of canopy management on root growth and distribution, and to analyse the influence of root development on vine performance.

2.2 ROOT SYSTEM

The morphology of root systems is directed by genetic codes and attenuated by historical and contemporary environmental conditions (Smucker, 1993). In general, the term root system is used instead of references to individual roots, due to the fact that roots are much less variable morphologically than leaves and it is likely that root systems rather than individual roots are the focus of natural selection, meaning that architecture is more important than morphology (Fitter, 1987). Most of the roots are found in the top one metre of soil, although they can be found at depths of 6 m (Seguin, 1972). The root system is formed by the main framework roots (6-100 mm in diameter), which are usually found at a depth of 30 cm to 35 cm from the soil surface, and smaller, permanent roots (2-6 mm in diameter), which arise from this framework and grow either horizontally, in which case they are known as “spreaders”, or downwards, in which case they are called “sinkers”. These roots undergo repeated branching to produce the fibrous or absorbing roots, which are ephemeral and are continually being replaced by new lateral roots (Mullins *et al*., 1992).

Lateral root growth is characterised by first- and second-year growth. At the beginning of each growing season, the over-wintering roots develop new absorbing roots from many growing points. Each young root is characterised by anatomically and functionally distinct regions, which exist only in relation to the growing point, for they are transitional stages to maturity (zone of conduction) (Figure 2.1). The second-year growth of roots includes the resumption of cell division and cell elongation in the over-wintering root tips, which produces young absorbing roots, and the radial expansion of persistent roots. New lateral roots sometimes develop from old roots in midsummer, especially if the old roots have been cut off (Pratt, 1974).

Therefore, the root system is not uniform, as it is formed by different roots with dissimilar stages of differentiation (Mapfumo & Aspinall, 1994) that are anatomically and physiologically different, even if they present a similar size. In this respect, Wells & Eissenstat (2003) found heterogeneity within the fine, absorptive root system (<1-2 mm in diameter) in terms of morphology, anatomy, physiology and life history; a situation that may influence their ability to take up water and nutrients. In addition, the root system is not static: the ageing of the roots change their functioning. The apical regions of the root exhibit the greatest rates of nutrient uptake and a rapid decline in this capacity with age (Wells & Eissenstat, 2003), specifically in the case of nitrate uptake, the rate of which declines to 50% of the starting rate after a single day (Volder *et al.*, 2005).

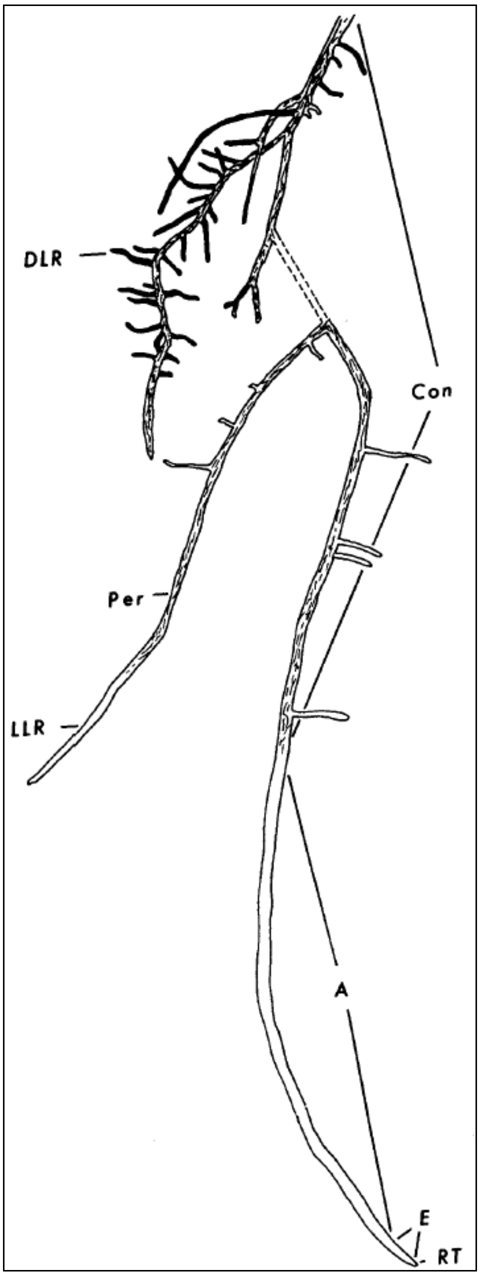

Figure 2.1. Root of *Vitis vinifera* showing actively growing and inactive or dead portions. Abbreviations: A, zone of absorption; Con, zone of conduction; DLR, dead lateral root; E, zone of cell elongation; LLR, living lateral root; Per, periderm; RT, root tip. (Pratt, 1974).

Studies done in South Africa (Mediterranean climate) showed that the formation of new roots reaches a peak at flowering and in the post-harvest period (Figure 2.2) (Van Zyl, 1984). However, a study done in New York, USA showed a lack of root flushes in the fall, which was explained by the relatively short season that ends very quickly following harvest in comparison to that of other grape-producing regions (Comas *et al*., 2005). Even so, secondary growth and thickening occurred throughout the growing season in both cases (Mullins *et al*., 1992).

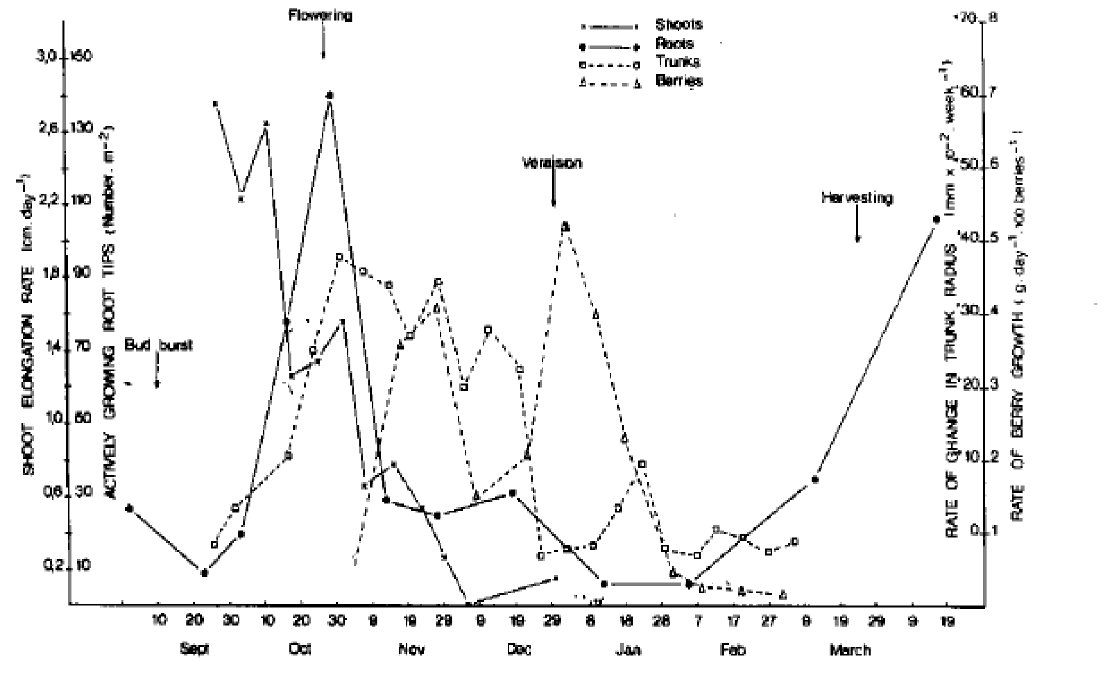

Figure 2.2. Seasonal pattern of root growth in grapevine and the interrelationship between the growth rates of various plant parts (Van Zyl, 1984).

2.2.1 ROOT FUNCTIONS

The root system is involved in several functions: water and nutrient uptake, structural support of the plant, and storage (Fitter, 1987) and synthesis of plant hormones (Davies *et al*., 2005; Dodd, 2005; Jiang & Hartung, 2008), which are linked to the root-to-shoot signalling processes. Because of the importance of water uptake and root signalling for grapevine physiology, these two factors will be analysed in more detail.

2.2.1.1 Water uptake

The water movement from the soil to the grapevine is through the roots and is dependent on soil water with a potential greater than -0.1 MPa. Water uptake becomes progressively more difficult as the water content of the soil is depleted. The greatest loss of water from a plant is via transpiration through the stomata, so when the plant loses water from the leaves its water potential is reduced. The loss of water from the leaves by transpiration is the driving force for the uptake of water from the soil. The decrease in leaf water potential establishes a gradient in water potential between the leaf and the soil so that water flows into the vine's roots (Mullins *et al*., 1992). Mapfumo & Aspinall (1994), in a study using the roots of pot-grown 212-day-old grapevines and the young roots of 20-year-old field-grown grapevines, suggest that water flow into the roots would take place not only through the apical regions, but also through the basal regions, which are heavily suberised but have more mature xylem vessels.

2.2.1.2 Root-to-shoot signalling

The relationship between the root system and the canopy is mediated by the process of root-to-shoot signalling, where signal molecules (other than water and nutrients) are supplied from the root system, regulating mainly shoot growth and water use (Dodd, 2005). During & Dry (1995) found that osmoregulation (the accumulation of solutes due to water stress) in the roots and the maintenance of a positive root water status under conditions of soil water deficit, were shown to have a positive influence on gas exchange by the leaves. These authors speculated that, due to osmoregulation, the roots may reduce their sensitivity as sensors and therefore make it difficult to produce root signals such as abscisic acid (ABA).

According to Dodd (2005), in order for a compound to fulfil the criteria for a root-to-shoot signal, it must:

- move acropetally in the plant via apoplastic (predominantly the xylem) or symplastic pathways, and
- influence physiological processes in a target organ (such as leaves or fruit) that is remote from the putative site of synthesis (the root).

Some molecules that have been ascribed a role as root signals are: ABA, aminocyclopropane carboxylic acid (ACC), cytokinins (CKs), gibberellins and nitrate (Dodd, 2005). Due to the complexity of the nature of long-distance signalling, there still are uncertainties about the exact processes that occur in the plant. In this review, only ABA and CK root signals will be analysed briefly, as they have been suggested to have a major impact on water use by the plant.

ABA currently is receiving a lot of attention in the context of climate change and its implications for plant water use. ABA in the xylem has an external and internal source of origin. The former comes from root exudation and ABA-producing soil organisms, and the latter from biosynthesis in the root and shoot (via phloem import). This hormone is a stress signal that moves in the xylem from the roots to the aerial parts of the plant, where it regulates stomatal movement and the activity of shoot meristems (Jiang & Hartung, 2008). ABA causes the leaf stomata to close, and thus causes both water loss and photosynthesis to cease, resulting in a slowdown in vegetative growth (Gladstones, 1992). ABA has also been linked to the berry-ripening process as a promoter (Antolín *et al*., 2003; Wheeler *et al*., 2009), an enhancer of anthocyanin biosynthesis (Jeong *et al*., 2004), and as being involved in the regulation of the uptake of assimilates by and sucrose metabolism in berries (Pan *et al*., 2005). Nevertheless, it is currently not known where the ABA that accumulates in the berries is synthesised (Wheeler *et al*., 2009). The intensity of the root-to-shoot ABA signal is regulated on four different anatomical levels, namely the rhizosphere, the root cortex, the stem and the leaves (Jiang & Hartung, 2008).

Cytokinins are formed in actively growing root tips, and possibly in growing seed embryos. CKs move in the xylem from the roots to the upper plant parts and have two major functions: promoting cell multiplication in newly differentiating tissues and attracting sugar and other nutrients to where they are in greatest concentration (Gladstones, 1992). CK has been described as an antagonist to ABA in stomata closure (Dodd, 2005), but there still are many questions about the role of CKs in stomatal behaviour due to the fact that it is not clear which cytokinins will be affected by drought stress and, even more, which transport forms should be measured in the xylem (Davies *et al*., 2005). Cytokinin production and export by the roots are favoured by conditions of plenty of sunshine and leaf exposure, and a consequent ample supply of sugar to the roots, as well by a warm, well-aerated root environment (Gladstones, 1992). The availability of nitrate (NO_3^-) regulates cytokinin biosynthesis (Davies *et al*., 2005). Nitrate is considered not only a resource, but also a signal. Lateral roots can be initiated by the presence of high external nitrate concentrations even when root N status is adequate (Dodd, 2005).

Recently, a conceptual model of root signalling was proposed by Whitmore & Whalley (2009) (Figure 2.3). Even so, the advances in root-to-shoot signalling still leave many scientific questions unanswered, one of which is to resolve, in a multi-stress environment, what physical stress (or combinations thereof) triggers the signalling processes (Whitmore & Whalley, 2009).

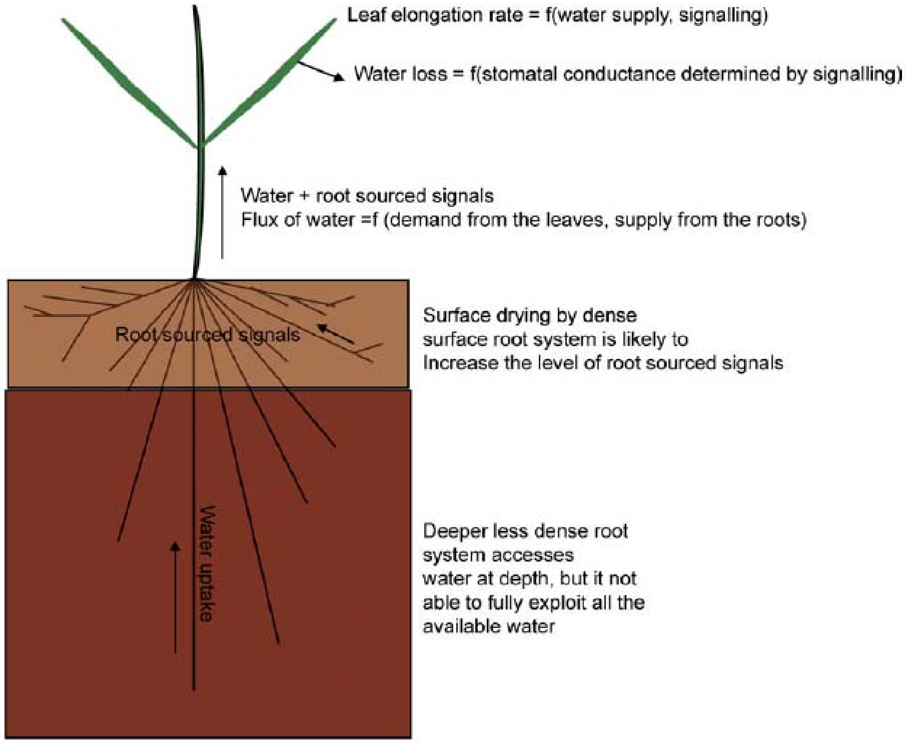

Figure. 2.3. A conceptual model of how roots might integrate signalling processes over a whole profile (Whitmore & Whalley, 2009)

Due to the relevance of the root system in vine physiology, a limitation on its growth or functioning will affect aboveground growth. A restriction in the rooting volume led to a smaller trunk, shorter shoots, smaller leaf area, and lower photosynthetic rate (Wang *et al.*, 2001), and even a root severance of two major lateral framework roots had an immediate effect on grapevine water status, stomatal conductance to water vapour, net photosynthetic assimilation and transpiration rate (Smart *et al.*, 2006a).

2.2.2 METHODS OF STUDYING ROOTS

Traditionally, destructive methods such as soil coring, in-growth cores, whole root system excavation and trenching have been used to investigate root processes, while non-destructive techniques, including rhizotrons and minirhizotrons, have been used more recently (Johnson *et al.*, 2001). Sequential soil coring is the most common approach to determining fine root biomass and NPP (net primary production) in the field. Since a mean fine root biomass value is usually obtained by summing all sampling dates during a year, mean fine root biomass values do not fluctuate as much during a year and there are fewer errors in obtaining this value than when using measurements of net primary production. The most serious restraints are the amount of time and labour, and the resultant financial costs, associated with the cleaning and sorting of roots from the cores and the problem of deciding what is the best way of predicting fine root production after the root cores have been processed (Vogt *et al.*, 1998). In-growth cores is a method that replaces an intact soil core removed from the ground with an equivalent area of root-free soil from the site or with sand. The root-free soil added back into the hole is contained within a sleeve with mesh openings that can be used to remove the cores after leaving them in the field for different periods of time. The subsequent growth of roots into this core is used to estimate fine root production in the field. The main disadvantages are the inability to physically and chemically reconstruct the root-free soil environment, so that similar root production is measured inside and outside the core, and to determine how root production differs in a root-free zone from that already occupied by roots and whether root-free soil produces microsites of higher root growth than recorded previously (Vogt *et al.*, 1998).

The most commonly accepted method in viticulture has been the profile wall method described by Böhm (1979). The profile wall method typically consists of excavating a trench of 1-2 m in depth at some predetermined location, generally parallel to the vine row, establishing a grid of fixed subquadrat areas on a wall of the trench, and then recording root-wall intercepts. There are many drawbacks to this method. One is the explicit assumption that the three-dimensional distribution of roots around the vine is relatively uniform. This assumption is probably not always true (Smart *et al.*, 2006b).

Rhizotrons consist of a chamber with glass panels installed underground for studying root growth in situ. The main advantage in comparison with the wall method is that it allows for following root growth during the season in the same vine. A serious disadvantage is the high cost involved, which reduces the possibility of having a greater number of repetitions. The minirhizotron technique is a visual method of studying roots in which clear tubes are inserted into the ground (to depths of up to 3 m) into which miniature cameras can be inserted to capture photographic images of fine-root growth at different depths outside of the tube surface (McLean *et al.*, 1992; Vogt *et al.*, 1998). According to

Johnson *et al*. (2001), the minirhizotron is one of the best tools for a non-destructive method of root observations in situ under field conditions. Minirhizotron observations are generally more effective than other means to examine fine root phenology, the production and mortality of roots (lifespan), as well as incremental growth (Smart *et al*., 2005). Another highly relevant advantage is the option to have a higher number of repetitions in comparison with the rhizotron technique. Among the disadvantages are the cost and the fact that anomalous root growth can be produced after minirhizotron installation (Smart *et al*., 2005). Also, a comparison of data obtained by different techniques is in many cases impossible (Giulivo & Pitacco, 1996).

2.3 SOIL FACTORS IMPACTING ROOT GROWTH AND DISTRIBUTION

Soil properties are divided into physical and chemical. The former affect the entry, storage and drainage of water through the soil, aeration, the growth of roots and the likelihood that the soil will be subject to erosion and how it will react to tillage operations. The latter influences the nutritional status of the vine and also the physical soil conditions, and thus moisture regimes (Maschmedt, 2005). Therefore, the effect of the soil on grapevine performance is complex, because it affects many aspects of the vine, namely vine mineral nutrition, water uptake, rooting depth and temperature in the root zone (Van Leeuwen & Seguin, 2006). Deep, vigorous roots result in a steady supply of moisture and nutrients (Gladstones, 1992), which allow optimum development of the canopy.

The distribution of roots in the soil profile is influenced by edaphic characteristics and by cultural practices (Mullins *et al*., 1992). A recent review and analysis done of the data available on vertical and horizontal root distribution of the species and hybrids of *Vitis* growing in diverse soil environments, concluded that soil properties, such as the presence of soil layers impermeable to root penetration, stoniness and the presence of gravel lenses, have a greater influence on depth distribution than does genotype, even in deep, fertile soils (Smart *et al*., 2006b). Roots grow in response to the available water supply and, in contrast, a limitation is expected in soils and soil horizons with higher hydromorphic intensity, penetrometer soil strength and bulk density (Morlat & Jacquet, 1993). Nowadays, it is known that a single stress or a combination of several soil physical stress conditions can limit root elongation (for a review, see Bengough *et al*., 2006), and that the physical effects of drought on root growth are due to multiple factors and not only to a lack of water. These other factors include the interaction with factors such as heat, disease, soil strength, low nutrient status and even hypoxia (Whitmore & Whalley, 2009).

2.3.1 SOIL TEXTURE AND STRUCTURE

Soil texture is a measure of the relative proportions of sand, silt and clay particles in the soil (Figure 2.4). It is one of the most important soil properties due to its influence on nutrient retention, erodibility and water-holding capacity (Maschmedt, 2005). For example, a very sandy texture and a low level of organic matter can induce minimal root growth due to excessively rapid drying (Morlat & Jacquet, 1993). Soil texture influences the rooting depth as well the vertical distribution of roots (Nagarajah, 1987). Morlat & Jacquet (1993), after analysing several soil types from the Loire Valley, found that soil textural differentiation has a negative effect on root growth, whereas the higher clay percentage presents a favourable effect. Nonetheless, it is possible that there is a clay level beyond which the soil strength is increased to such an extent that it affects root penetration negatively. In a study done on viticultural terroirs in Stellenbosch, it was found that a heavy-textured soil (clay higher than 25%), especially in the subsoil, was linked to reduced vegetative growth due to reduced root growth (Carey *et al*., 2008).

Maschmedt (2005) defines soil friability as the ease with which soil material crumbles and retains the aggregated (crumbly) condition. It is a complex attribute and is linked to particle size (texture), the arrangement of particles and the spaces between them (structure), and the nature of bonding between the particles (affected by organic matter, oxides, carbonates, etc.). Agricultural lime and organic matter improve friability, while sodicity affects it negatively. Friability influences the rate of movement of water and air through the soil and, similarly, the ease with which roots can penetrate the soil and the efficiency of tillage. Therefore, the more friable the soil, the better is the below-ground growth of the grapevine.

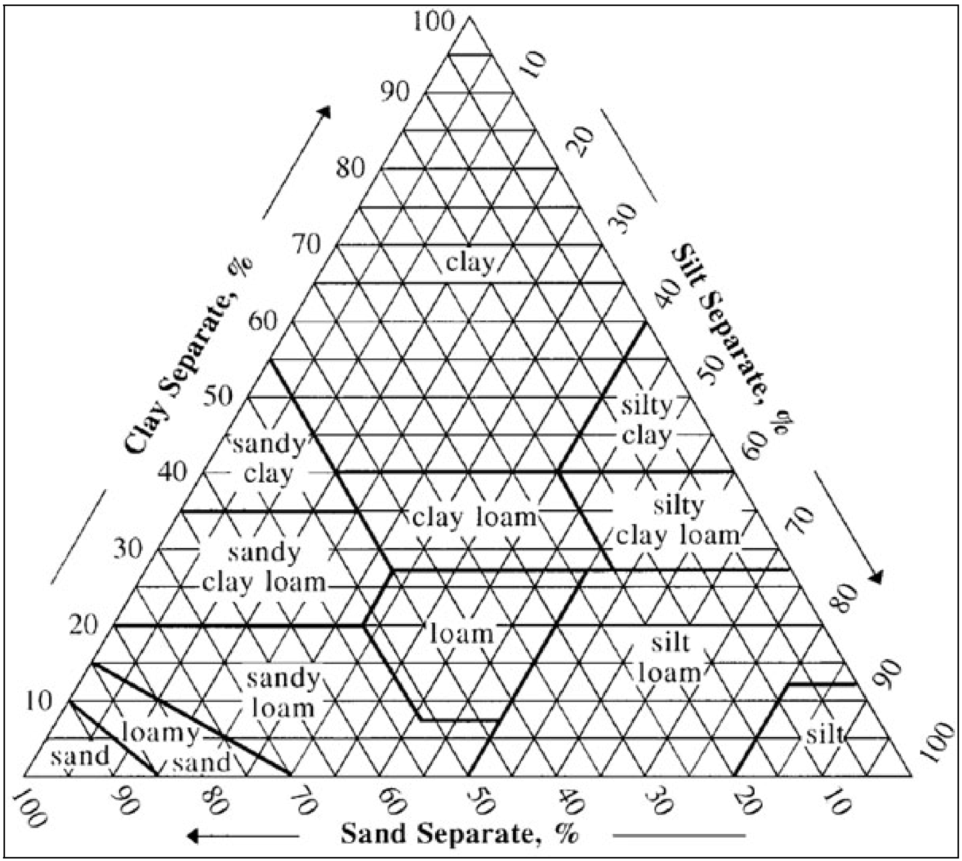

Figure 2.4. Diagram for determining soil texture classes (United States Department of Agriculture, n.d.).

2.3.2 SOIL CHEMICAL COMPOSITION AND pH

The chemical composition of the soil affects not only vine nutrition (Figure 2.5), but also the physical soil conditions and thus the moisture regimes (Maschmedt, 2005). Root growth and development, therefore, can also be affected. A high soil Cu concentration decreases root growth (Toselli *et al*., 2009); saline conditions negatively affect water transport (Shani *et al.,* 1993); and acidic soil conditions alter the uptake of nutrients by the roots and the anatomy of roots (Conradie, 1988). Kirchhof *et al*. (1991) found that, under favourable soil chemical conditions, root growth may be decreased by other factors, such as soil physical parameters, but that low pH and high Al dominated under acid conditions (pH (KCl) lower than 4.5). On the other hand, root development is plastic and root production, its length, longevity and mortality can be enhanced by the availability of soil resources (Pregitzer *et al*., 1993).

Finally, it is important to mention the complexity of the interaction between soil properties and the grapevine root system. For example, if we consider the availability and nutrient uptake of K we have to take into account, on the one hand, soil factors such as soil texture, clay mineralogy, cation exchange capacity (CEC), soil pH, soil moisture, soil aeration, soil temperature, and the amount of exchangeable K in the soil and subsoil. It is also necessary to take into account the amount of clay particles in a soil and the clay mineralogy of the soil, which indirectly influences K availability by impacting on the CEC and soil water-holding capacity. On the other hand, one also has to take into account rooting depth (Sipiora *et al.,* 2005), root distribution and root functioning.

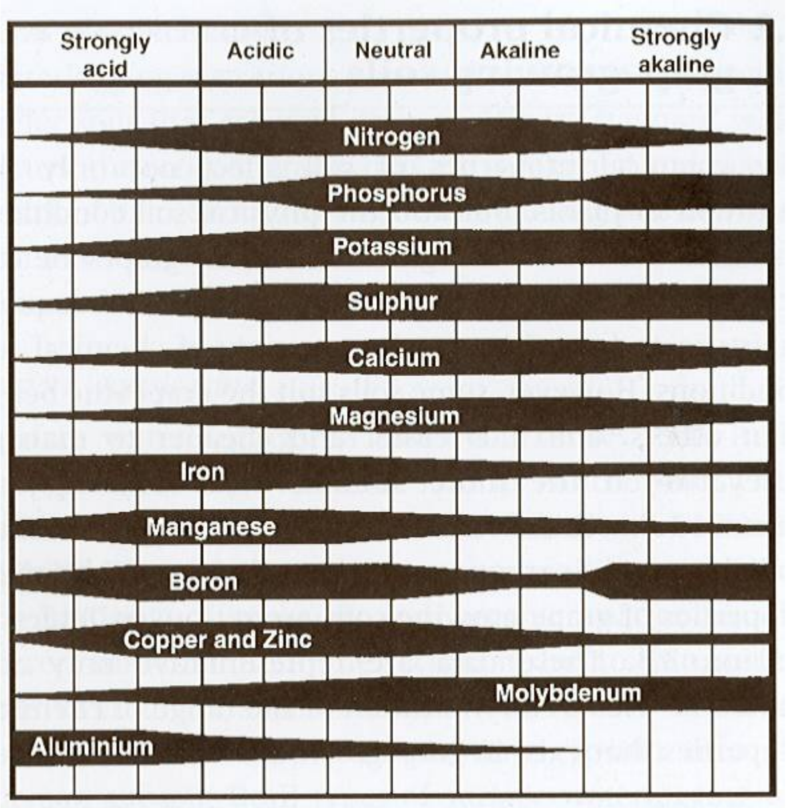

Figure 2.5. Effect of pH on relative availability of nutrient elements (Maschmedt, 2005).

2.3.3 SOIL TEMPERATURE

Soil temperature affects the growth of root system components, initiation and branching, the orientation and direction of growth and root turnover. As soil warming advances downward during the growing season, progressively deeper soil layers become suitable for root growth. Soil temperature often limits both root system expansion and proliferation, particularly during the early growing season (Kaspar & Bland, 1992). However, the effect of soil temperature on root respiration is linked to N availability. Soil temperature primarily controls seasonal variation in root respiration within stands, whereas net N mineralisation rates and associated root tissue N concentrations influence the pattern of root respiration among geographically separate stands (Zogg *et al*., 1996).

2.4 ROLE OF IRRIGATION IN ROOT GROWTH AND DISTRIBUTION

Irrigation is a highly relevant tool for the viticulturist due to the fact that, by using it, it is possible to modify the vine vigour, the yield, but also berry composition (Ojeda *et al.* 2002; Roby *et al.,* 2004) and wine quality (Myburgh, 2006). Water availability has a great impact on root growth (Morlat & Jacquet, 1993). By modifying the timing and intensity of the water stress it is possible to alter root growth. Root growth can be decreased by severe soil water stress, although moderate stress can enhance it (Van Zyl, 1984). In addition, root distribution is altered by the type of irrigation. In a study that involved the conversion of vines from sprinkler irrigation to drippers (Soar & Loveys, 2007), it was found that this change resulted in a significant increase in total root mass under the drip line, particularly 25-50 cm below the surface (Figure 2.6). However, it also shows that the roots were influenced differentially by irrigation history according to their diameter class. Under drip irrigation, the largest increase in root density occurred with roots in diameter classes between 1-4 mm in diameter. Grapevines established under sprinklers and subsequently converted to drip irrigation had significantly larger root systems than did vines maintained under sprinklers throughout. In contrast, Bassoi *et al.* (2003) found in a trial comparing root distribution under drip and microsprinkler irrigation that irrigation system had no significant effect on root parameters, although is important to point out that the study was done in a tropical fruit-growing area, with two harvests per year, and that the root growth during the rainy season therefore may have contributed to minimise differences in root development under microsprinkler and drip irrigation systems. Similar results were noted by Sipiora *et al.* (2005) in a trial with two K-sulphate fertiliser application rates and two irrigation regimes in a Mediterranean fruit growing area. They found that neither the irrigation nor the fertiliser had a significant effect on root density or distribution. In certain situations, the explanation for the lack of response of root growth to irrigation can be related to the soil texture, such as in cases where a deep, medium-textured soil provided large soil reservoirs of water for the plant, limiting the quick response to irrigation strategy (Van Zyl, 1984).

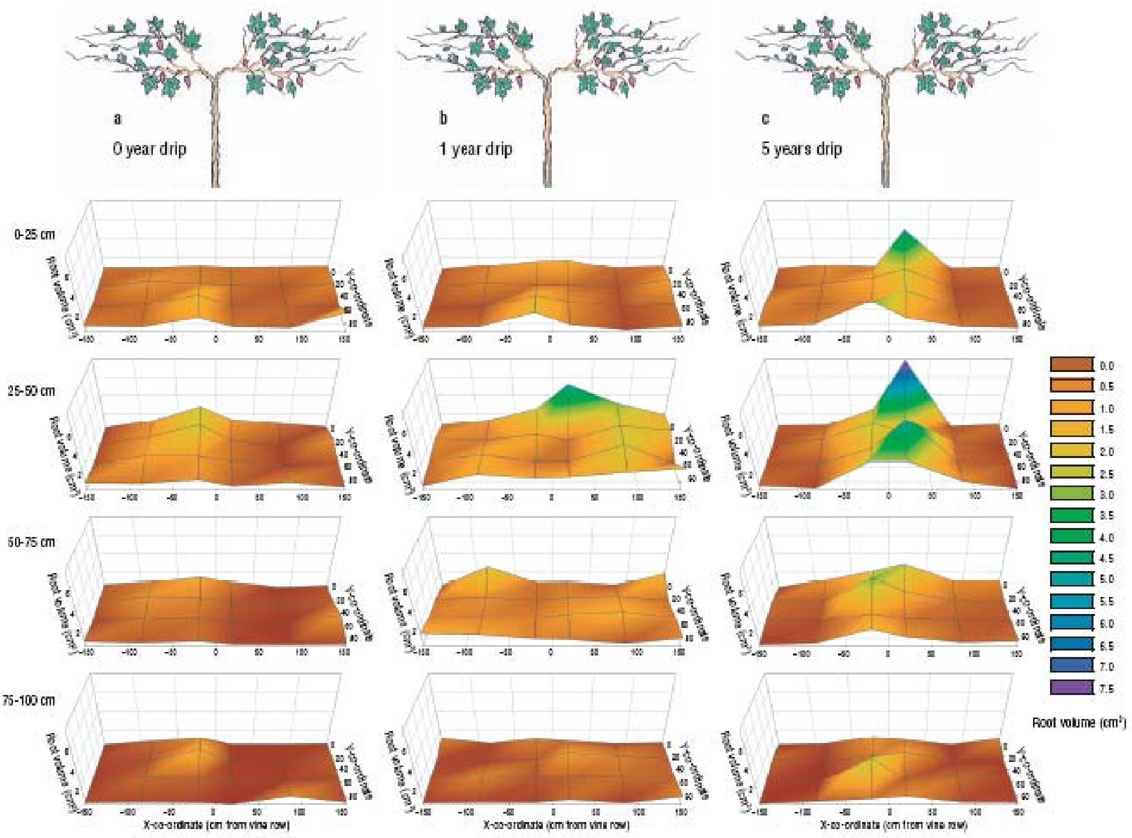

Figure 2.6. Volume of roots at four depths (0-25, 25-50, 50-75 and 75-100 cm) for Cabernet Sauvignon established under sprinkler irrigation and then either maintained under sprinklers or converted to drip one year or five years prior to measurement (Soar & Loveys, 2007).

2.5 ROLE OF CANOPY MANAGEMENT AND TRAINING SYSTEM IN ROOT GROWTH

The amount of annual root production can be affected by carbohydrate demand from competing sinks. High crop loads generally lead to reduced root growth. Limited pruning and irrigation can also lead to greater root production. Root production can also be affected by plant photosynthesis, which can be affected by light interception and by leaf area (Eissenstat, 2007). Comas *et al.* (2005), in a long-term study, found that heavy pruning treatments produce fewer fine roots, even though pruning influences may vary from year to year linked to annual weather conditions (Anderson *et al.,* 2003). McLean *et al.* (1992) noted enhanced root density with fruit cluster removal, while another study even showed an influence of fruit load on root activity, reporting a decrease in fine root respiration and ^{15}N absorption in vines with a heavier fruit load than in those with a lower fruit load (Morinaga *et al.,* 2000). In the case of defoliation, the influence is not as clear, with a relatively low influence found in some research (Hunter *et al.,* 1995), while in other cases there is a significant effect of increasing root density, especially with later defoliations (Hunter & Le Roux, 1992). The effect of defoliation on root growth can be rapid when there is an effect. Eissenstat & Duncan (1992) found that partial canopy removal in a subtropical sweet orange evergreen orchard caused diminished root growth within one or two weeks, which led to the assumption that current photosynthate or other actively produced compounds in the leaves directly affect root processes.

Trellis system influences root production and the production of different types of roots (Slavtcheva & Pourtchev, 2007). Trellis systems that allow a bigger canopy size will increase the root system, mainly due to an increase in root density, especially of fine roots (Archer *et al*., 1988). Hunter & Volschenk (2001), in a study in which a vertically trellised system was converted to double the original cordon length by either removing alternate vines or implementing a Lyre trellising system, root volume was doubled in the former case, whereas in the latter case it remained the same as for the non-converted vines, found that the expansion of the root system occurred when both spatial aboveground and belowground plant volume was increased, whereas higher root system efficiency was apparent when the ratio of cordon length to root volume was increased. Interestingly, by preventing compensation by the root system, individual shoot vigour was decreased and balanced growth and improved microclimatic conditions for grape ripening were promoted. Vine spacing can also affect root growth. Hunter (2000) found that the distance between rows has a major direct effect on soil conditions, whereas in-row spacing has a dominant effect on subterranean growth. The higher root densities of closely spaced vines contributed to the higher performance of the vines per square metre of soil surface.

2.6 EFFECTS OF ROOTSTOCKS ON GRAPEVINE PERFORMANCE

The use of rootstocks is common in most viticultural areas. In general, the scion is a cultivar of *Vitis vinifera*, and the rootstock is either a North American species or an interspecific hybrid that is resistant to soil-borne pests such as phylloxera or nematodes. An exception to this generalisation is the use of interspecific hybrids between *Vitis vinifera* as scion/cultivar and cold-hardy native species in parts of North America with extremely cold winters (Mullins *et al*., 1992). Rootstocks have largely been used to prevent the negative effects of phylloxera and later of nematodes. The other attributes of rootstocks, such as drought tolerance and lime tolerance, have been regarded as secondary factors of selection (Whiting, 2005). Table 2.1 shows some selected rootstocks and their properties. There are many variables to take into account when choosing a rootstock, namely phylloxera resistance, nematode resistance, adaptability to low-pH soils, adaptability to wet or poorly drained soils, and adaptability to drought.

Many studies have shown that rootstocks can affect vine growth and development. The rootstock may have a direct effect, or it may produce indirect effects on the scion. Figure 2.7, for example, shows potential rootstock effects on the scion in relation to cold hardiness (Striegler & Howell, 1991). Studies have shown that the rootstock can modify the gas exchange behaviour of the scion cultivar (Candolfi-Vasconcelos *et al.,* 1994), even though vine water status is not altered (Padgett-Johnson *et al*., 2000). Rootstock can also affect scion leaf gas exchange by affecting scion response to soil nitrogen level in terms of leaf chlorophyll content (Keller *et al*., 2001). In contrast, another study showed that the scion genotype has predominance in the determination of transpiration efficiency under well-watered and non-saline conditions (Virgona *et al*., 2003). Yield also can be affected by rootstock, and its reduction is mainly due to a reduction in berry mass (Koblet *et al*., 1994). There are many studies that support the idea that the rootstock can influence the composition of the scion berries, although the nature and magnitude of the effect varies. There are some studies that show that the uptake of calcium (Attia *et al*., 2007) and potassium (Brancadoro *et al.* 1995) may be influenced by the different rootstocks. But the distribution in the berry can also be affected. Walker *et al.* (1998) found that the distribution of K^+ between the skin, pulp and seeds is affected by different variety/rootstock combinations, and the wines made by fermenting must from Ramsey-grafted vines had higher concentrations of K^+, in contrast with the higher concentration of tartaric acid and higher tartaric acid/malic acid rations in wines made by fermenting juice from own-rooted vines. However, the spatial root distribution of a particular scion-rootstock combination is governed predominantly by the soil environment, whereas root density appears to be predominantly due to the rootstock (Southey & Archer, 1988; Morano & Kliewer, 1994).

Table 2.1. Select rootstocks according to properties (Southey, 1992).

Rootstock	Phylloxera	Nematodes*	Phytophthora	Crown gall	Acidity	Salinity	Drought	Water-logging	Propagation	Affinity	Vigour
110 Richter	4	2	2	1	3	2	4	2	B	A	Q
99 Richter	4	3	1	1	3	2	3	1	A	A	P
1103 Paulsen	3	3	2	2	2	3	3	3	A	A	Q
St. George	3	1	1	-	2	3	2	2	B	B	Q
140 Ruggeri	3	1	2	1	4	4	4	2	B	B	P
101-14 Mgt	3	3	2	4	1	4	3	4	B	C	R
SO4	3	4	1	2	3	1	1	3	C	B	R
3309 Couderc	4	2	1	4	-	1	1	3	B	C	Q
420A	2	2	1	-	-	1	1	2	C	B	R
Harmony	2	4	-	4	-	-	2	2	B	B	R
Freedom	2	4	-	4	-	-	-	-	C	-	R
Ramsey	3	4	4	1	3	4	2	2	C	C	P
Dog Ridge	3	4	4	-	-	4	2	3	D	D	P
143-B Mgt	3	3	4	1	2	4	3	4	A	B	P

4 = Resistant; 3 = Moderately resistant; 2 = Moderately susceptible; 1 = Susceptible-

A = Excellent; B = Good; C = Fair; D = Poor.

P = Vigorous; Q = Moderately vigorous; R = Moderately low vigour; S = Low vigour-

**Meloidogy* spp.

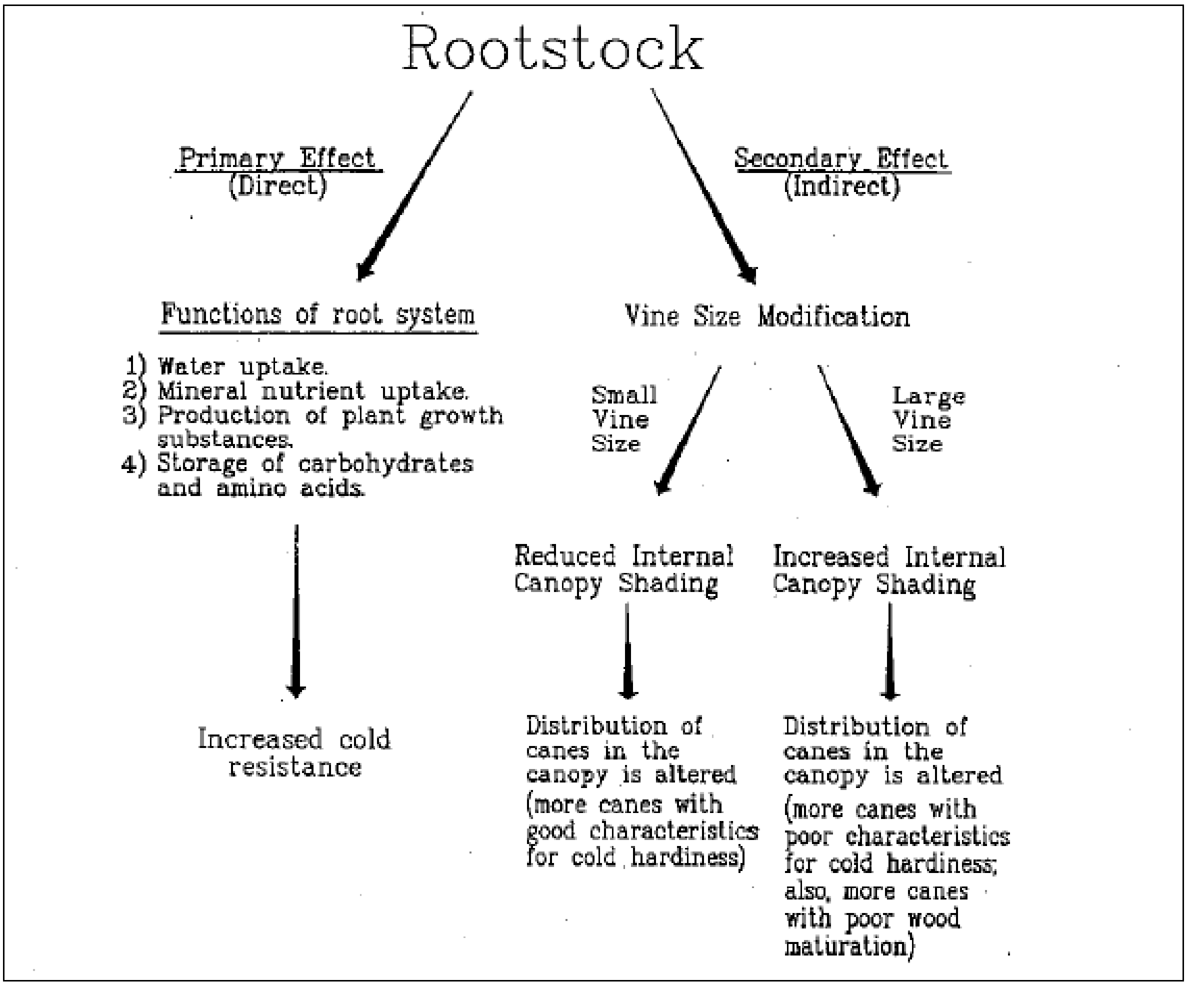

Figure 2.7. Potential mechanisms of rootstock involvement in cold hardiness of grapevine primary buds and canes (Striegler & Howell, 1991).

2.7 CONCLUSION

Water uptake and root-to-shoot signalling are the most important functions of the roots due to their influence on photosynthesis. In this respect, soil water availability plays a key role, in conjunction with root growth and functioning. Because of this, and due to the soil conditions that are found in the Stellenbosch Wine of Origin District and the relevance of soil texture and chemical properties to soil water-holding capacity and the effect on root growth and distribution, it was concluded that this study should focus on the soil clay percentage and the soil pH. The former is a factor that is considered favourable up to a certain threshold, beyond which it becomes negative, and the latter can be a key factor in root limitation in the subsoil under the acidic conditions of the soils of the Western Cape.

Due to the complex interaction between the aboveground parts and the root system (through long-distance signalling and the carbohydrate demand by competing sinks), the effect of canopy management on root growth and development is difficult to predict. The potential effect of canopy management will be on annual root production, and will influence mainly the amounts of fine roots.

Root growth can be affected mainly by a limitation in the rooting depth, changes in root density and modifications to the ratio of fine roots to thick roots. The profile wall method is considered an acceptable technique to determine these parameters, and is also commonly accepted, which is favourable when comparing the data obtained in this study with that from other studies. The associated costs are also lower.

The importance of studying edaphic factors that influence the development of the grapevine root system as part of terroir studies is clear when considering the important role that soil conditions play in determining root growth and distribution and the important relationship between aboveground and subterranean growth, as demonstrated in this survey of existing research on these topics.

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Chapter 3

Research results

Root growth, canopy functioning and berry ripening response to lateral shoot removal in Sauvignon blanc/Richter 110 on two soils

RESEARCH RESULTS

3.1 ABSTRACT

Root growth is affected by several factors, including biotic and abiotic stresses. In this respect, edaphic parameters seem to be highly relevant but also annual root production can be altered by canopy manipulation. The aims of this study were to determine the effect of canopy size and the presence of laterals on the growth of the root system under field conditions; to determine the influence of soil parameters on root distribution in two different vineyards; and to investigate the relationship between root growth and selected measures of grapevine performance. The experiment was conducted in two commercial Sauvignon blanc vineyards, each grafted onto Richter 110 and non-irrigated. Two treatments were applied: undisturbed lateral shoot growth and complete lateral shoot removal. The laterals were removed at approximately pea size and at approximately véraison, obtaining a reduction of approximately 93% in the lateral leaf area. Aspects of soil, roots, canopy, vine water status and berries were evaluated. The effect of the soil in the analysed parameters was larger than the effect of the lateral shoot removal. Nevertheless, the significant impact of the different canopy structures on root growth cannot be dismissed, therefore studies that aim to investigate the effect of soil on root distribution, using different vineyards, should take the vineyard canopy characteristics into account.

Key words: grapevine, root distribution, soil pH, water stress, canopy structure.

3.2 INTRODUCTION

Root growth and functioning are affected by several factors, including biotic and abiotic stresses. Among the latter, edaphic factors have been mostly investigated. The effect of water stress on grapevine root growth was studied by Van Zyl (1984), when he found that severe soil water stress decreased root proliferation, while moderate stress can enhance it. Nowadays, it is known that a single stress or a combination of several soil physical stress conditions can limit root elongation (for a review, see Bengough *et al*., 2006), and that the physical effects of drought on root growth are due to multiple factors and not only to a lack of water. Among the other factors are aspects such as heat, disease, soil strength, low nutrient status and even hypoxia (Whitmore & Whalley, 2009). In addition, the chemical composition of the soil might affect root development: a high concentration of Cu in the soil decreases root growth (Toselli *et al*., 2009); saline conditions affect water transport (Shani *et al.,* 1993); and acidic soil conditions can alter the uptake of nutrients (N, P, K, S, Ca and Mg) by the roots (Dry, 2007) and produce poor root growth (Conradie, 1988), as well as shallow root systems due to the low pH of the subsoil and associated aluminium toxicity (Kirchhof *et al.,* 1991). On the other hand, root morphology is plastic and root proliferation, its length and longevity can be enhanced by the availability of soil resources (Pregitzer *et al*., 1993). A recent study has shown that aboveground growth vigour has an impact on root plasticity, with plants with higher vigour having a greater morphological plasticity, as indicated by the greater preferential growth in irrigated soil during the summer, and a larger change in root diameter in response to lateral heterogeneity in soil moisture than plants with lower vigour (Bauerle *et al.,* 2008).

Annual root production can also be altered by canopy manipulation, due to modifications in the carbohydrate demand by competing sinks (Eissenstat, 2007). In a long-term study, Comas *et al.* (2005) found that heavy pruning treatments resulted in the production of fewer fine roots, even though the pruning influences varied from year to year, linked to annual weather conditions (Anderson *et al.,* 2003). McLean *et al.* (1992) noted an enhanced root density following fruit cluster removal. In the case of defoliation, the influence is not as clear, as a relatively low influence was found even within the same combination of cultivar/rootstock (Hunter *et al.,* 1995). In other cases a significant effect of increased root density was noted, especially with later defoliations (Hunter & Le Roux, 1992). Lateral removal is often used as a way to modify the canopy density, altering mainly aeration, humidity and light conditions in order to improve berry composition (Smart, 1985) and to reduce diseases (English *et al.,* 1989; Gubler *et al.,* 1987). The presence of lateral shoots can have a positive effect in terms of berry ripening in a vineyard with moderate vigour. Retaining laterals shoots hastens fruit maturation and improves berry colour in cv. Pinot noir (Vasconcelos & Castagnoli, 2000). Similar results were reported for Kyoho grapevines, where, in the treatments with a higher percentage of lateral leaf area, the titratable acidity of the berries decreased more rapidly than in the treatments with a low percentage of lateral leaf area or no laterals (Hirano *et al*., 1994).

The development of the root system is highly relevant for the viticulturist due to the fact that vine growth and functioning are dependent on root growth (Archer *et al*., 1988, Hunter & Le Roux, 1992; Hunter *et al*., 1995). Some studies show that a restriction in the rooting volume leads to a smaller trunk, shorter shoot, smaller leaf area and lower photosynthetic rate (Wang *et al.,* 2001), and that even a root severance of two major lateral framework roots had an immediate effect on vine water status, stomatal conductance to water vapour, net photosynthetic assimilation and transpiration rate (Smart *et al*., 2006).

Because of the strong interaction between aboveground and belowground growth that has been found by various authors (Archer *et al*., 1988, Hunter & Le Roux, 1992; Hunter *et al*., 1995), it is possible that root studies to compare soil effects on root growth in two vineyards may in fact be affected strongly by the differing aboveground growth. In this research we therefore compare the effect of a standardised canopy (topping of shoots and removal of laterals) versus a normal canopy (as managed by the producer) on the root distribution in two vineyards, with the following objectives: to determine the effect of canopy size and the presence of laterals on the growth of the root system under field conditions; to determine the influence of soil parameters on root distribution in two different vineyards; and to investigate the relationship between root growth and selected measures of grapevine performance.

3.3 MATERIALS AND METHODS

3.3.1 PLANT MATERIAL AND TREATMENTS

The experiment was conducted in two commercial Sauvignon blanc vineyards: Morgenhof and Delheim of 15 and 16 years old respectively, each grafted onto Richter 110, non-irrigated, located in the Stellenbosch Wine of Origin District. These vineyards are referred to by their names from here on. In both vineyards, vines were spaced 1.2 m apart with a row width of 2.7 m at Delheim and 3.0 m wide at Morgenhof. Vines were trained on a 5-wire lengthened Perold system at Delheim and on a 5-wire Perold system at Morgenhof. The shoots were topped at approximately 14 to 15 nodes. . In each vineyard, 3 miniplots were delimited in areas of visually similar vigour. Each miniplot consisted of 10 vines. Two treatments, namely undisturbed lateral growth and complete lateral removal were each applied on five consecutive vines within each miniplot, i.e. there were three repetitions of each treatment within each miniplot. The laterals were removed on 16 December (approximately pea size) and 6 January (approximately véraison), obtaining a reduction of approximately 93% in the secondary leaf area at harvest.

3.3.2 SOIL PROFILE DESCRIPTIONS AND ANALYSES

The two vineyards were selected because of different soil conditions. The Morgenhof vineyard was known to have a lower pH in the subsoil and a higher clay content, while the Delheim vineyard had a higher pH in the subsoil and a lower clay content. Soil profiles from each plot were examined in 2009 and described by an experienced soil scientist using the South African taxonomic system (Soil Classification Working Group, 1991). Soil samples were collected from each horizon per treatment and standard soil chemical and physical analyses were performed in a commercial laboratory.

3.3.3 ROOT MEASUREMENTS

Three vines from each treatment, one from each row, were chosen for root studies. A profile wall method (Böhm, 1979) was used to plot the roots. A trench of 1.0 m deep was dug parallel to the vine row and 20 cm from the vine trunk. The grid used was 10 cm X 10 cm; 1.0 m high and 1.0 m wide. The grid was positioned with the middle grapevine trunk central. Roots were classified into five root diameter classes: < 0.5 mm = fine roots; 0.5-2.0 mm = thin roots; 2.0-5.0 mm = medium roots; 5.0-7.0 mm = medium to thick roots; and > 7.0 mm = thick roots. Root profiles were performed during the dormant period (June/July).

3.3.4 LEAF AREA MEASUREMENTS

Nine shoots from nine vines, one shoot per vine from three vines in each miniplot, were sampled at two phenological stages as defined by Coombe (1995): 27 January (approximately berries with intermediate Brix values) for Delheim and Morgenhof and 18 February (harvest) for Delheim. In Morgenhof the shoot sampling at harvest was not performed due to the harvest of the experimental plot by the workers of the farm and the resulting damage to the leaves during the harvest process. Primary and secondary shoot length was measured. For both primary and secondary shoots, leaves were removed, counted and leaf area was measured using a leaf area meter (Delta T device Ltd, Cambridge, UK).

3.3.5 LEAF GAS EXCHANGE MEASUREMENTS

Leaf gas exchange measurements were conducted on well-exposed leaves, for each treatment, using an open system gas exchange device (LI-COR 6400, Lincoln, NE) under clear-sky conditions. Photosynthetic rate (A), transpiration rate (E) and stomatal conductance (g_s) were measured on 28 January and 7 February from approximately 10h00 to 16h00 at Morgenhof and on 8 February and 17 February from approximately 10h00 to 15h00 at Delheim. The dates were chosen based in weather conditions and availability of apparatus. It is important to mention that the comparison was between treatments at each vineyard. For each measurement, nine leaves located at node 6 of principal shoots/canes were chosen for each treatment. For each of the selected leaves, the leaf gas exchange measurements were performed first, after which the leaf water potential readings were taken.

3.3.6 PLANT WATER STATUS MEASUREMENTS

Plant water status was measured as pre-dawn leaf water potential (ψ_{PD}), using the pressure chamber technique (Scholander *et al.,* 1965). For each measurement, nine fully expanded leaves from principal shoots/canes were chosen for each treatment. Measurements were carried out at four approximate phenological stages, namely flowering, bunch closure, véraison and harvest. Leaf water potential (ψ_{leaf}) readings were performed on an hourly basis on 28 January and 7 February from approximately 10h00 to 16h00 at Morgenhof and on 8 February and 17 February from approximately 10h00 to 15h00 at Delheim. For each measurement, nine leaves located at node 6 on principal shoots/canes were chosen for each treatment.

In addition, carbon isotope discrimination ($\delta^{13}C$) was determined on the berry must. For Delheim, the clusters harvested from 15 vines (5 vines per each miniplot) were crushed and then three samples were taken per treatment. In the case of Morgenhof, due to a loss of the total harvest of the experimental plots as a result of harvest of the grapes by the vineyard owner, two samples were taken from 20 vines harvested on two adjacent rows in the same vineyard. The volume of each sample was 2 ml. The must samples were sent to the Stable Light Isotope Laboratory at the University of Cape Town for the analysis of the C_{12}/C_{13} ratio. They were analysed by combustion in a Thermo 1112 Elemental Analyser coupled via a Thermo Conflo III to a Thermo Delta XP stable light isotope mass spectrometer. Samples were run against in-house reference materials and the results were normalised against and reported relative to international standards (PDB for carbon).

3.3.7 BERRY MEASUREMENTS

From véraison, two 150-berry samples were collected from each treatment every week. In the case of Morgenhof, due to the loss of the total harvest of the experimental plot, the berry samples were only performed until 2 February. The first set of berry samples was used to determine fresh berry mass and the concentration of total soluble solids (°Brix), using a temperature compensating refractometer, in order to calculate the amount of sugar per berry per day. The second set of berry samples was used to determined malic and tartaric acid contents using the enzymatic test of Roche Boehringer Mannheim (Germany) for the former and the colorimetric test of Isitec Lab Seppal for the latter.

3.3.8 STATISTICAL ANALYSES

The data were analysed with repeated measures analysis of variance (ANOVA), using the mixed model approach.

3.4 RESULTS AND DISCUSSION

3.4.1 SOIL CHARACTERISTICS

The soil form at Morgenhof was classified as Tukulu and Swartland, characterised by a medium textured topsoil with a medium to heavy textured yellowish to reddish brown neocutanic block structured subsoil, on medium to heavy textured, mottled, soft weathered granite rock. The Delheim soil was classified as Oakleaf form, having a light to medium textured topsoil with light to medium textured yellowish to reddish brown, weakly structured (neocutanic), slightly gravely subsoil. The soil from Morgenhof had a higher clay content than that from Delheim, although both soils present the same pattern of increasing clay with depth (Table 3.1). Nagarajah (1987) postulated that soil texture can influence the vertical distribution of roots, as well as the rooting depth, directly by limiting root extension or indirectly via influencing the depth of the water table.

Even though 110 Richter is considered relatively tolerant to soil acidity (Conradie, 1983; Dry, 2007), the pH in the Morgenhof subsoil (from the shallow depth of 30 cm) could seriously affect root growth negatively (Conradie, 1988) (Figure 3.2 and Table 3.2). Conradie (1988) recommends liming soils to a pH (KCl) of at least 5.5 in order to have a well-developed root system. Soil pH, P, K, Ca and Mg decreased with depth (Table 3.2). Concerning K soil content, Sipiora *et al.* (2005) found that root density and distribution are not affected by K fertilization.

Table 3.1 Soil particle size distribution (%) for soils in two vineyards in the Stellenbosch Wine of Origin District (depth weighted means for three soils at each vineyard). Values for each parameter designated by the same letter do not differ significantly ($p \leq 0.05$).

Depth (mm)	**Clay (%) (<0.002 mm)**		**Silt (%) (0.05-0.002 mm)**		**Fine sand (%) (0.25-0.05 mm)**		**Medium sand (%) (0.5-0.25 mm)**		**Coarse sand (%) (2.0-0.5 mm)**	
	Delheim	Morgenhof	Delheim	Morgenhof	Delheim	Morgenhof	Delheim	Morgenhof	Delheim	Morgenhof
0-300	6.8c	18.0a	13.4ab	13.9a	49.0a	47.3ab	18.5a	10.6a	12.3a	10.2a
300-600	13.3a	24.9b	12.6ab	11.1b	44.2b	46.3ab	17.1b	10.0ac	12.8a	10.7a
600-1000	13.3a	26.7b	12.6ab	10.8b	44.2b	44.7ab	17.1b	9.3c	12.8a	10.0a

Table 3.2 Chemical characteristics of soils in two vineyards in the Stellenbosch Wine of Origin District (depth weighted means for three soils at each vineyard). Values for each parameter designated by the same letter do not differ significantly ($p \leq 0.05$).

Depth (mm)	**pH (KCl)**		**P Bray II (mg kg^{-1})**		**K (mg kg^{-1})**		**Ca (cmol$_c$ kg^{-1})**		**Mg (cmol$_c$ kg^{-1})**	
	Delheim	Morgenhof	Delheim	Morgenhof	Delheim	Morgenhof	Delheim	Morgenhof	Delheim	Morgenhof
0-300	6.4a	5.9ab	34.5c	11.7a	293.7c	90.8a	6.5a	5.4ab	2.1d	0.8a
300-600	5.4b	4.3c	10.2ab	2.5b	95.2ab	41.9b	3.3bc	2.1c	1.3ab	0.3c
600-1000	5.4b	4.2c	10.2ab	1.9b	95.2ab	33.7b	3.3bc	1.8c	1.3ab	0.3bc

3.4.2 ROOT GROWTH AND DISTRIBUTION

The number of thin root (0.5-2.0 mm) contacts in the profile was significantly increased by lateral shoot removal at both sites (Figure 3.1). Similar results were reported by Hunter & Le Roux (1992), who found that a partial defoliation, of 33% of the number of total leaves, increased root density for roots < 0.5 mm to 5 mm, increasing with later defoliations (done at pea size and véraison). This situation is reflected in the results of this study, due to the fact that, in this case, the lateral removal was also done relatively late in the season (from approximately pea size). However, the results contrast with the data of Hunter *et al.* (1995), who noted that a defoliation of 33% done on primary and lateral shoots had a relatively small influence on root density.

Comparing Delheim to Morgenhof, by implication soil type was found to have a significant effect on the number of roots, specifically of the thin roots (0.5-2.0 mm) (Figure 3.1). The lower number of thin roots that were found at Morgenhof may be due partly to the lower soil pH (Conradie, 1988; Kirchhof *et al.,* 1991). Kirchhof *et al*. (1991) suggest that, under favourable soil chemical conditions, root growth may be decreased by other factors, such as soil physical parameters, but that low pH and high Al dominate in acid conditions (pH (KCl) lower than 4.5) . The medium to severe water stress at Morgenhof during berry ripening (Figure 3.8 and Table 3.3) might also contribute to the lower number of thin roots. In a study of different soil moisture regimes, Van Zyl (1984) found that the driest treatment (25% moisture regime) presented significantly fewer actively growing root tips compared to the rest of the treatments with higher soil moistures values. The differences found in the number of thin roots (0.5-2.0 mm) were located predominantly in the subsoil (Figure 3.2). It is relevant to consider that, in this case, the fewer thin roots at Morgenhof may have contributed to increased water deficits. However, with the available data it is not possible to determine whether increased plant water deficits were caused by or in fact caused the limited presence of fine roots at Morgenhof.

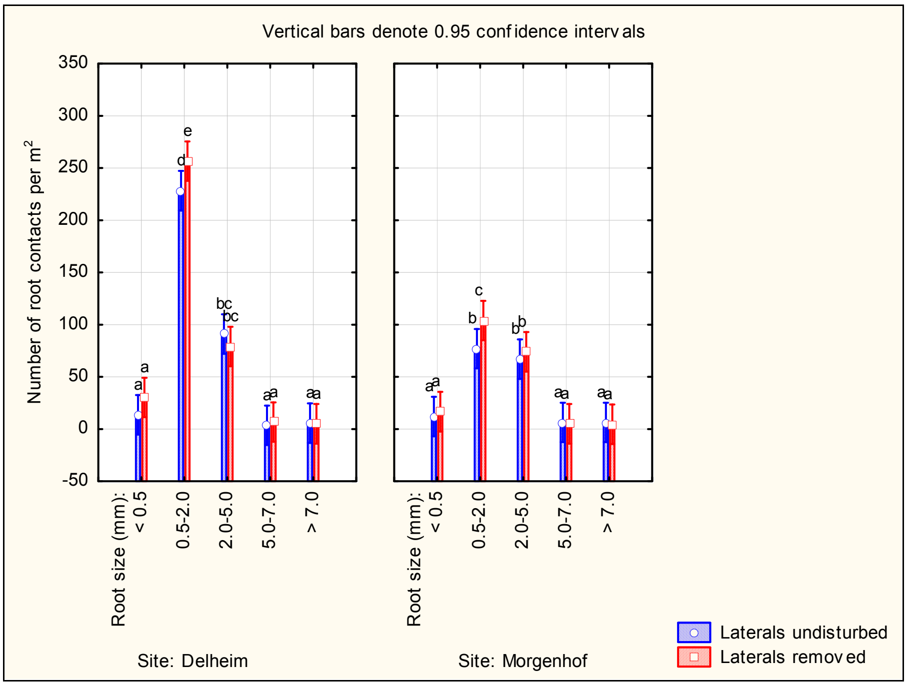

Figure 3.1. Difference in mean number of different categories of roots between two different canopy management treatments in two vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

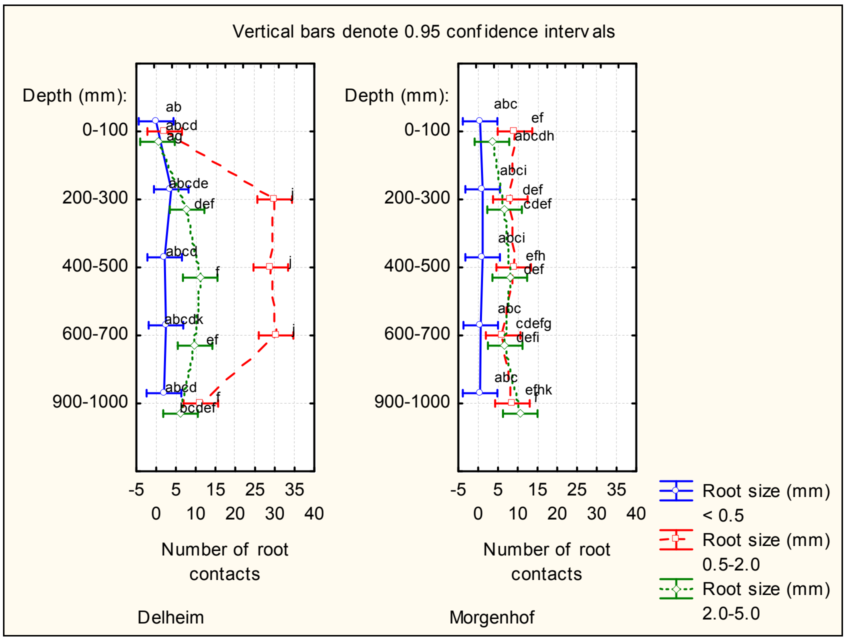

Figure 3.2. Difference in mean number of different categories of roots with depth at Delheim and Morgenhof in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p≤ 0.05).

3.4.3 CANOPY GROWTH AND FUNCTIONING

The lower total leaf area per hectare in the treatments comprising undisturbed laterals at Morgenhof, in comparison with Delheim (Figure 3.3) can be ascribed in part to water limitation in the former vineyard (Figure 3.8 and Table 3.3), due to the fact that shoot growth and leaf expansion is extremely sensitive to water deficit (Keller, 2005; Koundouras *et al*., 2008). With lateral shoot removal the total leaf area of both sites was similar (Figure 3.3), which illustrates the relative importance of the laterals in the potential differentiation between sites in terms of microclimate and leaf area available for photosynthesis. Neither at Morgenhof nor at Delheim did lateral shoot removal significantly affect the individual leaf gas exchange or the leaf water potential (Figures 3.4, 3.5, 3.6 and 3.7). Nevertheless, at Delheim lateral shoot removal tended to induce a trend of having lower leaf water status (Figure 3.7) and higher leaf gas exchange rates (Figure 3.6), which may be due in part to an improvement in microclimatic conditions, such a better light penetration. It is important to mention that conclusions drawn from measurements taken on well-exposed single leaves do not necessarily reflect the behaviour in the whole canopy and might lead to unrealistic evaluations in terms of a true water-saving strategy (Poni *et al*., 2009).

Table 3.3. Carbon isotope discrimination (δ^{13}C) measured on grape must at harvest in two vineyards in Stellenbosch Wine of Origin District.

Vineyard	**Treatment**	**δ^{13}C (‰)***
Delheim	lateral undisturbed	-27.94a
Delheim	lateral removal	-27.63a
Morgenhof	**	-21.92

*Statistical analyses were performed only for Delheim.

**Data from adjacent vines to the experimental plot.

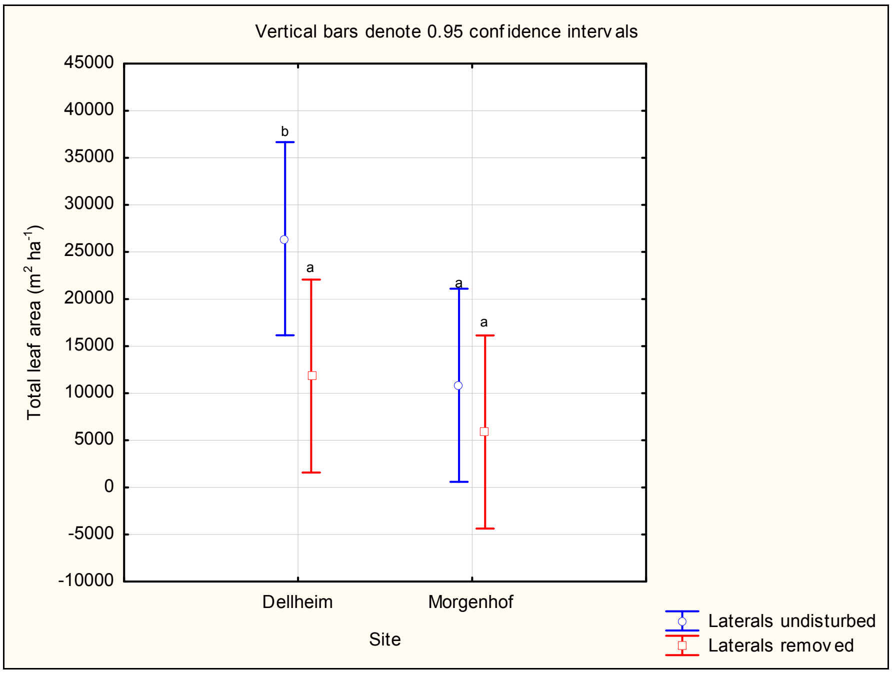

Figure 3.3. Total leaf area of two vineyards of Sauvignon blanc/Richter 110 in the Stellenbosch Wine of Origin District as affected by lateral shoot removal. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

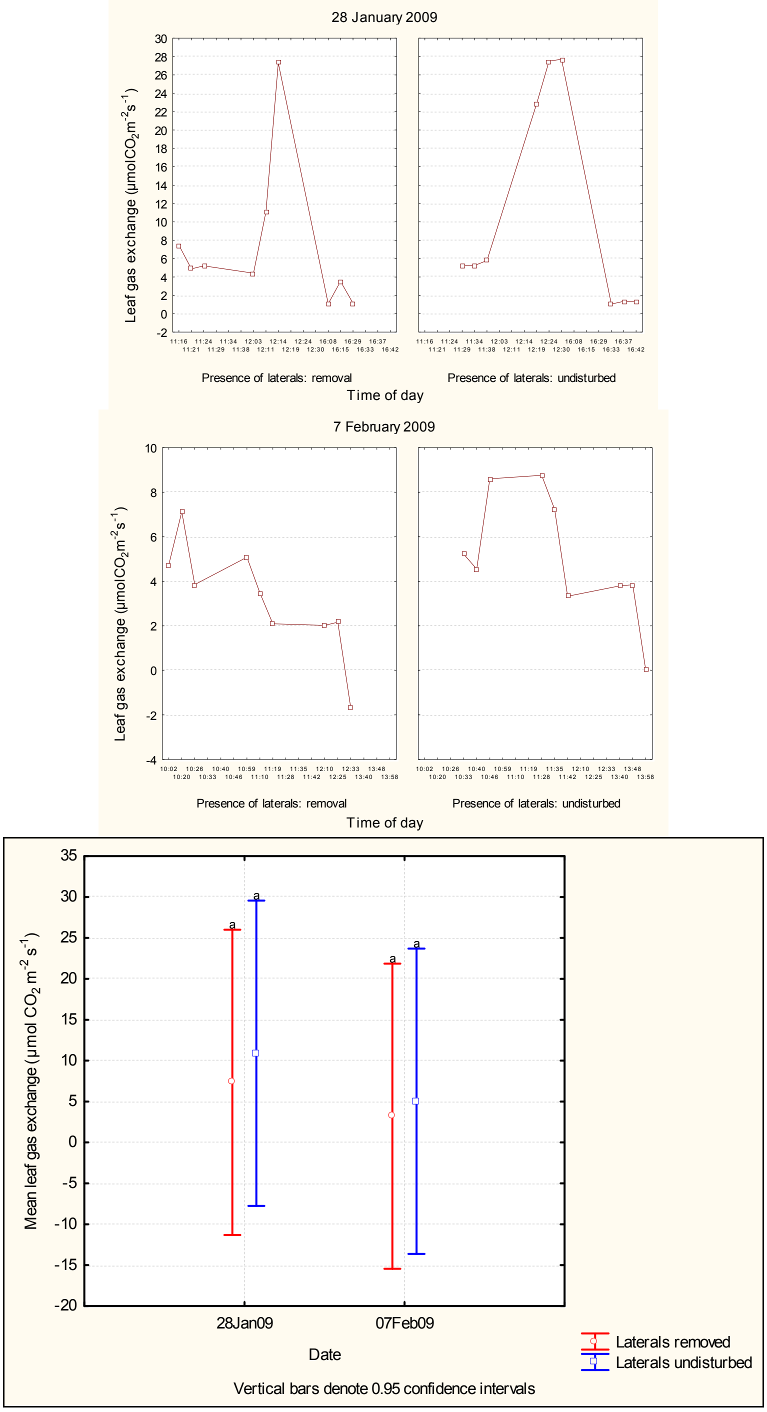

Figure 3.4. Leaf gas exchange in Sauvignon blanc/Richter 110 vines at Morgenhof, Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

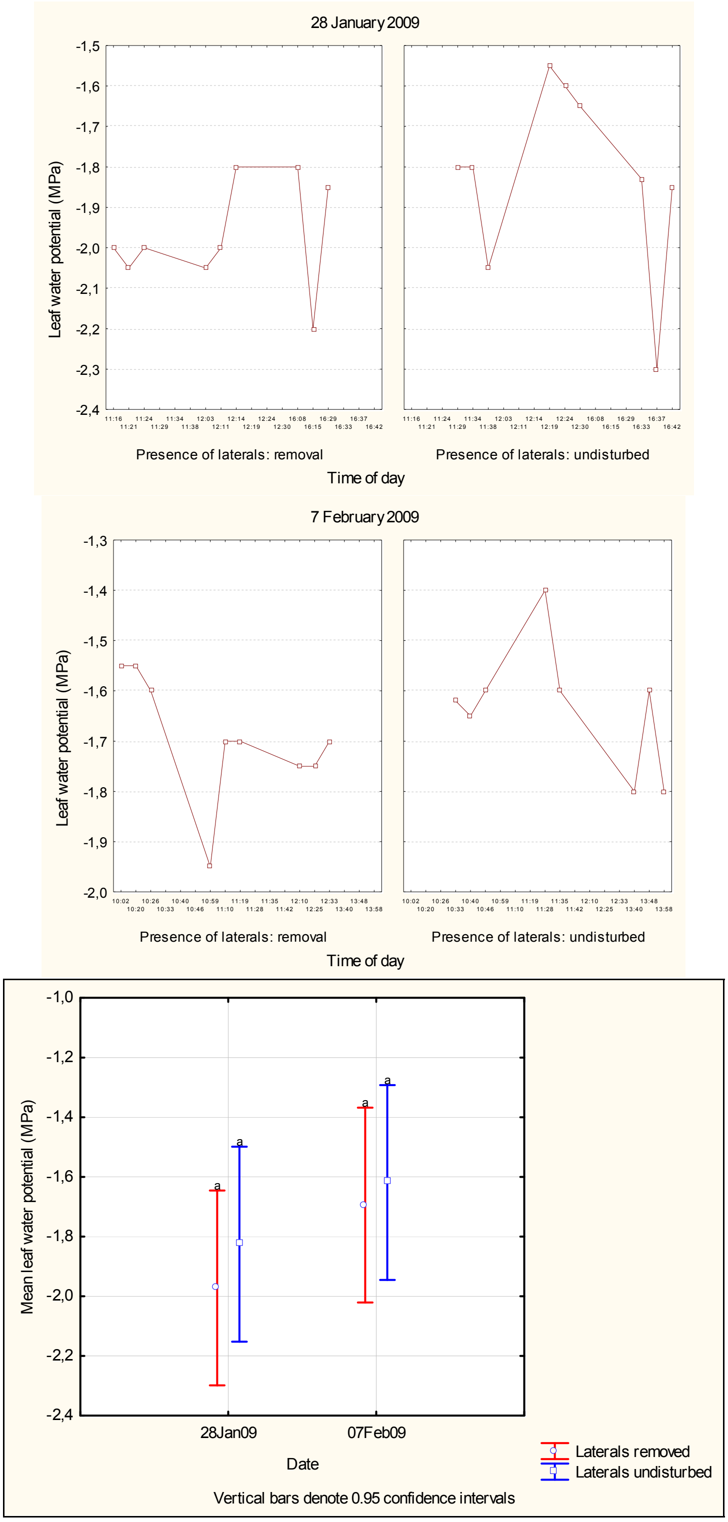

Figure 3.5. Leaf water potential of Sauvignon blanc/Richter 110 vines at Morgenhof, Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

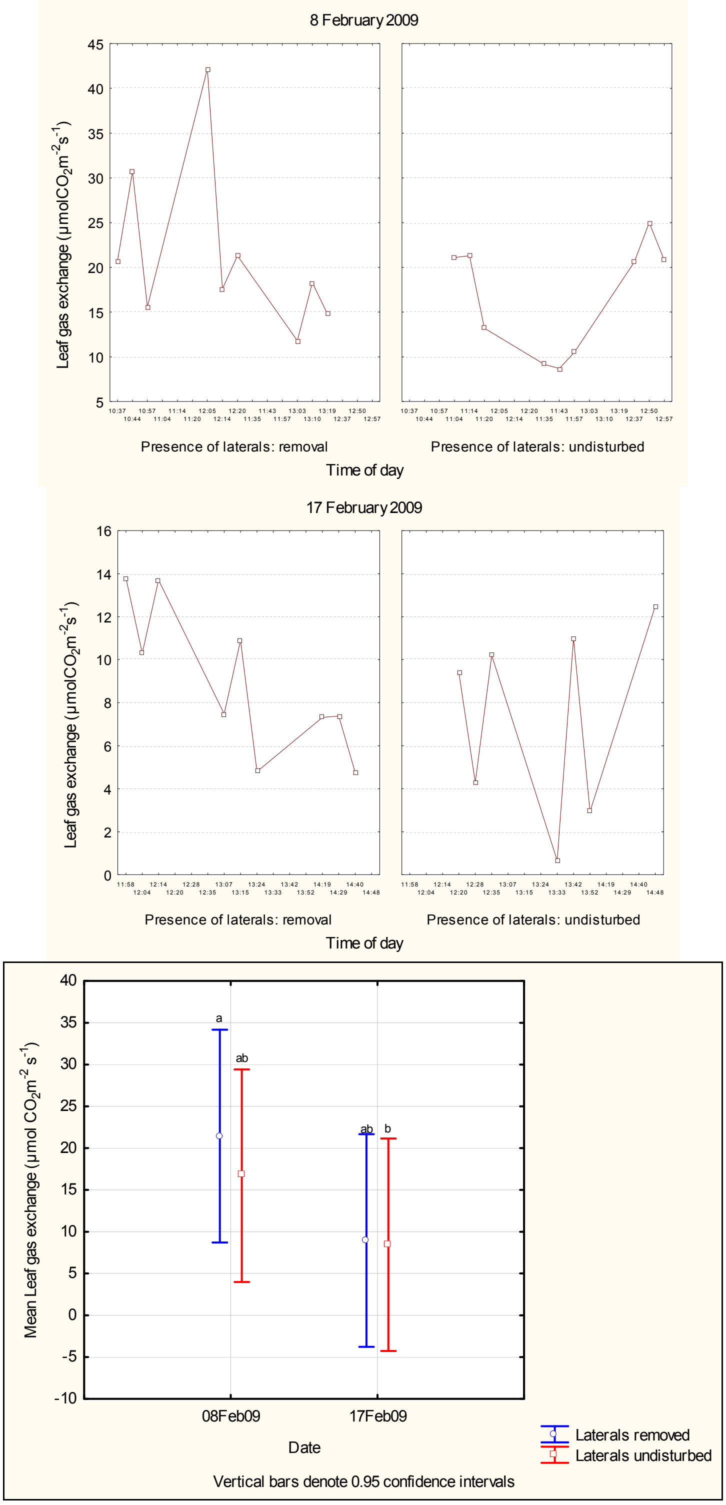

Figure 3.6. Leaf gas exchange in Sauvignon blanc/Richter 110 vines at Delheim, Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

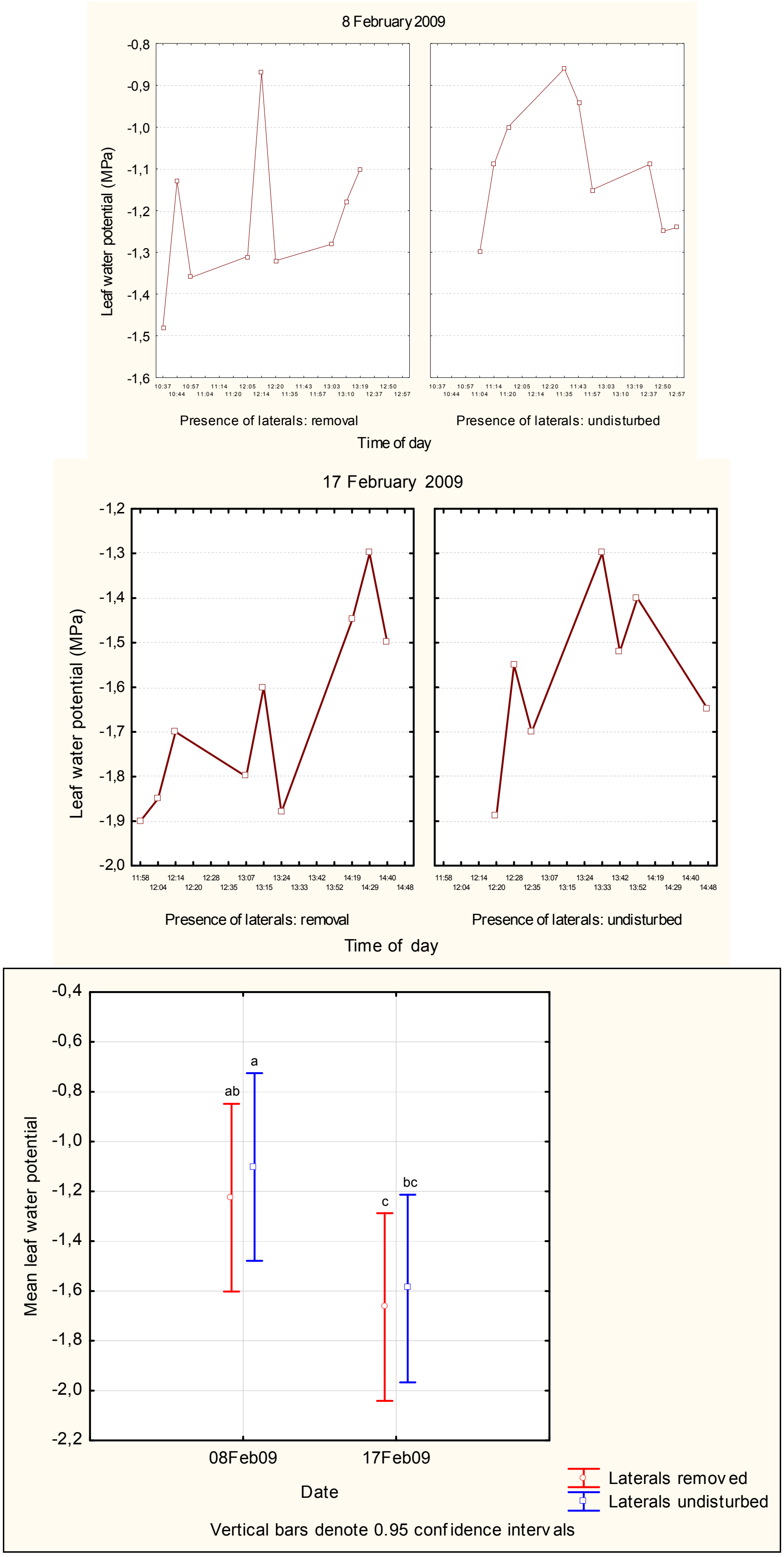

Figure 3.7. Leaf water potential of Sauvignon blanc/Richter 110 vines at Delheim, Stellenbosch Wine of Origin Distric . Values designated by the same letter do not differ significantly ($p \leq 0.05$).

3.4.4 PLANT WATER STATUS

The data of predawn leaf water potential for four seasons is presented in Figure 3.8. Despite the fact that Richter 110 is consider tolerant to drought (Dry, 2007), the vines at Morgenhof showed moderate to severe water stress condition in two seasons and severe in the rest of the seasons during berry ripening. In contrast, vines from Delheim only present a moderate water stress throughout the seasons (Fig 3.8) according to classification by Deloire *et al.* (2004). This situation is confirmed by the carbon isotope discrimination done in 2009 (Table 3.3), where a value of -20 p. 1000 represents severely water stressed vines and a value of -27 p. 1000 no water deficit (Deloire *et al.,* 2005).

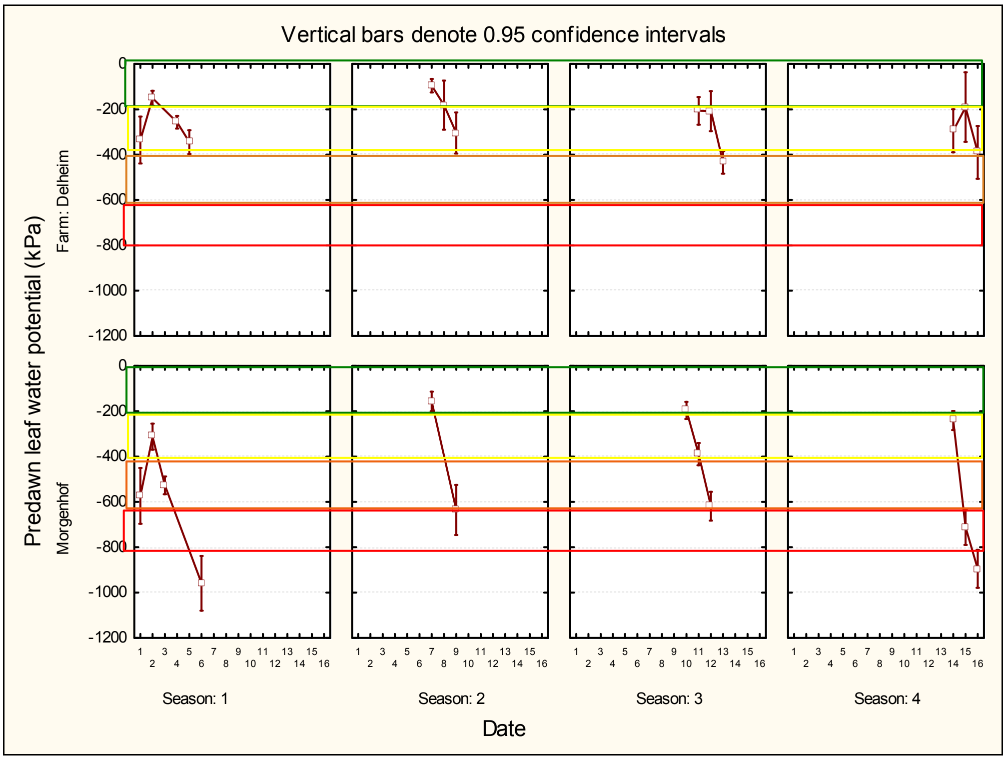

Figure 3.8. Predawn leaf water potential over four seasons in two Sauvignon blanc/Richter 110 vineyards in the Stellenbosch Wine of Origin District.

Dates: 1 = 25 October 2005; 2 = 7 December 2005; 3 = 11 January 2006; 4 = 12 January 2006; 5 = 20 February 2006; 6 = 21 February 2006; 7 = 21 November 2006; 8 = 12 December 2006; 9 = 17 January 2007; 10 = 19 November 2007; 11 = 18 December 2007, 12 = 22 January 2008; 13 = 29 February 2008; 14 = 5 December 2008; 15 = 19 January 2009; 16 = 27 February 2009.

Values of predawn leaf water potential (KPa)	Degree of water stress (Deloire *et al*., 2004)
0 to -200	Absent to very mild
-200 to -400	Moderate and progressive
-400 to -600	Moderate to severe
-600 to -800	Severe

3.4.5 BERRY RIPENING

Due to lateral shoot removal, the reduction of the secondary leaf area at Morgenhof and Delheim was approximately 92% and 94% respectively (Figure 3.9), changing the leaf age pattern in the canopy (Vasconcelos & Castagnoli, 2000) and leaving a higher proportion of main mature leaves in the total leaf area. However, the lateral removal did not affect the berry sugar loading at either Morgenhof or Delheim (Figures 3.10 and 3.11). The lack of response is probably related to the lack of any effect of the lateral removal on the whole-vine photosynthesis, despite the fact that secondary leaves can have gas-exchange rates comparable to the main leaves at the top of the canopy (Candolfi-Vasconcelos *et al.,* 1994), or it could be related to the capacity of photosynthetic compensation in the retained leaves triggered by the defoliation (Candolfi-Vasconcelos & Koblet, 1991; Poni & Giachino, 2000). The timing of the defoliation can play a key role in the effect thereof on total photosynthesis. In this experiment, the lateral removal was done late in the season (around pea size), thus possibly reducing the effect thereof on total photosynthesis. Candolfi-Vasconcelos *et al.* (1994), in a study of defoliation at pea size, found that the defoliated plants had similar or only slightly lower photosynthetic rates and water-use efficiency in the remaining leaves, meaning that the potential effect of later defoliations on the berry ripening might be lower in comparison with earlier defoliations.

On the other hand, the site (soil) had an effect on sugar loading. At Delheim a higher sugar accumulation per day occurred than at Morgenhof (Figures 3.10 and 3.11) during the period between approximately intermediate Brix values and berries not quite ripe (approximately between 27 January and 4 February). This could be related to the fact that Delheim had a higher total leaf area and higher number of thin roots, with a consequent higher potential of water uptake and reduced water deficits. This could also result in a higher photosynthetic rate per leaf compared to leaves from Morgenhof.

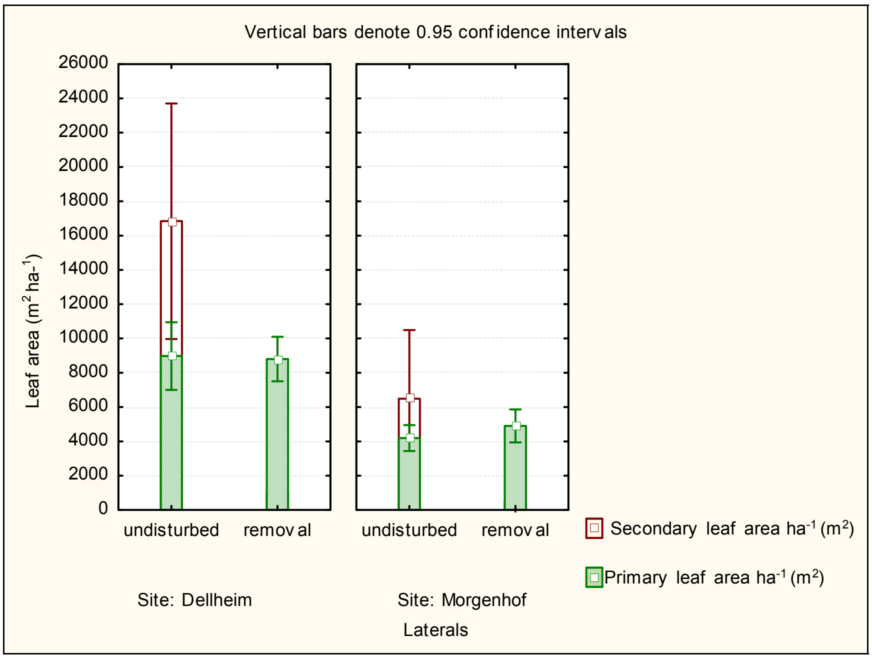

Figure 3.9 Primary and secondary leaf area of two Sauvignon blanc/Richter 110 vineyards in the Stellenbosch Wine of Origin District, as affected by lateral shoot removal.

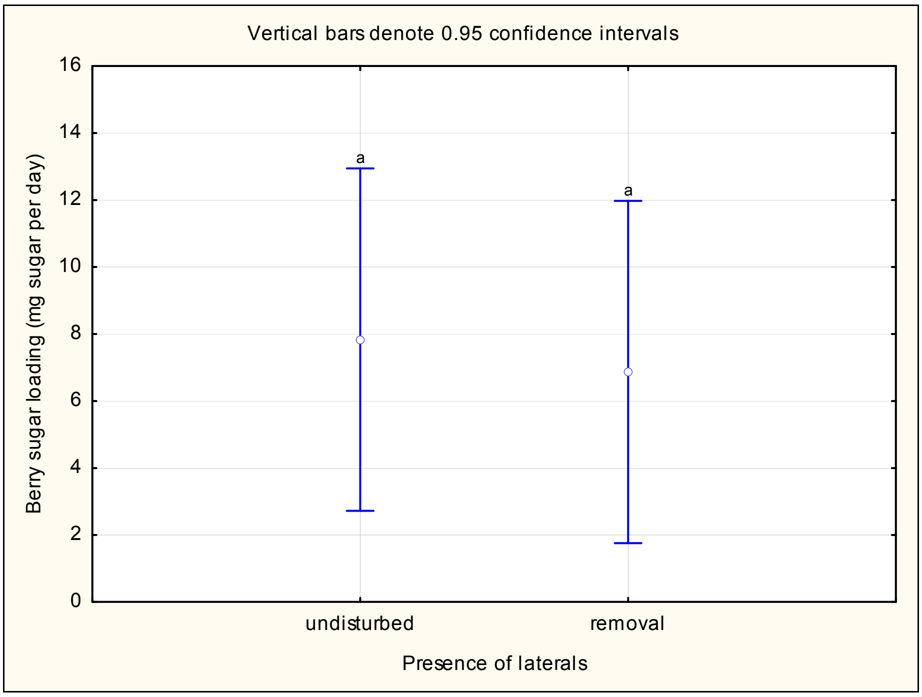

Figure 3.10. Accumulation of sugar per day during berry ripening (from 27 January until 2 February), with and without lateral shoot removal, at Morgenhof, on Sauvignon blanc/Richter 110 in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

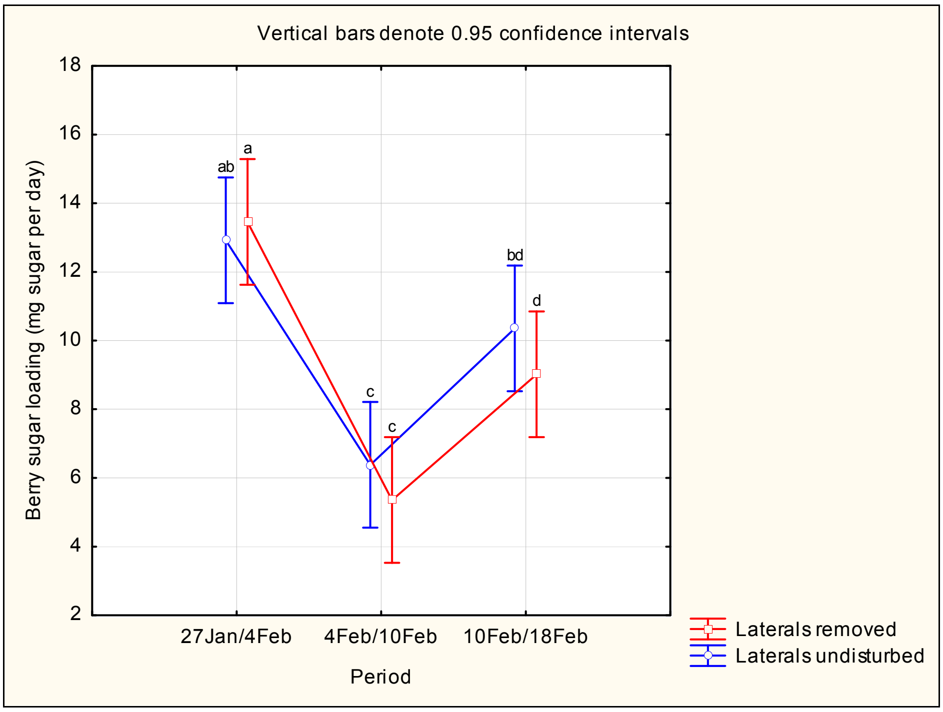

Figure 3.11. Accumulation of sugar per day during berry ripening (from 27 January until 18 February), with and without lateral shoot removal, at Delheim, on Sauvignon blanc/Richter 110 in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

Neither malic acid nor tartaric acid were affected by lateral shoot removal (Figures 3.12, 3.13, 3.15 and 3.16). In general, leaf removal can reduce titratable acidity, especially because of reduced malic acid content (Smart & Robinson, 1991), due on the one hand to the higher sun exposure of the berries and consequent higher temperatures, and on the other hand to the accumulation of organic acids, which is dependant on sucrose supply from the leaves (Ruffner, 1982a, 1982b). Nevertheless, in a study in which the total leaf area distal to the cluster comprised 100, 70, 30 and 0% of the lateral leaf area, Hirano *et al.* (1994) found that, in the treatments with a higher percentage of lateral leaf area, the titratable acidity of the berries decreased more rapidly than they did on the treatments with a low percentage of laterals and complete lateral removal

When the sites are compared, it is possible to visualise an effect on the organic acids. Morgenhof presents a significantly higher content of tartaric acid (Figure 3.14) and a lower content of malic acid in the berries (Figure 3.17) than Delheim in the period of approximately intermediate Brix values. The lower malic acid level might be due, in part, to the lower canopy density at Morgenhof compare to Delheim, with more exposed berries as a result. Although the exposed clusters can be influenced by light and temperature, organic acids in the berry pulp are affected more by temperature than by light in the sun-exposed clusters (Pereira *et al.,* 2006). The diminution of organic acids thus is explained by the higher temperatures of the exposed berries (Spayd *et al.,* 2002). It is important to bear in mind that, due to the effect of site, Morgenhof is historically harvested at least one week before Delheim.

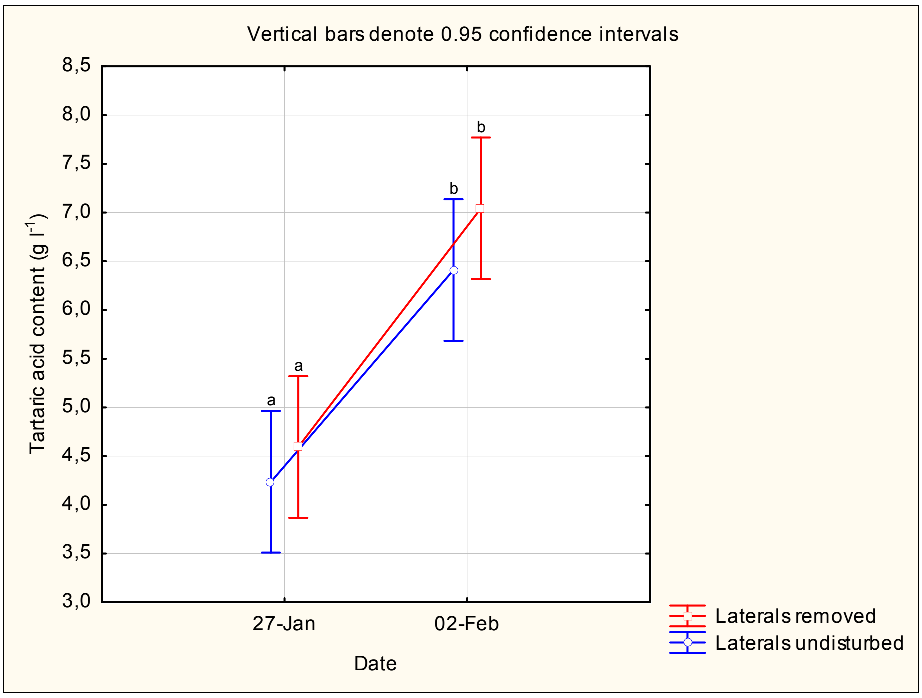

Figure 3.12. Tartaric acid content in berries during berry ripening (from 27 January until 2 February) in vines with and without lateral shoot removal at Morgenhof, in Sauvignon blanc/Richter 110, in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

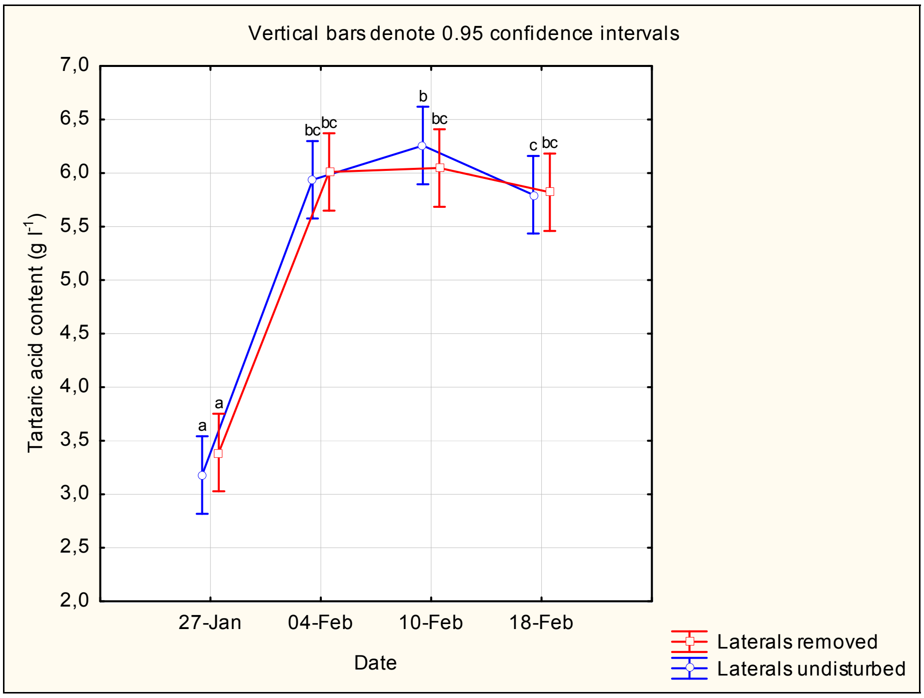

Figure 3.13. Tartaric acid content in berries during berry ripening (from 27 January until 18 February) in vines with and without lateral shoot removal at Delheim, in Sauvignon blanc/Richter 110, in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

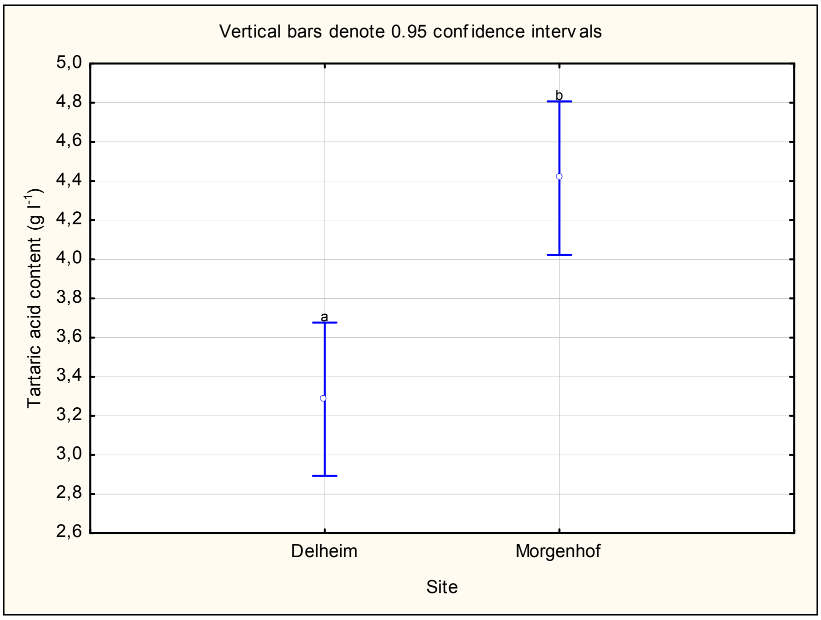

Figure 3.14. Tartaric acid content in berries at approximately intermediate Brix values (27 January) in two vineyards of Sauvignon blanc/Richter 110, in the Stellenbosch Wine of Origin District. Values designated by the different letters differ significantly ($p \leq 0.05$).

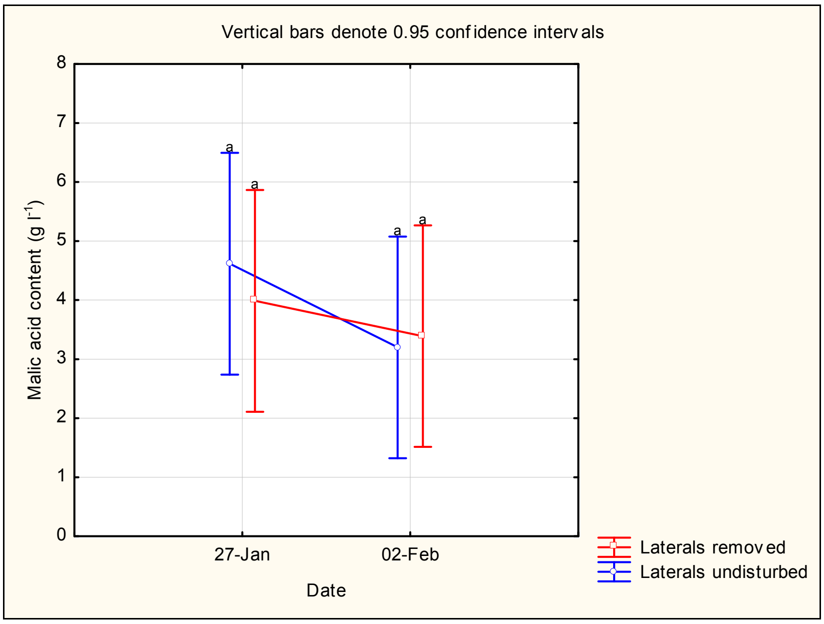

Figure 3.15. Malic acid content in berries during berry ripening (from 27 January until 2 February) in vines with and without lateral shoot removal at Morgenhof, in Sauvignon blanc/Richter 110 in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

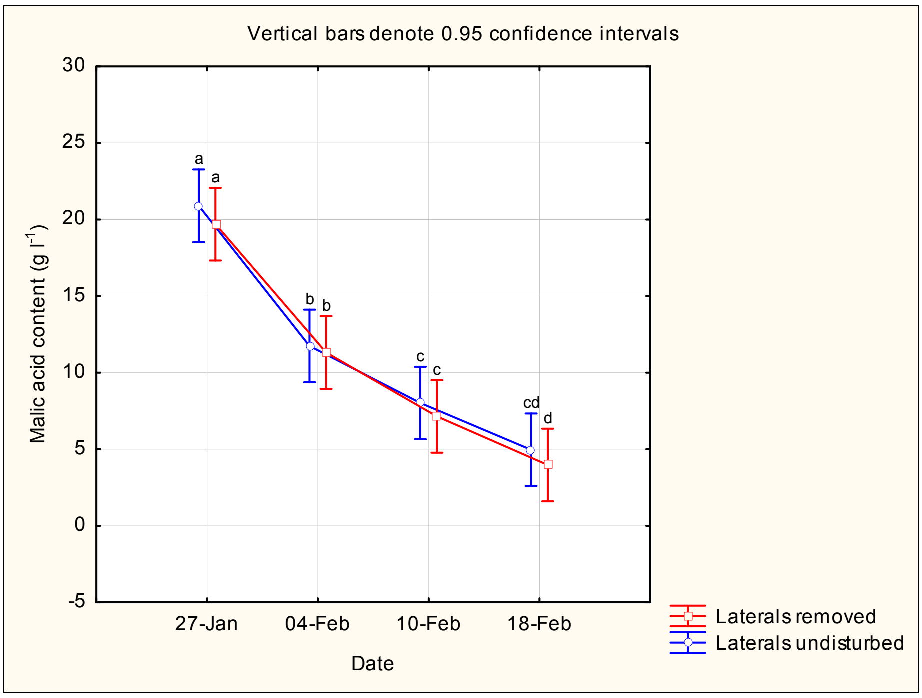

Figure 3.16. Malic acid content in berries during berry ripening (from 27 January until 18 February) in vines with and without lateral shoot removal at Delheim, in Sauvignon blanc/Richter 110 in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

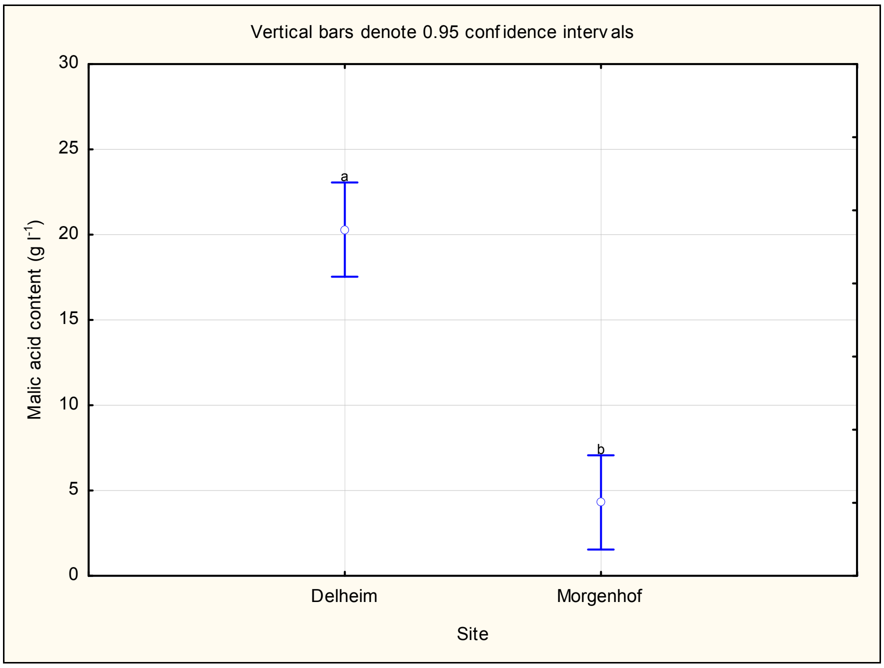

Figure 3.17. Malic acid content in berries at approximately intermediate Brix values (27 January) in two vineyards of Sauvignon blanc/Richter 110, in the Stellenbosch Wine of Origin District. Values designated by different letters differ significantly ($p \leq 0.05$).

3.5 CONCLUSION

The influence of lateral shoot removal and soil (site) on root growth, canopy functioning and berry ripening was investigated. In this study, the modification of the secondary leaf area was associated with a significant change in root growth, with an increase in the thin roots (0.5-2.0 mm) being related to a reduction of the lateral leaf area. The soil effect appeared to be due mainly to the effect of the soil pH and the effect on vine water status. Nevertheless, it is important to mention that other relevant parameters, such as penetrometer soil strength, were not evaluated. A low pH in the subsoil (pH (KCl) lower than 4.5), in conjunction with water stress, is expected to produce a lower number of thin roots.

The difference in water status between the two sites explains the differences found in canopy size in the undisturbed lateral shoot condition, but this effect of site on canopy size is diminished with lateral shoot removal, a situation that emphasises the relevance of lateral leaf area in the whole canopy. However, with the data collected it cannot be proven whether the lateral removal has an effect on whole-canopy photosynthesis. The effect of the removal of laterals on vine growth and berry ripening was probably largely due to a modification of the carbohydrate demand by competing sinks and the effect on the bunch microclimate. The sites had a relevant effect on grape composition, with significant differences in malic and tartaric acid, contrasting with the lack of effect of the modification of the secondary leaf area.

In general, the effect of the soil in the analysed parameters was larger than the effect of lateral shoot removal. Nevertheless, the significant impact of the different canopy structures on root growth cannot be discarded, therefore studies that aim to investigate the effect of soil on root distribution using different vineyards should take the vineyard canopy characteristics into account.

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Chapter 4

Research results

Root growth and distribution of Sauvignon blanc/110 Richter and Sauvignon blanc/99 Richter under different soil conditions in the Stellenbosch Wine of Origin District

RESEARCH RESULTS

4.1 ABSTRACT

Soil characteristics can strongly influence root growth and distribution. Due to the importance of root growth to the aboveground development of the vine, it is critical to gain understanding of the relationship between the soil factors, root growth, its distribution and the central role that the subterranean environment plays in the concept of terroir. The aim of this study was to characterise the root distribution of the rootstocks Richter 99 and Richter 110 on eight selected sites located throughout the Stellenbosch Wine of Origin District and to investigate the relationship between soil parameters and the grapevine root system. The experiment was conducted in eight commercial Sauvignon blanc vineyards grafted onto Richter 99 and Richter 110. Aspects of soil, roots, canopy and vine water status were evaluated. The combination of favourable edaphic conditions, such as subsoil pH (KCl) higher than 5.0, light- to medium-textured subsoil and moderate water stress, favoured growth of thin roots.

Key words: grapevine, soil pH, water stress, soil texture.

4.2 INTRODUCTION

Soil characteristics can strongly influence root growth and distribution, even more so than genotype (Smart *et al.,* 2006). Soil physical properties can affect vertical rooting depth and vertical distribution (Nagarajah, 1987), as well as water-holding capacity and nutrient retention (Maschmedt, 2005). On the other hand, soil chemical properties affect nutrient availability and also the physical soil conditions, and thus the moisture regime (Maschmedt, 2005). The Stellenbosch Wine of Origin District presents an extremely large number of natural terroir units due, in part, to different soil types related to varying geological parent material (Carey *et al.,* 2008a), which set up the existence of several soil-root system interactions.

The use of a rootstock/scion combination is common in most viticultural areas (Mullins *et al.,* 1992), primarily to avoid soil-borne pests and secondly to achieve better adaptation to certain soil conditions, such as saline soils, acidic soils or intense drought conditions (Whiting, 2005). Most of the soils of the Western Cape, South Africa, especially the subsoils, are acidic (Saayman & Van Huyssteen, 1981). Rootstocks 140 Ruggeri, 110 Richter and 99 Richter are some of the cultivars recommended for such conditions (Conradie, 1983). The two latter rootstocks share a common origin, with both coming from the cross *V. berlandieri* x *V. rupestris* (Dry, 2007), a situation which explains similar characteristics such as their relative tolerance of soil acidity (Conradie, 1983). Their other characteristics are shown in Table 4.1.

Table 4.1 Main characteristics of 99 Richter and 110 Richter (from Whiting, 2005).

Rootstock	Relative scion vigour	Lime tolerance	Drought tolerance	General comments
99 Richter	Moderate to high	Moderate	High	Is suited to a wide range of soil types, but not wet, poorly-drained situations.
110 Richter	Low to moderate	Moderate	Very high	Less vigorous, more drought tolerant and grapes are later maturing than 99 Richter. Suited to hillsides and dry-farmed sites.

Due to the importance of root growth to the aboveground development of the vine (Archer *et al*., 1988), it is critical to gain understanding of the relationship between soil factors and root growth and distribution, and the central role that the subterranean environment plays in the concept of terroir, which is based mainly on three parameters, namely climate, cultivar and soil (Van Leeuwen *et al.,* 2004). In this context, studies done on viticultural terroirs show that different soil types defined by differences in depth and clay content can significantly affect the composition and quality of the berries (Morlat & Bodin, 2006). Therefore, the aim of this study was to characterise the root distribution of the rootstocks Richter 99 and Richter 110 on eight selected sites located throughout the Stellenbosch Wine of Origin District and to investigate the relationship between soil parameters and the grapevine root system.

4.3 MATERIALS AND METHODS

4.3.1 PLANT MATERIAL AND TREATMENTS

The experiment was conducted in eight commercial Sauvignon blanc vineyards grafted onto Richter 99 and Richter 110 located in the Stellenbosch Wine of Origin District. Table 4.2 shows the main characteristics of the selected vineyards: Aan-den-Weg, Amperbo, Delheim, Helderkruin, Leiberg, Morgenhof, Rustenberg and Swartrivier. These sites will be referred to by their vineyard designations. In each vineyard, three miniplots were delimited in areas with visually similar vigour. The miniplots consisted of 10 vines each.

Table 4.2 Characteristics of the eight selected vineyards in the Stellenbosch Wine of Origin District.

Vineyard	Year of plantation	Rootstock	Irrigation	Spacing (m)
Aan-den-Weg	1998	Richter 99	Drip	1.2 X 2.5
Amperbo	1991	Richter 99	Drip	1.2 X 2.7
Delheim	1993	Richter 110	Non-irrigation	1.2 X 2.7
Helderkruin	2000	Richter 99	Drip	1.5 X 2.6
Leiberg	1995	Richter 99	Micro-irrigation	1.5 X 2.4
Morgenhof	1994	Richter 110	Non-irrigation	1.2 X 3.0
Rustenberg	1995	Richter 99	Drip	1.0 X 1.5
Swartrivier	1990	Richter 99	Drip	1.0 X 2.7

Vines were trained on a 4-wire vertical hedge at Aan-den-Weg, Helderkruin and Swartrivier; 5-wire vertical hedge at Amperbo and Leiberg; 5-wire lengthened Perold system at Delheim and Rustenberg; and on a 5-wire Perold system at Morgenhof.

4.3.2 SOIL PROFILE DESCRIPTIONS AND ANALYSES

The sites were selected because of their different growing conditions and in order to represent the two rootstocks under investigation. Soil profiles of each plot were examined and described using the South African taxonomic system (Soil Classification Working Group, 1991) by experienced soil scientists. One soil sample was collected from each horizon per treatment, and standard soil chemical and physical analyses were performed in a commercial laboratory.

4.3.3 ROOT MEASUREMENTS

Three vines from each treatment, one from each row, were chosen for root studies. A profile wall method (Böhm, 1979) was used to plot the roots. A trench of 1.0 m deep was dug parallel to the vine row and 20 cm from the vine trunk. The grid used was 10 cm X 10 cm, 1.0 m high and 1.0 m wide. The grid was centred on the middle grapevine trunk. The roots were classified into five root diameter classes: < 0.5 mm = fine roots; 0.5-2.0 mm = thin roots; 2.0-5.0 mm = medium roots; 5.0-7.0 mm = medium to thick roots and > 7.0 mm = thick roots. Root profiles were done during the dormant period (June/July).

4.3.4 LEAF AREA MEASUREMENTS

Due to the findings reported in the previous chapters regarding the effect of lateral shoot leaf area on root growth, the relevance of the inclusion of leaf area measurements in this chapter became clear. Six shoots from six vines, one shoot per vine and two vines per miniplot, were sampled at vèraison, as defined by Coombe (1995). Primary and secondary shoot length were measured. For both the primary and secondary shoots the leaves were removed and counted, and leaf area was measured using a leaf area meter (Delta T device Ltd, Cambridge, UK).

4.3.5 PLANT WATER STATUS MEASUREMENTS

Plant water status was measured as leaf water potential before dawn (ψ_{PD}), using the pressure chamber technique (Scholander *et al.*, 1965). For each measurement, nine fully expanded leaves from principal shoots/canes were selected, three leaves per miniplot. Measurements were carried out at four approximate phenological stages, namely, flowering, pea size/bunch closure, véraison and harvest (Coombe, 1995). In addition, carbon isotope discrimination ($\delta^{13}C$) was determined in the berry must. The clusters harvested from the 30 experimental vines per plot were crushed and a sample of 2.0 ml of grape must was taken. These must samples frozen at -20ºC and were sent to the Stable Light Isotope Laboratory at UCT for the analysis of the C_{12}/C_{13} ratio on a single date at the end of harvest. They were analysed by combustion in a Thermo 1112 Elemental Analyser coupled via a Thermo Conflo III to a Thermo Delta XP stable light isotope mass spectrometer. Samples were run against in-house reference materials and the results were normalised against and reported relative to international standards (PDB for carbon).

4.3.6 STATISTICAL ANALYSES

The data were analysed using repeated measures analysis of variance (ANOVA), using the mixed model approach.

4.4 RESULTS AND DISCUSSION

4.4.1 SOIL CHARACTERISTICS

In relation to soil texture, Aan-den-Weg and Delheim were classified as sandy loam; Amperbo, Helderkruin, Leiberg and Rustenberg as loamy sand-sandy loam; Morgenhof as sandy clay loam, and the Swartrivier soil was described as a duplex soil, with a topsoil of loamy sand and a subsoil of clay loam. The textural differences are shown in Figures 4.1, 4.2, 4.3, 4.4 and 4.5. Duplex soils are characterised by a clear, abrupt change in texture from the topsoil to the subsoil. The impact of the “duplex” character lies in the restriction imposed by the sudden increase in clay content at the topsoil-subsoil interface (Maschmedt, 2005). This textural differentiation in the profile can have a negative influence on root growth (Morlat & Jacquet, 1993) and on water movement. Morgenhof and Swartrivier are the two vineyards with the highest clay content and in addition the latter vineyard is the site with the highest silt content. In a study done on viticultural terroirs in Stellenbosch, it was found that a heavy-textured soil (clay higher than 25%), especially in the subsoil, was linked to reduced vegetative growth of Sauvignon blanc and it was assumed that this was due to reduced root growth (Carey *et al.*, 2008b). Nagarajah (1987) postulated that soil texture can influence the vertical distribution of roots, as well as the rooting depth, directly by limiting root extension or indirectly via influencing the depth of the water table.

With respect to the soil chemical analyses, all the macro and micronutrients decrease with depth, except for the P content of the Rustenberg soil, the K, Ca and Mg content of the Helderkruin soil, and the Ca and Mg content of the Swartrivier soil (Figures 4.6, 4.7, 4.8, 4.9 and 4.10). A $\log_{10}$ (Variable (V) +1) transformation was used to improve the normality of the data to meet the assumptions of the ANOVA. Concerning K soil content, Sipiora *et al*. (2005) found that the root density and distribution are not affected by K fertilization. Even though 110 Richter and 99 Richter are considered relatively tolerant to soil acidity (Conradie, 1983; Dry, 2007), the pH of the subsoil of Morgenhof, Aan-den-Weg, Rustenberg and Swartrivier (pH of 4.1, 4.6, 4.6 and 4.5 respectively) might have a negative effect on root growth (Conradie, 1988) (Figure 3.2 and Table 3.2). Conradie (1988) recommended liming soils to a pH (KCl) of at least 5.5 in order to have a well-developed root system. Marcelin (1974) noted that acid soils are usually poorly supplied with calcium and magnesium.

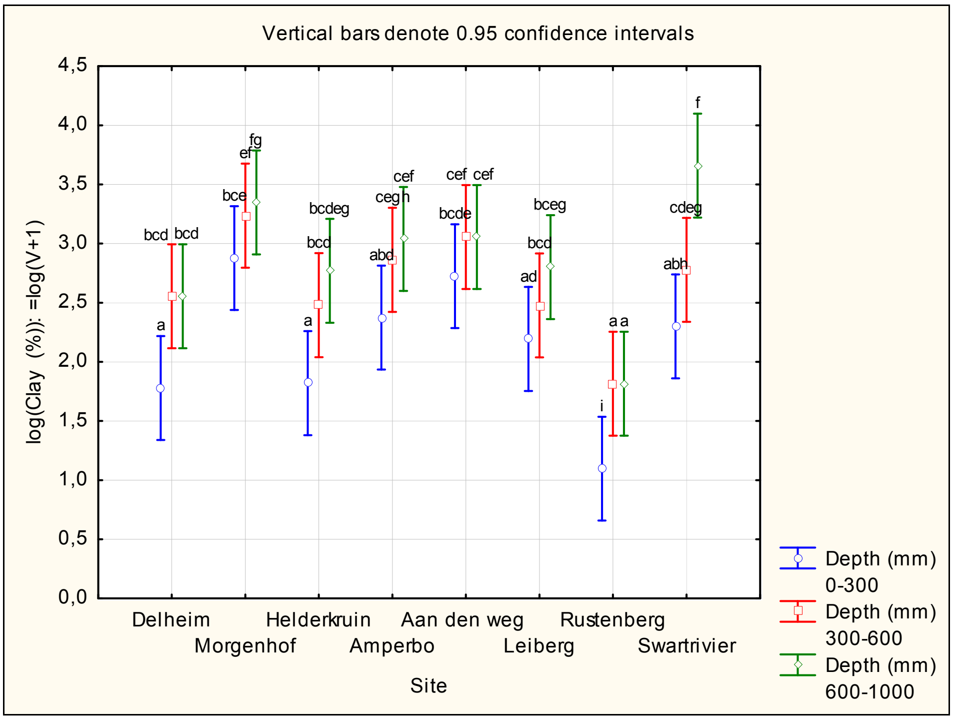

Figure 4.1. Difference in clay content of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

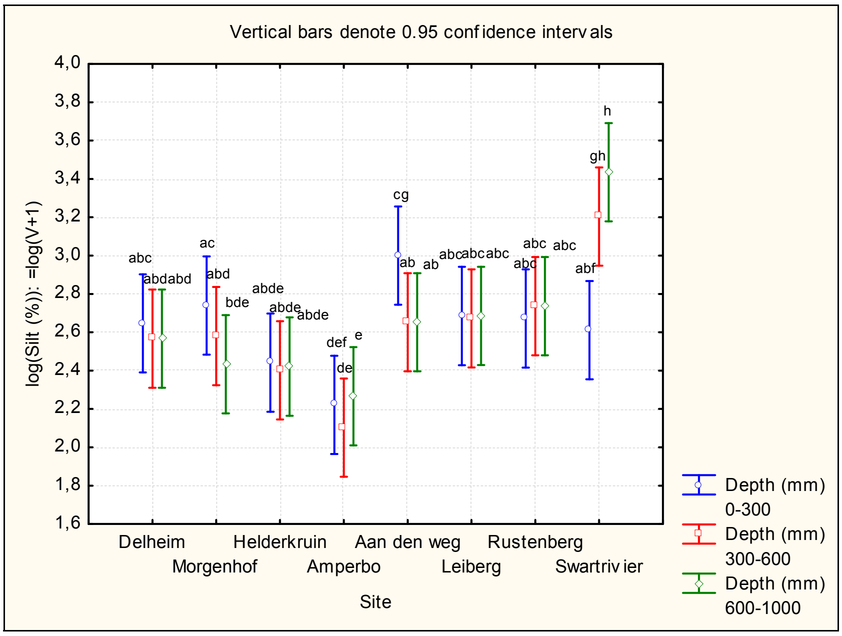

Figure 4.2. Difference in silt content of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

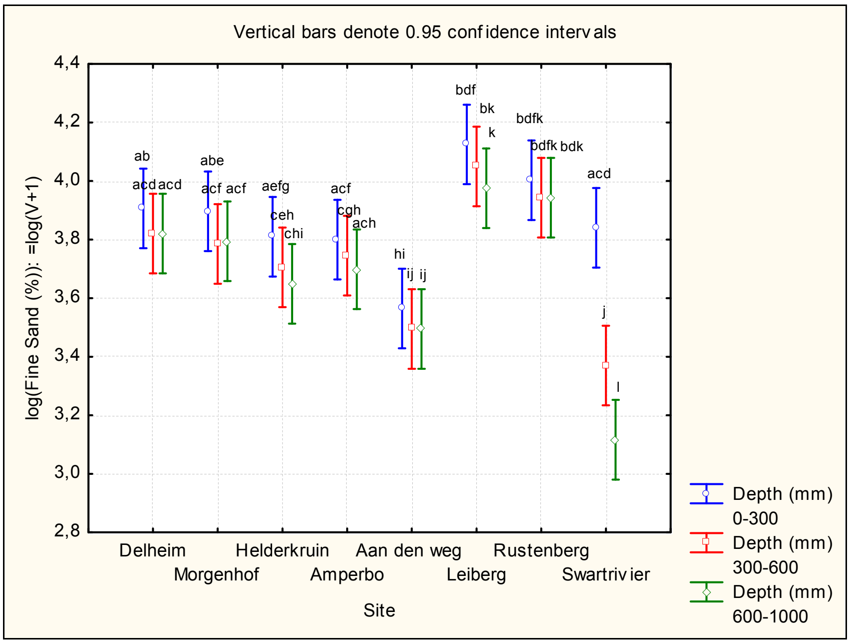

Figure 4.3. Difference in fine sand content of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

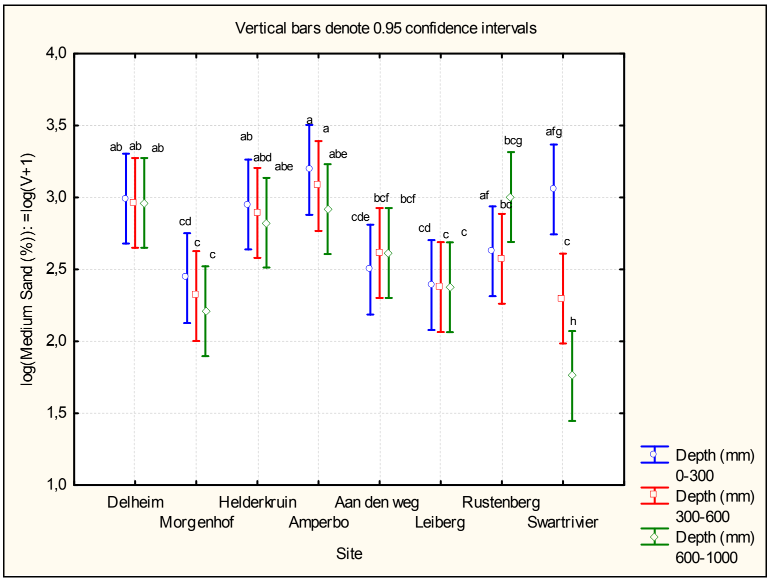

Figure 4.4. Difference in medium sand content of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

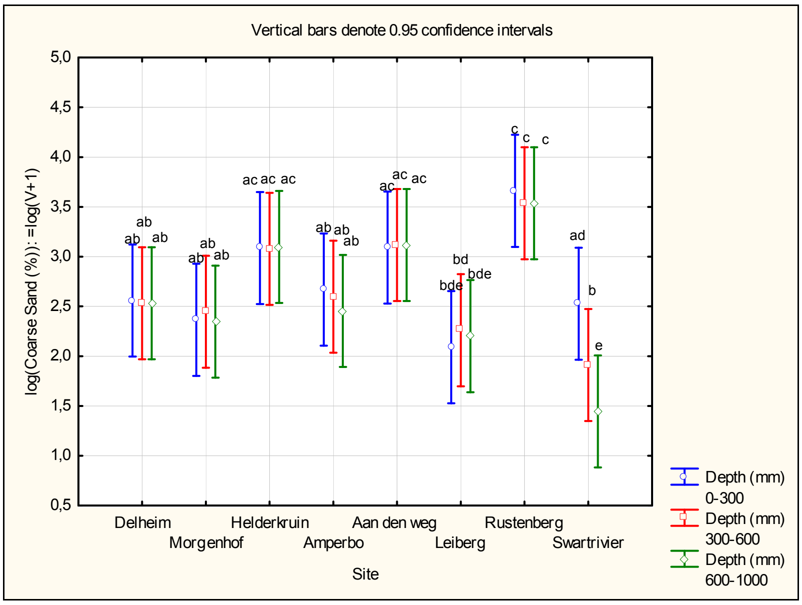

Figure 4.5. Difference in coarse sand content of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

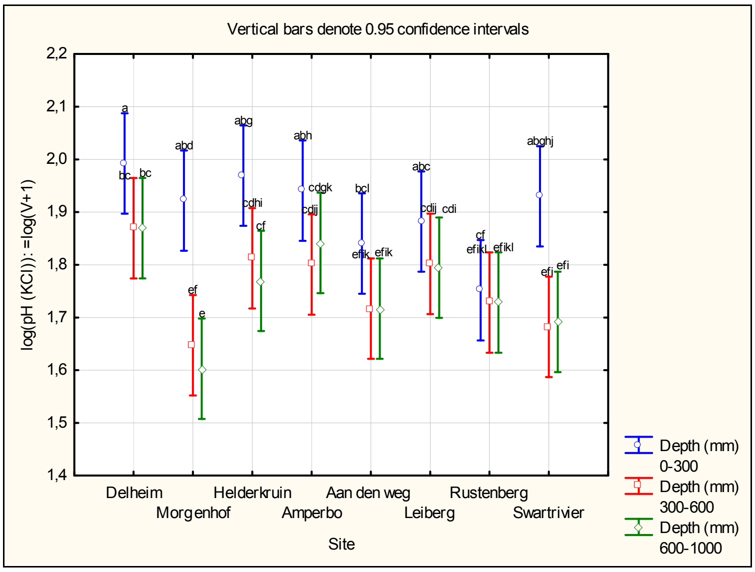

Figure 4.6. Difference in soil pH of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

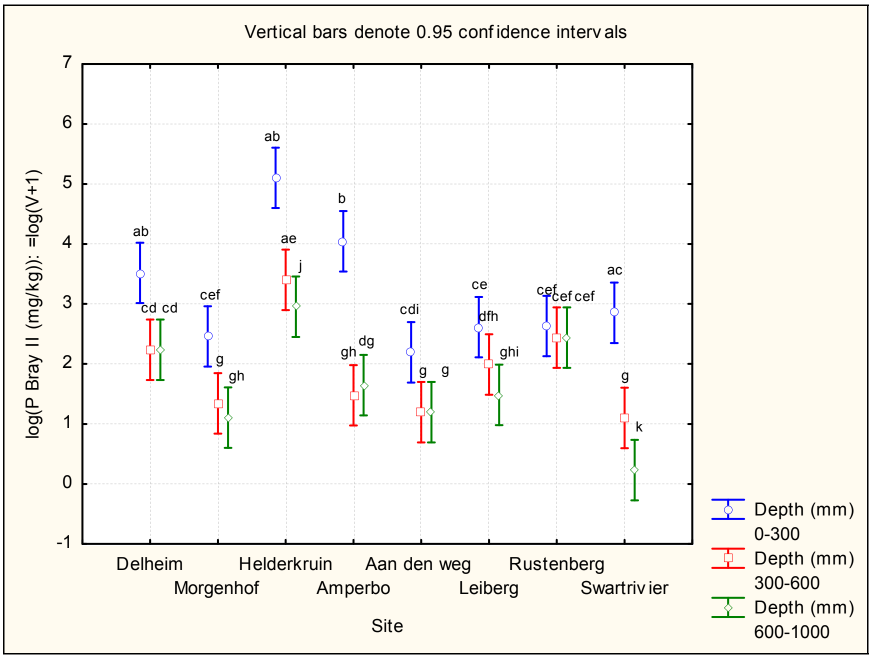

Figure 4.7. Difference in soil P of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

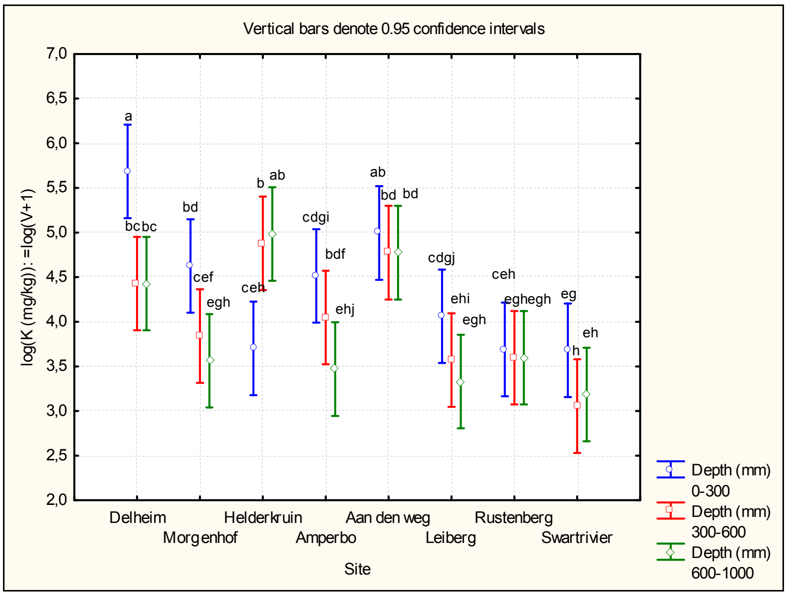

Figure 4.8. Difference in soil K of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

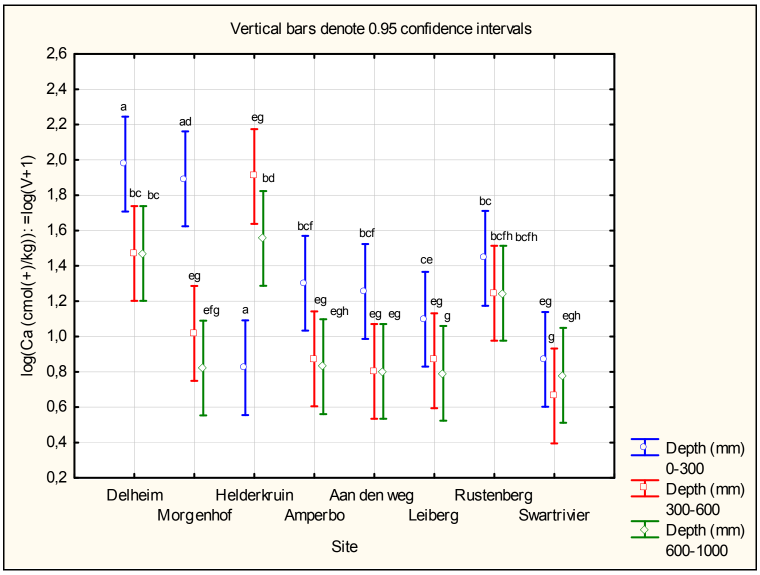

Figure 4.9. Difference in soil Ca of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

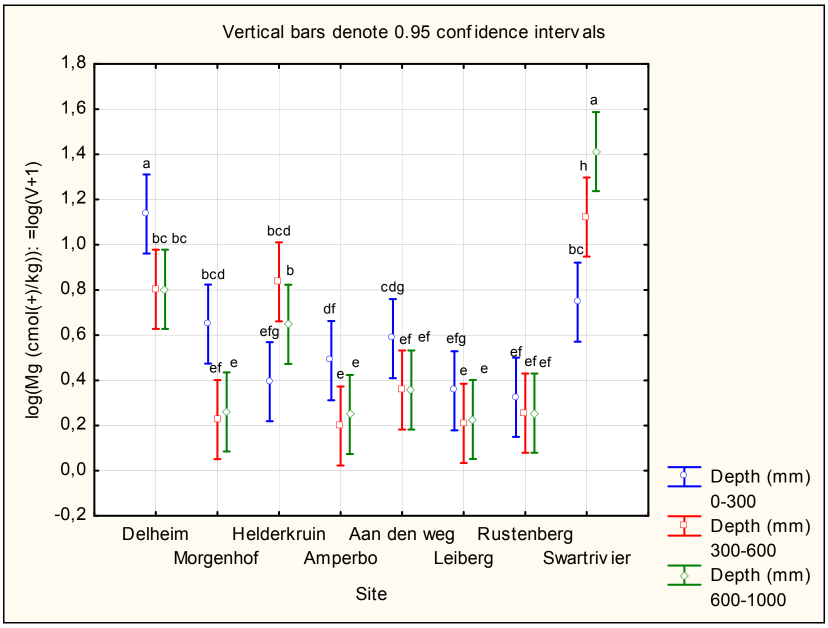

Figure 4.10. Difference in soil Mg of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly (p ≤ 0.05).

4.4.2 ROOT GROWTH AND DISTRIBUTION

The biggest difference in terms of number of roots within the thin roots class (0.5-2.0 mm) at Delheim (Figure 4.11). The higher number of thin roots found at Delheim might be due in part to the fact that this is the site with the least acidic subsoil (subsoil pH of 5.5) (Figure 4.6), moderate water stress (Figure 4.14 and Table 4.3), and with light- to medium-textured and weakly structured subsoil. It is well known that soil acidity negatively affects root development (Conradie, 1988; Kirchhof *et al*., 1991), as does severe water stress (Van Zyl, 1984) or soil that is too wet (Conradie *et al.,* 2002), but moderate stress can enhance root development (Van Zyl, 1984). The distribution of the fine, thin and medium roots (<0.5 mm; 0.5-2.0 mm and 2.0-5.0 mm respectively) throughout the soil profile is shown in Figure 4.12. Except for Rustenberg at a depth of 200 - 300 mm, most of the sites present a similar pattern in distribution throughout the soil profile, despite the different types of irrigation on the sites. Similar results were reported by Bassoi *et al.* (2003) in a trial comparing root distribution under drip and microsprinkler irrigation, in which it was found that the irrigation system had no significant effect on root parameters. Nevertheless, it is important to point out that the study was done in a tropical fruit-growing area, with two harvests per year, and that the root growth during the rainy season therefore may have contributed to minimise differences in root development under microsprinkler and drip irrigation systems. Furthermore, in a trial with two K-sulphate fertiliser application rates and two irrigation regimes, Sipiora *et al.* (2005) found that the root density and distribution were not affected by the irrigation or the fertilization. In certain situations, the explanation for the lack of response of root growth to irrigation can be related to the soil texture, such as in cases where a deep, medium-textured soil provided large soil reservoirs of water for the plant, limiting the quick response to irrigation strategy (Van Zyl, 1984). In a study that involved the conversion of vines from sprinkler irrigation to drippers, Soar & Loveys (2007) found that this conversion resulted in a significant increase in total root mass under the drip line, particularly 25 - 50 cm below the surface. Araujo *et al.* (1995) also noted that root growth and branching proliferated in the wetted zone under the drip.

At Delheim, Morgenhof and Swartrivier, the peak in thin roots (0.5-2.0 mm) was matched by a corresponding reduction in medium roots (2.0-5.0 mm) (Figure 4.11). This situation might be associated with reduced lateral growth of roots, meaning that older roots stay thinner; this could possibly be linked with reduced storage or carbohydrates and nutrients as a result of the smaller canopies. The roots systems seemed to differ mostly with respect to root contacts in the category of medium (2.0-5.0 mm), thin (0.5-2.0 mm) and fine (<0.5 mm) roots. The permanent structural thick roots appeared to be much more constant. In a study done on peaches, Wells *et al.* (2002) found that the position of the root within the branched hierarchy of the root system appeared to be an important determinant of life span: apparent first-order roots had median survival times that were less than half those of higher-order roots. In addition, roots with greater diameters have a lower risk of mortality and this risk also decreases with soil depth. The cause of the depth effect is not clear, but it is likely that roots at depth experience fewer fluctuations in soil temperature and water availability. The degree to which individual roots respond to these factors could be a function of a root age.

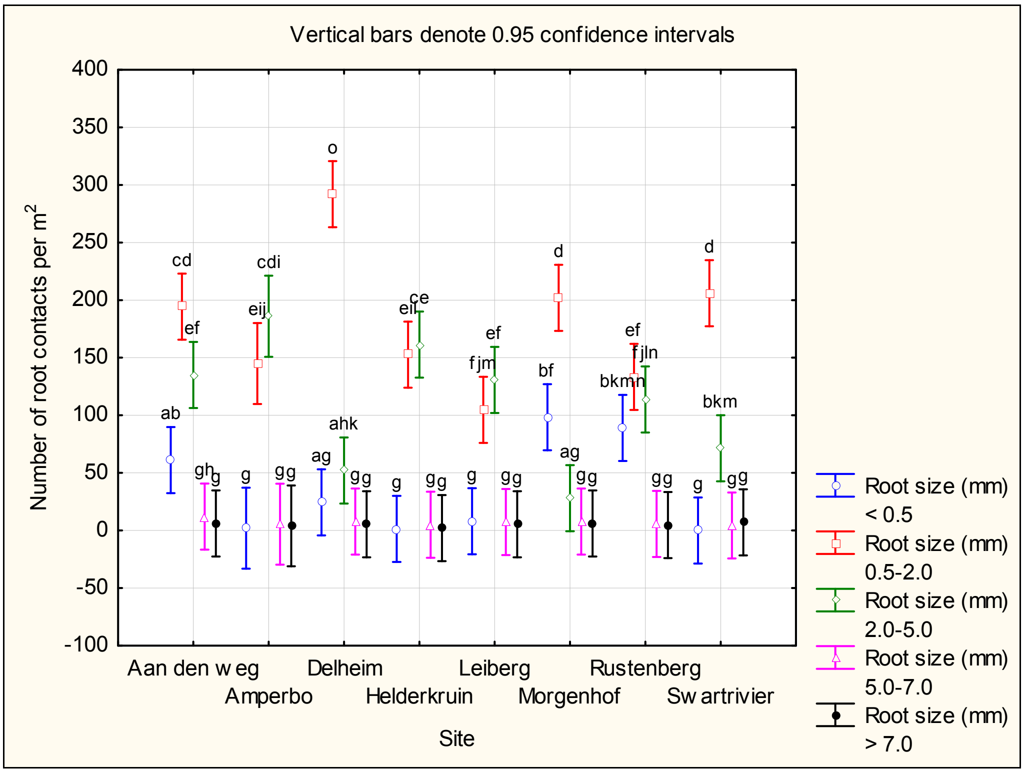

Figure 4.11. Number of root contacts per diameter class in eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District. Values designated by the same letter do not differ significantly ($p \leq 0.05$).

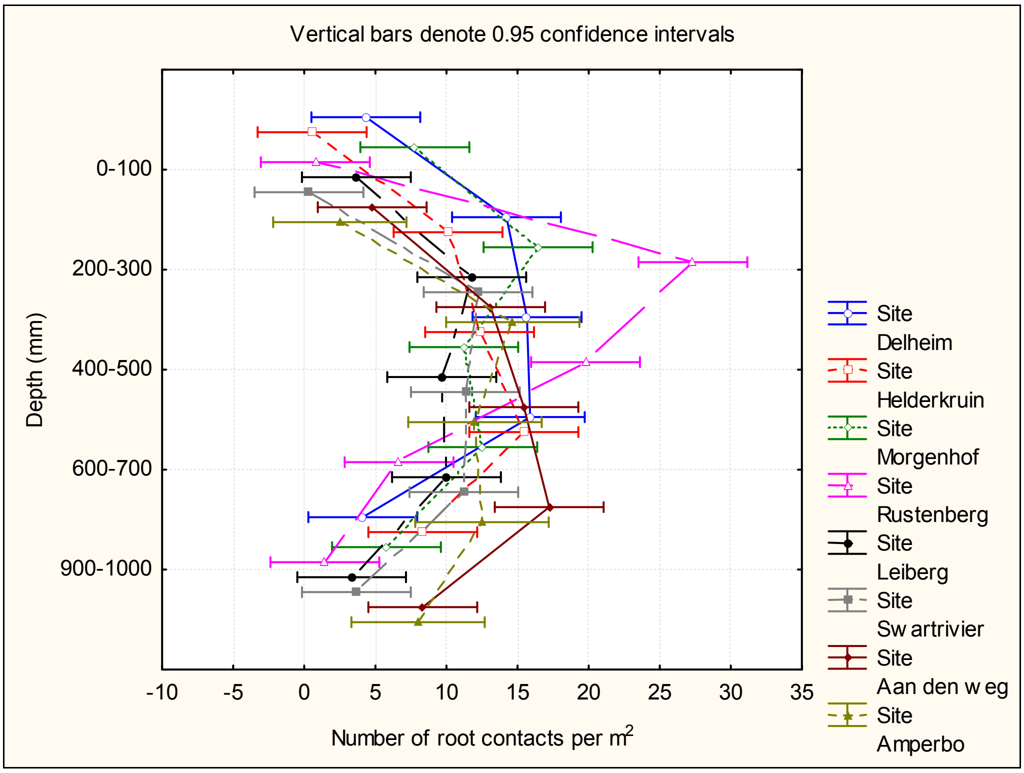

Figure 4.12. Number of total root contacts per depth category in eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District.

4.4.3 CANOPY GROWTH

Comparison between the different vineyards did not show any significant differences in secondary shoot leaf area (Figure 4.13). Therefore, the differences that were seen between vineyards in terms of thin root growth would seem to be related to edaphic factors rather than canopy structure. In relation to the primary leaf area, the Morgenhof vines apparently had the lowest primary leaf area (Figure 4.13), a situation that can be ascribed in part to the water limitation in this vineyard (Figure 4.14 and Table 4.3 as was also found by Koundouras *et al*. (2008)) because of the fact that shoot growth is extremely sensitive to water deficit (Keller, 2005). It is relevant to mention that the secondary leaf area represents at least the same leaf area as the primary leaf area in all the vineyards (Figure 4.13), which illustrates the relative importance of the laterals in the total leaf area of the vine and the potential importance in terms of microclimate and leaf area available for photosynthesis.

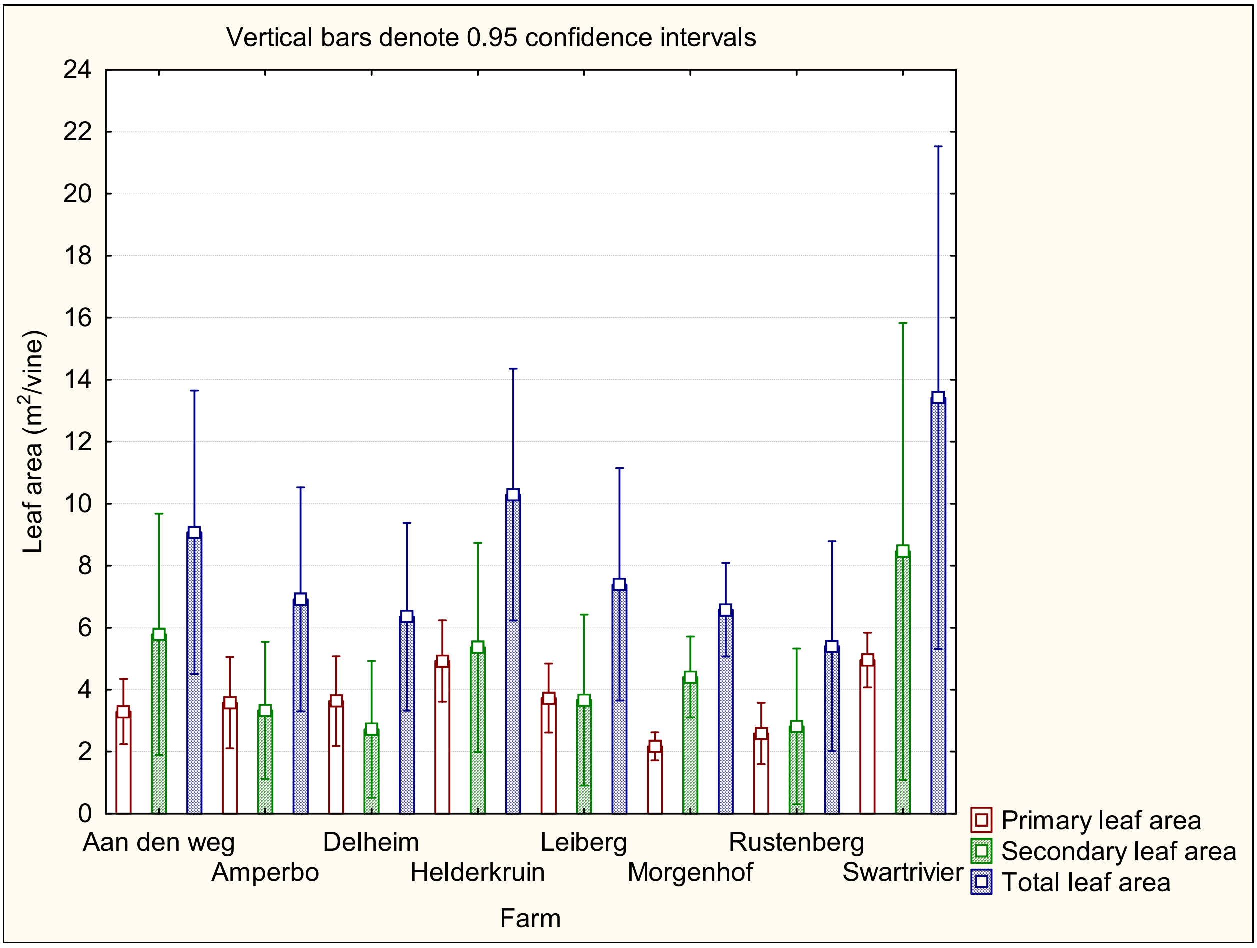

Figure 4.13 Primary, secondary and total leaf area of eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District.

4.4.4 PLANT WATER STATUS

Despite the fact that Richter 110 is considered very highly tolerant to drought, and that Richter 99 is highly tolerant to drought (Dry, 2007), carbon isotope discrimination data shows that the vines from Morgenhof experienced high water stress, followed by Swartrivier and Aan-den-Weg (Table 4.3), where a value of -20/1000 represents severely water-stressed vines and a value of -27/1000 represents no water deficit (Deloire *et al.*, 2005). If the data from the predawn water potential over the last five seasons is analysed, Rustenberg can also be considered to experience moderate to severe water stress (Figure 4.14) (Deloire *et al.,* 2004), these four vineyards correspond with the acidic subsoil condition, a situation that might be linked to root growth or functioning. Water uptake is proportional to the root surface area (Keller, 2005), therefore a higher density of fine roots and a well-distributed root system might result in less stressed vines, although it also is a matter of root functioning.

Table 4.3. Carbon isotope discrimination ($\delta^{13}C$) measured on grape must at harvest in eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District.

Vineyard	$\delta^{13}C$ (‰)
Aan den weg	-25,97
Amperbo	-26,26
Delheim	-27,54
Helderkruin	-27,20
Leiberg	-26,88
Morgenhof	-22,86
Rustenberg	-27,63
Swartrivier	-25,04

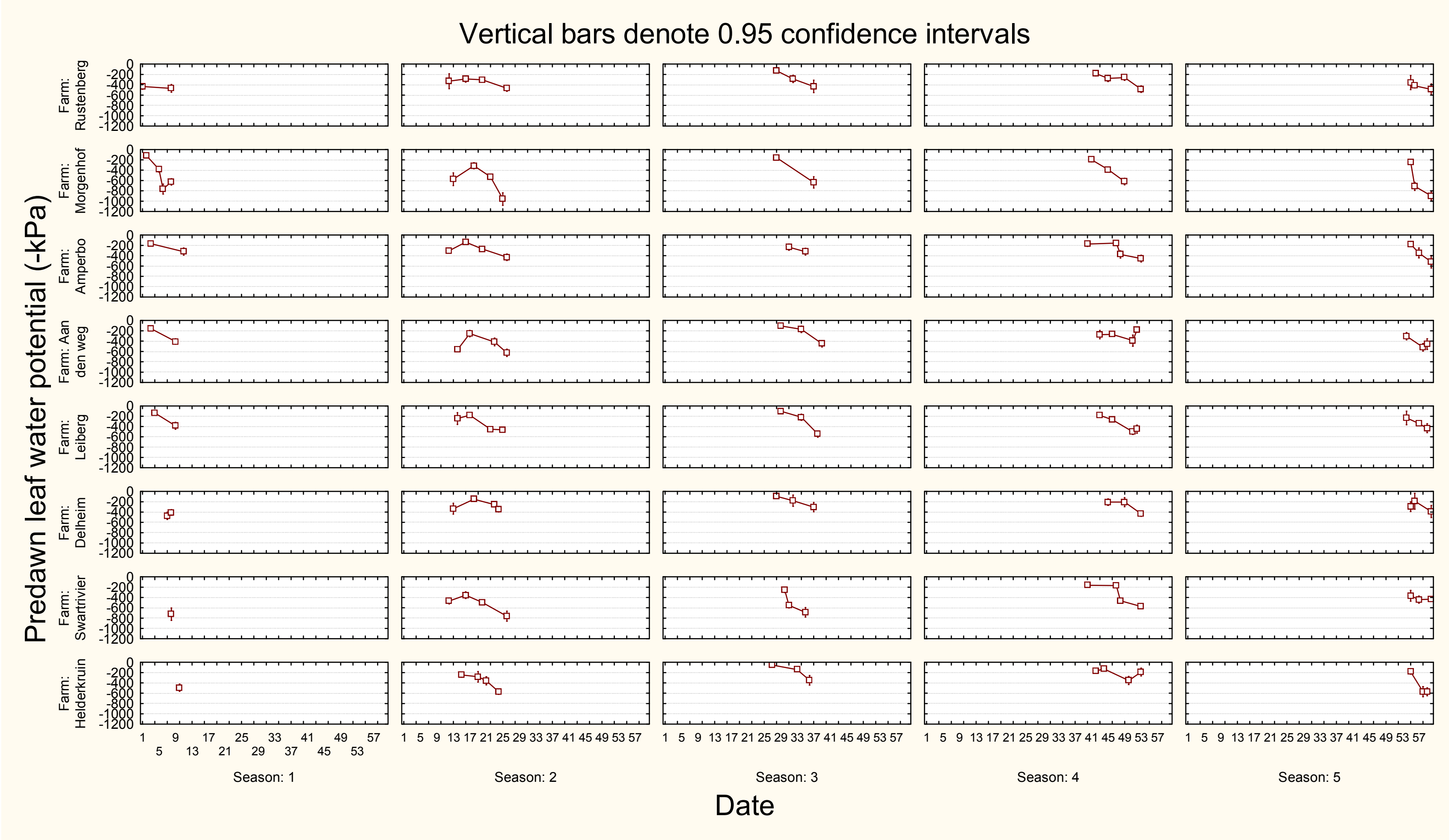

Figure 4.14. Predawn leaf water potential over five seasons in eight Sauvignon blanc vineyards in the Stellenbosch Wine of Origin District.
Dates: 1 = 16 November 2004; 5 = 14 December 2004; 9 = 9 February 2005; 13 = 25 October 2005; 17 = 6 December 2005; 21 = 10 January 2006; 25 = 21 February 2006; 29 = 22 November 2006; 33 = 13 December 2006; 37 = 17 January 2007; 41 = 19 November 2007; 45 = 18 December 2007; 49 = 24 January 2008; 53 = February 2008; 57 = 20 January 2009.

4.5 CONCLUSION

The root growth and distribution of 99 Richter and 110 Richter rootstocks under different soil conditions were investigated on eight farms in the Stellenbosch Wine of Origin District. In this study, the combination of favourable edaphic conditions, such as subsoil pH (KCl) higher than 5.0, light to medium textured subsoil and moderate water stress, induced higher thin roots growth. From this study, it was not clear whether a high subsoil clay content causes reduced aboveground growth as a result of reduced below ground growth. The main differences in root contacts between vineyards seemed to exist in the medium to fine roots category. The permanent structural thick roots appeared to be much more constant. Analysis of the canopy growth confirmed the negative effect of severe water stress on shoot growth. It appears that there is a relationship between acidic subsoil and plant water status. Differences in the response of the different rootstocks to the evaluated parameters were not evident.

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Chapter 5

General discussion and conclusions

GENERAL DISCUSSION AND CONCLUSIONS

5.1 INTRODUCTION

This study was aimed to investigate the effect of selected soil physical and chemical parameters on vine root growth and distribution and to investigate whether very different canopies affect root growth or grapevines.

5.2 GENERAL DISCUSSION

The edaphic factors appeared to be one of the most important parameters that affect root development by determining soil water availability and possibly causing physical or chemical limitations on root growth. From the results of this study, it is clear that severe water stress and a pH (KCl) lower than 4.5 play a key role in the limitation of root growth. Due to the fact that most of the soils from the Stellenbosch Wine of Origin District, especially the subsoils, are acidic, this is a factor to consider before planting. On the other hand, the combination of favourable edaphic conditions, such as a subsoil pH (KCl) of higher than 5.0, light- to medium-textured subsoil and moderate water stress, enhanced the growth of thin roots.

However, the effect of canopy management on root growth cannot be discounted due to its importance in the variation of carbohydrate demand by competing sinks. This study showed that lateral shoot removal, done from when the berries are at pea size, results in an increase in the number of thin roots (0.5-2.0 mm). The secondary leaf area represents at least the same leaf area as the primary leaf area in all the vineyards evaluated, which illustrates the relative importance of laterals shoots and the potential importance in terms of microclimate and leaf area available for photosynthesis. The main differences in root densities between vineyards seemed to exist in the medium to fine roots category, where the number of lateral shoot leaves in the canopy may play an important role. The permanent structural thick roots appeared to be much more constant. Studies of root growth should take the vineyard canopy architecture into account.

5.3 LIMITATIONS OF THE STUDY

The complexity of the study of the roots became clear, not only due to the inherent difficulties of underground measurements, which involve digging holes to a depth of at least one meter. Because of these difficulties, it is not easy to have high numbers of repetitions. Another problem was the high heterogeneity of the soil within a vineyard, among others. In addition, there are several factors and their interactions that affect root development. An important limitation of this study was the fact that the root studies were done only in winter, without considering the dynamics of root growth throughout the season. This situation could be improved by using rhizotrons or minirhizotrons. On the other hand, root studies based only on aspects of root growth, without considering root functioning, cannot fill the gaps of knowledge still remaining, such as aspects of root-to-shoot signalling.

5.4 PERSPECTIVES AND FUTURE RESEARCH

Due to the fact that the dynamics of the berry ripening, and therefore the final berry composition, can be affected by water stress and canopy management practices, such as lateral shoot and leaf removal, further research on the effect of these two variables and their interaction is needed.

5.5 CONCLUSIONS

The importance of studying edaphic factors that affect the development of the grapevine root system as part of terroir studies, is clear when considering the important role that soil conditions play in determining root growth and distribution and the relevant relationship between canopy structure and subterranean growth, as demonstrated in this study.