Open hydroponic systems in table grape production: A case study

by

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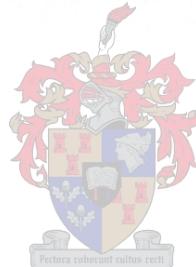
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DECLARATION

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

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SUMMARY

An open air hydroponic production system (OHS) is based on classic hydroponic principles, with the difference that it lacks climatological control because the plants are not produced in greenhouses and are cultivated in the outside environment. In these systems the plant is provided with all the essential nutrients through the irrigation system, which is scheduled according to accurate measurements of the available soil water, in three to seven pulses a day. The rationale is that, by delivering nutrients each day, the mixes can be representative of what the plant actually requires for that specific phenological stage.

The aim of this study was to monitor the usefulness and impact of OHS on table grape production within the framework of a case study. For this purpose, it was necessary that all factors involved in the development and growth of the plant should be studied and integrated in a multidisciplinary approach. Currently very limited information exists on basic guidelines for the effective implementation of these systems for table grape production, particularly with regard to local conditions. As a start, and to establish some guidelines and measurable parameters for the implementation of these systems, vegetative growth parameters were analysed within the framework of yield and fruit quality. The experiments were performed in a commercial vineyard in the Paarl region and the cultivars used were Dan ben Hannah (DBH) and Waltham Cross (WC). Relevant soil and climatic conditions, irrigation scheduling, fertiliser application, as well as cultivation practices, were taken into account. The soil maps provided information on the soil types identified in the blocks prior to the establishment of the two cultivars. The conventionally treated vines were irrigated and fertilised according to historical block data, and the OHS-treated vines according to programmes established by two different consultants.

The experimental layout included a comparison of conventional cultivation methods and vines that had been switched over from conventional methods to OHS in the middle of 2000. All measurements within the different treatments were done at specific measuring points laid out statistically. Ten phenological stages were chosen to monitor the various aspects throughout the season for both cultivars treated conventionally and hydroponically. All relevant climatic parameters were collected for this specific production unit. The growth, fertility and quality indicators of these cultivars under the mentioned cultivation practices are discussed and established through quantitative analysis

One of the aims, namely to show that established table grape vines could adapt from micro-irrigation to drip irrigation within two seasons in terms of root adaptation, was proven in this study. Initially the soil types were identified as Cartref, Clovelly and Glenrosa for both cultivars. The WC block contained an Avalon and the DBH a Westleigh soil type as well. The soil pits in all four treatments revealed the soil type to be a Tukulu form with differences in the clay content. Active roots developed underneath the drip lines for the OHS-treated cultivars, while the roots were still evenly

distributed over the entire soil profile for the conventionally treated vines. Also, both cultivars adapted to OHS in terms of yield and production within two seasons, especially WC, which produced a higher yield in the 2001/2002 season than in the previous four seasons.

DBH showed a strong vegetative reaction to OHS in terms of excessive vegetative growth, which had an indirect effect on fruit quality and bud fertility. A higher rate of bud mite infection in the OHS-treated vines also had a negative influence on bud fertility. The excessive vegetative growth was due to a rainy 2001/2002 growth season, in combination with the irrigation and fertiliser programmes. The irrigation and fertiliser programmes were changed from the 2000/2001 to the 2001/2002 season because of the change in consultants. As a result of this change, the OHS-treated vines were given very high nitrogen, phosphorus, potassium and micronutrient applications in the 2001/2002 season. The penetration of light in the canopy of the OHS-treated DBH was lower than in the conventionally treated DBH as a result of the above-mentioned factors, but the situation in Waltham Cross was the opposite. In the winter season of 2001, both OHS-treated cultivars were not fully adapted to the new system, as their pruning mass was lower than in the conventionally treated cultivars. No significant differences were determined for the winter cane starch content of both cultivars under conventional and OHS treatments.

Effective fertiliser uptake proved to be suboptimal, especially in the case of calcium. Fruit analyses showed a lower calcium content in the OHS-treated fruit, which led to a poor skin cell structure and higher *Botrytis* infection during cold storage. The OHS-treated cultivars showed more compact bunches, with an overall smaller rachis structure, which was another reason for the higher *Botrytis* infection during cold storage. However, the more compact rachis structure could not be explained on the basis of the elemental analyses. The OHS-treated DBH showed a more intense red berry colour, while the OHS-treated WC had a higher Fosscan Brix value. Both OHS-treated cultivars therefore ripened earlier than the conventional treatments.

One of the advantages of the use of OHS in table grape production shown in this study was the ability to manipulate the phenology of the grapevine to provide fully ripened grapes a few days earlier than the conventionally treated grapes. This kind of advantage could be used to manipulate the production of table grapes for a better market window.

Despite its limitations, this study concluded that the use of OHS for table grape production might be a useful tool for future production management, but that accurate management regarding irrigation and nutrient applications is a prerequisite. This will have to be developed systematically through experimentation to fully unlock the potential of the OHS management system for table grape production. This study provides a starting point for future research to elucidate these aspects and has clearly shown that even established vineyards can be switched to OHS in a relatively short period of time. It is envisaged that the advantages of this system, as long as the correct management protocols are in place, could have a positive effect on the production of high quality fruit for the international market.

OPSOMMING

'n Oop hidroponiese produksiestelsel (OHS) is gebaseer op klassieke hidroponiese beginsels, met die verskil dat OHS nie klimatologies beheer kan word nie. Die plante word nie in glashuise of tonnelsisteme verbou nie, maar wel onder buitelug toestande. Binne hierdie sisteme word die plante van alle noodsaaklike voedingstowwe deur die besproeiingstelsel voorsien. Hierdie voedingstowwe word in drie tot sewe pulse per dag volgens akkurate beskikbare grondwaterbepalings geskeduleer. Die rasionaal is dat, deur die daaglikse lewering van voedingstowwe, die mengsels verteenwoordigend is van die plant se behoefte vir 'n spesifieke fenologiese stadium.

Die doel van die studie was om die bruikbaarheid en impak van OHS op tafeldruifproduksie binne die raamwerk van 'n gevallestudie te monitor. Alle faktore wat by die groei en ontwikkeling van die plant betrokke is, moet in 'n multidissiplinêre benadering bestudeer en geïntegreer word. Daar is tans slegs beperkte inligting oor die basiese riglyne en effektiewe implementering van dié sisteme vir tafeldruifproduksie wat spesifiek is vir plaaslike toestande. As 'n beginpunt, en om sekere riglyne en meetbare parameters vir die implementering van die sisteme te vestig, is vegetatiewe parameters binne die raamwerk van opbrengs en vrugkwaliteit geanaliseer. Alle eksperimente is in kommersiële wingerdblokke in die Paarl-omgewing uitgevoer. Die kultivars wat vir die studie gebruik is, is Dan ben Hannah (DBH) en Waltham Cross (WC). Alle relevante grond- en klimaatstoestande, sowel as besproeiingskedulering, bemestingprogramme en verbouingspraktyke is vir die projek in ag geneem. Ou grondkaarte het inligting ten opsigte van die verskillende grondtipes wat voor die vestiging van die verskillende kultivars geïdentifiseer is, verskaf. Die wingerde, onder konvensionele behandeling, is volgens historiese blokdata besproei en bemes, terwyl die wingerde onder OHS volgens geskeduleerde programme wat vanaf konsultante verkry is, besproei en bemes is.

Die eksperimentele uitleg het 'n vergelyking van konvensionele verbouingsmetodes en wingerde wat in die middel van 2000 van konvensionele na OHS-verbouing oorgeskakel is, ingesluit. Alle metings en analises binne die verskillende behandelings het by spesifieke statistiesbepaalde punte plaasgevind. Tien fenologiese stadia is gekies om die verskillende aspekte vir beide kultivars onder konvensionele en OHS-behandeling gedurende die seisoen te monitor. Alle relevante klimaatsdata is vir die spesifieke produksie-eenheid aangevra. Alle groei-, vrugbaarheids- en kwaliteitsparameters van die kultivars onder die bogenoemde behandelingsmetodes is bespreek en gevolglik deur kwantitatiewe analises bepaal.

Een van die doelwitte, naamlik om uit te vind of reeds gevestigde ouer wingerde in terme van wortelaanpassing binne twee seisoene kan aanpas van mikrobesproeiing na drup OHS, is deur die studie bevestig. Aanvanklik was die grondtipes geidentifiseer as die vorme, Cartref, Clovelly en Glenrosa vir beide kultivars, met 'n Avalon vorm adisioneel by WC, en 'n Westleigh vorm by die DBH. Grondprofiele het egter getoon dat die grondtipes vir al vier behandelings 'n Tukulu vorm is met verskillende klei inhoude. Aktiewe wortels het vir die OHS-behandelde wingerde onder die druppers ontwikkel, terwyl die wortels in die konvensionele behandeling steeds eweredig oor die hele grondprofiel versprei was. Beide kultivars het ook in terme van opbrengs en produksie

binne twee seisoene ná die oorskakeling van die konvensionele behandeling na OHS aangepas. WC het in die 2001/2002 seisoen 'n hoër opbrengs gelewer as in die vorige vier seisoene.

Afgesien van die goeie aanpasbaarheid, het DBH 'n sterk vegetatiewe groeireaksie ten opsigte van die OHS-behandeling getoon, wat 'n indirekte effek op vrugkwaliteit en oogvrugbaarheid geopenbaar het. 'n Hoër mate van knopmiet infeksie in die OHS-behandelde stokke kon ook 'n negatiewe bydrae tot oogvrugbaarheid gemaak het. Die sterk vegetatiewe groei kon aan die hoër reënval gedurende die 2001/2002 groeiseisoen, tesame met die besproeiings- en bemestingsprogramme, toegeskryf word. Die besproeiings- en bemestingsprogramme is verander van die 2000/2001 seisoen na die 2001/2002 seisoen weens die aanstelling van 'n ander konsultant. As gevolg van hierdie verandering het die OHS-behandelde stokke baie hoë toedienings van stikstof, fosfaat, kalium en mikroelemente in die 2001/2002 seisoen ontvang. Sonligpenetrasie in die wingerdlower van die OHS-behandelde DBH was laer as in die konvensionele behandeling as gevolg van die bogenoemde faktore. Die situasie vir WC was egter die teenoorgestelde. Tydens die winterseisoen van 2001 was beide oorgeskakelde kultivars nie ten volle by die nuwe OHS-behandeling aangepas nie, soos gesien kan word in die laer lootmassas in vergelyking met die konvensionele kultivars. Geen beduidende verskil is vir die hoeveelheid stysel in die winterlote van beide kultivars onder konvensionele en OHS-behandeling verkry nie.

Effektiewe voedingstofopname was suboptimaal, veral betreffende kalsium. Vruganalises het 'n laer kalsiuminhoud in die OHS-behandelde druiwe getoon, wat aanleiding gegee het tot 'n swakker selstruktuur in die druiwedoppe en 'n hoër mate van Botrytis-infeksie gedurende koelopberging. Die OHS-behandelde kultivars het meer kompakte trosse getoon met kleiner trosraamwerke, wat ook aanleiding kon gegee het tot 'n hoër Botrytis-infeksie. Die kleiner trosraamwerke kon nie deur voedingstofanalises verklaar word nie. Die OHS-behandelde DBH het 'n hoër kleurintensiteit getoon, en die OHS-behandelde WC het 'n hoër suikerinhoud getoon ten opsigte van die konvensionele behandeling. Beide OHS-behandelde kultivars was dus vroeër ryp as die konvensionele behandelings.

Een van die voordele van OHS wat uit die studie voortspruit, is die vermoë om wingerdfenologie te manipuleer om ryper druiwe vroeër in die seisoen te verkry. Hierdie tipe voordeel kan aangewend word om druiwe vir 'n beter markvenster te produseer.

Hierdie studie, tesame met al sy beperkinge, kom tot die gevolgtrekking dat die gebruik van OHS vir tafeldruifproduksie 'n nuttige instrument vir toekomstige produksiebestuur is, maar dat die optimale bestuur van besproeiing en bemesting as kritiese faktore beskou moet word. Hierdie faktore sal sistematies deur intensiewe navorsing ontwikkel moet word om die volle potensiaal van OHS te ontsluit, spesifiek vir tafeldruifproduksie. Hierdie studie kan as 'n beginpunt gebruik word vir toekomstige navorsing vir meer toegeligte verklarings van die bogenoemde aspekte, veral met die voordeel dat reeds gevestigde wingerde maklik en vinnig by OHS kan aanpas. Die voordele van OHS kan 'n groot positiewe invloed op die produksie van hoër kwaliteit

tafeldruiwe vir die internasionale mark hê, mits die regte bestuursriglyne in plek is en toegepas word.

BIOGRAPHICAL SKETCH

Sonet van Zyl was born in Johannesburg on 23 November 1977. After matriculating at Brandwag High School in 1995, she enrolled at Stellenbosch University and obtained a BScAgric degree in Viticulture and Genetics (Plant Breeding). In 2001, Sonet enrolled for an MScAgric degree in Viticulture.

ACKNOWLEDGEMENTS

PREFACE

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

Chapter 1: **General Introduction and Project Aims**

Chapter 2: **Literature Review**
Integrated nutrient management to achieve optimal vine growth, development and fruit quality

Chapter 3: **Research Design**
Base description of two cultivars, Dan ben Hannah and Waltham Cross, studied under conventional and open air hydroponic systems

Chapter 4: **Research Results**
The influence of conventional and open air hydroponic systems on root distribution, taking the soil status into account

Chapter 5: **Research Results**
The influence of open air hydroponic systems on the vegetative parameters of Dan ben Hannah and Waltham Cross in comparison to conventional systems

Chapter 6: **Research Results**
The effective uptake of nutrients and its effect on the fruit quality of grapes cultivated under conventional and open air hydroponic systems

Chapter 7: **General Discussion and Conclusions**

CONTENTS

Chapter 1

GENERAL INTRODUCTION AND PROJECT AIMS

GENERAL INTRODUCTION AND PROJECT AIMS

1.1 INTRODUCTION

The table grape industry in South Africa is growing rapidly and is characterised by the production of high quality export fruit. Improved yields and quality remain high priority factors within the industry. Countries such as Chile and Australia are competing for the same marketing window as South Africa, and the sustainable production of excellent quality grapes is a prerequisite.

Optimal fruit quality in combination with a high yield can only come from an understanding of the plant's needs. A combination of factors might have a positive or negative influence on yield and quality. Climatic factors, such as rain, hail, wind, temperature and humidity, are some of the factors which cannot be controlled except for in a greenhouse environment.

Factors such as soil properties, irrigation scheduling, fertiliser programmes, pruning methods, canopy management, disease and pest management and many more are also contributing factors that determine yield and fruit quality. There are different types of management systems, such as different irrigation scheduling methods, different types of fertiliser programmes and different types of vineyard management practises. One management system that strives to optimise all the factors involved in crop production is the open air hydroponic system (OHS), which is a relatively new type of management system for fruit production in general and that has specific application in table grape production.

Using OHS for table grape production is advocated as being one way to establish better quality fruit, with a higher yield (Gurovich, 1994b), in a shorter period of time. These advantages have been proved by the hydroponic production of other crops, such as citrus (Pijl, 2001), plums (Southwick *et al.*, 1999) and various vegetable crops. However, vegetables such as tomatoes (Logendra & Janes, 1997) and lettuce (Buxton & Jia, 1997), as well as small fruits (Economakis & Krulj, 1999) and flowers (Sakamoto *et al.*, 1999) can also be produced in a greenhouse environment under classical hydroponics.

Classical hydroponics is based on a soilless culture, whereby the plant is grown in a water medium enriched with all the basic nutrients. These systems are typically open or closed circulation systems used in greenhouses, where climatological factors are strictly controlled and kept optimum for the growth of the specific plant. The well-established advantages of this type of cultivation are the more efficient use of fertilisers, a reduction of water consumption (Gurovich, 1994b), increased yields, shorter growth cycles, production throughout the year, improved health of the plants as well as superior quality of the products (Benoit & Ceustermans, 1995).

Open air hydroponic systems are based on the same principle; the plants are not kept in greenhouses, however, but are established in the soil outside. The plant is provided with all the essential nutrients through the irrigation system in several pulses a day; the scheduling of these pulses is based on accurate measurements of available soil water. The rationale is that, by delivering nutrients each day, the nutrient mixes can be representative of what the plant actually requires for its specific stage of growth. The nutrient mixes that are used are therefore determined according to the phenological stage of the plant.

An OHS system consists of a pipe network, water pumps, drip irrigation lines, tanks for the nutrient solutions and a computer system. The computer captures and integrates weather data, irrigation data and fertiliser information. In table grape production, these systems are not yet widespread, but more and more producers are showing an interest and/or are starting to invest in them. At this point, basic guidelines as to the usefulness and the effective implementation of these systems for table grape production under local conditions are lacking. However, research published in other countries could provide the South African table grape industry with basic guidelines in terms of irrigation scheduling and fertiliser programs (Gurovich *et al.*, 1994a). There are many plant factors that have to be studied in reaction to these systems before a clear view of their applicability will emerge. This involves factors such as root growth and development, effective uptake of water and nutrients, shoot growth and fertility, fruit quality and physiological processes, such as respiration, transpiration and photosynthesis. Ultimately, a multidisciplinary approach is needed to address certain issues of plant physiology and plant production with reference to OHS.

1.2 SPECIFIC PROJECT AIMS

The aims of this study were to monitor the usefulness and impact of OHS on table grape production within the framework of a case study. The influence of OHS, specifically on vegetative and reproductive vine growth, was monitored through the establishment of measurable parameters.

These aims were used to determine the effect of OHS on yield and fruit quality, as well as the assessment of system efficiency, with conventional micro-irrigation as a control measure.

The following approaches were followed in order to achieve these goals:

1. The collection of all relevant background information on the specific vineyard blocks chosen for the project;
2. The collection of phenological data on the different cultivars and treatments to develop phenological data maps;

3. The determination of the influence of OHS on the soil status, root development and root distribution, and the influence of the soil status as such on the roots;

4. The establishment of measurable parameters to determine the influence of OHS on vegetative growth;

5. The determination of the adaptation ability of grapevines from conventional irrigation and fertiliser programmes to OHS programmes; and

6. The determination of the influence of nutrient uptake on fruit quality within the framework of conventional and OHS fertiliser programmes.

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Chapter 2

LITERATURE REVIEW

Integrated nutrient management to achieve optimal vine growth, development and fruit quality

LITERATURE REVIEW

2.1 INTRODUCTION

There are growing concerns that agriculture will not be able to provide in the food needs of the world population by the year 2020. Another problem is the long-term sustainability of agriculture. Both the over- and underapplication of fertilisers and the poor management of resources have damaged the environment. Agriculture is a soil-based industry that extracts nutrients from the soil and will rely on effective and efficient approaches to maintain and increase crop productivity in the future (Gruhn *et al.*, 2000).

Grapevines can adapt themselves to a wide range of soil fertility. They are less exacting than many other horticultural crops in the quantitative level of soil nutrients required (Winkler *et al.*, 1974). Grapes are typically used in the wine, table grape and dried fruit industries. International competition in these industries provides a driving force to strive for increased yields while maintaining or improving product quality.

The overall strategy for increasing grapevine yields and sustaining them at a high level must include an integrated approach to the management of soil and applied nutrients, along with other complementary measures (Gruhn *et al.*, 2000). The perspective of the crops should also be taken into consideration, because over- or underapplication of nutrients may affect the yield and the quality of the grapevine product.

Throughout this chapter, it will become clear that grapevine and soil nutritional diagnosis is still an inexact science, despite decades of research and practice. In short, the sufficiency of any nutrient depends on the relative supply of all the other nutrients, and many environmental factors, such as water, sunlight and temperature, also play a role. In addition, particular nutrients interact both chemically and physiologically with respect to their uptake, transport and function within plant tissues (Mills & Jones, 1996).

To understand the concept of nutritional status in the grapevine, this chapter will give an overview of the 16 essential elements necessary for plant growth, and of their functions in the plant. The influence of soil on nutrient uptake will be discussed, as well as three techniques to determine grapevine nutritional status.

As a possible solution for the above-mentioned concerns, nutrient application for grapevines will be integrated with irrigation management practices. To integrate these practices, we need to understand the phenological cycle of the grapevine, as well as the nutrient uptake patterns for certain nutrients throughout the season.

This chapter will clearly state that virtually everything in a plant's environment affects plant growth, that plant growth affects tissue nutrient concentrations, that each nutrient affects every other nutrient, and that everything in the plant's environment affects everything else; it will be easy to see why it is difficult to decide how much of a nutrient is enough (Mills & Jones, 1996).

2.2 ESSENTIAL GRAPEVINE NUTRIENTS

During the past 10 years there has been increased understanding of the nutritional needs of grapevines. This has been stimulated to a great extent by the expansion of the industry into new areas with a wider range of soils than had previously been used. Individual cases of nutritional deficiencies in the South African grape growing areas have prompted research into specific fertiliser requirements (Robinson, 1999).

Although chemical analyses of plant tissues reveal that most of the elements are used in one plant species or another, only 16 elements are known to be absolutely essential for the normal vegetative and reproductive growth of green plants. These elements are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulphur (S), iron (Fe), calcium (Ca), magnesium (Mg), boron (B), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo) and chlorine (Cl) (Winkler et al., 1974). Elements such as aluminium (Al), sodium (Na), silicon (Si), barium (Ba), strontium (Sr), chromium (Cr), nickel (Ni), cadmium (Cd), mercury (Hg), lead (Pb) and fluorine (F) are not essential for plants.

An element must meet three basic criteria to be considered essential: i) it must be necessary for complete, normal plant development through a full life cycle; ii) the element itself must be necessary, with no effective substitution possible; and iii) it must act within the plant (Mauseth, 1995).

The essential elements are divided into two categories, namely macronutrients and micronutrients. The only distinction in classification between the macronutrients and micronutrients is their concentration requirement for sufficiency. Concentration requirements for the macronutrients are 10 to 5000 times greater than those for most micronutrients (Mills & Jones, 1996).

2.2.1 THE ESSENTIAL NUTRIENTS

Carbon, H and O are derived from air and water. They are combined in photosynthesis, a process exclusive to green plants (Mills & Jones, 1996). They are essential parts of the protoplasm and cell walls, and compose the principal energy materials, namely carbohydrates, fats and oils. Along with N and some other elements, they are components of all proteins. Hydrogen and O constitute water, the latter functioning as a building material for other compounds, as a transport medium, and in numerous other ways (Winkler et al., 1974). Tables 2.1 and 2.2 summarise the functions and movement of the essential macro- and micronutrients respectively.

Table 2.1: The functions of the essential macronutrients in grapevines.

Element	Function
Nitrogen (N)	- Primary component of proteins (Robinson, 1999) - Component of energy transfer systems (Robinson, 1999) and cytokinin synthesis (Stassen *et al.*, 1999) - Component of chlorophyll (Robinson, 1999) - Inflorescence primordium formation (Srinivasan & Mullins, 1981)
Phosphorus (P)	- Component of the fatty portion of cell membranes – takes part in the fixation of carbon dioxide and the metabolism of sugars (Robinson, 1999) - Energy storage and transfer (Stassen *et al.*, 1999) - Vital component of the genetic material (Robinson, 1999) - Initiation and profile development of the root laterals (Stassen *et al.*, 1999) - Promotes bud fruitfulness (Srinivasan & Mullins, 1981)
Potassium (K)	- Vital role in the internal vacuole, providing electrical balance for organic and inorganic anions (Robinson, 1999) - Associated with grape composition (Jackson & Lombard, 1993) and fruit development (Stassen *et al.*, 1999) - Indirectly maintains the structure of the non-woody parts through an effect on turgor of cells (Robinson, 1999) - Enzyme activation (Srinivasan & Mullins, 1981) - Translocation of sugars and starch synthesis (Stassen *et al.*, 1999)
Magnesium (Mg)	- Component of chlorophyll (Robinson, 1999) - Enzyme activator (Stassen *et al.*, 1999) - Takes part in nucleic acid synthesis (Stassen *et al.*, 1999) - Electrostatic function (Mills & Jones, 1996)
Calcium (Ca)	- Structure and permeability of cell membranes (Stassen *et al.*, 1999) - Stabilises the mitotic spindle apparatus during cell division (Mills & Jones, 1996)
Sulphur (S)	- Synthesis of S-containing amino acids (Stassen *et al.*, 1999) - Constituent of Coenzyme A and the vitamins biotin and thiamine (Mills & Jones, 1996)

Table 2.2: The functions of the essential micronutrients in grapevines.

Element	Function
Boron (B)	- Involved in the internal regulation of growth by plant hormones (Robinson, 1999) - Development of apical growing meristems (Stassen *et al.*, 1999) - Plays a structural role in the synthesis of pectin and lignin for cell wall formation (Napier, [S.a.]) - Plays a primary role in the function of membranes (Napier, [S.a.]) - Translocation of sugars (Stassen *et al.*, 1999)
Chlorine (Cl)	- Required for the splitting of water during photosynthesis (Mills & Jones, 1996) - Functions in the transfer of electrons (Mills & Jones, 1996)
Copper (Cu)	- Component of the enzymes of oxidation (Robinson, 1999) - Synthesis of chlorophyll (Stassen *et al.*, 1999) - Influences metabolic reactions (Stassen *et al.*, 1999)
Iron (Fe)	- Involved in both chlorophyll formation and energy trapping (Robinson, 1999), thus enhances photosynthesis rate (Bavaresco *et al.*, 1999) - Indirect roles attributed to Fe include chlorophyll and protein synthesis, root tip meristem growth, and control of alanine synthesis (Robinson, 1999)
Manganese (Mn)	- Component of catalysts involved in the synthesis of chlorophyll and in nitrogen metabolism (Robinson, 1999) - Maintenance of the chloroplast membrane structure (Stassen *et al.*, 1999) - Involved in pollen germination and growth of the pollen tube (Mills & Jones, 1996)
Molybdenum (Mo)	- Involved in N metabolism (Robinson, 1999) - Vitamin C synthesis (Stassen *et al.*, 1999) - Enhances N, K and Ca uptake (Stassen *et al.*, 1999)
Zinc (Zn)	- Acts as a catalyst in oxidation processes (Stassen *et al.*, 1999) - Vital for transformation of carbohydrates (Stassen *et al.*, 1999) - Acts as a catalyst in the formation of triptophane which is a precursor of auxin (Stassen *et al.*, 1999) - Important for photosynthesis (Mills & Jones, 1996) - Stabilises cytoplasmic ribosomes (Mills & Jones, 1996)

2.2.2 THE INTERACTION BETWEEN ESSENTIAL NUTRIENTS

It is apparent that there are relationships between nutrients, due to their accumulation and dilution in plant tissues, which are caused by growth limitation and stimulation. There are also physiological relationships between plant nutrients that affect their relative concentrations in these plant tissues. Some pairs of nutrients are known to have either antagonistic or synergistic relationships regarding their uptake by plant roots. It is believed that the positively charged nutrients, such as K and ammonium, compete for the same uptake sites on the root membranes. An abundance of one of these nutrients may therefore induce or exacerbate a relative insufficiency of another in the tissues of the plant (Mills & Jones, 1996).

Mills & Jones (1996) refer to the different elemental interactions of nutrients, which are summarised in Table 2.3.

Table 2.3: A summary of the different elemental interactions (Mills & Jones, 1996).

	N	P	K	Mg	Ca	S	B	Cl	Cu	Fe	Mn	Mo	Zn
N		Ammonium increases availability	Close relationship; example: N sensitivity to diseases, K resistance	Mg uptake affected by ammonium	Ca uptake affected by ammonium presence	Addition of S increases N content of plant		Cl influences nitrate uptake	High N levels increase requirement for Cu	N accentuates Fe deficiency	High ammonium increases Mn uptake		
P	Nitrate depresses P uptake				Acidic soil: P favours Ca uptake. Alkaline soil: Ca availability reduced		Low B affects P incorporation into nucleic acids		In citrus: heavy P fertilisers induce Cu deficiency	High P levels decrease Fe solubility in plant	P increases Mn uptake	Mo uptake enhances by P	Excessive P interferes with Zn uptake, translocation, metabolism
K	Ammonium depresses K uptake			Mg uptake mostly affected by K			High K decreases B content in plant		K foliar sprays reduce levels of foliar Cu (pecans)	K increases mobility, solubility of Fe			
Mg	Ammonium depresses Mg uptake	Mg activates reactions involving P	K has depressing effect on Mg								Mg depresses Mn uptake through competition		
Ca	Ammonium depresses Ca uptake	Increase in Ca increases P uptake	K has depressing effect on Ca	Mg uptake affected by Ca			Must have good B/Ca balance. Ca added to soil helps decrease incidence of B toxicity				>pH reduces Mn solubility and uptake deficiency. <pH toxicity may occur		
S	Nitrate depresses S uptake											Mo uptake inhibited by S	

	N	P	K	Mg	Ca	S	B	Cl	Cu	Fe	Mn	Mo	Zn
B					B deficiency after excessive liming ->pH	S antagonistic to B				B competes with Fe for uptake			
Cl	Cl competes with nitrate for uptake									Cl may enhance Fe uptake			
Cu										Cu competes with Fe for uptake			
Fe		Interferes with absorption, translocation, assimilation of P			Fe deficiency after excessive liming ->pH	S antagonistic to Fe			Citrus and lettuce: high Cu induces Fe chlorosis		Fe-Mn antagonism involves competition for absorption		Excessive Zn depresses Fe uptake, can result in deficiency
Mn				Mg depresses Mn uptake	Mn deficiency after excessive liming ->pH				Cu may stimulate Mn uptake	Mn competes with Fe for uptake			

	N	P	K	Mg	Ca	S	B	Cl	Cu	Fe	Mn	Mo	Zn
Mo	Mo deficiency reduces rate of nitrate reduction					S antagonistic to Mo			Cu interferes with Mo role in reduction of nitrate				
Zn		High P levels induce Zn deficiency and vice versa			Zn deficiency after excessive liming – >pH				Cu inhibits Zn uptake and vice versa				
Al		Increased Al induces P deficiency		Acidic soil: Al competes with Mg for root uptake	Acidic soil: Al toxicity – competition between Al and Ca for binding sites				Al adversely affects Cu uptake				
Na			Ionic size the same, Na may replace K; but K essential, Na not	Mg uptake affected by Na									
F						S synergistic with F							

2.3 THE INFLUENCE OF SOIL PROPERTIES ON GRAPEVINE NUTRITION

Knowledge of the soils within a vineyard and of their general and local properties often provides enough information to allow a prediction of nutrient status (Robinson, 1999).

The supply of mineral nutrients available in the soil will depend upon several factors, such as the concentration and balance of mineral elements, the pH (acidity), the rooting depth, the method of vineyard floor management, and the extent of the correction of problems through the provision of soil drainage, addition of organic matter, and addition of fertiliser. Factors such as soil microorganisms, soil temperature, plant condition and competition from other plants play a more indirect role in nutrient uptake.

The wealth of information available on soil properties can be used to develop good fertiliser programmes for many areas and has been the basis for the district recommendations that have evolved in all grape-growing areas (Robinson, 1999). Soil properties can be divided into physical and chemical properties. These characteristics of the soil interact closely, and both are reflected in the morphological or descriptive features of the soil (Northcote, 2000). Only the most important soil properties will be discussed in the following section.

2.3.1 PHYSICAL PROPERTIES

The physical properties of a soil affect tillage operations, the entry and passage of water through the soil, aeration, the growth of plant roots and the tendency of the soil to erode (Northcote, 2000). According to Northcote (2000), Pencov showed in 1974 that grapevines respond to good physical soil conditions by developing vigorous root systems that permeate the soil evenly and deeply.

2.3.1.1 Soil moisture

The most important characteristic of a soil for growing grapevines is its capacity to supply moisture over the longest possible period, while at the same time remaining sufficiently well drained to avoid periodic oxygen deficiency arising from waterlogging of the root zone (Northcote, 2000).

Most nutrients are taken up via the soil solution, therefore soil water is needed to dissolve them. Soil moisture also affects the conversion of unavailable nutrients into available nutrients. The soil composition has an effect on soil moisture; soils with a high clay content will absorb more nutrients, whereas fertiliser will leach faster through sandy soil (Northcote, 2000).

Soil moisture and transpiration affect the flow and accumulation of some mineral elements in the grapevine berry, in particular N, P, K, Ca, and Fe (Boselli et al., 1998), and K availability (Bates et al., 2002), as well as NO_3 and Cl availability is dependent on soil moisture (Jones, 2002). There is also a positive correlation between soil water status and the flow of Ca towards the berries. In other

words, when the substrate has a favourable water content, the xylem flow of Ca is efficiently maintained or the phloem flow efficiency is improved in the ripe berry. Thus, considering the importance of Ca in plants and its relation to many physiological diseases, it would appear that the flow of Ca towards the berries is related to the soil-plant-air water flow continuum (Boselli *et al.*, 1998).

Sand does not retain nutrients well against leaching by downward-percolating water (Robinson, 1999), because sandy soils have many voids and little clay and the permeability consequently remains high even when the soil is saturated (Northcote, 2000). Deficiencies of both macro- and micronutrients can and do occur in these soils (Robinson, 1999).

Impeding layers obstruct both root growth and water movement and may cause waterlogging. Waterlogging is a serious problem, as grapevines prefer soils that are well drained. Where stagnant soil water occurs, the roots of grapevines are weakened, causing a loss of vigour and eventual loss of the vine. Unless an impeding layer occurs at a great depth, both the layer itself, and its effect on the supply of water and oxygen, will affect root growth. Proper drainage must be installed or there should be a natural draining topography if vines are grown on soils with impeding layers (Northcote, 2000).

2.3.1.2 Soil depth

In a vineyard, grapevines established at a given spacing have a fixed area of soil available to each vine. However, the growth of the vine above the soil must be in balance with the root growth in the soil. The depth of the soil then determines the volume of soil available to each grapevine for root growth (Northcote, 2000).

In a shallow soil with limited potential rooting depth, heavy rain can quickly raise the root zone to beyond its moisture storage capacity. Such soils can readily alternate between waterlogging and drought after only average fluctuations in rainfall. In contrast, well-drained, deep soils permit deep and more dispersed rooting, which buffers the vine against most fluctuations in moisture supply, provided that the soil has a reasonable water-holding capacity per unit volume (Gladstones, 1992).

The importance of soil depth, particularly in providing an adequate reservoir of water while also supplying adequate oxygen for the growth of roots, is the best reason for studying soils and their effects on the growth of grapevines (Northcote, 2000). The best vineyards are characterised by their ability to produce good grapes, even in poor vintages, whereas the effects of poor vintage years are magnified on marginal sites (Gladstones, 1992).

2.3.2 CHEMICAL PROPERTIES

The chemical properties of soil not only affect the nutrition of plants, but also the physical soil conditions and thus the moisture regimes. Since grapevines can grow in a wide range of soils, they are able to obtain adequate moisture and nutrition under a variety of chemical soil conditions (Northcote, 2000).

2.3.2.1 Soil pH

Soil pH is controlled by the cation exchange capacity. The amount of exchangeable cations per unit mass of soil is often measured as milli-equivalents per 100 g of soil. It has a significant influence on the availability of nutrients for uptake by plants. A simple pH test gives good clues about the composition of nutrients in the soil. A pH value greater than eight indicates the presence of Ca carbonate, and a pH value greater than nine indicates the presence of Na bicarbonates. A value higher than nine also indicates that the soil may be saline and sodic, although not all sodic soils have a high pH. Soil pH can be altered by the addition of fertilisers (Northcote, 2000).

Acidic soil conditions, where the pH is less than 5.5, may render P unavailable, whereas micronutrients are usually readily available under these conditions. Also, in some cases Al and Mn may be available to the plants in toxic quantities (Robinson, 1999). Aluminium solubility increases as the soil pH decreases from 5 to 3.5. The micronutrient Cu also becomes more available at a low pH. As the soil pH approaches 4.5, exchangeable Al ions disappear, and above pH 6 there are few Al ions that are potentially available. Below a soil pH of 4.5, both root and shoot growth decrease. Excessive H ions in the soil solution can also have an effect on root cell membrane potential. At low pH levels, Ca and Mg become unavailable and Mn can concentrate at toxic levels. Phosphorus becomes insoluble at a low pH because high levels of free Al precipitate P (Bates *et al.*, 2002).

Alkaline soils, in which the pH is greater than 8.0, may render P insoluble and convert most micronutrients to unavailable forms. If free lime is present, particularly if it is finely divided, iron deficiency may be induced (Robinson, 1999) due to Fe precipitation from the soil solution (Bates *et al.*, 2002). At high pH values, Fe, Cu, Zn, B and Mn become less available, as shown in Figure 2.1 (Robinson, 1999). Iron solubility depends on pH, the redox state and the composition of the soil, which means that, in well-aerated and alkaline conditions, the availability of Fe for plant uptake is extremely low (Mengel & Geurtzen, 1986).

2.3.2.2 Soluble salts

A high concentration of soluble salts in the soil can limit plant growth, or even kill a crop, by creating an osmotic potential so high that plants have difficulty in obtaining water and nutrients from the soil solution (Northcote, 2000). The effects will vary with the substrate, the composition of the salts, the plant species and the particular growth stage (Mills & Jones, 1996).

Sodium chloride (NaCl) constitutes up to two-thirds or more of the soluble salts, while bicarbonate, sulphate and other salts make up the rest. Salinity becomes a problem when surface soils have 0.15% w/w or more of total soluble salts, or when sub-soils contain 0.30% w/w or more salts. Soils with total soluble salts contents between these levels must be irrigated with care. Poor irrigation practices may cause a water table to develop in the soil, which can concentrate much of this salt at the top of the water table zone, causing severe salinity (Northcote, 2000).

Soils with a considerable clay content, such as clay and silt loam soils, can undergo significant physical changes in the presence of salts composed of high concentrations of Na, leading to a reduction of soil porosity (Mills & Jones, 1996).
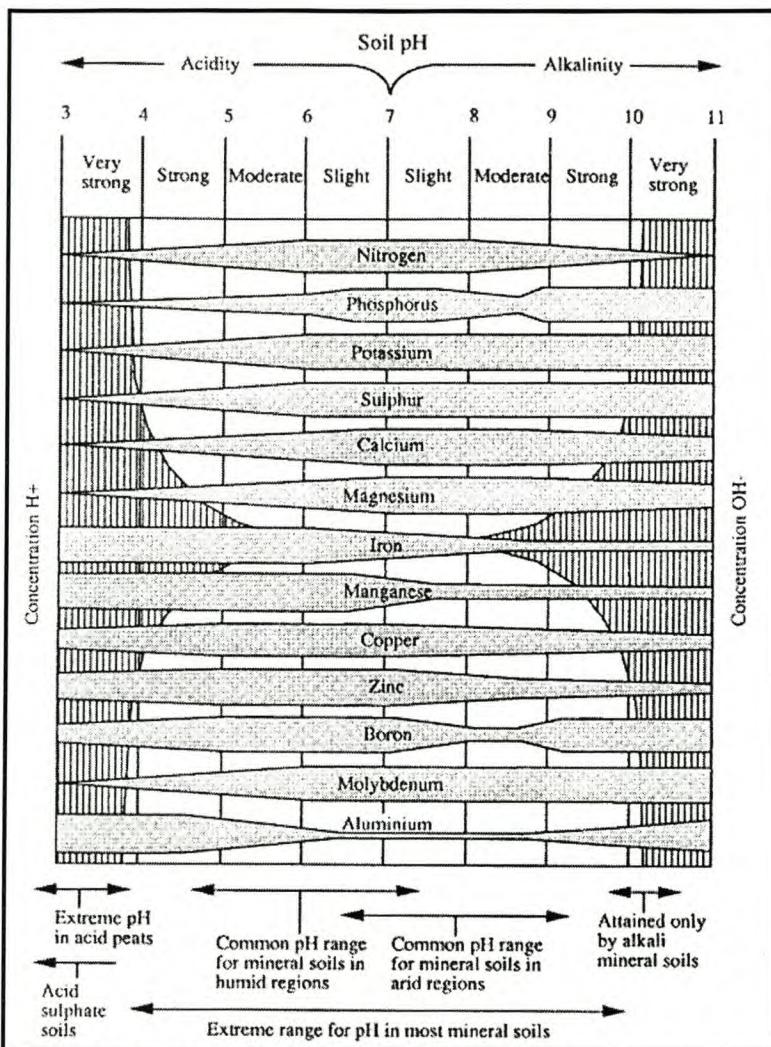
Figure 2.1: Effect of soil pH on availability of minerals. The width of each bar at any particular pH value shows relative potential availability (Diagram by A.M. Alston in Robinson, 1999).

2.4 DETERMINATION OF GRAPEVINE NUTRIENT STATUS

Maintaining good vine health is critical if a grower wishes to optimise vine growth, yields, fruit quality and winter hardiness. Although there are many factors that contribute to overall vine health, proper nutrition is certainly a key factor in achieving optimal vine performance (Christensen, 1995).

All the essential nutrients are required by plants in balanced proportions. Deviation from this may result in nutritional disorders. The early detection of nutritional deficiency stress is important. Stress might extend to the entire plant and lead to a loss in yield if it is not eliminated early enough. Continuous shortage of a nutrient or nutrients may cause plant death. When two or more elements are deficient simultaneously, the

composite picture of symptoms may resemble no single known deficiency (Bennett, 1993), making the identification of nutrient limitations difficult.

Mineral deficiency symptoms are sometimes confused with other complex field events, such as damage caused by insects or pests, fungal infections, viral infections, herbicides and even climatic factors (Winkler *et al.*, 1974).

There are a number of quite diverse approaches to the matter of deciding if grapevines in any given situation need particular fertilisers. The methods range from careful observation, through field experimentation, to chemical analysis of either the grape tissue or the soil. Several methods are usually employed together (Robinson, 1999) for optimal results.

2.4.1 DEFICIENCY AND TOXICITY SYMPTOMS

Nutritional disorders in grapevines are manifested by changes in the shape, colour, chemical composition, performance and attainable age of individual organs of the vine. The visible symptoms provide clues about their cause, but the appearance of the whole vine and of the vineyard may also aid in the diagnosis (Pearson & Goheen, 1994). However, visual symptoms on the various vine organs are usually not enough to make an accurate diagnosis. Soil, petiole and leaf blade analyses are used to confirm a nutrient imbalance.

An important diagnostic aspect is whether the symptoms appear on young leaves or older leaves. This is related to the mobility of the essential element. Elements such as B, Ca and Fe are relatively immobile, meaning that once they have been incorporated into plant tissues, they remain there. These elements do not return to the phloem and cannot be moved to younger parts of the plant. Thus, when a plant suffers a deficiency in one of these elements, the newly formed tissues are affected (Mauseth, 1995).

The elements Cl, Mg, N, P, K and S are mobile elements and can be translocated to younger tissue, even after they have been incorporated into a tissue. When one of these elements is deficient, the plant will sacrifice the older leaves (Mauseth, 1995) in favour of the new growth.

Two common symptoms in vegetative tissues are chlorosis and necrosis. Chlorosis is when leaves lack chlorophyll, tend to be yellowish and are often brittle and papery. Necrosis is the death of tissues and typically occurs in patches (Mauseth, 1995).

By knowing the symptoms of deficiency or toxicity and observing the health of vines closely, it is possible to make decisions regarding the use of many nutrients, particularly Zn, Mn, B and Fe (Robinson, 1999). Tables 2.4 and 2.5 provide a concise overview of the most important visual nutrient deficiency and toxic symptoms on grapevines.

Deficiency symptoms of the macronutrients P, K and Mg on grapevine leaves are shown in Figures 2.2 to 2.8. Toxic and deficient symptoms of the micronutrients B, Fe,

Mn and Zn occurring on grapevine leaves, shoots and bunches are shown in Figures 2.9 to 2.19.

Table 2.4: Most important visual symptoms of macronutrient deficiencies and toxicities.

Element	Organ	Deficiency symptoms	Toxicity symptoms
N	Leaves	Yellowing of older leaves (Call, 1998); Leaves are small and older leaves often fall prematurely; necrosis occurs at very severe stages of deficiency (Mills & Jones, 1996)	Blades become thick, deep green and cupped (Pearson & Goheen, 1994)
	Petioles	Become pink or red (Pearson & Goheen, 1994)	
	Roots	Growth is reduced and branching is restricted (Mills & Jones, 1996)	
	Shoots	Become pink or red, and growth is reduced (Pearson & Goheen, 1994)	Internodes excessively long (Pearson & Goheen, 1994)
	Fruit	Cluster stems become pink or red and berries may be small (Pearson & Goheen, 1994); Yield and quality significantly reduced (Mills & Jones, 1996)	Poor fruit set (Mills & Jones, 1996), bud fertility (Robinson, 1999), and excessive fruit drop (Stassen et al., 1999)
	Whole plant	Often light green (Call, 1998), grows slowly, is weak and stunted (Mills & Jones, 1996)	Increases overall growth (Pearson & Goheen, 1994)
P	Leaves	Older leaves dark green or reddish-purple (Call, 1998); Leaves smaller, leaf margins may turn down without rolling (Pearson & Goheen, 1994); Basal leaves may turn yellow and fall before flowering time (Robinson, 1999)	
	Roots	Poor root growth (Stassen et al., 1999)	Toxic to roots (Stassen et al., 1999)
	Shoots	Growth reduced (Pearson & Goheen, 1994; Robinson, 1999) Reduced lateral bud break (Call, 1998)	
	Fruit	Low production of fruits, seeds and flowers (Mills & Jones, 1996); Fruit are small (Stassen et al., 1999)	
	Whole plant	Retarded growth (Mills & Jones, 1996)	Growth depressed because of decreased uptake and translocation of Zn, Fe and Cu (Mills & Jones, 1996)
K	Leaves	Older leaves scorched, with interveinal chlorosis beginning at base, scorching inward from margins (Call, 1998); Leaves light in colour in early season, and blades of older leaves become violet brown later in season, especially near clusters (Pearson & Goheen, 1994); Premature leaf fall (Peacock & Christensen, 1996; Robinson, 1999)	

	Fruit	Fewer, smaller tight clusters with unevenly coloured small berries. In Sultana the lower portion of the bunch may collapse by midsummer, resulting in raisined, immature berries by harvest (Peacock & Christensen, 1996); Shelf life reduced for table grapes (Mills & Jones, 1996)	
	Whole plant	Reduced vine growth (Peacock & Christensen, 1996); Deficient plants easily lodge and are sensitive to disease (Mills & Jones, 1996)	Can cause salt burn (Rosen, 1998)
Ca	Leaves	New leaves distorted or irregularly shaped (Call, 1998);	
	Roots	Root tips die and growth is slow (Rosen, 1998)	
	Shoots	Dark brown pimples (1 mm) may develop on the primary bark of internodes (Pearson & Goheen, 1994)	
	Fruit	Clusters dry up starting from the tip (Pearson & Goheen, 1994)	
Mg	Leaves	Early season, leaf necrosis dominates (Pearson & Goheen, 1994); Older leaves turn yellow at edge, leaving a green arrowhead shape in the centre (Call, 1998); Leaves become stiff and brittle, veins become twisted (Mills & Jones, 1996)	
	Roots		Prevents Ca uptake (Stassen et al., 1999)
	Fruit	Premature fruit drop (Kessel, 2001)	
S	Leaves	Younger leaves turn yellow first (Call, 1998), and become red or purple later (Mills & Jones, 1996)	Water-soaked areas on leaves, which will develop into well-defined dry white necrotic spots on underside of leaves (Mills & Jones, 1996)
	Roots	Longer than normal (Mills & Jones, 1996)	
	Stems	Stunted, chlorotic growth with shorter and thinner stems that become woody (Mills & Jones, 1996)	
	Fruit	Fruits appear light green and lack succulence, and fruit set is reduced (Mills & Jones, 1996)	
	Whole plant	Retarded plant growth (Stassen et al., 1999)	

Figure 2.2: Leaf chlorosis on mature grapevine leaves caused by P deficiency (Mauseth, 1995).
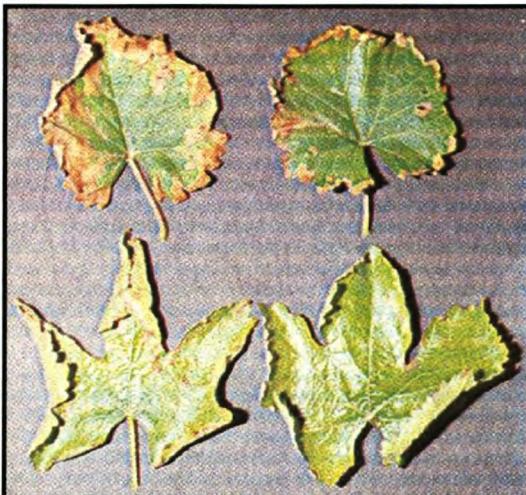
Figure 2.3: Scorching and curling of grapevine leaves caused by K deficiency (Saayman, 1981).
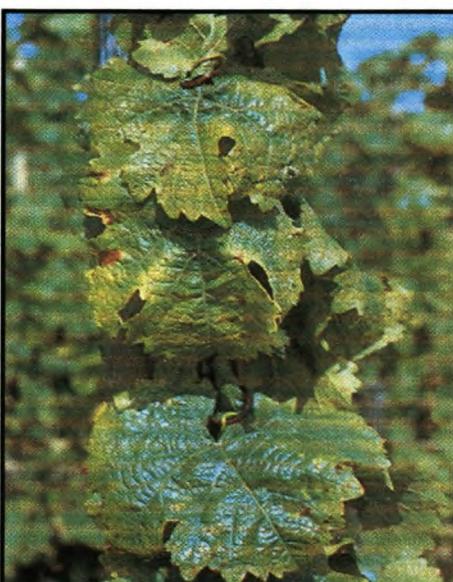
Figure 2.4: Spring symptoms of K deficiency on grapevine (Pearson & Goheen, 1994).
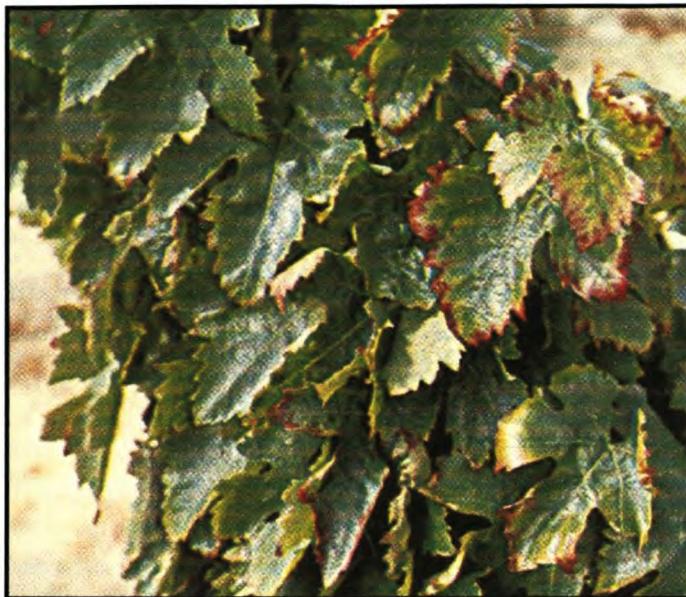
Figure 2.5: Advanced spring symptoms of K deficiency on grapevine (Saayman, 1981).

Figure 2.6: Black leaf symptoms of K deficiency in late summer on grapevine leaves that receive direct sunlight (Pearson & Goheen, 1994).

Figure 2.7: Mild Mg deficiency on table grape leaves (Robinson, 1999).

Figure 2.8: Severe Mg deficiency on leaves of a white wine grape cultivar (Saayman, 1981).

Table 2.5: Most important visual symptoms of micronutrient deficiencies and toxicities.

Element	Organ	Deficiency symptoms	Toxicity symptoms
B	Leaves	Early season: Faded yellow foliage (Rahn, 1998); Leaves thicker and darker in colour, with misshapen, wrinkled young leaves (Mills & Jones, 1996)	Younger leaves severely malformed; Necrosis develops on the tips of serrations of older leaves and progresses from margin to interveinal areas (Pearson & Goheen, 1994); Leaves drop prematurely (Mills & Jones, 1996)
	Petioles	Short, thick petioles, sometimes showing longitudinal lesions or necrotic caverns (Pearson & Goheen, 1994)	
	Tendrils	Dark knotty bulges form on tendrils near shoot tip and become necrotic (Pearson & Goheen, 1994)	
	Roots	Remain short, thickened, and swell into knots that break open longitudinally (Pearson & Goheen, 1994); Slimy roots with necrotic tips (Mills & Jones, 1996)	
	Shoots	Terminal buds die, witches' broom form (Call 1998); Pith becomes necrotic (Pearson & Goheen, 1994)	Growth of main shoot tips decrease in favour of lateral shoots (Pearson & Goheen, 1994)
	Fruit	Early season: burnt flower clusters (Rahn, 1998); Reduction in fruit set (Stassen et al., 1999) and small seedless berries develop (Pearson & Goheen, 1994); Berries misshapen and fruit quality is poor (Mills & Jones, 1996)	Disturbs pollen germination (Stassen et al., 1999)
	Whole plant	Early season: Deformed growth (Rahn, 1998)	
Cl	Leaves	Become wilted and bronze in appearance, later chlorotic (Call, 1998)	Marginal scorching of older leaves (Rosen, 1998); Leaves fall prematurely (Mills & Jones, 1992)
	Whole plant		Can cause salt burn (Rosen, 1998)

		Leaves	Leaves dark green (Call, 1998) and small (Robinson, 1999)	
Cu		Roots		Causes stunted root systems (Rosen, 1998), with little lateral root formation (Mills & Jones, 1996)
		Shoots	Short canes with shortened internodes (Robinson, 1999); Lateral buds may be distorted (Mills & Jones, 1996)	
		Fruit	Flowering and fruiting affected or absent, since pollen and ovaries are sensitive to deficiency (Mills & Jones, 1996)	
		Whole plant	Stunted growth (Call, 1998)	Stunted growth (Stassen *et al.*, 1999)
Fe		Leaves	Yellowing between veins of young leaves (Call, 1998); Whole leaf becomes pale yellow in severe cases (Kessel, 2001); Leaves may dry and fall (Pearson & Goheen, 1994)	Bronzing of leaves, followed by the appearance of tiny brown spots (Mills & Jones, 1996)
		Roots		Affected in flooded soils (Call, 1998)
		Shoots	Lateral shoot growth reduced (Saayman, 1981)	
		Fruit	Set is reduced (Pearson & Goheen, 1994)	
		Whole plant	Often only one side of vine affected (Kessel, 2001)	
Mn		Leaves	Yellowing between veins of older leaves (Robinson, 1999); Pattern not as distinct as for Fe (Call, 1998; Kessel, 2001)	Chlorosis symptoms (Rosen, 1998)
		Shoots	Growth affected (Pearson & Goheen, 1994)	Black specks on canes of tree fruits (Mills & Jones, 1996)
		Fruit	Growth of berries affected and maturation of clusters delayed (Pearson & Goheen, 1994)	Black specks on fruit (tree fruit) (Mills & Jones, 1996)
		Whole plant	Reduction in size of plant parts, with dead spots or patches (Call, 1998)	
Mo		Leaves	Yellowing of older leaves (Call, 1998), followed by marginal curling and wilting with eventual necrosis (Mills & Jones, 1996)	
		Roots		Reduced Fe availability (Stassen *et al.*, 1999)
		Fruit	Yield affected (Stassen *et al.*, 1999)	
		Whole plant	Light green (Call, 1998)	
Zn		Leaves	Terminal leaves may be rosetted, and yellowing occurs between veins of new leaves (Call, 1998); Small narrow leaves (Kessel, 2001) with opened petiolar sinuses and sharp teeth (Pearson & Goheen, 1994)	Reduction in leaf expansion (Mills & Jones, 1996)
		Roots		Reduction in root growth (Mills & Jones, 1996)
		Shoots	Short internodes with die-back of shoots and branches (Kessel, 2001)	
		Fruit	Fruit abscission (Stassen *et al.*, 1999); Produces fewer seeds and smaller berries (Pearson & Goheen, 1994)	
		Whole plant	Stunted growth (Stassen *et al.*, 1999)	Induces Fe, Mn or P deficiencies (Mills & Jones, 1996)
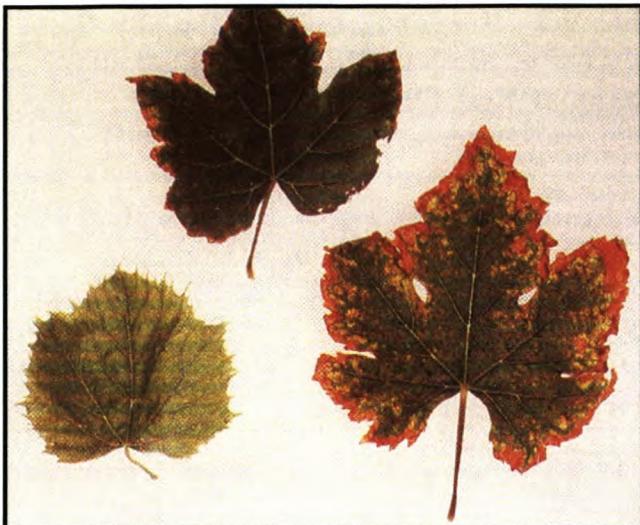
Figure 2.9: B deficiency shows burned edges on grapevine leaves (Robinson, 1999).
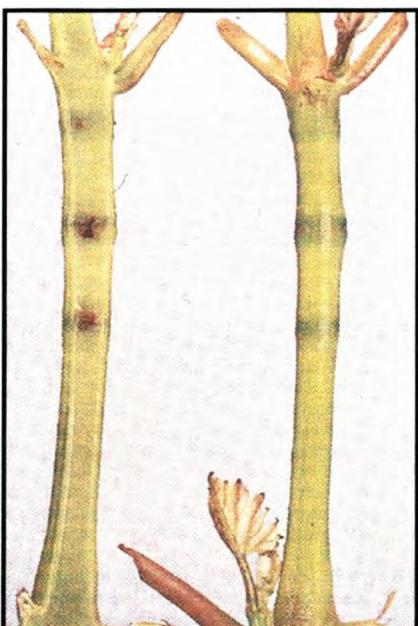
Figure 2.10: Internal and external necrosis on green grapevine shoots caused by B deficiency (Pearson & Goheen, 1994).
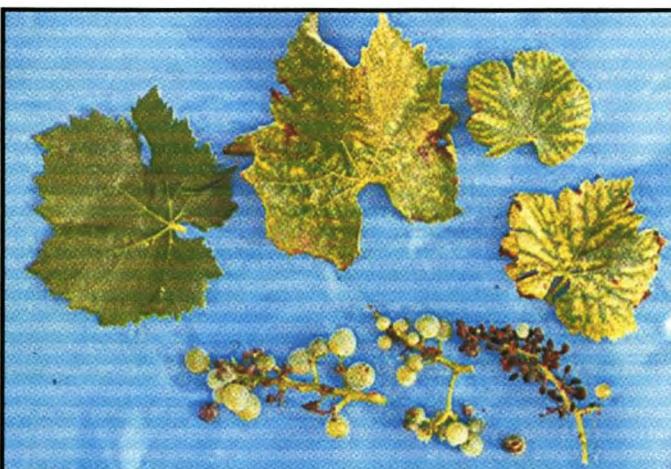
Figure 2.11: Chlorosis on grapevine leaves and millerandage bunches caused by B deficiency. A normal leaf is shown on the left (Saayman, 1981).

Figure 2.12: Small grapevine leaves without any teeth definition caused by B toxicity. A normal leaf is shown in the lower right corner (Saayman, 1981).
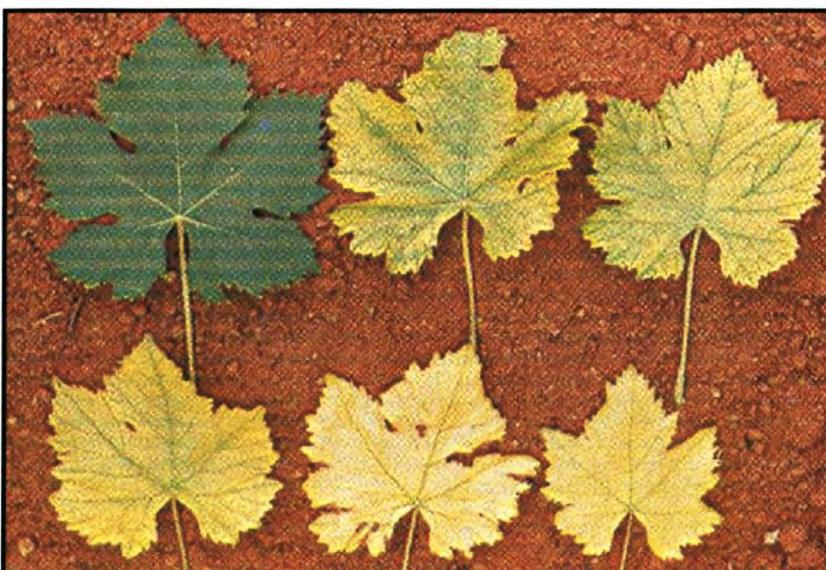
Figure 2.13: Chlorosis on grapevine leaves caused by Fe deficiency, with a normal leaf in the upper left-hand corner (Saayman, 1981).
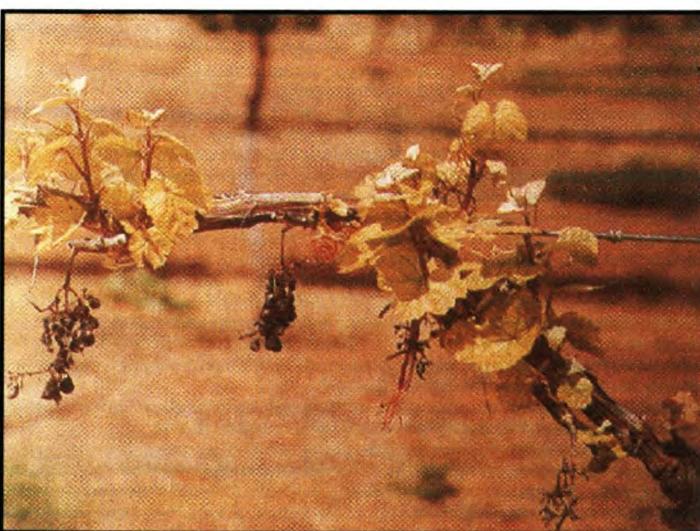
Figure 2.14: Fe deficiency symptoms in the field, causing stunted growth and stem and leaf death in grapevine (Robinson, 1999).

Figure 2.15: Interveinal chlorosis and necrosis caused by Fe deficiency in grapevine (Pearson & Goheen, 1994).
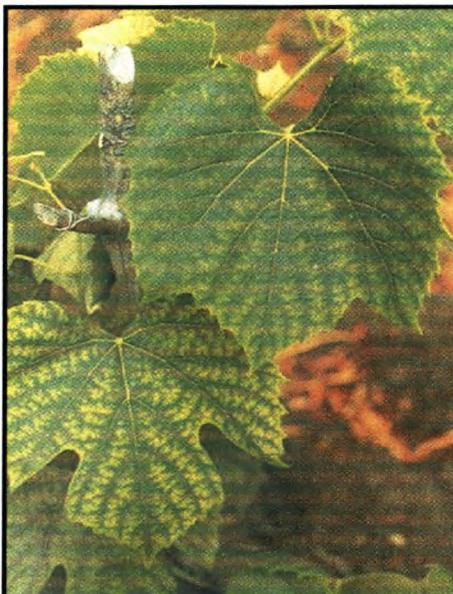
Figure 2.16: Mn deficiency causes grapevine leaves to have interveinal chlorosis, which begins as chlorotic islands (Pearson & Goheen, 1994).

Figure 2.17: Mn toxicity causes dark, swollen spots in the nodal areas of *Vitis* (Saayman, 1981).
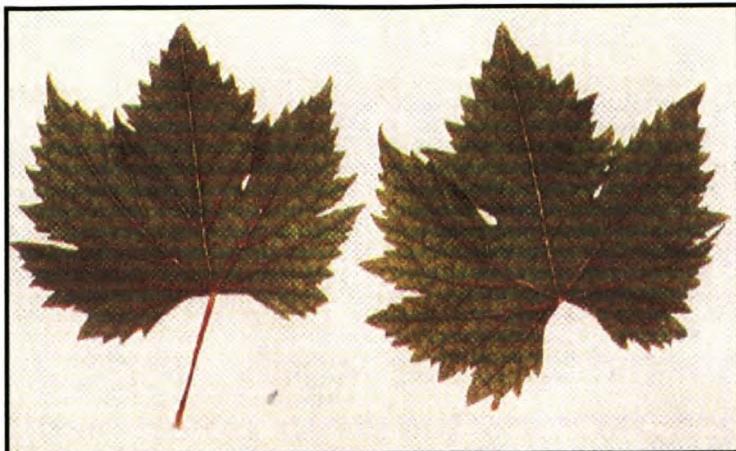
Figure 2.18: Zn deficiency on grapevine leaves (Robinson, 1999).
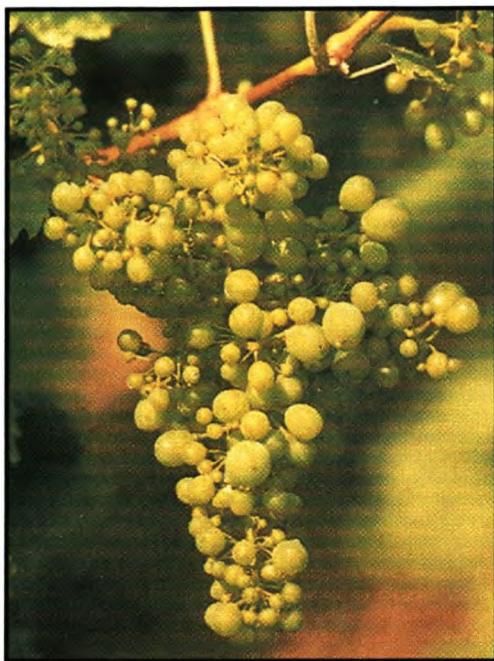
Figure 2.19: Zn deficiency symptoms shown on grape bunches as loose clusters of seeded berries that vary in size (Pearson & Goheen, 1994).

2.4.2 SOIL ANALYSIS

Soil tests do not provide an absolute assessment of soil fertility; rather, they give an index of the availability of particular nutrients that should be calibrated with the crop response in fertiliser experiments. For perennial plants such as grapevine, it has been difficult to use soil analyses for the determination of fertiliser needs. The main reason is that the roots of a grapevine explore a large volume of soil that can vary greatly in chemical composition, even over short distances, and it is not easy to obtain representative samples of this soil (Robinson, 1999). Soil analysis, however, is helpful to determine soil pH, cation exchange capacity, organic matter content, exchangeable sodium and other important elements in the soil. Soil analysis can also be used as an indicator of soil fertility (Rahn, 1998).

The accuracy of the interpretation of soil analyses is highly dependent on the number and representativeness of samples taken from a specific size vineyard (Conradie, 1994; Rosen, 1998). Knowledge of the chemical and physical properties of the soil is also extremely important to interpret the results (Conradie, 1994).

Soil samples can be collected any time of the year, although spring and autumn samples are usually the most convenient. If the results of soil tests from a given field are to be compared over several years, it is important to collect the samples at the same time of the year (Rosen, 1998). Soil sampling is less useful during the cropping season, but it is a relatively easy and inexpensive method (Gruhn *et al.*, 2000) that can be used to predict the performance in the coming season.

A soil sample for analysis must be taken with care, otherwise the results can be misleading (Robinson, 1999). Each field to be sampled should be divided into uniform areas. Each area should have the same soil texture and colour, cropping history, and fertiliser, manure, and lime treatments (Rosen, 1998). Surface samples (0 to 15 cm) are satisfactory for assessments of cover crop behaviour. If the soil type varies across the vineyard, separate groups of samples should be taken from each area. Sub-samples should be mixed thoroughly. Samples representing the bottom of the root zone should be taken over a depth interval of 90 to 100 cm (Robinson, 1999).

The geological nature of the soil also plays a role, since it has been shown that, in certain primitive soils, N has a favourable impact, whereas N addition has no noticeable positive effect in modern alluvial soils (Galet, 2000).

Wide ranges of commercial and government laboratories offer soil and plant analysis services. The interpretation of the analysis should be done by someone who is familiar with the soils of the district. It is important to know which soil analysis methods are to be used, because the quantities of nutrients extracted by different methods vary widely. The results should be compared with appropriate standard values (Robinson, 1999).

2.4.3 PLANT TISSUE ANALYSIS

Plant analysis is a powerful tool that can be used by growers to help diagnose nutrient disorders that may occur during the growing season. Plant analysis can also be used to help fine-tune the efficiency of a fertiliser program before the symptoms of nutrient deficiency appear. The technique involves determining the elemental composition of plant tissue during the growing season and then comparing these values with those already established for a normal, healthy vine. Nutrient deficiencies or excesses can be determined from this comparison (Rosen, 1998).

It is necessary to realise that plant analysis is not a substitute for soil analysis (Conradie, 1992). When used in conjunction with soil testing, plant analysis can provide additional information related to crop nutrition and the effectiveness of a particular fertiliser program (Rosen, 1998).

The first problem with any tissue analysis system is the choice of the organ to be sampled. The tissue must be easy to identify and collect, must provide easily

reproducible results, and should be taken at a time when its chemical composition is changing slowly. Samples of both leaf laminae and petioles can be taken at flowering and véraison. Petiolar tissue gives better assessments of K deficiency and Cl and Na toxicities, whereas laminar tissue can be effective for the detection of deficiencies of N, Mg, Zn, B (and toxicity), Ca, Cu, Mn and Fe (Robinson, 1999). Leaf blade analyses are normally used to determine non-visual deficiencies (Saayman, 1981).

Elemental norms (Table 2.6) have been determined for grapevines by Conradie (1994). These should not be seen as exact norms, but rather be used as guidelines. Differences in opinion also occur for these elemental norms in grapevines, for example with regard to the minimum and maximum range for elements, the specific phenological stage at which tissue samples must be taken, and also which part of the vine (leaf blade or petiole) will give the most accurate results.

Table 2.6: Elemental norms for leaf blades and petioles: *Vitis vinifera* (Conradie, 1994).

| Element | Leaf blade | | | | | | Petiole | | | | | |
| | Fruit set | | | Véraison | | | Fruit set | | | Véraison | | |
	Min	Max	Toxic	Min	Max	Toxic	Min	Max	Toxic	Min	Max	Toxic
N (%)	1.60	2.70	-	1.50	2.40	-	0.60	0.98	-	0.50	0.95	-
P (%)	0.14	0.55	-	0.12	0.45	-	0.11	0.62	-	0.09	0.64	-
K (%)	0.65	1.30	-	0.55	1.05	-	1.00	2.90	-	0.90	1.80	-
Ca (%)	1.20	2.20	-	1.50	2.40	-	0.60	1.40	-	1.10	1.90	-
Mg (%)	0.16	0.55	-	0.20	0.60	-	0.25	0.80	-	0.40	1.45	-
Na (%)	-	0.25	-	-	0.25	-	-	0.50	-	-	0.50	-
Fe (ppm)	60	-	-	60	-	-	25	-	-	25	-	-
Zn (ppm)	15	-	-	15	-	-	15	-	-	15	-	-
Mn (ppm)	10	250	650	20	300	750	18	200	1400	20	200	1500
B (ppm)	15	80	150	25	100	200	20	70	100	25	90	150
Cu (ppm)	3	-	-	3	-	-	2.5	-	-	2.5	-	-
Cl (ppm)	-	-	0.50	-	-	0.50	-	-	1.00	-	-	1.00
Mo (ppm)	-	-	-	-	-	-	-	-	-	-	-	-

The nutrient status of plants is always relative. The reason is that it is difficult to define an absolute amount of any single nutrient that is sufficient for plant growth. Furthermore, different plants require varying amounts of the same nutrient, and each plant requires different amounts of each nutrient (Mills & Jones, 1996).

The metals Al, Cd, Cu, Fe, Hg, Mn, Pb and Zn tend to accumulate in the roots when they are present at high levels. Root analysis is therefore an accurate method to detect toxic concentrations of these elements. Unfortunately, collecting and cleaning soil contamination from roots is a difficult task and roots are seldom used for routine analysis (Mills & Jones, 1996).

As fruits increase in size throughout the season, the movement of Ca from the leaves to the fruit is very restricted. As a result, the leaf analysis of Ca is of limited value in diagnosing the Ca status of the fruit. Calcium analysis of the fruit without the seeds is a better indicator of the fruit storage potential. The storage potential of table grapes is rather poor if the Ca in the fruit, especially in the skin, is low (Mills & Jones, 1996).

According to Galet (2000), Lagatu and Maume proposed leaf diagnosis in 1927. They sampled proximal leaves for macroelements at predetermined intervals, for example once the first cluster had bloomed, after bloom, at the beginning of véraison and at maturity. The problem is that analyses of the samples taken at pre-set periods correspond only partially to the physiological phenomena going on in the vine, particularly in the clusters and roots (Galet, 2000). The diagnosis is often influenced by factors such as rootstocks, cultivars, climate, diseases and different viticultural practices (Conradie, 1994).

Areas with distinctly different soils, vine appearance or any other condition should be sampled separately (Peacock & Christensen, 1996). For example, sampling strong, weak and optimal growth areas separately will give a more accurate analysis than collecting one average sample (Rahn, 1998). For this purpose, leaves or petioles are taken from opposite flower clusters near the base of the shoot (Peacock & Christensen, 1996).

Critical nutrient levels, as determined by tissue analysis, should be considered only as guidelines if nutrient deficiencies are expected (Christensen, 1995). A tissue analysis is carried out in a series of steps, as shown in Figure 2.20, where sampling and sample preparation are followed by laboratory analysis and interpretation (Mills & Jones, 1996).
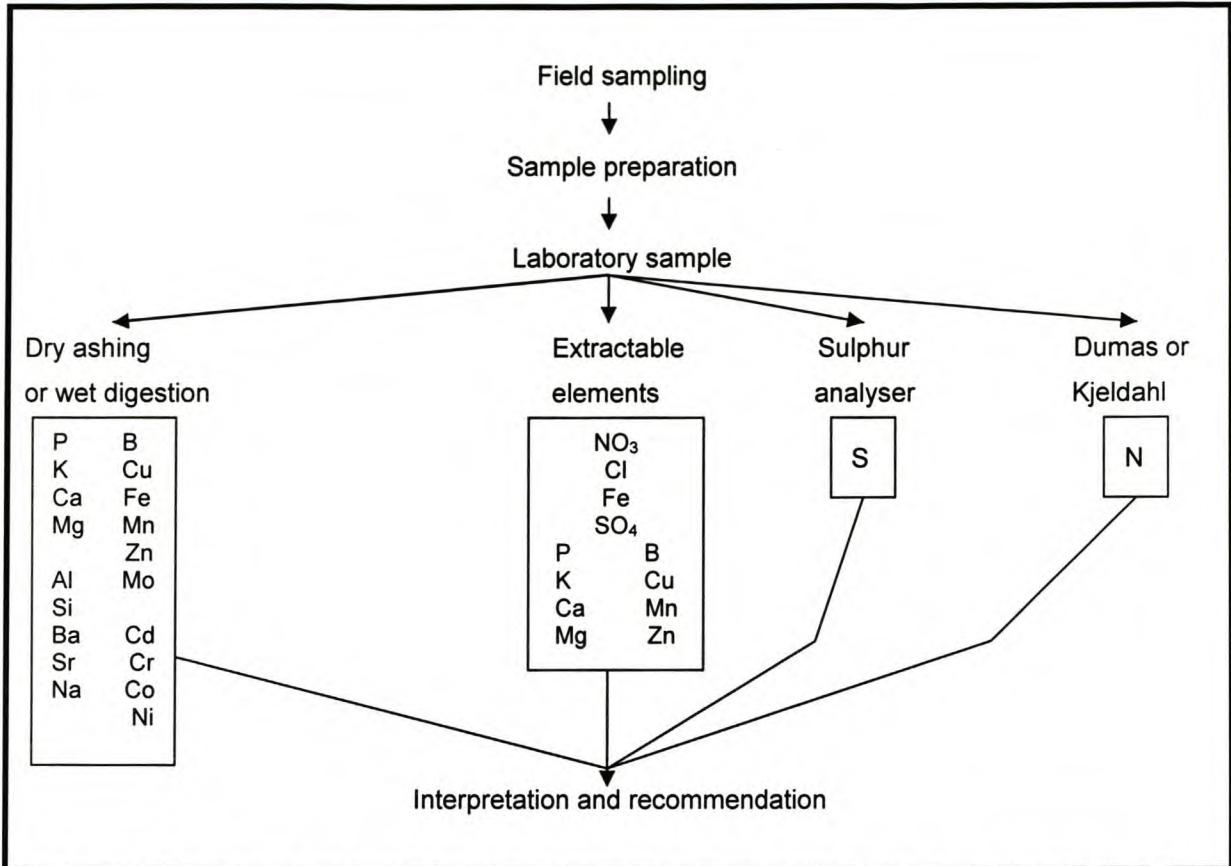
Figure 2.20: Sequence of procedures for conducting a plant analysis (Mills & Jones, 1996).

2.5 UPTAKE PATTERNS OF NUTRIENTS

2.5.1 THE ANNUAL PHENOLOGICAL CYCLE OF A GRAPEVINE

Phenology is the study of natural phenomena that recur periodically in plants, and of the relationship of these phenomena to climate and changes in season. It aims to describe the causes of variation over time by seeking correlations between weather indices, the dates of particular growth events and the intervals between them. For the grapevine, the most emphasis is put on its growth and development during each annual cycle (Coombe, 2000). Dormancy separates the two growing seasons involved in grape production (Pearson & Goheen, 1994).

Phenological data are essential for making good decisions during the phases of grapevine cultivation, for example selecting a vineyard site, planning fertiliser needs and soil management, irrigation, pest and disease control, etc. (Coombe, 2000).

According to Galet (2000), the grapevine has two different vegetative rhythms because it is cultivated in both the northern and southern hemisphere. In temperate climates, the grapevine has a discontinuous vegetative rhythm, while it has a continuous rhythm in tropical climates. As a perennial plant, the grapevine must carry out three functions, namely the vegetative cycle, the reproductive cycle and lignification, as shown in Figure 2.21 (Galet, 2000).
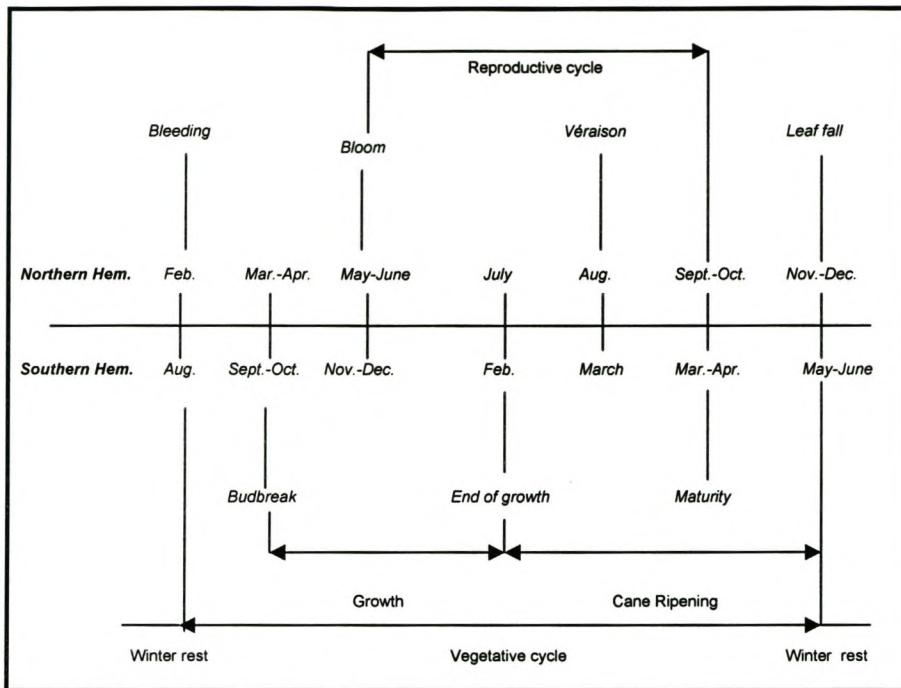
Figure 2.21: Vegetative rhythms for grapevines in the northern and southern hemisphere indicated by months (Galet, 2000).

2.5.1.1 Events in the grapevine phenological cycle

The developmental events are subject to variations in timing according to variety, region and season. The key events that take place are bud burst, flowering, véraison and harvest (Coombe, 2000), although many more events are also present, as seen in Figure 2.22 (Coombe, 2000) and Table 2.7. Only the more important stages or events will be described.
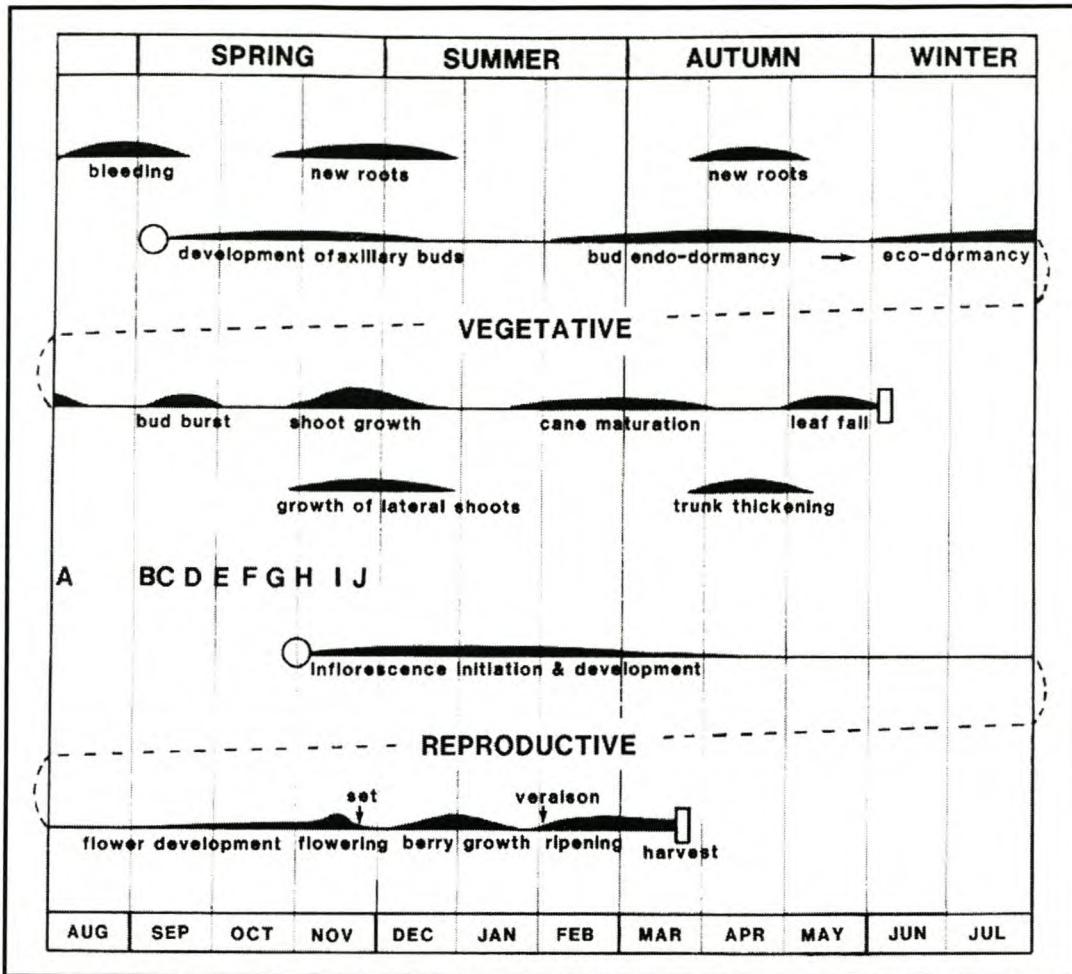
Figure 2.22: Cycle of vegetative and reproductive growth events in the grapevine in relation to months. Each cycle begins at the circle and ends at the rectangle. Letters A-J describe different phenological stages of the grapevine, as shown in Table 2.7 (Coombe, 2000).

Table 2.7: Description of different phenological stages for grapevines as done by Baggiolini in 1952. Stages K-O are not shown in Figure 2.22, but are important phenological events occurring during the summer and autumn (Coombe, 2000).

Event or stage	Description
A	A bud in the dormant state covered with two brown protective scales.
B	A bud in which the scales are separating as the bud swells, revealing brown woolly hairs.
C	Further bud swell revealing the tip of the young green shoot.
D	Leaf emergence during which a rosette of young leaves appears. The scales and wool are still obvious.
E	The shoot becomes clear and the first leaf blades are completely free. Varietal characteristics are evident.
F	The inflorescence primordia become visible at the shoot tip. Four to six leaves are unfolded.
G	The inflorescences grow and enlarge, but the flowers are still clumped.
H	The inflorescence attains its typical form and individual unopened flowers separate.
I	Calyptras fall and expose the ovary and five stamens.

J	Ovaries which have set commence growth, but dried stamens still adhere. The new berries already display some varietal characteristics.
K	Véraison, during which berries become soft and colouring starts.
L	Cane maturation for the storage of reserves for the winter.
M	Ripeness.
N	Leaf colouration.
O	Leaf fall.

2.5.2 SEASONAL UPTAKE OF NUTRIENTS ACCORDING TO GRAPEVINE PHENOLOGY

The nutrient requirement of grapevines are relatively low when compared to those of other crops. There might not always be a visual reaction to applied fertilisers, but nutrients still play a critical role in grape quality, especially relating to storage ability. Thus, proper fertilisation for grapevines is of no less importance than for other crops (Conradie, 2001). For grape growing, the objective is to find a proper balance between the accumulation of food reserves in the vegetative organs and the movement of these reserves to the berries and seeds (Galet, 2000).

2.5.2.1 The annual nutrient requirements of table grapes

Grapevines use different ratios of nutrients to produce a specific amount of grapes. For an average of 25 tonnes per hectare, the different elemental requirements per annum are given in Table 2.8. These values may change when soil, cultivar and cultivation are taken into account.

Table 2.8: Annual nutrient uptake for a vineyard producing 25 tonnes per hectare (Conradie, 2001).

Nutrient	Uptake
Nitrogen	97 kg/ha
Phosphorus	18 kg/ha
Potassium	76 kg/ha
Calcium	50 kg/ha
Magnesium	15 kg/ha
Manganese	150 g/ha
Zinc	250 g/ha
Boron	200 g/ha
Copper	50 g/ha
Iron	635 g/ha

2.5.2.1.1 Nitrogen

The response of the grapevine to N is stronger to other elements, especially in the case of vegetative growth. Excessive vegetative growth is normally correlated with a

lower yield of poorer quality due to a suboptimal microclimate (Conradie, 2001).

According to Conradie (1980), N is absorbed in two distinct peaks. The first peak starts after bud burst and continues until véraison. The second absorption period is post harvest, coinciding with active root growth. Except for a short period preceding véraison, the roots will lose N during the period building up to harvest. After harvest, the roots will actively accumulate N, a situation that might continue into the leaf fall stage, even though the roots have stopped active growth (Conradie, 1980). After harvest, the accumulation of N is higher than that of the other macronutrients (Conradie, 1981). Table 2.9 gives an indication of the seasonal uptake of N during the different phenological stages of grapevine growth.

Table 2.9: The seasonal uptake of N in the different phenological stages of the growing season for a vineyard that produce 25 tonnes of grapes per hectare (Conradie, 2001).

Phenological stage	Nitrogen uptake (%)
Bud burst – Beginning of flowering	11.3
Flowering	10.9
End of flowering – Pea size berries	12.8
Pea size berries – Véraison	22.9
Véraison – Harvest	4.5
End of harvest – Five weeks after harvest	12.5
Five weeks after harvest – Until the end of April *	9.2
End of April * – End of leaf fall	12.4
End of leaf fall – Bud burst	3.5
Total	**100**

* Southern hemisphere

Four different approaches can be used to determine the N requirement of grapevines. These are total production or yield, soil analyses, leaf blade and petiole analyses and vine vigour. Only low potential soil, typically a sandy soil with a low organic material content, can be used to determine the N requirement according to yield. The organic material in the soil can give a broad guideline for the N requirement. The nitrate content in petioles will only provide a guideline for the N requirement in some cultivars. Thus, vine vigour is the most important norm for the determination of N (Conradie, 2001).

The cropping level also plays a role in the accumulation of macronutrients. Nitrogen, P and K are stored in larger concentrations in vines with little or no crop in comparison to heavily cropped vines. With a heavy crop beyond the capacity of the vine, the nutrient reserves are depleted in the canes (Balasubrahmanyam *et al.*, 1978).

2.5.2.1.2 Phosphorus

Phosphorus absorption starts about three weeks after bud burst and lasts until véraison. A second absorption peak period begins five weeks after harvest until leaf

fall, after which the P will be translocated to the permanent parts of the vine, especially the roots (Conradie, 1981). Table 2.10 gives an indication of the seasonal uptake of P during the different phenological stages of grapevine growth.

In comparison to N, the amount of P required by grapevines is relatively small. Because P is almost immobile in soil, the P levels in the soil must be corrected during soil preparation, after which only P maintenance is needed. Three approaches can be used to determine the P status of the vineyard, namely leaf blade analyses, soil analyses and the yield. For P, the most accurate method is making use of soil analyses (Conradie, 2001).

Table 2.10: The seasonal uptake of P in the different phenological stages of the growing season for a vineyard that produce 25 tonnes of grapes per hectare (Conradie, 2001).

Phenological stage	Phosphorus uptake (%)
Bud burst – Beginning of flowering	15.2
Flowering	15.4
End of flowering – Pea size berries	16.5
Pea size berries – Véraison	22.6
Véraison – Harvest	2.0
End of harvest – Five weeks after harvest	5.7
Five weeks after harvest – Until the end of April *	13.5
End of April * – End of leaf fall	5.6
End of leaf fall – Bud burst	3.6
Total	**100**

* Southern hemisphere

2.5.2.1.3 Potassium

Potassium plays a critical role in table grapes because of the important role it plays in the sugar levels of berries and in berry size (Conradie, 2001). Potassium absorption also begins about three weeks after bud burst. At harvest, the absorption rate will slow down but, after harvest, the absorption rate will continue normally. No absorption of K will occur during leaf fall. During leaf fall, K will apparently be translocated from the leaves to the permanent parts of the vine (Conradie, 1981); K is highly mobile in plants (Mauseth, 1995). Table 2.11 gives an indication of the seasonal uptake of K during the different phenological stages of grapevine growth.

Table 2.11: The seasonal uptake of K in the different phenological stages of the growing season for a vineyard that produce 25 tonnes of grapes per hectare (Conradie, 2001).

Phenological stage	Potassium uptake (%)
Bud burst – Beginning of flowering	15.9
Flowering	11.0
End of flowering – Pea size berries	22.5
Pea size berries – Véraison	26.4
Véraison – Harvest	9.0
End of harvest – Five weeks after harvest	15.2
Five weeks after harvest – Until the end of April *	Not detectable
End of April * – End of leaf fall	Not detectable
End of leaf fall – Bud burst	Not detectable
Total	**100**

* Southern hemisphere

The same norms to determine P levels in grapevines, namely leaf blade analyses, soil analyses and yield, can be used to determine the K status. Soil analyses and production levels are the most accurate norms to determine K status. Leaf blade analyses are only useful to determine deficiencies (Conradie, 2001).

2.5.2.1.4 Calcium

The amount of Ca translocated to the bunches is very small. The bunches will receive Ca only before véraison. Calcium is only transported by the xylem, which gets disrupted in the berries later in the season, leading to the xylem no longer being functional. Thus, no Ca can be transported to the bunches after véraison (Conradie, 2001). Very active Ca absorption occurs from after bud burst until véraison, followed by a decreased rate which will last until the end of leaf fall. For Ca, more than 60% of the Ca gained by the permanent parts of the vine is contained in the bark (Conradie, 1981). This phenomenon may be caused by the immobility factor of Ca (Mauseth, 1995). Table 2.12 gives an indication of the seasonal uptake of Ca during the different phenological stages of grapevine growth.

Table 2.12: The seasonal uptake of Ca in the different phenological stages of the growing season for a vineyard that produce 25 tonnes of grapes per hectare (Conradie, 2001).

Phenological stage	Calcium uptake (%)
Bud burst – Beginning of flowering	10.6
Flowering	14.7
End of flowering – Pea size berries	22.4
Pea size berries – Véraison	23.3
Véraison – Harvest	7.4
End of harvest – Five weeks after harvest	3.8
Five weeks after harvest – Until the end of April *	9.5
End of April * – End of leaf fall	5.6
End of leaf fall – Bud burst	2.6
Total	**100**

* Southern hemisphere

2.5.2.1.5 Magnesium

The absorption of Mg starts at the same time as K. It will continue evenly and stop before the onset of leaf fall. Most of the Mg absorbed after harvest is lost through leaf fall (Conradie, 1981). Mg is translocated by the xylem and the phloem and can therefore be transported to the bunches during most of the growing season (Conradie, 2001). Table 2.13 gives an indication of the seasonal uptake of Mg during the different phenological stages of grapevine growth.

Table 2.13: The seasonal uptake of Mg in the different phenological stages of the growing season for a vineyard that produce 25 tonnes of grapes per hectare (Conradie, 2001).

Phenological stage	Magnesium uptake (%)
Bud burst – Beginning of flowering	10.7
Flowering	10.8
End of flowering – Pea size berries	16.6
Pea size berries – Véraison	26.4
Véraison – Harvest	12.8
End of harvest – Five weeks after harvest	11.1
Five weeks after harvest – Until the end of April	11.7
End of April – End of leaf fall	Not detectable
End of leaf fall – Bud burst	Not detectable
Total	**100**

* Southern hemisphere

2.5.2.1.6 Micronutrients

The seasonal uptake pattern of micronutrients according to phenological growth has not yet been determined. The annual total amount of Mn, Zn, B, Cu and Fe absorbed by grapevines which produce 25 tonnes of grapes per hectare is shown in Table 2.8. According to Conradie (2001), the grapevine needs 635 g/ha Fe during the growth season, which is more than double the amount of Zn and B. It is more than four times as much as Mn, and almost seven times as much as Cu. The micronutrients will be discussed in more detail with regard to their important role in foliar fertilisation (Conradie, 2001).

2.6 THE EFFECT OF DIFFERENT NUTRIENT APPLICATION METHODS ON GRAPEVINE MANIPULATION

2.6.1 CONVENTIONAL FERTILISER PROGRAMMES

Conventional soil applications, if correctly managed with regard to the time and quantity of the application, can give very good results. However, the system is limiting, since finer management of the nutrients and moisture at critical phenological stages is not possible (Stassen et al., 1999). There is no definite recipe, but only guidelines, for vineyard fertilisation (Conradie, 1994). To achieve optimum success with fertilisation, chemical adjustments must be made during soil preparation, and a complementary nutrient programme must be followed (Stassen et al., 1999). Well-known conventional fertiliser programmes and methods include broadcasting, banding and foliar sprays, which will be discussed briefly.

2.6.1.1 Broadcasting and banding

Broadcasting involves even manual or mechanical spreading of the fertiliser material over the surface of the soil. Tractor-mounted equipment is available to perform this operation. Banding is a modification of broadcasting, involving placement of the fertiliser in narrow bands adjacent to the vine row (Robinson, 1999). According to Conradie and Saayman (1989), 3.9 kg N is needed in a conventional fertiliser programme for each ton of Chenin blanc grapes, with an average of yield of 13 t/ha, produced annually. Annual applications of 9 kg P/ha and 45 kg of K/ha are adequate for wine grape production (Conradie & Saayman, 1989), but these norms do not always apply for table grapes.

2.6.1.2 Foliar sprays

Dissolved material and fine suspensions can be applied to vine foliage alone or in combination with insecticides and fungicides. Care must be taken with the concentration of these applications. It is not advisable to apply higher concentrations than those specified, because they might cause leaf burn (Robinson, 1999).

Some elements, such as N, are taken up readily by the leaves. One single foliar application might lead to an uptake of 500 g/ha for a certain element, whereas only 100 g/ha of other elements might be taken up in a single foliar application. Thus, only a fraction of the annual requirement for macroelements can be provided by foliar applications, although it is possible to provide in most of the vine's need for microelements through foliar sprays (Conradie, 2001).

In the case of Ca, foliar sprays are not recommended, because Ca might be absorbed by vine leaves, but will not necessarily move to the bunches. However, direct bunch sprays are being investigated. For example, fruit sprays are a standard practise in the apple industry (Conradie, 2001).

Foliar applications are used in combination with normal fertiliser programmes, but will never be a substitute for normal fertilisation. An appropriate time to consider foliar fertilisation would be when a shortage of a nutrient is evident, as indicated by tissue analysis or visual symptoms (Rosen, 1998). This was discussed in section 2.4 of this chapter.

Nutrient foliar sprays are most commonly used to correct micronutrient problems, because nutrients such as Zn, B, Mn and Fe are required in relatively small quantities by grapevines. Foliar sprays can therefore prevent or correct a problem through the small amounts that are absorbed by the foliage (Boynton, 1954). However, in the case of B, care must be taken not to over- or under-apply, because the range from deficiency to toxicity is very small (Conradie, 2001).

According to Failla *et al.* (1996), nutrient spray applications have an effect on malic and tartaric acid levels in the grapevine berry of various *Vitis vinifera* cultivars. A relationship is established between K and malic acid at véraison, but the relationship may not necessarily last until the ripening of the berry (Failla *et al.*, 1996).

2.6.2 NUTRIENT APPLICATION THROUGH IRRIGATION MANAGEMENT

2.6.2.1 Irrigation methods

Sprinklers and drippers are the two most commonly used irrigation methods for grapevines and the primary nutrient applied is N (Rosen, 1998). Overhead irrigation systems may also be used, although this method is rarely seen in vineyards. These methods can be used in combination with conventional nutrient applications, as well as with liquid fertiliser programmes, such as fertigation and open air hydroponic systems (OHS). Both methods are used for fertigation, whereas drippers are mostly used for OHS. According to Rosen (1998), the advantages of using drip irrigation include better control of foliar diseases and more efficient water use. A disadvantage is clogging problems in the drip lines, for example when using calcium nitrate in high pH water (Rosen, 1998).

2.6.2.2 Fertigation

Fertigation is done when crops are irrigated with enriched water. It is applied more often than conventional fertilisation and irrigation, which may differ between once a month up to three applications per week. Since these applications take place more often, crop manipulations can be adapted to the advantage of yield and quality (Stassen *et al.*, 1999).

The fertigation system lends itself to rapid adaptation, as nutrients are supplied mainly through the irrigation system. Chemical adjustments of the soil still need to be done during soil preparation, but the supplementary annual nutrient supply can be applied through fertigation. In this system, the contribution of the soil is not completely neutralised, but N management in particular can be controlled better. Calcium and K can be supplemented during the periods when they are most important for fruit development (Stassen *et al.*, 1999).

2.6.2.3 Open air hydroponic systems

2.6.2.3.1 The importance of open air hydroponic systems

Open air hydroponic systems are sensitive nutrient and moisture management systems, as they are set to a daily application schedule according to a computer program. Intensive production vineyards currently demand a crop-orientated management system. In ideal circumstances, a well-controlled conventional system will be successful. When conditions are less favourable, finer management systems are required. Fruit size and internal quality are becoming more and more important for export-orientated industries. Finer management systems, through controlled nutrient application, together with chemical and physical manipulations, must help to evenly balance reproductive fruit bud development and vegetative growth. In this way, plant energy will mainly be utilised to bring about strong fruit bud development, good fruit set, optimal fruit retention, strong competing fruit and exceptional internal quality (Stassen *et al.*, 1999).

2.6.2.3.2 The difference between total and open air hydroponic systems

In total hydroponic systems, the plants are totally controlled without interference from soil and environmental influences, as in greenhouses. Water cultures, sand, vermiculite and peat are used as anchoring structures for the plant roots. Open air hydroponic systems operate where the plant is established outside in soil. Thus, the contribution of the soil is not completely neutralised in this system, but N management in particular can be controlled better (Stassen *et al.*, 1999).

The OHS concept is also different from fertigation in the sense that, with the OHS, the plant is fed water and nutrients on a daily basis. It therefore tends to be a more intensive management system than conventional fertilisation and irrigation, as well as fertigation.

2.6.2.3.3 The basic setup of and guidelines for an open air hydroponic system

An OHS consists of various basic elements. These include tanks for the nutrient mixes, water pumps, filters, valves, and pipelines to the various blocks with individual stop valves. The drip lines within each block are connected to the pipelines and a central computer system captures all the relevant data (Figure 2.23).

Application by drip is essential in an OHS system (Stassen *et al.*, 1999). Drip irrigation wets a limited area of the root zone. Nutrients applied through the system are therefore placed where the roots are concentrated and the uptake is supported by high soil-water matrix potentials if the irrigations are properly scheduled (Christensen *et al.*, 1991). The roots automatically adapt and only grow in the area normally irrigated. The fertiliser is therefore placed in the root zone and nutrient uptake should be more effective (Conradie, 2001).

In the case of OHS, the role of the soil should be limited. Root growth, soil pH and other factors are now dependent on the environment created by the nutrient medium. When irrigation is done with enriched water, it is important to know the water and nutrient requirement of the grapevine for every given stage of development, as seen in section 2.5 in his chapter. This means that one cannot rely on the conventional methods of irrigation scheduling alone. The only thing that takes both water and nutrients into consideration is the plant itself. This means that a plant-based method must also be used for scheduling (Stassen *et al.*, 1999).

Providing nutrients through the irrigation system enables more flexibility in a fertiliser program (Rosen, 1998). For example, growers have successfully applied the nutrient B through a drip system in very small amounts without vine injury and with good results (Peacock & Christensen, 1999). The uptake of N and K can be improved in sandy soils, which may lead to improved growth and yield. However, over-fertilisation of K can occur easily (Conradie & Myburgh, 2000). Calcium and K can be supplemented during periods whey they are most important for fruit development (Stassen *et al.*, 1999). A recent study on tomatoes showed that the mineral content (P, K, Ca, Mg) of the fruit was higher if fertilisation was combined with an irrigation system (Shi *et al.*, 1999). Studies on citrus fruit in South Africa have shown that the internal quality of the fruit was excellent and that the fruit size was even if an OHS production system was used (Groenewald, 2002).
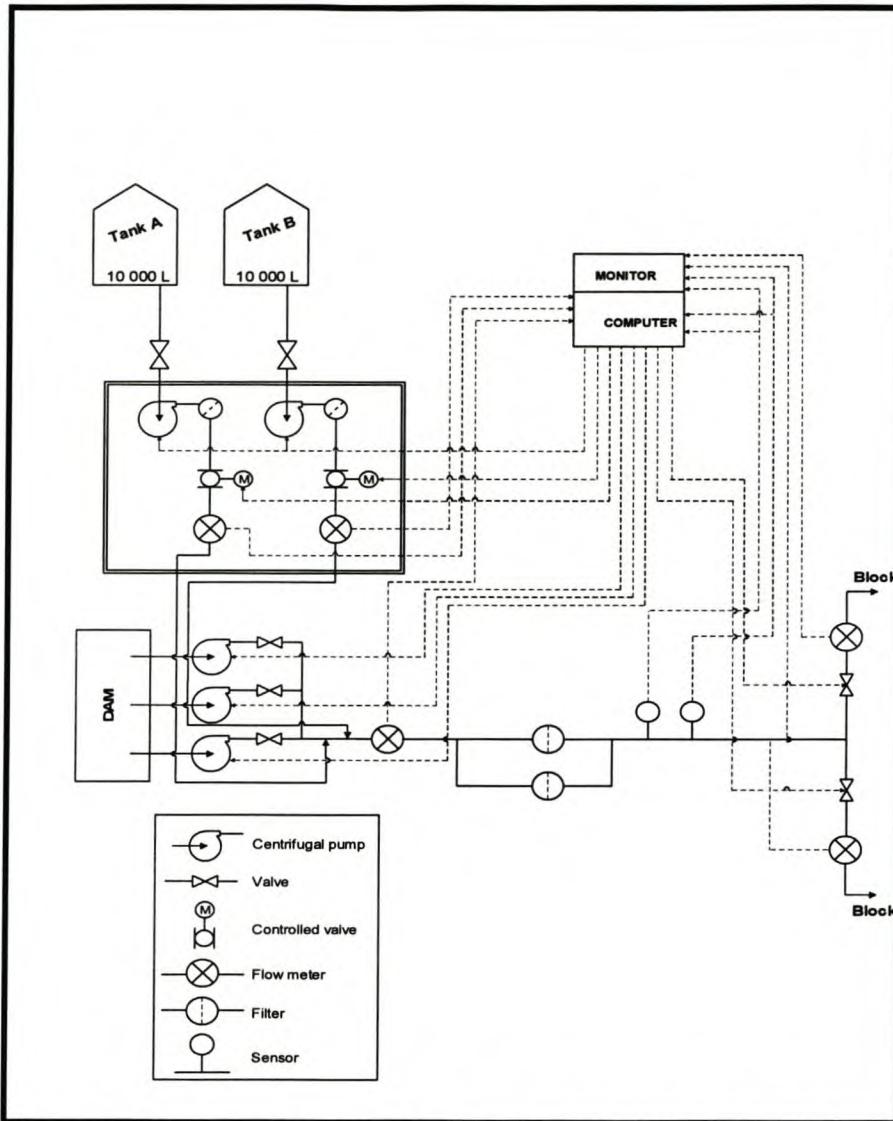
Figure 2.23: The basic layout of an open hydroponic system (Anonymous, 2000).

2.6.2.3.4 Advantages and disadvantages of open air hydroponic systems

Many advantages and disadvantages exist for OHS. The most important advantages are: i) OHS is of value on poorer soils and where other soil restrictions may occur (as discussed in section 2.3 in this chapter), although it can still be used as a highly sensitive crop management system in all soils (Stassen, *et al*, 1999); ii) growers claim that younger vines are brought into production sooner (Burt *et al.*, 1998); iii) the use of OHS has shown an increase in crop tonnage (Jones, 1997), better fruit quality in terms of uniform size and colour, and improved ability to more precisely control the content of fruit solids (Burt *et al.*, 1998); and iv) unnecessary stress situations can also be eliminated by better moisture and nutrient management (Stassen *et al.*, 1999).

However, some of the disadvantages should also be mentioned. These include: i) irrigation scheduling becomes more complicated with OHS because the nutrient needs are sometimes higher than the water needs of the plant, which will at times result in over-irrigation, or vice versa (Stassen et al., 1999); ii) the system is expensive; iii) the continued application of fertilisers and irrigation water to a restricted root zone

leaches nutrients over time (Burt *et al.*, 1998); and iv) the producer has no control over climatic conditions such as rain.

2.6.2.3.5 Examples of crops grown successfully under either total or open air hydroponics

Many crops have proven to be very successful when grown in any type of hydroponic culture. Grapes are quite new to the hydroponic industry. The reason is that grapes, such as any other fruit tree, are not optimally suited for greenhouse growth due to their large canopies. In the past it was impossible to use OHS on the scale of an outside vineyard or orchard, although computer-controlled applications have been adapted to OHS and now make this possible.

Other crops grown successfully under total hydroponics include bell peppers, where the drip irrigation system enables producers to control *Phytophthora*, lettuce, where producers harvested sooner than in traditional fields, and tomatoes, where various producers claim to have double the average yield per acre (Burt *et al.*, 1998).

Chicory plants (De Rijck & Schrevens, 1998) and cucumbers (Jensen, 1999) are also successfully cultivated under total hydroponics, whereas kiwifruit (Marsh & Stowell, 1993), ,pecan trees (Worley *et al.*, 1995) and plums (Southwick *et al.*, 1999) are cultivated successfully under fertigation. Citrus (Groenewald, 2002; Pijl, 2001) and mangos (Stassen *et al.*, 1999) are crops grown successfully under OHS production.

However, as discussed throughout this chapter, grapes have only been produced under OHS for a short period of time. For all table grape producers, OHS is a relatively new concept and literature on OHS, specifically with regard to table grapes, is almost impossible to obtain due to a lack of previous research. Literature was found on many crops grown in greenhouses with total hydroponics, and even on other crops grown under OHS. These concepts for other crops grown hydroponically (either total or OHS) must be taken into consideration only as a guideline when producing table grapes under OHS, for every crop has its own unique composition and reaction to OHS. Research on table grape production under OHS is a necessity. Only when every individual aspect mentioned in this chapter is integrated into a multidisciplinary research program, will table grape production under OHS be fully optimised.

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Chapter 3

RESEARCH DESIGN

Base description of two cultivars, Dan ben Hannah and Waltham Cross, studied under conventional and open air hydroponic systems

RESEARCH DESIGN

3.1 INTRODUCTION

Open air hydroponic systems (OHS) are a fairly new concept for growing crops, especially table grapes. Very limited information on OHS for table grapes is available with regard to the optimisation of its usefulness and application.

These systems need intensive planning to be economically viable, due to their expensive implementation and maintenance costs, especially in the table grape industry, which competes strongly in foreign markets. OHS is a very intensive management system with various propagated advantages, but intensive and systematic studies are needed to evaluate its usefulness.

Since no previous work on OHS in table grapes was available, a study was initiated to examine certain aspects of OHS in table grape production. This study attempted to establish quantitative data for the plant's reaction under OHS. This was done by means of a case study in which no actual parameters were experimentally varied, except for a comparison of two different table grape cultivars cultivated under OHS and conventional microjet irrigation.

Two table grape cultivars were used in this project, namely Dan ben Hannah (DBH), a black, seeded cultivar, and Waltham Cross (WC), a white, seeded cultivar. Both these cultivars had already been established under OHS and conventional cultivation for approximately five months when the study commenced in January 2001.

Dan ben Hannah (Black Emperor) originated in Israel as a cross between Black Mikevh and Alphonse Lavallée. It was imported from Israel in 1965, but only released in South Africa in 1973. The vegetative characteristics of DBH include strong vigour and good fruitfulness, with bud burst in the middle of September, full bloom late in October, and harvest late in January to early February. Dan ben Hannah should be pruned with semi-long bearers with four to six buds. The bunches have a long-conical shape, with a well- filled density, and are of medium to large size. Berries are black and oval shaped with a tough, slightly tannin-like skin. Berry mass is normally from 7 to 8 g, with a moderate to firm texture and a sweet, natural taste. Dan ben Hannah thrives well on most soil types, but it is generally not cultivated in very fertile soils because of its strong vigour. Dan ben Hannah has good affinity with most known rootstocks. Berry split might become a problem under unfavourable conditions, but to a lesser extent than in Alphonse Lavallée. Dan ben Hannah also has good storage ability (Anonymous, [S.a.]).

Waltham Cross was cultivated as a table grape cultivar in South Africa since 1910. The vigour and fruitfulness of this cultivar is considered medium. Bud burst occurs early in September, followed by full bloom in early November and harvest in the middle of February. Bunches are medium to large and have a conical-long shape, with a medium-loose density. Berries are large with an average berry mass of 8 g

and an oval-long shape. The berry colour is greenish-yellow, with a medium to firm texture, natural taste, and medium skin strength (Anonymous, [S.a.]).

The following sections of this chapter contain the relevant background information that was gathered for this project. The information that will be presented includes site selection, cultivar background, irrigation programmes, fertiliser programmes, climatic parameters, vine phenology and the statistical layout of measuring points within the blocks. These background parameters will provide a basic understanding of the management system used at the particular production unit, and establish the framework to interpret the results obtained and presented in chapters 4, 5 and 6 of this thesis.

3.2 MATERIALS AND METHODS

3.2.1 SITE SELECTION

Only a few existing vineyards with table grapes produced under OHS were available for this study. One site, namely Vredenhof in the Paarl region, was chosen at the beginning of January 2001. Vredenhof provided two cultivars that were already established under conventional and OHS practices.

The OHS was introduced to both DBH and WC in the study blocks five months prior to the starting date of the study. The DBH block was originally established in 1978. In August 2000, when the block was approximately 22 years old, one hectare was changed from micro-irrigation to drip irrigation and managed under OHS. The same procedure was followed in a WC block, which was established in 1984, and was thus approximately 16 years old when the system change took place in August 2000. All the relevant information gathered in these blocks was for the one full growing season in 2001/2002 only.

3.2.2 PRIMARY OR BASE DESCRIPTION PER CULTIVAR

3.2.2.1 Base description per block

To establish a meaningful base for this study, the aim of this section was to gather as much background information as possible on the cultivation practises for DBH and WC under conventional and OHS production at Vredenhof. An appointment was made with the production manager, during which the relevant historical information was obtained easily due to the good recordkeeping system at Vredenhof.

3.2.2.2 Phenological stages chosen for the accurate determination of results

For this project, only 10 phenological stages were chosen to monitor vine growth throughout the season. The stages were chosen on the basis of visual identification in the field. The stages therefore had to be physically discernable as the vines grew during the season. The initiation dates for each phenological stage for both conventionally and OHS-grown DBH and WC were recorded.

3.2.2.3 Irrigation and fertiliser programmes

The irrigation programmes were also obtained from the production manager. The fertiliser programmes for the 2001 season were collected from the responsible consultant, and the 2002 fertiliser program was obtained from the production manager.

3.2.2.4 Climatic parameters

Vredenhof has an automatic weather station on the farm. All the relevant data are sent automatically to AgroMet at the ARC Institute at Infruitec Nietvoorbij. Any section of data can be collected electronically, and daily and monthly summaries are provided. The relevant data for this study included the records from January 2001 to August 2002. The data were analysed and presented as monthly average parameters.

3.2.3 STATISTICAL LAYOUT WITHIN THE BLOCKS

Old soil maps containing information on the study blocks were studied to plan the layout of the experimental plots. The layout of the two cultivar blocks was done statistically to ensure an even spread of measuring points throughout the blocks. As many as possible measurements were done at these points, which were marked within the block.

Thirty-two groups of three vines each were selected for each treatment for each cultivar. Thus, 96 vines for conventionally grown DBH, 96 vines for OHS-grown DBH, 96 vines for conventionally grown WC and 96 vines for OHS-grown WC were chosen and marked with plastic bands.

The five vines at each end of a row were not included in the layout because of outside factors, such as soil compaction due to roads next to the vineyard, which could have an influence on the data. Diseased vines and vines with exceptionally strong or poor growth were also excluded from the study.

Frequent visual inspections of the marked vines were carried out in the vineyard throughout the project to ensure that the plastic bands were always in place. During the winter season in 2002, three soil pits were made by hand in the vineyard for each of the four treatments. Old soil maps were studied, and the pits were made in the Glenrosa soil type, which was represented within each of the four treatments according to the old soil maps.

3.3 RESULTS AND DISCUSSION

3.3.1 PRIMARY OR BASE DESCRIPTION PER CULTIVAR

3.3.1.1 Base description per block

All relevant data received from the production manager were analysed and the most important background information and cultivation practices are summarised in Tables 3.1 and 3.2. Table 3.1 describes all the important criteria in the base description for the cultivation of DBH at the Vredenhof.

Table 3.1: A base description summary including all relevant data for DBH under both conventional and open air hydroponic production.

Criteria	Description
Cultivar	Dan ben Hannah
Rootstock	Ramsey
Planting date	1978
Total amount of vines planted	1085
Plant spacing	3.5 m between rows and 1.5 m between vines
Block size	2.762 ha (0.99 ha = OHS)
Soil type	Cartref, Clovelly, Glenrosa, Longlands, Westleigh
Irrigation – Conventional	Microjet sprinklers (32 L/h)
Irrigation – Hydroponic	Drippers – 2.3 L RAM – 0.75 spacing
Pruning method	Stronger canes – 10 buds allocated Weaker canes – 8 buds allocated 8 to 10 bearers per vine
Trellis system	Gable system
Weed control	Chemical control Roundup @ 3 L/ha in August Roundup @ 3 L/ha in October Simazine flo @ 3 L/ha in October
Girdling	5% flowering
Summer canopy management	Suckering at 30 cm shoot length Topping action once during season
Yield control	Weak shoots – no bunches Strong shoots – 2 bunches
Diseases, insects and pests present	Oidium Downy mildew Mealybug

Table 3.2 describes the important management practices for the cultivation of WC at Vredenhof.

Table 3.2: A base description summary including all relevant data for WC under both conventional and open air hydroponic production.

Criteria	Description
Cultivar	Waltham Cross
Rootstock	Ramsey
Planting date	1984
Total amount of vines planted	2035
Plant spacing	3.5 m between rows and 1.5 m between vines
Block size	3.07 ha (1.07 ha = OHS)
Soil type	Cartref, Clovelly, Glenrosa, Avalon, Longlands
Irrigation – Conventional	Microjet sprinklers (32 L/h)
Irrigation – Hydroponic	2.3 L RAM – 0.75 spacing
Pruning method	Stronger canes – 8 buds allocated Weaker canes – 6 buds allocated 8 to 10 bearers per vine
Weed control	Chemical Roundup @ 3 L/ha – August Roundup @ 3 L/ha – October Simazine flo @ 3 L/ha – October
Girdling	5% flowering
Summer canopy management	Suckering with bud burst Topping action once during season
Yield control	Weak shoots – No bunches Stronger shoots – 2 bunches
Diseases, insects and pests present	Downy mildew Mealybug Fruit fly

3.3.1.2 Phenological stages selected

The development of plants can be influenced by temperature, heat units or photoperiod, amongst others. The life cycle of adapted plants is synchronised with seasonal changes in the average climate through the influence of photoperiod and/or temperature on development, resulting in an optimal phenology (Hall, 2001).

Phenology is the sequence of developmental events during the life cycle of a plant that is determined by environmental conditions (Hall, 2001), and is therefore a series of natural phenomena that recur periodically (Coombe, 2000).

The literature on viticulture divides grapevine phenology into as many as 47 different stages in one season. All these phenological stages cannot be recognised in the field, as some of them take place within the vine structure. It is critical to monitor phenology in the field to be able to make management decisions throughout the season for the production of table grapes. The 10 phenological stages selected for this study, their descriptions and their initiation dates are shown in Table 3.3.

From the beginning of the season, DBH grown under OHS showed earlier bud burst than that under the conventional treatment, although the pruning dates for both treatments were the same (9 July - 15 July). As the season progressed, the difference of one day between bud burst under OHS and under conventional treatments became two days for the beginning of flowering, three days for fruit set and four days for véraison and colour development. Harvest started on the same day for DBH under both treatments.

The situation for WC was almost the same as for DBH, although bud burst was initiated on the same day. The pruning dates were the same as for DBH. A three-day difference was noted between WC grown under OHS and under conventional systems in respect of véraison and colour development. The harvest of WC grapes from both treatments started on the same day.

3.3.1.3 Irrigation scheduling

Since the planting of DBH in 1978 and of WC in 1984, the two cultivars have been irrigated only by micro-sprinklers. In the winter season of 2000, one hectare of each cultivar was changed to drip irrigation, with fertilisation taking place through the drip lines as described in section 3.3.1.4.

Both conventionally grown DBH and WC are irrigated via microjets or sprinklers (32 L/h). During the winter, no additional water was given to the conventionally treated cultivars through the irrigation system. Irrigation scheduling only started later, in the spring, when soil water was being depleted. One set of two tensiometers was used to schedule the irrigation for the conventionally treated DBH. Two sets of two tensiometers each were used for the conventionally treated WC, one of which was placed in the upper part of the block and the other in the lower part. A set of two tensiometers consisted of a shorter tensiometer placed at a soil depth of 30 cm, and a longer tensiometer placed at 60 cm. The irrigation season started on 1 October 2001, but the first tensiometer reading was taken the 11 October 2001. The

tensiometers were monitored every two to six days and the irrigation was scheduled according to the soil water matric potential. When the tensiometer at a depth of 30 cm reached -20 to -25 kPa, irrigation would be applied for two hours if the tensiometer at a depth of 60 cm gave a reading less than -30 kPa. If the 60 cm tensiometer read between -30 and -35 kPa, three hours of continuous irrigation was applied (Figures 3.1 to 3.3).

Hydroponically-grown DBH and WC received one pulse of drip irrigation for 30 minutes per day during winter. Each vine has two drippers (2.3 L RAM), one on either side of it. The vines are spaced 1.5 m apart, thus the drippers are spaced 0.75 m apart. At the end of October, two pulses of 30 minutes each per day was given to WC, and a few days later to DBH. No more than three pulses ranging from 20 to 40 minutes each per day was given during the growth season. Irrigation amounts were determined in terms of the calculated total amount (L) of water per vine per day. The total amount of water was divided into two to three irrigation pulses (Figures 3.4 to 3.7). The tensiometers were monitored daily at 08h00, 12h00 and 17h00.

Figure 3.1 shows the average soil water matric potential for the conventionally treated DBH. In comparison to the OHS-treated DBH (Fig. 3.4 to 3.5), the conventionally treated vines received more fluctuating irrigation between véraison and harvest. The subsoil (60 cm tensiometer) would dry out to almost -70 kPa and irrigation would then be applied until the topsoil (30 cm) nearly reached saturation point. The OHS-treated DBH was irrigated more consistently between véraison and harvest. The topsoil never dried out past -20 kPa for both the upper and lower block. Severe soil water depletion was induced in the OHS-treated DBH after harvest, although not in the conventionally treated vines.

The irrigation applied to the conventionally treated WC (northern and southern parts of the block) was more consistent than that applied to the conventionally treated DBH. The soil matric potential was never allowed to reach -40 kPa before harvest in the OHS-treated WC (upper and lower parts of the block). The same regime as that for DBH was followed post harvest.

Table 3.3: Phenological maps for DBH and WC under conventional and hydroponic production at Vredenhof, Paarl in the 2001/2002 season.

	Phenological stage		Approx. duration (days)	Initiation date			
				Dan ben Hannah		Waltham Cross	
No.	Description			Conventional	Hydroponic	Conventional	Hydroponic
1	Bud burst – 10 cm shoot length		14	18/09/2001	17/09/2001	19/09/2001	19/09/2001
2	10 cm shoot length – Beginning of flowering		28	22/09/2001	21/09/2001	04/10/2001	03/10/2001
3	Beginning of flowering – Fruit set		7	21/10/2001	19/10/2001	02/11/2001	31/10/2001
4	Fruit set – Beginning of véraison		40	29/10/2001	26/10/2001	09/11/2001	07/11/2001
5	Véraison		7	10/12/2001	06/12/2001	20/12/2001	17/12/2001
6	Colour development – Beginning of harvest		30	17/12/2001	13/12/2001	05/01/2002	02/01/2002
7	Harvest		18	23/01/2002	23/01/2002	01/02/2002	01/02/2002
8a	Post harvest – 3 weeks post harvest		38	14/02/2002	14/02/2002	25/02/2002	25/02/2002
8b	3 weeks post harvest – End of leaf fall		45	21/03/2002	21/03/2002	28/03/2002	28/03/2002
8c	Beginning of dormancy		31	02/05/2002	02/05/2002	15/05/2002	15/05/2002
9	Dormancy – Initiation of bleed at pruning wounds		76	07/06/2002	06/06/2002	18/06/2002	18/06/2002
10	Initiation of bleed – Just before bud burst		31	28/08/2002	27/08/2002	28/08/2002	27/08/2002
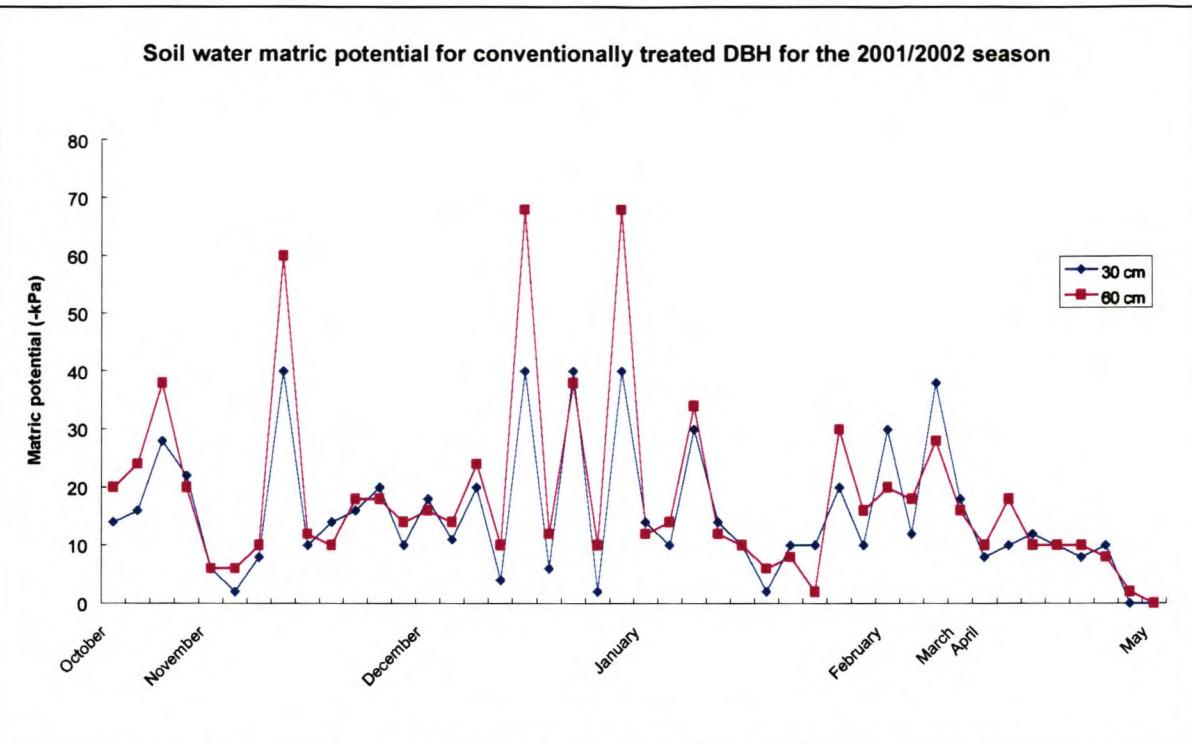
Figure 3.1: The average soil water matric potential for conventionally treated DBH. The season started on 11/10/2001 and ended on 01/05/2002.
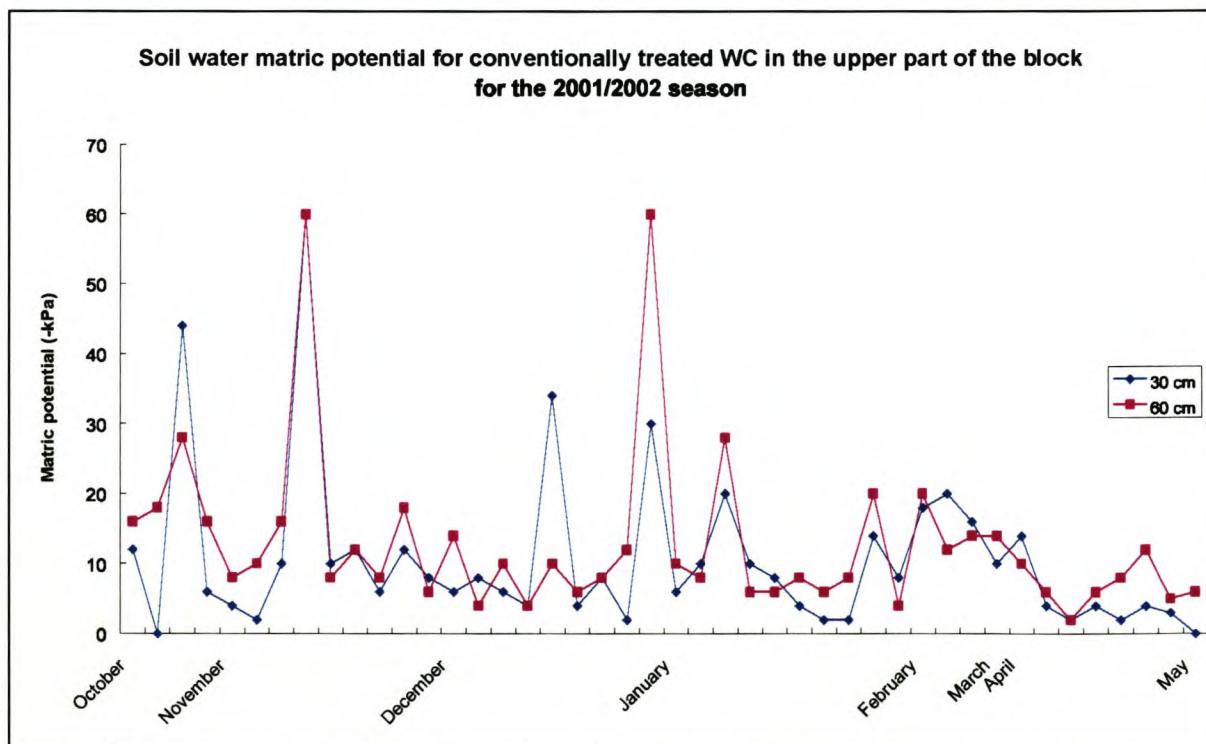
Figure 3.2: The average soil water matric potential for the upper part of the WC block treated conventionally. The season started on 11/10/2001 and ended on 01/05/2002.
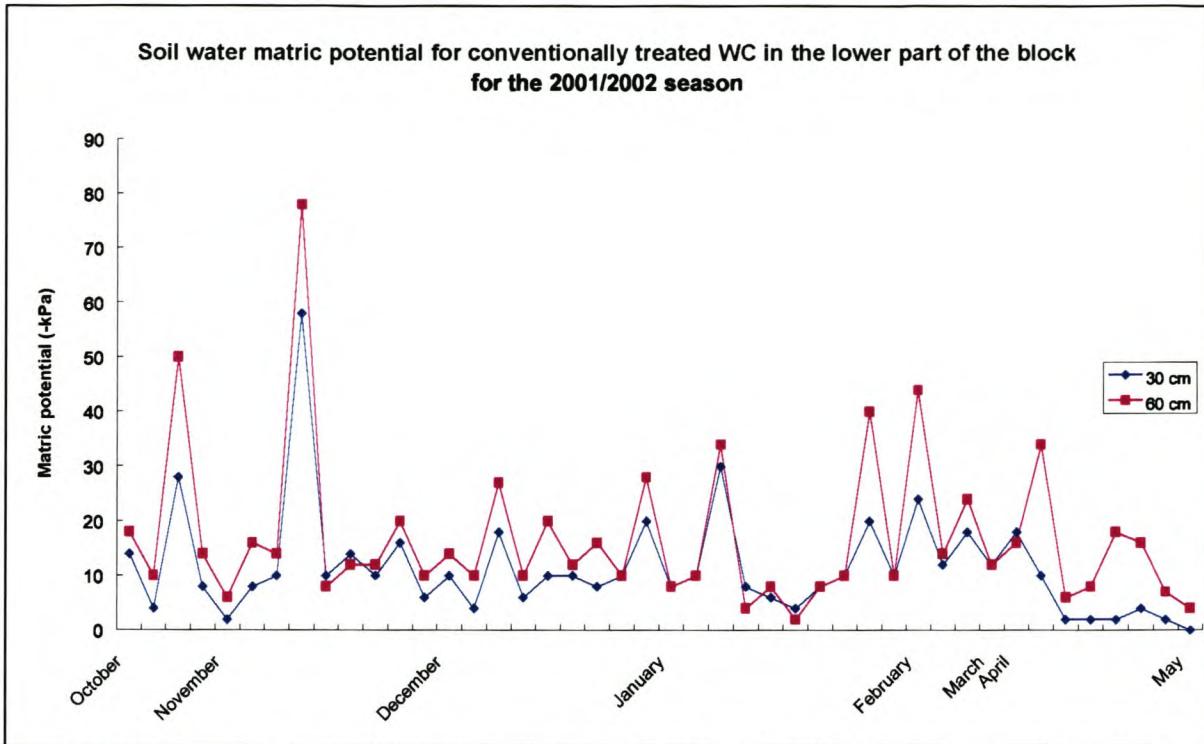
Figure 3.3: The average soil water matric potential for the lower part of the WC block treated conventionally. The season started on 11/10/2001 and ended on 01/05/2002.
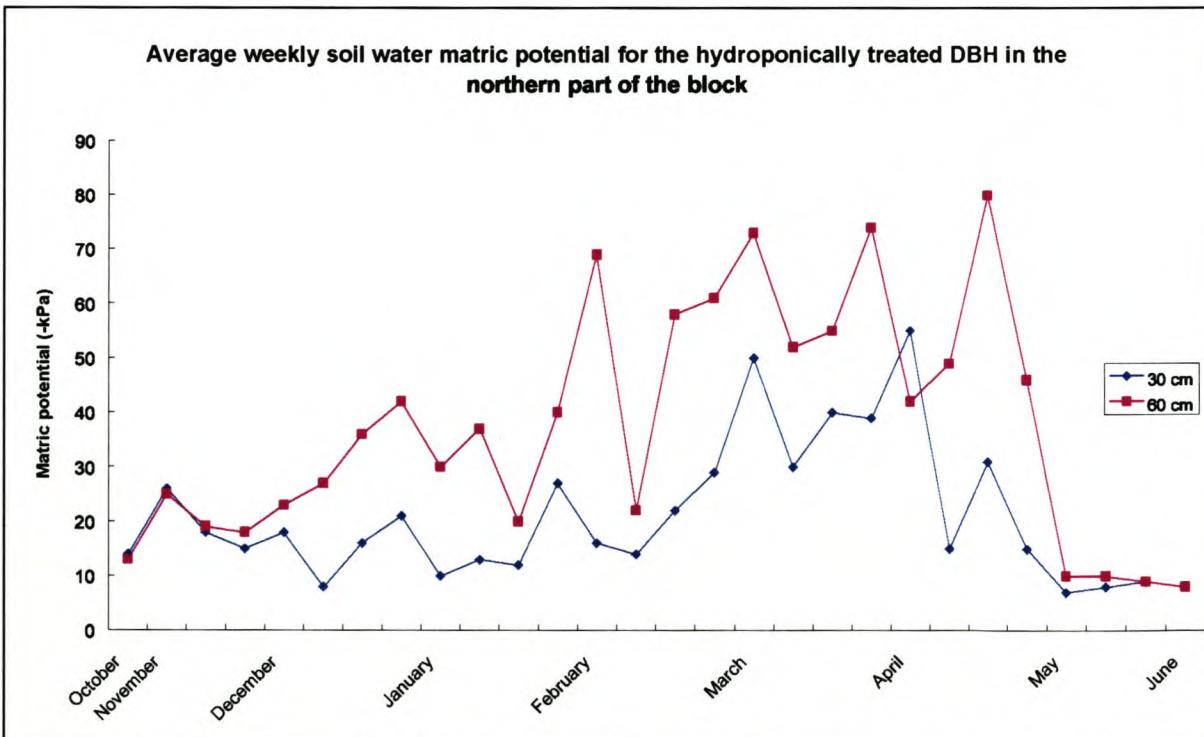
Figure 3.4: The average soil water matric potential for the northern part of the DBH block treated hydroponically. Water application started at the end of October 2001 and ended in June 2002.

Average weekly soil water matric potential for the hydroponically treated DBH in the southern part of the block
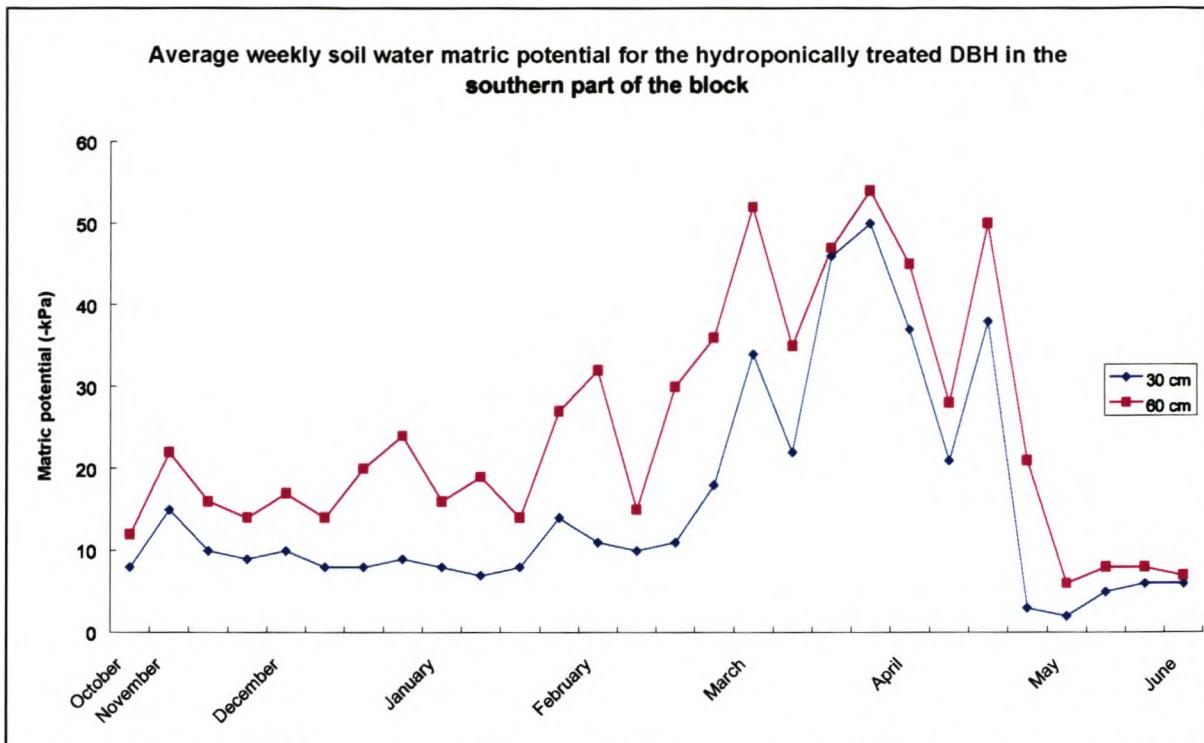
Figure 3.5: The average soil water matric potential for the southern part of the DBH block treated hydroponically. Water application started at the end of October 2001 and ended in June 2002.

Average weekly soil water matric potential for the hydroponically treated WC in the northern part of the block
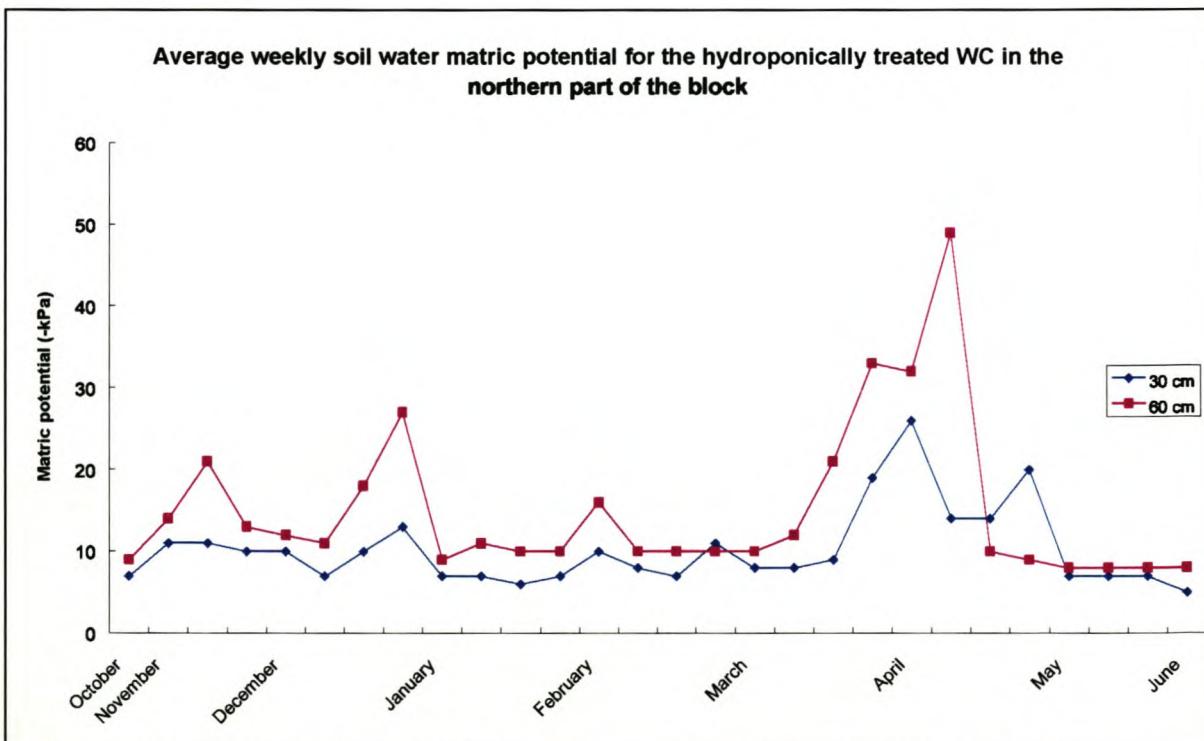
Figure 3.6: The average soil water matric potential for the northern part of the WC block treated hydroponically. Water application started at the end of October 2001 and ended in June 2002.
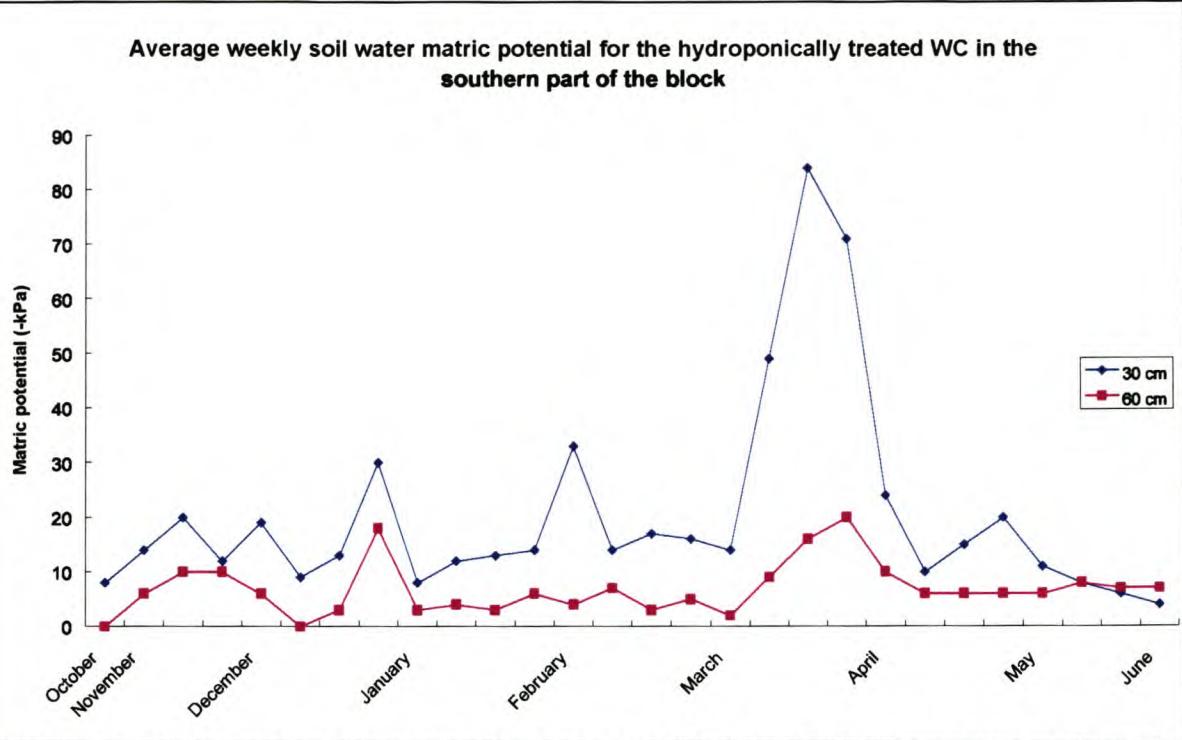
Figure 3.7: The average soil water matric potential for the southern part of the DBH block treated hydroponically. Water application started at the end of October 2001 and ended in June 2002.

3.3.1.4 Fertilisation programmes

The fertiliser programme for conventionally grown DBH and WC is adapted every year according to the needs of the plants. However, the conventional fertiliser programme for DBH and WC stayed the same for both the 2000/2001 and 2001/2002 seasons. The need for fertilisers is determined by leaf blade and petiole analyses at different critical phenological stages. The fertiliser programme for the conventionally grown DBH and WC is summarised in Table 3.4.

The fertiliser programmes for the OHS-treated DBH and WC started at the end of October 2000. From August 2000 until the winter season of 2001, a separate fertiliser programme was followed for each cultivar. This programme was developed by an outside irrigation and fertiliser consultant. During the winter season of 2001, the fertiliser programme was changed to a single one for both DBH and WC, administered and developed by a different consultant.

During the 2000/2001 season, three separate tanks were used for the fertiliser mixtures, namely the Ca tank, the Fe tank and the mixture tank for OHS-grown DBH and WC. The Ca and Fe were put in separate tanks because negative interactions between the elements can cause precipitation. For both DBH and WC, the pH of the water arriving at the vines through the drip lines was kept between 5.8 and 6.3.

Table 3.4: Fertiliser programmes for conventionally grown DBH and WC for the 2001/2002 season. The WC block was divided into a northern and a southern part due to soil differences.

Phenological stage	Fertiliser	Dan ben Hannah	Waltham Cross	Waltham Cross
			South	North
		Kg/ha/block		
Bud Burst	LAN	0	450	0
	1.0.1. *	0	0	0
Post flowering Berry set	1.0.1.(36) *	0	0	0
	1.0.0.(40) *	0	0	0
Post harvest	1.0.1.(36) *	290	0	321
	1.0.0.(40) *	0	292	0

* The NPK ratio with the total amount of active ingredient in brackets.

The fertiliser programme for the 2000/2001 season is summarised in Tables 3.5 and 3.6. Table 3.5 deals with the OHS-treated DBH, and Table 3.6 with OHS-treated WC. Table 3.7 shows the combined fertiliser programme for OHS-treated DBH and WC for the 2001/2002 season (the study season). The elemental breakdown of both the conventional and OHS fertiliser programmes for DBH and WC is shown in Tables 3.8 and 3.9 respectively. These tables also include the microelement fertilisers.

Table 3.8 shows significant differences for the individual elements applied to DBH over the two seasons. Twice as much N was given to the OHS-treated DBH in 2000/2001 than to the conventionally treated DBH. In the 2001/2002 season, the amount of N given hydroponically was even higher than in the previous season. The OHS-treated vines received three times as much K in 2000/2001 than the conventionally grown DBH. Phosphorus was significantly higher in the OHS-treated vines in 2001/2002 than in 2000/2001. Elements such as S and Mg were higher for the OHS-treated vines in 2000/2001, and Ca was higher in the 2001/2002 season. The microelements B, Zn and Mn were higher for the OHS-treated vines in the 2000/2001 season, while Cu, Mo and Fe were lower.

The amount of N for the conventionally treated WC was significantly higher in the northern part of the block because of different soil types (Table 3.9). The same situation with regard to N and P occurred for the OHS-treated WC and DBH vines. The amount of K for the OHS-treated vines was lower in the 2000/2001 season, although Ca was higher. With regard to Mg, S and the microelements, the situation for DBH and WC was the same. Only the amount of Fe for the OHS-treated vines was exactly the same in both seasons.

Table 3.5: The OHS fertiliser programme for the different tanks and phenological stages used for DBH during the 2000/2001 season.

Fertiliser	Amounts applied	Phenological stage *												
		1	2	3	4	5	6	7	8a	8b	8c	9	10	Total
Tank A (Calcium tank)														
Kynitro 19%	L	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcium nitrate flakes	Kg	26	87	22	72	19	46	25	53	80	40	46	28	544
Calcium chloride	Kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Iron tank														
Micrel Fe 130 Fe-EDTA 13%	Kg	0.4	0.83	0.21	0.55	0.25	0.99	0.50	0.43	0.71	0.28	1.25	0.37	6.77
Mixing tank														
Potassium nitrate	Kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Magnesium nitrate	Kg	22	44	5	3	0	2	0	32	80	30	22	18	258
Potassium chloride	Kg	2	9	1	8	9	0	8	11	0	5	11	0	64
Nitric acid 55% sd=1.34	L	0	0	0	0	0	0	0	0	0	0	0	0	0
Kynoso 23P	L	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonium phosphate (Agrifos)	Kg	8	19	3	6	2	5	4	9	21	10	8	4	99
Mono-potassium phosphate (Climax)	Kg	12	2	2	12	6	30	14	4	8	3	2	0	95
Magnesium sulphate (10%)	Kg	2	11	5	30	7	18	9	14	0	5	11	4	116
Solupotasse K_2SO_4	Kg	15	25	10	19	12	53	37	17	50	16	9	12	275
Solubor (B: 20.5%) (Agribor)	Kg	0.28	0.57	0.09	0.25	0.11	0.42	0.23	0.20	0.33	0.13	0.57	0.26	3.44
Zinc sulphate $ZnSO_4.7H_2O$ 22%	Kg	0.21	0.35	0.09	0.23	0.11	0.44	0.21	0.16	0.27	0.11	0.53	0.16	2.87
Manganese sulphate $MnSO_4.H_2O$	Kg	0.12	0.27	0.06	0.15	0.08	0.27	0.13	0.10	0.17	0.07	0.34	0.12	1.88
Copper sulphate $CuSO_4.5H_2O$	Kg	0.01	0.03	0.01	0.02	0.01	0.04	0.02	0.01	0.02	0.01	0.04	0.01	0.23
Sodium molybdenum $Na_2MoO_4.2H_2O$	Kg	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.04

* Refers to descriptions provided in Table 3.3.

Table 3.6: The OHS fertiliser programme for the different tanks and phenological stages used for WC during the 2000/2001 season.

Fertiliser	Amounts applied	Phenological stage *												
		1	2	3	4	5	6	7	8a	8b	8c	9	10	Total
Tank A (Calcium tank)														
Kynitro 19%	L	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcium nitrate flakes	Kg	28	93	24	78	20	49	27	57	86	43	49	30	586
Calcium chloride	Kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Iron tank														
Micrel Fe 130 Fe-EDTA 13%	Kg	0.45	0.89	0.22	0.59	0.27	1.07	0.53	0.46	0.77	0.31	1.35	0.40	7.31
Mixing tank														
Potassium nitrate	Kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Magnesium nitrate	Kg	24	47	5	3	0	2	0	35	56	32	24	19	247
Potassium chloride	Kg	2	10	1	9	9	0	1	12	0	5	12	0	61
Nitric acid 55% sd=1.34	L	0	0	0	0	0	0	0	0	0	0	0	0	0
Kynoso 23P	L	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonium phosphate (Agrifos)	Kg	9	21	3	6	2	5	5	10	23	11	9	5	109
Mono-potassium phosphate (Climax)	Kg	12	2	2	12	6	32	15	5	9	3	2	0	100
Magnesium sulphate (10%)	Kg	2	12	5	32	7	20	10	15	1	6	12	4	126
Solupotasse K$_2$SO$_4$	Kg	17	27	10	20	13	68	40	19	53	15	10	13	305
Solubor (B: 20.5%) (Agribor)	Kg	0.31	0.61	0.10	0.27	0.11	0.45	0.25	0.21	0.35	0.14	0.62	0.28	3.7
Zinc sulphate ZnSO$_4$.7H$_2$O 22%	Kg	0.23	0.38	0.09	0.25	0.12	0.47	0.23	0.17	0.29	0.12	0.57	0.17	3.09
Manganese sulphate MnSO$_4$.H$_2$O	Kg	0.14	0.29	0.06	0.16	0.09	0.29	0.14	0.11	0.18	0.07	0.36	0.13	2.02
Copper sulphate CuSO$_4$.5H$_2$O	Kg	0.02	0.03	0.01	0.02	0.01	0.04	0.02	0.02	0.03	0.01	0.05	0.01	0.27
Sodium molybdenum Na$_2$MoO$_4$.2H$_2$O	Kg	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.04

* Refers to descriptions provided in Table 3.3.

Table 3.7: The OHS fertiliser programme used for both DBH and WC during the 2001/2002 season according to the selected phenological stages shown in Table 3.3.

Fertiliser	Amounts applied	Phenological stages												Total
		1	2	3	4	5	6	7	8a	8b	8c	9	10	
Tank A														
AN19	Kg/ha/phenological stage	0	0	0	0	0	0	0	13	25	11	0	0	49
P. acid		9	21	5	31	7	29	16	13	28	13	14	7	193
1.0.1.(14)		32	67	12	119	24	83	46	135	222	66	0	0	806
MAP		0	0	0	0	0	0	0	0	0	0	0	0	0
$MgSO_4$		18	29	2	1	1	1	1	1	14	16	28	24	136
K_2SO_4		7	12	6	19	12	30	20	0	0	5	12	6	129
MKP		0	0	0	0	0	0	0	0	0	0	0	0	0
Tank B														
KNO_3	Kg/ha/phenological stage	0	0	0	0	0	0	0	0	0	0	0	0	0
$CaNO_3$		40	124	28	120	5	5	5	5	41	45	84	54	556
$MgNO_3$		0	0	0	0	0	0	0	0	0	0	0	0	0

Trace elements: (g/tank A): Kynotem GA 833 g

Table 3.8: The total amount of individual fertiliser elements applied to conventionally and OHS-treated DBH vines in the 2000/2001 and 2001/2002 seasons.

Season	Cultivar	Treatment	Fertiliser product	Total amount applied kg/ha	kg/ha											
					N	P	K	Ca	Mg	S	B	Zn	Mn	Cu	Mo	Fe
2000/2001 2001/2002	DBH	Conventional	1.0.1. (36%)	290	52		52									
TOTAL					52		52									
2000/2001	DBH	OHS	CaNO$_3$ flakes	544	87			103								
			MgNO$_3$	258	28				23							
			MgSO$_4$	116					12	15						
			MPK	95		22	27									
			KCl	64			32									
			K$_2$SO$_4$ powder	275			116			50						
			Solubor (21%)	3.44							0.72					
			ZnSO$_4$.7H$_2$O (22%)	2.87								0.63				
			MnSO$_4$.H$_2$O (32%)	1.88									0.60			
			CuSO$_4$.5H$_2$O (26%)	0.23										0.06		
			Na$_2$MoO$_4$.H$_2$O (40%)	0.04											0.02	
			FeEDTA (13%)	6.77												0.88
TOTAL					115	22	175	103	35	65	0.72	0.63	0.60	0.06	0.02	0.88
2001/2002	DBH	OHS	AN (19% N)	49.014	9											
			Kynosol (23%)	193.8		45										
			1.0.1. (14)	806.13	56		56									
			CaNO$_3$ flakes	556	89			106								
			MgSO$_4$	136					14	18						
			K$_2$SO$_4$ powder	129			54			23						
			FeEDTA (13%) [KYNOTEM]	6.08												0.95
			MnEDTA (13%) [KYNOTEM]	3.22									0.50			
			ZnEDTA (15%) [KYNOTEM]	2.03								0.37				
			CuEDTA (15%) [KYNOTEM]	0.38										0.07		
			Ultrabor (17%) [KYNOTEM]	1.97							0.40					
			Na$_2$MoO$_4$ (39.50%) [KYNOTEM]	0.32											0.15	
TOTAL					154	45	110	106	14	41	0.40	0.37	0.50	0.07	0.15	0.95

Table 3.9: The total amount of individual fertiliser elements applied to conventionally and OHS-treated WC vines in the 2000/2001 and 2001/2002 seasons.

Season	Cultivar	Treatment	Fertiliser product	Total amount applied kg/ha	kg/ha											
					N	P	K	Ca	Mg	S	B	Zn	Mn	Cu	Mo	Fe
2000/2001 2001/2002	WC	Conventional (North)	1.0.1. (36%)	321	58		58									
TOTAL					58		58									
2000/2001 2001/2002	WC	Conventional (South)	KAN (28%)	450	126											
			1.0.0. (40%)	292	117											
TOTAL					243											
2000/2001	WC	OHS	CaNO₃ flakes	586	94			111								
			MgNO₃	247	27				22							
			MgSO₄	126					13	16						
			MPK	100		23	28									
			KCl	61			31									
			K₂SO₄ powder	305			28			55						
			Solubor (21%)	3.70							0.78					
			ZnSO₄.7H₂O (22%)	3.09								0.68				
			MnSO₄.H₂O (32%)	2.02									0.65			
			CuSO₄.5H₂O (26%)	0.27										0.07		
			Na₂MoO₄.H₂O (40%)	0.04											0.02	
			FeEDTA (13%)	7.31												0.95
TOTAL					121	23	87	111	35	71	0.78	0.68	0.65	0.07	0.02	0.95
2001/2002	WC	OHS	AN (19% N)	49.14	9											
			Kynosol (23%)	193.80		45										
			1.0.1. (14)	806.13	56		56									
			CaNO₃ flakes	556	89			106								
			MgSO₄	136					14	18						
			K₂SO₄ powder	129			54			23						
			FeEDTA (13%) *(KYNOTEM)*	6.08												0.95
			MnEDTA (13%) *(KYNOTEM)*	3.22									0.50			
			ZnEDTA (15%) *(KYNOTEM)*	2.03								0.37				
			CuEDTA (15%) *(KYNOTEM)*	0.38										0.07		
			Ultrabor (17%) *(KYNOTEM)*	1.97							0.40					
			Na₂MoO₄ (39.50%) *(KYNOTEM)*	0.32											0.15	
TOTAL					154	45	110	106	14	41	0.40	0.37	0.50	0.07	0.15	0.95

3.3.1.5 Climatic parameters

Daily data for all the available parameters were collected and converted to monthly data giving average, highest and lowest parameters. The parameters used were maximum temperature (Max T), minimum temperature (Min T), average temperature (Ave T), rainfall, evapotranspiration, wind, maximum humidity (Max H) and minimum humidity (Min H). Table 3.10 gives a summary of the monthly averages of the parameters from January 2001 to August 2002. The values for wind in August 2002 were not calculated because a problem with the wind meter led to the data being logged incorrectly.

Climatic parameters also played a role during the new season, which started in September 2001. Figures 3.8 and 3.9 show the minimum and maximum temperatures for the 2001/2002 season in comparison to the mean maximum and minimum temperatures for the preceding 10 seasons (1991 to 2001). Figure 3.10 shows the average rainfall for the 2001/2002 season in comparison to the average rainfall over the preceding 10 seasons (1991 to 2001).

Table 3.10: Monthly averages of climatic parameters for the production unit, Vredenhof.

Parameter 2001	Month	Max T °C	Min T °C	Ave T °C	Rain mm	Evap mm	Wind Km/day	Max H %	Min H %
Average		28.53	16.64	22.60	0.143	9.85	298.68	78.94	38.55
Highest	1	36	23	29.5	4.4	16	651.90	96	55
Lowest		18	11	14.5	0	3	103.60	40	24
Average		31.45	18.8	25.15	0.54	10.98	353.53	74	34.29
Highest	2	39	28	33.5	11.5	15	733.50	93	54
Lowest		20	10.5	17.5	0	6	147.70	51	19
Average		28.68	15.24	21.98	0	7.68	248.03	82.87	37.61
Highest	3	34	20	26	0	14	690.10	91	55
Lowest		22	12	18.5	0	1	99.30	54	17
Average		23.96	14.26	19.07	1.94	4.98	208.80	83.64	50.48
Highest	4	34	21.5	27.5	18	11	545.50	91	89
Lowest		15	7.5	12	0	0.5	90.30	46	29
Average		21.53	10.5	16.04	3.71	3.13	165.02	86.90	46.16
Highest	5	31.5	19	24.5	48	7	497.90	91	85
Lowest		13	4	10	0	0.4	65.70	58	24
Average		18.45	8.10	13.3	2.78	2.18	136.67	87.73	50.9
Highest	6	25.5	16	20.8	30.5	10.5	448.90	100	82
Lowest		11.5	2.5	9.3	0	0	54.40	51	30
Average		17.56	9.85	13.73	8.78	2.28	210.37	85.03	55.35
Highest	7	28	17	21.5	55.5	6	439	95	89
Lowest		10	3.5	8.3	0	0	79.2	51	29

|									
Average		16.61	10.72	13.69	6.37	2.49	250.85	87.26	58.19
Highest	8	28	17	19.8	29.6	8	556.3	95	89
Lowest		13	7	11	0	0	64.1	50	23
Average		19.13	12.51	15.84	2.62	3.79	245.15	86.4	54.67
Highest	9	29.5	20.9	23.7	14.3	8	522.7	94	84
Lowest		12	8	10.3	0	0	76.9	48	21
Average		23.63	15.54	19.61	2.19	6.13	271.65	82.71	46.52
Highest	10	33.5	23.5	28.5	32.2	12	513	93	79
Lowest		16.5	10.5	14.5	0	0.6	119.2	45	24
Average		26.49	17.25	21.90	2.58	8.95	300.01	80.03	43.67
Highest	11	34.5	24	28.3	58.5	18	766.5	97	69
Lowest		17.5	12	15.8	0	0	91.5	48	23
Average		27.95	16.42	22.20	0.08	8.97	288.46	82.14	38.29
Highest	12	36	23.5	29.7	2.5	13	517.4	95	55
Lowest		20.2	11.5	17.6	0	1	151.3	53	20
Average		26.7	15.4	21	26	8.3	280.9	88	45
Highest	1	33.0	22.0	27	38.7	14.0	723.7	97	60
Lowest		18.0	10.9	15.5	0	2.2	138.4	60	26
Average		30.8	18.9	24.8	0.8	9.8	299.6	77	34
Highest	2	38.0	26.4	32.2	10.0	18.0	567.2	93	56
Lowest		21.0	12.0	17.8	0	1.2	141.4	49	19
Average		29.8	15.2	22.2	0.6	6.9	200.2	87	38
Highest	3	36.0	24.4	29.7	13.6	11.0	537.3	91	51
Lowest		19.0	8.5	13.8	0	2.0	104.1	55	21
Average		25.2	13.2	19.3	2.1	4.3	187.2	85	41
Highest	4	33.0	20.9	25.7	29.2	8.0	149.0	95	84
Lowest		17.0	7.8	15.0	0	0.2	88.1	45	16
Average		19.9	9.6	14.8	3.6	2.5	160.8	88	49
Highest	5	32.0	15.0	21.8	23.5	6.0	346.1	91	75
Lowest		12.0	3.0	9.0	0	0.1	47.2	84	22
Average		16.4	7.4	11.9	4.2	2.0	156.6	88	57
Highest	6	26.0	12.5	16.8	19.8	5.0	360.2	97	87
Lowest		11.0	2.5	7.3	0	0	52.3	80	27
Average		16.6	7.5	12.1	4.4	2.2	158.0	92	61
Highest	7	23.5	14.7	18.9	22.6	5.5	362.1	97	90
Lowest		11.0	3.0	8.0	0	0.1	57.1	62	36
Average		18.8	9.3	14.1	3.7	3.6	***	77	37
Highest	8	29.5	18.8	22.5	40	6.4	***	99	75
Lowest		12.3	4.4	9.6	0	0.0	***	39	10
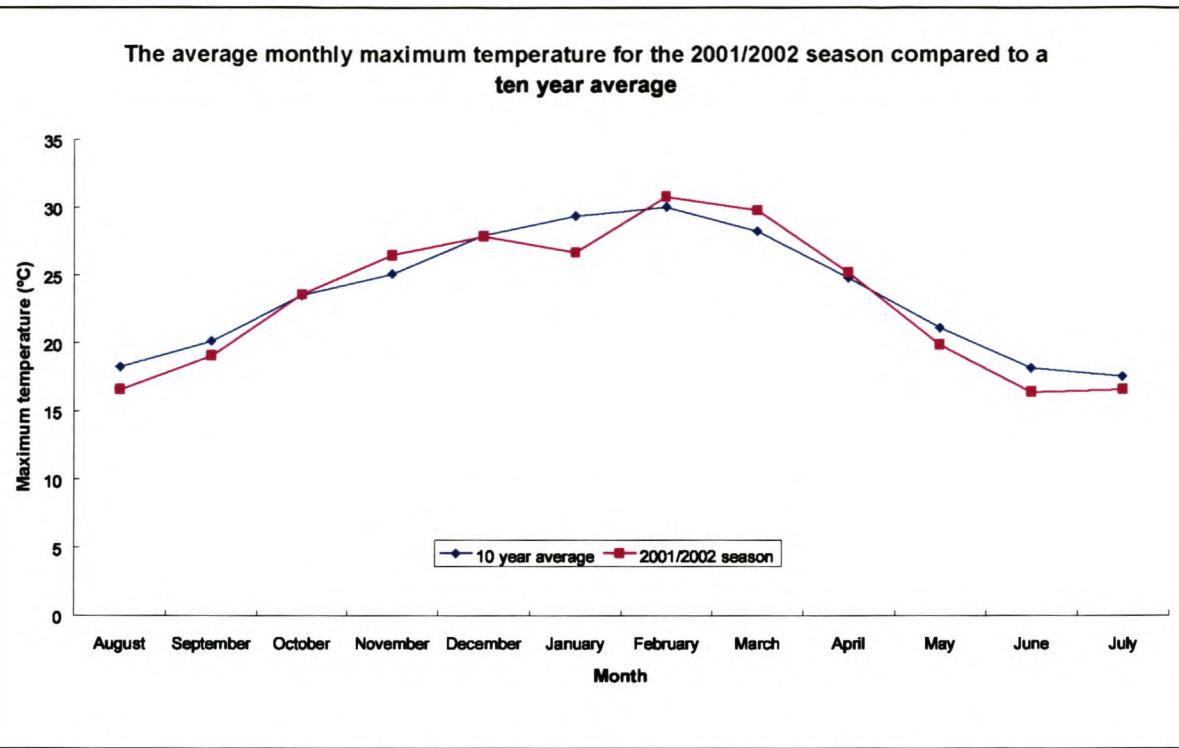
Figure 3.8: The average monthly maximum temperature for the 2001/2002 season at Vredenhof compared to the 1991 to 2001 10-year averages.
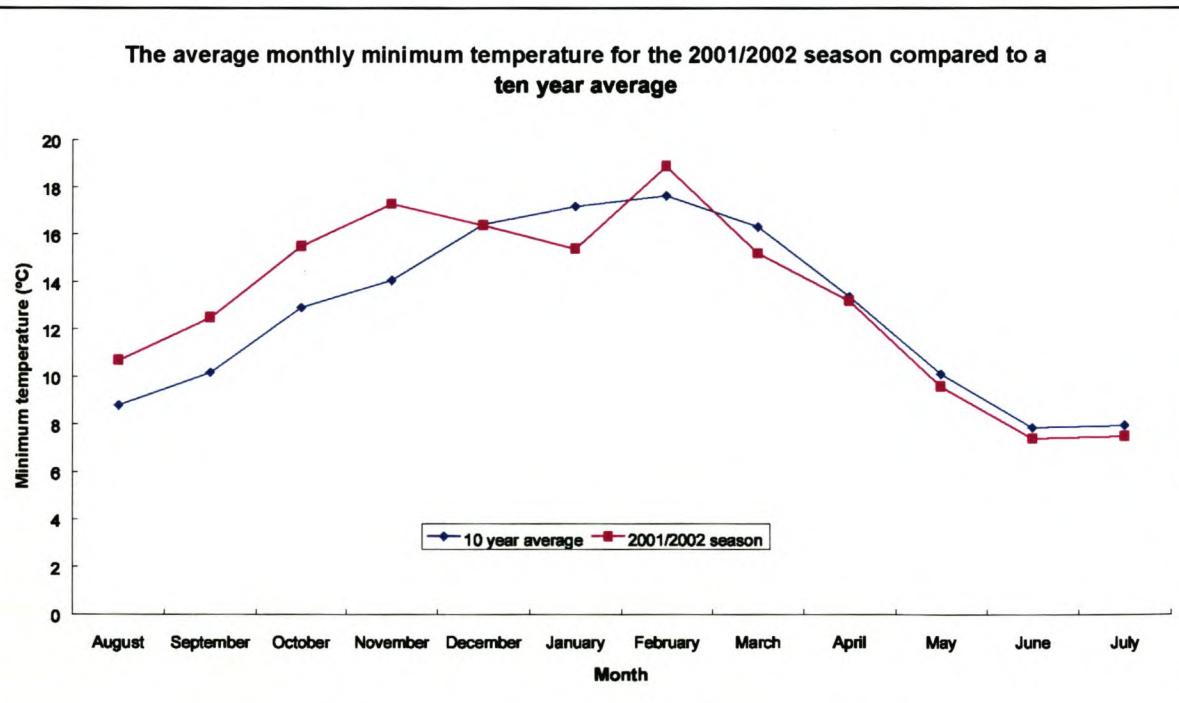
Figure 3.9: The average monthly maximum temperature for the 2001/2002 season at Vredenhof compared to the 1991 to 2001 10-year averages.

The average monthly minimum temperature for the 2001/2002 season compared to a ten year average
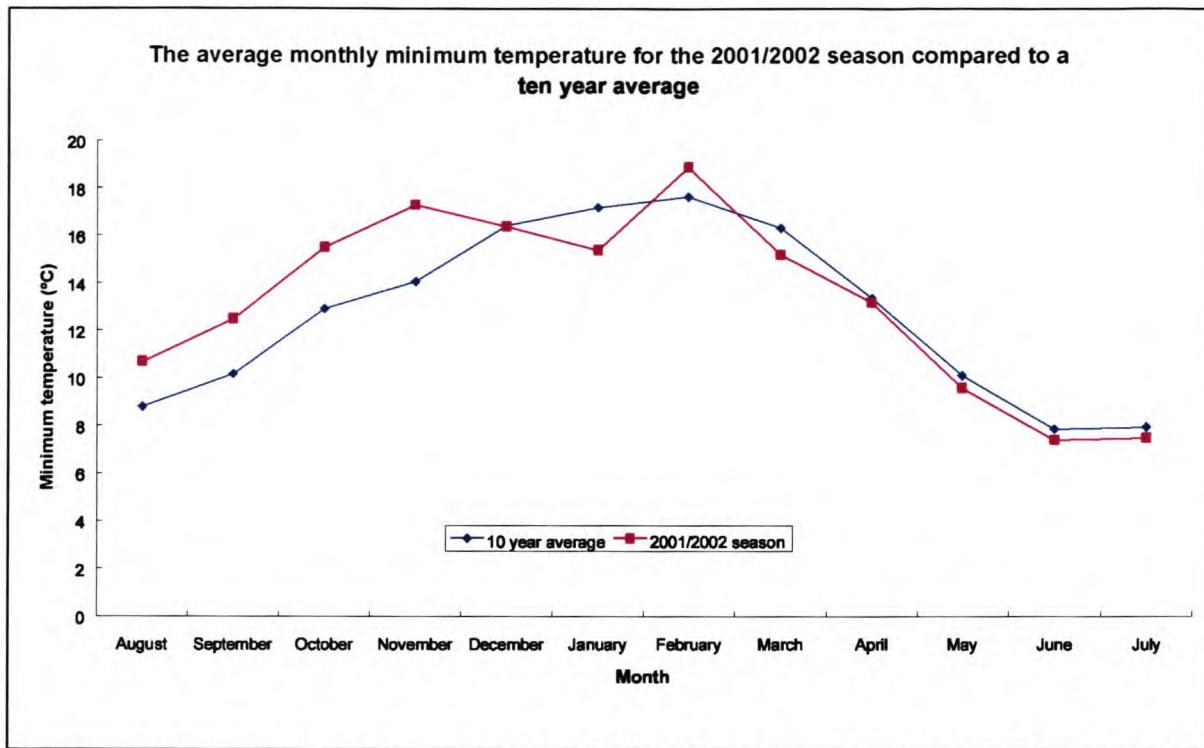
Figure 3.10: The total monthly rainfall for the 2001/2002 season at Vredenhof compared to the 1991 to 2001 10-year averages.

The average maximum temperature for the 2001/2002 season was the same as the average maximum temperature for the previous 10 seasons (Fig. 3.8). However, the average minimum temperature showed a significant difference compared to the average minimum temperature for the previous 10 seasons. From August until the end of November, the average minimum temperature was 2 to 3°C higher in the 2001/2002 season. From December until the end of the season, the average minimum temperature was closer to the average minimum temperature for the previous 10 seasons (Fig. 3.9). Overall, the total monthly rainfall was higher during the 2001/2002 season, except for December 2001 and June 2002, which could have resulted in more excessive vine growth.

3.3.2 STATISTICAL LAYOUT WITHIN THE BLOCKS

After careful study of the blocks and block maps, it was found that the DBH block consisted of 40 rows, 3 m apart, and 135 vines per row, 1.5 m apart. The WC block consisted of 46 rows, also 3 m apart, and between 100 and 150 vines per row, 1.5 m apart. The rows become longer in a westerly direction (Fig. 3.1 and 3.2). Rows number one to 25 of DBH were grown conventionally, while rows number 26 to 40 were changed to OHS in the winter of 2000. Rows one to 18 of WC were changed to OHS in the winter of 2000, while rows 19 to 46 were grown conventionally. This gives approximately one hectare of each cultivar under OHS. Figures 3.1 and 3.2 show the layout of these block maps, indicating the selected vines and soil pits mentioned earlier in this chapter.
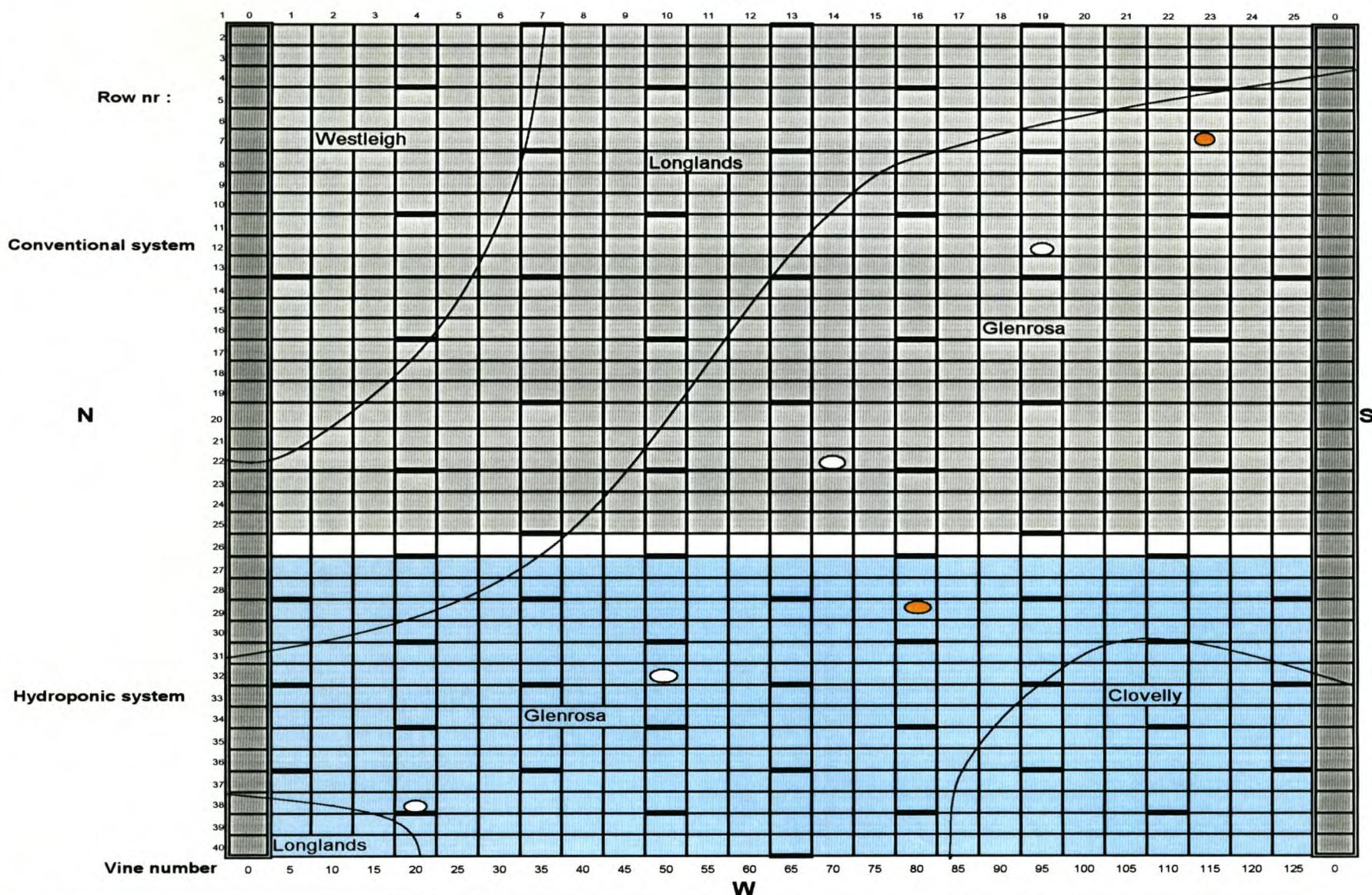
Figure 3.1: The layout of measuring points for both conventionally and hydroponically-grown DBH, where the darkened lines represent the measuring points and the ovals represent the soil pits. The red ovals are the evaluated soil pits.
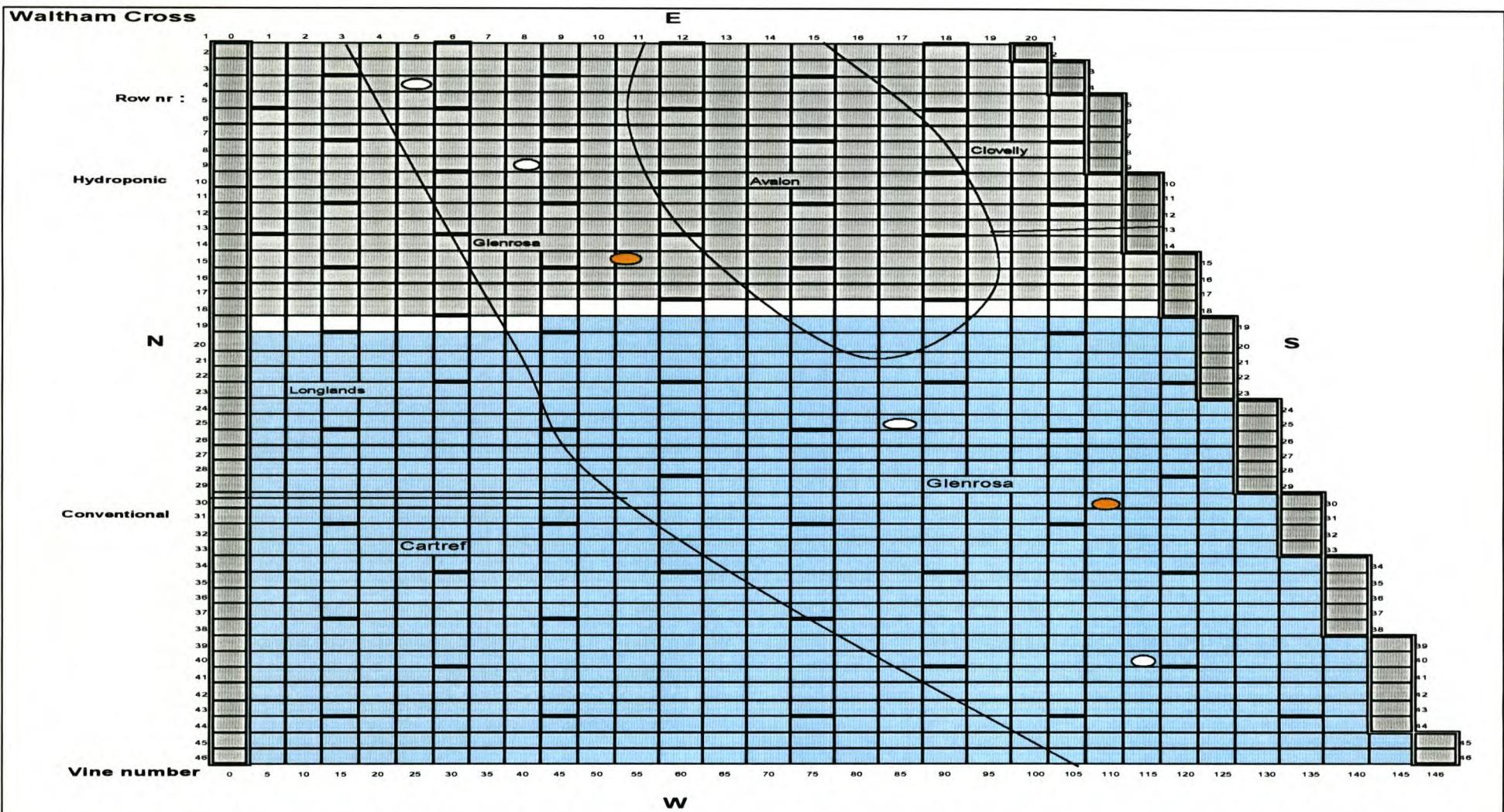
Figure 3.2: The layout of measuring points for both conventionally and hydroponically-grown WC, where the darkened lines represent the measuring points and the ovals represent the soil pits. The red ovals are the evaluated soil pits.

3.4 CONCLUDING REMARKS

The system change from micro to drip irrigation, as discussed in section 3.2 of this chapter, meant that the vine roots had to adapt their manner of growth. The adaptation of the roots to a new irrigation system had an effect on the vines, yield and fruit quality (Chapters 4, 5 and 6). In the winter of 2001, the producer changed from one fertiliser consultant to another, and the fertiliser programmes were therefore also changed. The climatic parameters measured during the 2001/2002 season also played a role in the data produced in this project. Higher average minimum temperatures at the beginning of the season and a higher monthly rainfall than normal could have caused more excessive vine growth, which is normally associated with poor fruit colour and quality.

3.5 LITERATURE CITED

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Chapter 4

RESEARCH RESULTS

The influence of conventional and open air hydroponic systems on root distribution, taking the soil status into account

RESEARCH RESULTS

4.1 INTRODUCTION

Roots are a key component of the soil-plant-atmosphere continuum. For horticultural crops, including those grown in greenhouses and containers, roots play a critical role with respect to the provision of water and nutrients for shoot and root growth and development. The roots also provide a foundation to anchor the vine to the soil medium. This is especially important for crops cultivated under normal soil or field conditions, but not as critical for horticultural crops grown under OHS (Hoogenboom, 1999).

Plant growth in all rooting media, including soil, is hydroponic, since elements absorbed by the plant roots must be in a water-based solution. The complexity of the chemistry of the soil solution is significantly simplified, however, when the support medium is inert, such as in sand, gravel, perlite and rockwool culture, and becomes even simpler when the plant roots are suspended in a nutrient solution (Hall, 2001).

In this study, the grapevines were situated in soil for both the conventional and OHS cultivation. The soil therefore had an impact on the OHS in this study. The aim of this chapter is to evaluate the soil status and the root growth and development of grapevines to determine the extent of their impact on OHS in comparison to a conventional system. Both cultivars were initially established under micro-irrigation and cultivated for 16 to 20 years before approximately one hectare of each was changed to drip irrigation (OHS). One of the most prominent questions to be answered in this chapter relates to the adaptation ability from a conventional micro-irrigation system to OHS. The soil structure, texture and chemical composition were analysed and the chemical analyses were linked to the nutritional status of the soil, enabling the determination of the exact influence of the soil on OHS production.

4.2 MATERIALS AND METHODS

4.2.1 ROOT DISTRIBUTION

Three soil profile pits were made by hand for both the conventionally and OHS-treated DBH and WC in the winter season of 2002. All the pits were studied closely, and the most representative one for each treatment was selected. Each pit was made 1 m deep, 1 m wide and 3 m in length, parallel to the row direction within the vineyard. The easterly soil horizons were exposed in all four profiles, with one vine centred for root investigation. The placement of these pits was 60 cm from the vine. A soil hammer was used to work the horizon back to 50 cm from the vine to expose the roots.

All the soil was carefully cleaned from the roots, which were cut to approximately 10 cm in length and then painted with white spray paint. All the paint was removed

from the soil profile to provide a contrasting background for the white roots. White elastic bands were used to provide the soil profile with a grid-like structure. The grid was kept in place with eight-inch nails that were hammered into the soil.

The first grid line was placed vertically into the pit in line with the vine trunk. Two other lines were placed at 20 cm intervals alongside the first line. The process was repeated until the middle grid line had four lines on either side, thus 80 cm on both sides. Grid lines were placed 20 cm apart horizontally from the soil surface up to one meter, leading to the demarcation of square blocks of 20 cm x 20 cm.

The soil profile containing the grid was photographed with an Epson digital camera. The four photos were modified with Corel Draw to insert labels for each block.

After all the relevant analyses had been done in each soil pit and the photographs had been taken, a horizontal layer around each vine was washed away with water under high pressure. About 20 cm of the topsoil was removed, revealing the fine root structure of each vine. Digital images of the fine roots were taken from either the top or the side.

4.2.2 SOIL ANALYSES AND THE DETERMINATION OF SOIL PH IN DIFFERENT SOIL LAYERS

Representative soil samples for each treatment were taken at three different soil depths. A sample for each of the 0 to 30, 30 to 60 and 60 to 90 cm fractions was collected in plastic bags and sent to Bemlab (Somerset West) for analysis. The samples were taken within the root zone 30 cm away from the vine. The analyses on the samples included all normal parameters, such as soil type, soil pH, resistance, H concentration, stone content, P, K, C, exchangeable cations and microelement concentrations.

The soil pH was determined for each of the five 20 cm horizontal layers. After photographing the soil profiles, a small soil sample was taken from the specific 20 cm layer in each block. These samples were put together in a plastic bag and mixed thoroughly. The five bags, one for each 20 cm soil layer, for each of the four soil pits were sent to Bemlab in Somerset West for determination of the soil pH in the different layers.

4.2.3 SOIL DENSITY

Soil density was measured with a penetrometer at five different places in each of the 40 blocks per treatment. The penetrometer measures in kg/cm^2 units and is held horizontally to the soil profile, as described by Van Huyssteen (1983). The meter was gently forced into the soil layer. The resistance or compactness of the soil was measured for one cubic centimetre. The average of the five measurements per block was calculated and given in the form of a figure that represents the exact soil profile seen on the digital images.

4.3 RESULTS

4.3.1 ROOT DISTRIBUTION

4.3.1.1 Conventionally and hydroponically grown Dan ben Hannah

The results for the root distribution will be discussed according to the digital images (Figures 4.1 to 4.4). The soil profile in Figure 4.1 shows five horizontal soil layers marked A to E. The soil profile in Figure 4.2 was not as deep, thus only four horizontal soil layers (A to D) are visible.

The conventional soil profile (Fig. 4.1) shows a dense, evenly distributed layer of fine roots in the top horizontal layer (A), 50 cm away from the vine trunk. Figure 4.3 shows a frontal view of the fine root distribution for conventionally grown DBH. The evenly distributed fine root system can clearly be seen, together with the irrigation system. The OHS soil profile shows fewer fine roots in layer A of Figure 4.2, but Figure 4.4 shows clearly that the root system adapted to the position of the drip lines. This image was taken from the back of the vine and revealed clumps of fine roots situated underneath the individual drippers (Fig. 4.4). Within two growing seasons after the system changed, all the fine roots in a radius of 50 cm around the trunks of the vines had died and the new, active fine roots had adapted to the OHS system.

Under both conventional and OHS production, a few thick and older roots were present in the deeper soil layers. However, more thick roots were visible in layers B to D of Figure 4.2 (OHS production) than in layers B to E (conventional production) of Fig. 4.1.

4.3.1.2 Conventionally and hydroponically grown Waltham Cross

The root distribution results for WC will be discussed with reference to the digital images in Figures 4.5 to 4.8. Figure 4.5 has four horizontal soil layers and Figure 4.6 has five, due to a deeper soil pit.

More fine roots can be seen in soil layer A of the conventionally grown WC (Fig. 4.5), whereas fewer fine roots can be observed in the corresponding areas for the OHS-treated WC (Fig. 4.6). It is clear that the fine roots also developed underneath the drip lines after the system was changed to OHS (Fig. 4.8).

Figure 4.7 shows a frontal view of the fine root distribution of the conventionally grown WC. The fine root system of the conventionally grown WC could not be seen clearly because the roots and the soil have almost the same colour.

More thick and older roots were visible in the deeper soil layers for the conventionally treated WC than for the OHS-treated WC. The root distribution and soil colour in both treatments were very uneven.

Figure 4.1: Root distribution of conventionally grown DBH.

Figure 4.2: Root distribution of hydroponically grown DBH.

Figure 4.3: Fine root distribution of conventionally grown DBH.

Figure 4.4: Fine root distribution of hydroponically grown DBH. The white arrows indicate the position of the drippers.

**Figure 4.5:** Root distribution of conventionally grown WC.
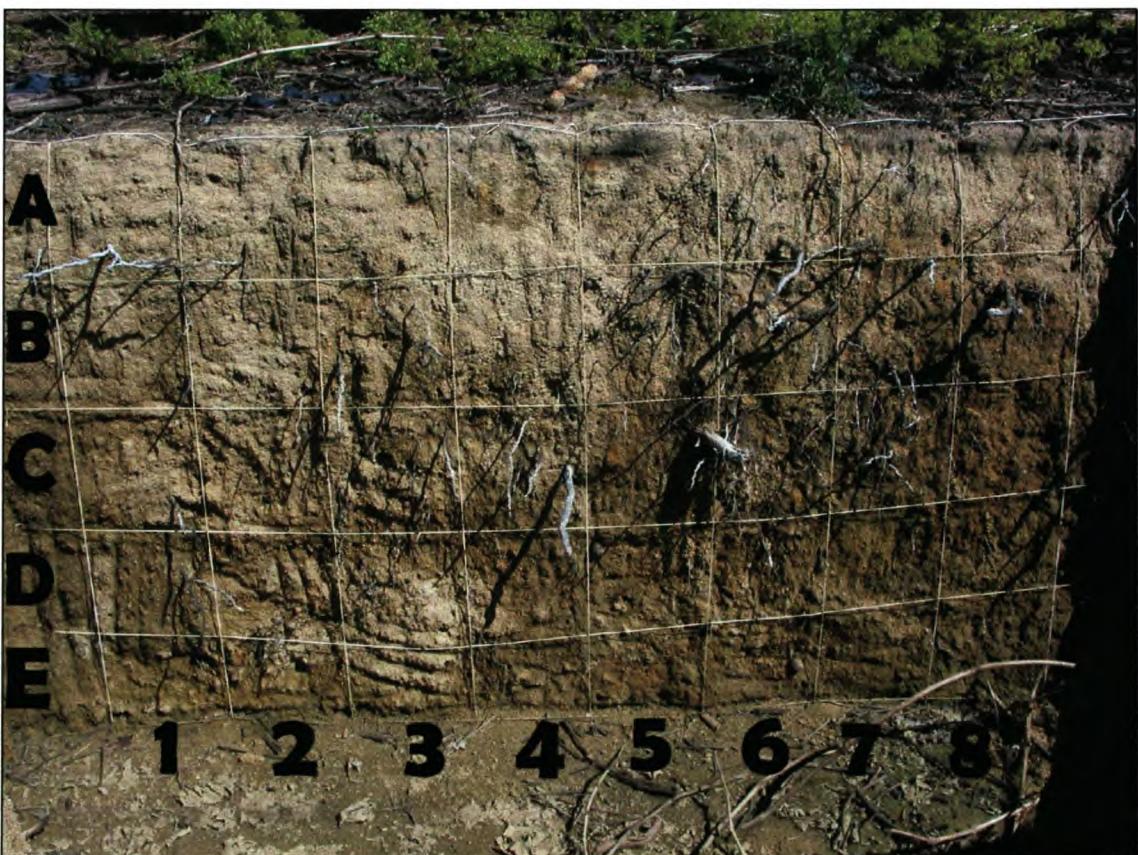
Figure 4.6: Root distribution of hydroponically grown WC.

Figure 4.7: Fine root distribution of conventionally grown WC.

Figure 4.8: Fine root distribution of hydroponically grown WC. The white arrows indicate the position of the drippers.

4.3.2 SOIL ANALYSES AND THE DETERMINATION OF SOIL PH IN DIFFERENT SOIL LAYERS

The areas for the soil profile pits were chosen carefully on the basis of old soil maps. According to the old maps, the soil type Glenrosa was present in both cultivar blocks and also within the different treatments. After the soil pits had been made, it became clear that the soil type was not a Glenrosa form for all four treatments, and this was also proven by the soil analyses. The soil type for all four treatments was identified as Tukulu forms with different clay contents. The soil for the conventionally treated DBH had a lower clay content than the OHS treated DBH. The clay content for both WC treatments was basically the same (Personal communication, Dr F.B. Ellis, Department of Soil Science, Stellenbosch University). The soil analyses for DBH under OHS and conventional cultivation will be discussed with reference to Table 4.1 and for WC under OHS and conventional cultivation with reference to Table 4.2.

In DBH, the first difference is the soil type. Conventionally grown DBH is situated in a sandy soil, whereas the OHS-treated DBH is situated in a loamy soil because of a higher clay content.

There is no difference in the percentage of stones in any of the layers in either the conventionally or OHS-treated DBH. The soil resistance, however, is much higher for the conventionally grown DBH. Soil resistance is a tool to determine the amount of soluble salts in the soil (Soil Classification Work Group, 1991). The soluble salt content should therefore be lower in the soil of conventionally grown DBH. The amounts of H, P, K and C available in the soil were higher in all three depth layers for OHS-treated DBH. The C content gives an indication of the organic N content in the soil. To determine the N status of the soil, the C% should be taken into consideration. If the C% is multiplied by a factor of 1.7, the result will give the organic material content of the soil (Conradie, 2001).

All the exchangeable cations were higher in the OHS-treated DBH. However, the difference for Na was not as significant as for K, Ca and Mg. There was no difference in Na content at the different soil depths between the conventional or OHS treatment of DBH.

The microelement content of Cu, Zn, Mn and B were lower in the first layer or topsoil (0 to 30 cm deep) of conventionally grown DBH. In the second soil layer (30 to 60 cm), the elemental content of Zn, Cu and Mn, but not B, was higher and, in the third layer (60 to 90 cm), the elemental content for Cu, Mn and B was lower for the conventionally grown DBH.

In both the conventionally and OHS-treated WC, the soil type was loam. There were no differences in stone content and C content in the two top soil layers for the conventionally and OHS-treated WC. The C content for the conventionally grown WC was higher than for the OHS-treated WC. The amount of soluble salts in the first two layers (0 to 60 cm) of the OHS-treated WC was lower because of the high resistance.

The P content for OHS-treated WC was higher in all three depth layers, whereas the amount of K was lower in all three layers.

All exchangeable cations (Na, K, Ca and Mg) were lower in all three soil layers of the OHS-treated WC. The microelements Mn and B also had a lower content in all three depth layers in the OHS-treated WC. The only difference was that Cu and Zn were higher in content in the second layer (30 to 60 cm) for OHS-treated WC.

The soil pH for the conventionally grown DBH was much higher in all three depth layers than for the OHS-treated DBH, especially in the top soil layer (0 to 30 cm). In both treatments, the top layer (0 to 30 cm) had a higher pH value than the deeper layers. The deeper soil layers in both the conventional and OHS treatment tend to be closer in pH value. See Table 4.3 for a more refined image of the soil pH across the five identified depth layers.

The soil pH for the conventionally grown WC was higher for the top soil layer (0 to 30 cm) than for the OHS-treated WC. The same result was obtained from the soil analyses for DBH, but WC was not as severe. There was no difference between the subsoil layers (30 to 90 cm) for conventionally and OHS-treated WC. Table 4.3 also shows the results for the pH differences in the different soil layers of conventionally and OHS-treated WC. The deeper the soil layer, the less is the difference in pH within these soil layers for both conventionally and OHS-treated WC.

Table 4.1: Soil analyses for DBH.

Treatment	Conventional			Hydroponic		
Depth	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm
Soil type	Sand	Sand	Sand	Loam	Loam	Loam
pH (KCl)	6.3	5.8	5.4	5.6	5.1	5.1
Resistance (Ohm)	4440	5240	4830	1550	2480	2220
H (cmol/kg)	0	0.23	0.27	0.41	0.45	0.45
Stone (Vol %)	2	3	3	1	2	2
P (mg/kg)	94	127	76	53	29	50
K (mg/kg)	28	37	26	182	140	98
C (%)	0.28	0.23	0.19	0.77	0.39	0.35
Exchangeable cations (% saturation)						
Na	1.99	3.39	2.92	1.01	1.99	2.52
K	3.59	5.52	5.10	7.83	8.88	6.24
Ca	74.44	63.88	56.53	59.00	58.60	57.91
Mg	19.99	13.88	14.73	25.28	19.35	22.19
Exchangeable cations (cmol/kg)						
Na	0.04	0.06	0.04	0.06	0.08	0.10
K	0.07	0.10	0.07	0.47	0.36	0.25
Ca	1.49	1.10	0.74	3.52	2.36	2.34
Mg	0.40	0.24	0.19	1.51	0.78	0.90
Microelements (mg/kg)						
Cu	11.41	5.68	2.88	22.04	3.72	5.89
Zn	4.4	3.4	2.3	8.2	1.1	2.0
Mn	12.6	10.5	4.8	14.5	4.1	6.5
B	0.14	0.17	0.29	1.36	0.94	0.50

Table 4.2: Soil analyses for WC (Southern part of the block).

Treatment	Conventional			Hydroponic		
Depth	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm
Soil type	Loam	Loam	Loam	Loam	Loam	Loam
pH (KCl)	5.9	4.9	4.9	5.3	4.8	4.9
Resistance (Ohm)	2070	2860	2550	3090	4090	2790
H (cmol/kg)	0.27	0.50	0.54	0.41	0.41	0.45
Stone (Vol %)	1	2	1	3	2	2
P (mg/kg)	53	23	30	101	86	82
K (mg/kg)	141	91	113	115	72	67
C (%)	0.48	0.30	0.34	0.44	0.31	0.20
Exchangeable cations (% saturation)						
Na	1.25	1.03	1.33	1.21	2.19	2.23
K	8.14	8.01	6.36	7.42	8.10	8.69
Ca	59.89	53.42	61.56	69.48	51.61	55.89
Mg	19.43	19.79	13.98	16.34	20.77	16.93
Exchangeable cations (cmol/kg)						
Na	0.06	0.06	0.07	0.05	0.02	0.04
K	0.36	0.23	0.29	0.30	0.19	0.17
Ca	3.38	1.49	1.86	2.17	1.23	1.65
Mg	0.80	0.60	0.56	0.71	0.46	0.37
Microelements (mg/kg)						
Cu	35.59	2.65	4.38	17.22	4.10	1.43
Zn	8.4	1.0	1.1	5.5	1.4	0.7
Mn	24.2	8.1	9.5	12.8	6.4	7.9
B	1.18	0.57	0.34	0.60	0.20	0.20

Table 4.3: Soil pH (KCl) within different soil depth layers for conventionally and hydroponically grown DBH and WC.

Soil layer	Depth	Dan ben Hannah		Waltham Cross	
	cm	Conventional	Hydroponic	Conventional	Hydroponic
A	0-20	6.4	5.8	6.0	5.5
B	20-40	6.1	5.5	5.8	5.0
C	40-60	5.8	5.4	5.3	4.9
D	60-80	5.4	5.1	4.9	4.7
E	80-100	5.4	5.1	4.7	4.7

4.3.3 SOIL DENSITY

Figures 4.9 to 4.12 are based on the different digital images (Figures 4.1 to 4.2 and 4.5 to 4.6) showing the grid-like soil profiles and the same numbering for the individual blocks. The values in the blocks represent the density of the soil in that area measured in $kg.cm^{-2}$. Each value is the average of five measurements in that specific block. The higher the soil density, the higher the value obtained.

The soil compaction for OHS-treated DBH (Fig. 4.10) and WC (Fig. 4.12) is higher in the top soil layers (row A for both cultivars) than for the conventionally grown DBH and WC. It is clear that fewer roots are found when the soil density for DBH under both treatments exceeds a value of 1.8 $kg.cm^{-2}$, and virtually no roots were found when the density exceeded 2.0 $kg.cm^{-2}$, as can be seen in Figures 4.1 and 4.2 earlier in this chapter.

A	1.24	1.1	1.34	1.1	1.2	0.83	1.17	1.3
B	1.5	2.17	2.88	1.8	1.62	2.02	1.98	1.08
C	1.67	1.3	1.72	1.82	1.8	1.38	1.78	1.76
D	2.5	1.99	1.22	2.48	1.90	1.52	1.58	1.98
E	2.07	2.58	1.26	1.32	2.46	2.88	2.42	1.54
	1	2	3	4	5	6	7	8

Fig. 4.9: Soil density in different soil depth layers for conventionally grown DBH.

A	1.86	1.42	1.2	1.78	1.7	1.4	1.22	1.58
B	1.26	1.68	1.24	1.92	1.42	1.16	1.18	1.42
C	1.22	0.72	0.78	1.38	1.5	1.08	1.82	1.22
D	1.1	0.98	1.04	1.68	2.46	1.16	1.12	0.86
	1	2	3	4	5	6	7	8

Fig. 4.10: Soil density in different soil depth layers for hydroponically grown DBH.

The scenario for WC was exactly the same as for DBH. Fewer roots were found in blocks in which the soil density exceeded 1.8 kg.cm^{-2}. No roots were found when the soil density exceeded a value of 2.0 kg.cm^{-2} (Figures 4.11 and 4.12).

In general, the OHS-treated DBH had only four blocks with a higher soil density (greater than 1.80 kg.cm^{-2}) than the conventional system, which had 17 blocks with a soil density higher than 1.80 kg.cm^{-2}. The results were exactly the opposite for WC. The soil in the case of conventionally grown WC was less dense, with only five blocks with density higher than 1.80 kg.cm^{-2}. The OHS-treated WC had 16 high density blocks.

A	1.46	1.62	1.18	1.28	1.08	1.36	1.18	1.14
B	1.3	1.52	1.14	1.58	1.74	1.52	1.96	1.24
C	1.32	1.22	1.14	1.44	0.92	1.28	2.06	1.54
D	1.82	1.74	2.32	1.22	0.94	1.14	1.48	1.32
	1	2	3	4	5	6	7	8

Fig. 4.11: Soil density in different soil depth layers for conventionally grown WC.

A	1.24	1.72	2.3	1.88	2.22	1.44	1.92	1.9
B	2.38	2.62	2.14	1.9	1.44	2.0	1.56	1.72
C	1.82	1.42	1.54	1.52	1.64	1.4	1.44	1.5
D	2.04	2.28	1.36	1.72	1.42	1.54	1.42	1.46
E	1.8	1.74	1.14	1.52	1.78	1.93	1.84	1.22
	1	2	3	4	5	6	7	8

Fig. 4.12: Soil density in different soil depth layers for hydroponically grown WC.

4.4 DISCUSSION

4.4.1 SOIL ANALYSES

The lower clay content in the soil for the conventionally grown DBH could have resulted in a higher infiltration rate for water. This might provide an explanation for the higher soil pH values in the conventionally grown DBH, where the accumulation

of nutrients was prevented in the root zone due to leaching. The higher soil resistance in the case of conventionally grown DBH (Table 4.1) was a direct effect of the lower amount of soluble salts in the soil. In this instance, however, the higher soil resistance in the conventionally grown DBH might also have been on account of a sandier soil type.

The lower amount of Ca in the soil of OHS-grown DBH might be due to the OHS system. The logical assumption is that the plant roots will absorb the Ca and that the Ca status in the OHS-grown plants will be higher. This kind of extrapolation is not always accurate, because interaction with other elements can depress Ca uptake via the root system. For example, excessive ammonium and K have depressing effects on Ca uptake. Also, the Ca availability is reduced in very alkaline soils (Mills & Jones, 1996).

The organic material content of the soil correlates with the amount of organic N represented by the same soil, thus C% can be used to give a broad spectrum of the N delivered by the soil (Conradie, 2001). The organic material content is normally higher in the top soil layer, as seen in the results for both DBH and WC. For WC, the C% within all the soil layers is not really different in the conventional and OHS treatments. This is due to the fact that the soil type is the same in both treatments. However, in the case of DBH, the loamy soil of the OHS treatment had a much higher ability to deliver N than the sandy soil of the conventional treatment. This effect might result in more vigorous vine growth and a poorer storage ability of table grapes (Conradie, 2001).

The distribution of microelements, soil resistance, stone content and H, P and K content were basically the same for the conventionally as well as OHS-treated WC. This is due to the fact that the soil type is the same.

The exchangeable cations (K, Ca and Mg) were higher for the OHS treated DBH, but lower for the OHS treated WC. The exchangeable Na were the same for both cultivars under conventional and OHS treatment. Both cultivars were exploited to OHS treatment for two seasons, and it was expected to have higher exchangeable cations due to the higher fertilisation rate. However, this only explains the situation for the OHS treated DBH and not for WC where the exchangeable cations are lower for the OHS treated cultivar. Sodium should be kept as low as possible (lower than 8%), Mg should be kept at 12 to 15%, K at 3 to 5% and Ca between 70 and 80% for a normal soil analysis (Personal communication, Dr W.A.G. Kotzé, Bemlab, AECI Building W21, De Beers Road, Somerset West).

The soil pH for both cultivars grown conventionally was higher than for the OHS-grown cultivars, especially in the top soil layer. This effect might be due to the concentrated nutrient status in the topsoil of the OHS-cultivated vines. For the OHS-grown WC, the soil pH in the top soil layer (0 to 30 cm) is lower than 5.5, which means that the amount of active hydrogen ions (H^+) is too high. This causes an acid problem in the soil that might affect root growth negatively (Van Schoor et al., 2000).

This phenomenon was also found in the subsoil layers of both cultivars treated conventionally and hydroponically.

The soil pH for both cultivars grown conventionally and hydroponically decreased with an increase in soil depth. The lower cation status in the subsoil layers and the higher N fertilisation rate, especially for the OHS treated cultivars, could be the explanation for the lower soil pH. There might also be competition between Ca and Al for binding sites, and if Ca leaches from the soil, Al causes higher acidity in the subsoil (Mills & Jones, 1996).

4.4.2 ROOT DISTRIBUTION

The conventional root distribution in DBH was in line with the expected patterns for micro-irrigation systems, with a layer of fine roots in the first few centimetres of the soil. The distribution was spread evenly 60 cm away from the vine. This kind of root distribution is due to a fine organic layer of topsoil with no compaction (Van Zyl, 1981).

The root system of the OHS-grown DBH showed no roots away from the vine trunk. The explanation for this phenomenon is that the vines managed to adapt their root systems well to the newly installed drip irrigation during two seasons. Fine roots appeared in clumps underneath the individual drippers (Van Zyl, 1988). The vines experienced some stress because there were more thick roots in the deeper soil layers of the OHS-treated vines and they therefore had to find water and nutrients deeper down in the soil, maybe possibly due to drought conditions (Van Zyl, 1981).

The situation is exactly the same for WC. The conventional system had a good root distribution in a radius of 50 to 60 cm around the vine, which correlated with the scenario for micro-irrigation. The OHS-treated vines showed adapted root systems within two seasons after drip irrigation had been installed.

For both cultivars, however, the soil colour was not evenly distributed throughout the profiles. In the case of all four treatments, this might be due to inefficient soil preparation or soil compaction.

4.4.3 SOIL DENSITY

Where the soil is hard and compact (1.80 kg.cm^{-2}), only a few vine roots will grow. No vine roots will be found in soil layers with a density of more than 2.0 kg.cm^{-2} (Van Huyssteen, 1989). The results for soil compactness in the case of both cultivars under conventional and OHS cultivation showed that there were no roots in the highly compact sections. This statement confirmed that roots will find the easiest way through the soil to water and nutrients. This is also a reason why the fine roots of OHS-grown cultivars only grow underneath the drip lines. The soil density in both OHS systems was slightly higher in the top soil layer than in the conventional systems. This might be due to the difference in soil type in the case of DBH.

4.5 CONCLUDING REMARKS

To study the effect of OHS on vine growth, soil status must be taken into account. The soil type and depth had an indirect influence on the soil composition, soil pH and soil density. These factors influence grapevine root distribution in collaboration with climatic parameters, irrigation scheduling and fertiliser programmes. In terms of grapevine root distribution, both cultivars adapted within two seasons from an extensive micro irrigation programme to a more intensive OHS programme.

4.6 LITERATURE CITED

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Chapter 5

RESEARCH RESULTS

The influence of open air hydroponic systems on vegetative parameters for Dan ben Hannah and Waltham Cross in comparison to conventional systems

RESEARCH RESULTS

5.1 INTRODUCTION

The vegetative growth of grapevines starts in the springtime with bud burst, followed by shoot and leaf growth. Shoot lignification in the autumn and trunk thickening are also regarded as vegetative growth.

If vegetative growth is dense due to excessive water and nutrients and optimal climatic conditions, it will have a negative impact on the reproductive growth of the vine. It therefore is important to manipulate the vine growth and canopy climate through good management practices. These include the choice of trellis system, pruning system, irrigation and fertilisation, as well as seasonal canopy management.

This chapter will focus on the description of the canopy management practices in the study blocks, with specific emphasis on measurements taken to characterise the canopies, as well as on the vegetative and reproductive growth capacity of the vines under either conventional or OHS production. To this end, the pruning mass, starch content of canes, predicted and actual bud fertilities and burst percentages, shoot lengths, shoot diameter and light intensity in the canopies were measured and compared in the conventional and OHS vines of DBH and WC.

To determine if there are any differences between the two treatments for the two cultivars, an ANOVA analysis (Statistica 6.0) was used to compare averages for the two groups. A significance level of 0.1 was used as a guideline, as described by Nelsen (2002).

5.2 MATERIALS AND METHODS

5.2.1 VEGETATIVE PARAMETERS MEASURED VISUALLY OR COUNTED FOR BOTH DAN BEN HANNAH AND WALTHAM CROSS

The vegetative parameters that were measured included the number of buds allocated during pruning, the number of buds that showed bud burst, and the number of shoots that grew throughout the season. These parameters were scored visually on two randomly selected bearers per vine for 32 vines in each of the four treatments (see Chapter 3 for statistical layout). An average was calculated from these measurements per parameter per treatment and per cultivar and analysed statistically. During the second phenological stage, the number of bunches per shoot per vine was counted and the averages were determined and analysed.

The same bearers used in the previous measurements were also used to measure shoot lengths during the second phenological stage. The length of the second internode on each of these shoots was also measured. An average value for the shoot length and internode length was statistically determined and analysed.

Shoot diameter was measured on the pruned canes. The second internode on each shoot was measured in the middle between two buds.

5.2.2 PRUNING MASS

The pruning mass for both conventionally and OHS-grown DBH and WC was determined for 32 vines from each treatment. Each vine was fully pruned and all the canes were collected in bundles. These bundles were weighed on an electronic scale. The average cane mass for each of the four treatments was determined and statistically analysed.

5.2.3 LIGHT INTENSITY IN THE GRAPEVINE CANOPY

The intensity of light that penetrated the bunch zone was measured during the two phenological stages in both the conventionally and OHS-treated DBH and WC. A Decagon Sunfleck Ceptometer (unit: $\mu E.m^{-2}.s^{-1}$) was used. This apparatus is the equivalent of the LiCor 6000 photosynthesis meter used by Smart et al. (1988). The meter consists of an electronic box connected to a 90 cm long aluminium tube. The tube contains 80 light sensors, one centimetre apart, covered with white plastic. The phenological stages monitored were stages four and seven, which represent berry set until colour development and harvest respectively.

The best time to measure light penetration in the bunch zone is between 10:00 and 15:00 on a sunny day with clear blue skies, when the sun is in a vertical position. Groups of three vines each were used for measuring light intensity. A total of 32 groups was measured for each of the four treatments. The ceptometer was calibrated at the end of each row to keep up with the increase in light intensity as the day progressed to 12:00. The calibration takes place in full sunlight, with the average of four values being stored in the electronic memory of the ceptometer.

The values were averaged per treatment and statistically analysed.

5.2.4 BUD FERTILITY AND BUD MITE INFECTION

Bud fertility and bud mite infection were determined by Hortech laboratory services in Stellenbosch. During the winter season, dormant canes containing at least 16 buds were pruned in the vineyard, together with a piece of older second-year wood at the base of the cane. All the canes were placed in cold storage at 4°C for one week. The cuttings were pre-warmed to room temperature overnight before being immersed in hot water (50°C) for 30 minutes. To induce bud burst, single node cuttings were maintained in water culture. The culture room temperature was set to 28°C under continuous light (Orth, 1994). A total of 32 canes were used for each treatment of conventionally and OHS-grown DBH and WC.

To establish the bud fertility figures, the bunches on the emerging shoots were counted and expressed as a percentage for all bud positions along the cane (Orth, [S.a.]). Lateral shoots and dead buds were also counted and expressed as a

percentage of all bud positions along the cane. Dead buds were microscopically analysed to determine the presence of grapevine bud mite. The number of buds infected by bud mite were counted and also expressed as a percentage of all the buds along the cane.

5.2.5 STARCH CONTENT OF CANES

The starch content of the canes was determined as described by Hunter *et al.* (1995). A total of 20 canes from each of the four treatments were collected randomly in the vineyard. The canes were cut into smaller pieces of about six centimetres. The pieces of material for each of the 20 canes per treatment were kept separately. Each individual cane was ground to a fine dust. The fine dust for each cane was transferred to a plastic bottle and marked according to cultivar and treatment.

The cane material was freeze-dried and a 50 mg sample was transferred to an Eppendorf vial. One mL of 80% (v/v) aqueous acetone was added, followed by vortexing for 10 seconds and sonication for 10 minutes. The suspension was left at -4°C for six hours, centrifuged for 10 minutes at 12 000 rpm in an Eppendorf centrifuge, and the supernatant was decanted. The residue was then taken up in 1 mL ethanol and treated as above, except that the time lapse between sonication and centrifugation was omitted. After addition of one mL of water, the sample was washed again and the sediment was frozen at -20°C and freeze-dried overnight. The lyophilised material was taken up in 550 µL of water, followed by vortexing for 10 seconds and sonication for 10 minutes, after which it was left at -4°C for 60 minutes and subsequently centrifuged for 10 minutes at 12 000 rpm. Immediately after centrifugation, a 50 µL aliquot was removed as control .

Starch was then gelatinised by incubating the sample in a bath of boiling water (five minutes with open caps and 55 minutes with caps closed). After allowing the material to cool, 500 µL of an enzyme mix containing 5 U α-amylase and 2 U amyloglucosidase in 0.1 M Na-acetate buffer (pH 5.0) was added, the mixture was vortexed for 10 seconds and then incubated at 40°C with constant shaking at 35 rpm to allow hydrolysation of the starch to take place. The vials were removed and vortexed for 10 seconds every 30 minutes. After three hours, the samples were centrifuged for 10 minutes and diluted with water (1:39).

The glucose generated from the starch was determined using ABTS[2,2' azino-di(3-ethylbenzthiazoline)-6'-sulphonate] reagent, which consisted of 3.45 g $Na_2HPO_4 \cdot 2H_2O$, 1.6 g $NaH_2PO_4 \cdot H_2O$, 2350 U glucose oxidase, 375 U peroxidase and 125 mg ABTS dissolved in 250 mL of water.

A 50 µL aliquot of the diluted sample was mixed with 950 µL of the above reagent. Absorbency was read at 436 nm after 30 minutes. The blank consisted of a mixture of water and reagent. To obtain a glucose standard curve, seven standards were prepared: *i.e.* 0, 5, 10, 20, 30, 40 and 50 mg glucose/100 mL. The results were

expressed in mg starch after multiplication with a factor of 0.9, which allows for the reduced molecular weight of glucose in the polymer.

5.3 RESULTS

5.3.1 VEGETATIVE PARAMETERS VISUALLY MEASURED OR COUNTED FOR BOTH DAN BEN HANNAH AND WALTHAM CROSS

All the measurements for this experiment were taken on 2 October 2001, before any topping action had been performed in the blocks, except for the cane diameter measurements, which were taken after pruning in July 2002 for DBH and in August 2002 for WC.

Tables 5.1 and 5.2 contain the results for the vegetative parameters of DBH and WC grown conventionally and hydroponically. The differences between conventionally and OHS-treated DBH and WC in terms of the amount of bud burst, the number of shoots that grew, average shoot diameter and average number of bunches per bearer per vine were not statistically meaningful. The differences between the average number of buds allocated during pruning in DBH and the average shoot length of WC were not statistically significant between the conventional and OHS treatments.

The average shoot length and internode length in the OHS-treated DBH were significantly higher than in the conventional system during the second phenological stage. See Figures 5.1 to 5.3 for comparative graphs.

The number of buds allocated and the average shoot length were significantly different between conventionally grown WC and that of the same cultivar grown under the OHS system. The number of buds allocated, as well as the average shoot length measured in the second phenological stage for WC, was lower in the OHS system (Figures 5.4 and 5.5).

Table 5.1: The averages and p values for certain vegetative aspects measured for DBH. The shaded values are statistically significant.

Criteria	Average		p value
	Conventional	Hydroponic	
Buds allocated during pruning	9	9	0.36
Amount of bud burst	93%	94%	0.63
Shoots grown	82%	88%	0.08
Shoot length (cm)	22.25	28.92	< 0.01
Internode length (cm)	4.33	5.92	< 0.01
Shoot diameter (cm)	0.922	0.906	0.58
Bunches per bearer per vine	1.46	1.58	0.46

Table 5.2: The averages and p values for certain vegetative aspects measured for WC. The shaded values are statistically significant.

Criteria	Average		p value
	Conventional	Hydroponic	
Buds allocated during pruning	10	9	0.01
Amount of bud burst	72%	74%	0.24
Shoots grown	60%	70%	0.41
Shoot length (cm)	28.33	24.58	0.05
Internode length (cm)	5.33	5.67	0.37
Shoot diameter (cm)	0.796	0.778	0.60
Bunches per bearer per vine	1.46	1.23	0.19

In DBH, the bud burst date was one day earlier for the OHS treatment than for the conventional treatment. Later in the season, berry set was three days earlier in the OHS-treated DBH, and two days earlier for the same treatment of WC. At the beginning of véraison, the OHS-treated DBH advanced to four days earlier than the conventional treatment, and the OHS-treated WC to three days earlier (see Chapter 3, Table 3.3).
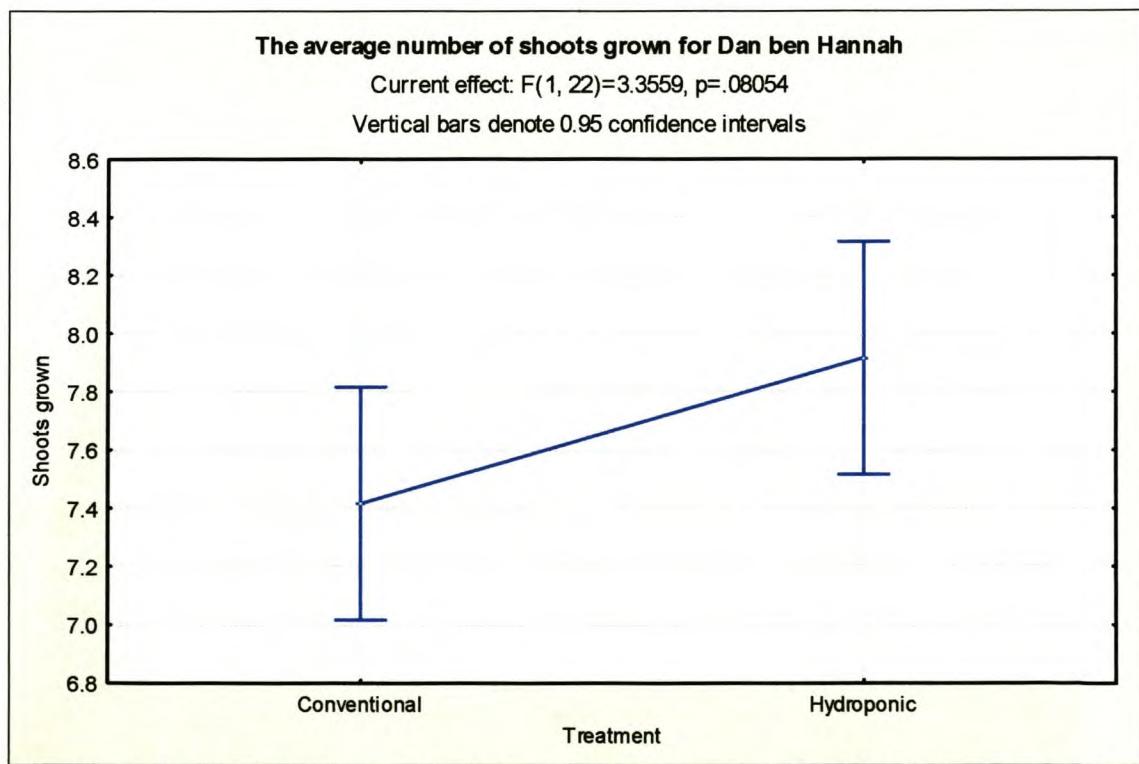

Figure 5.1: Statistically determined results for the average number of shoots grown by DBH under conventional and hydroponic treatment.
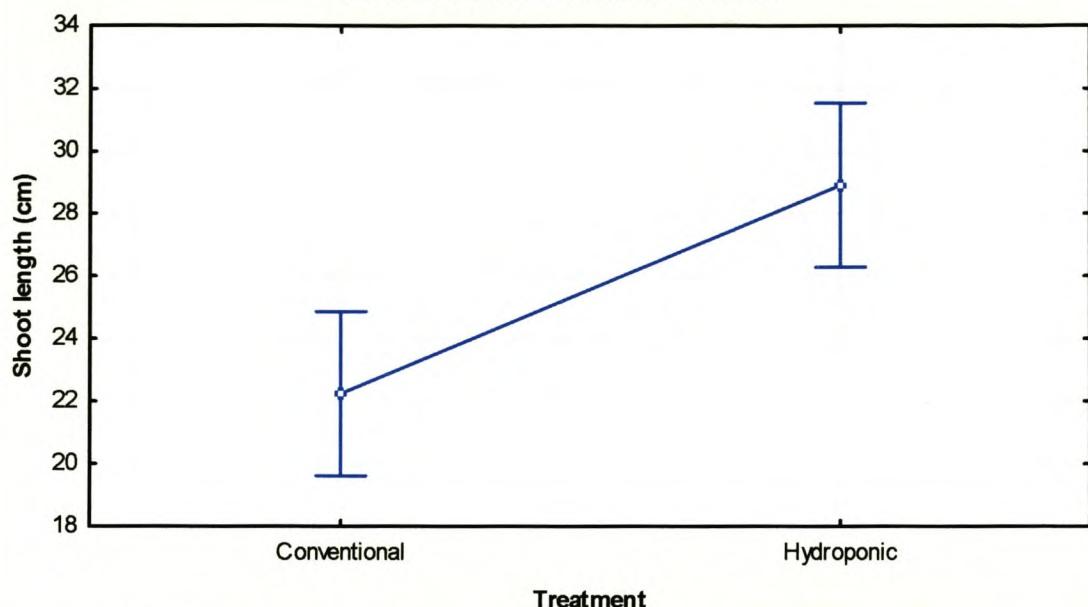
Figure 5.2: Statistically determined results for average shoot length in DBH under conventional and hydroponic treatment.
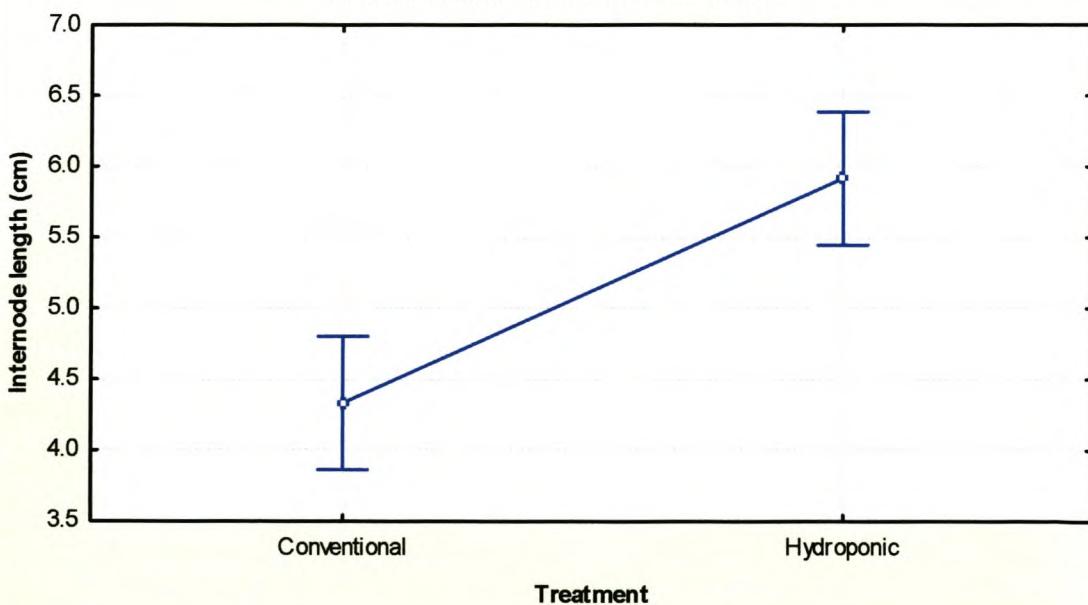

Figure 5.3: Statistically determined results for the internode lengths in DBH cultivated in both conventional and open hydroponic systems.
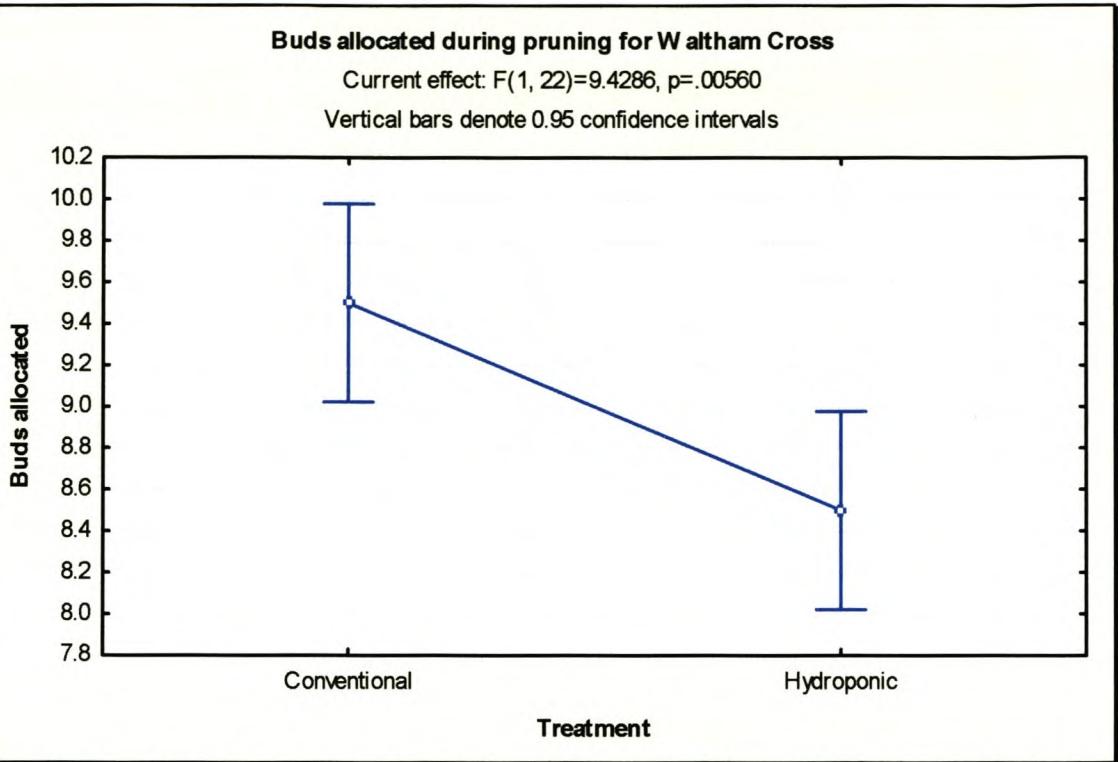
Figure 5.4: The average number of buds allocated for WC grown conventionally and hydroponically.
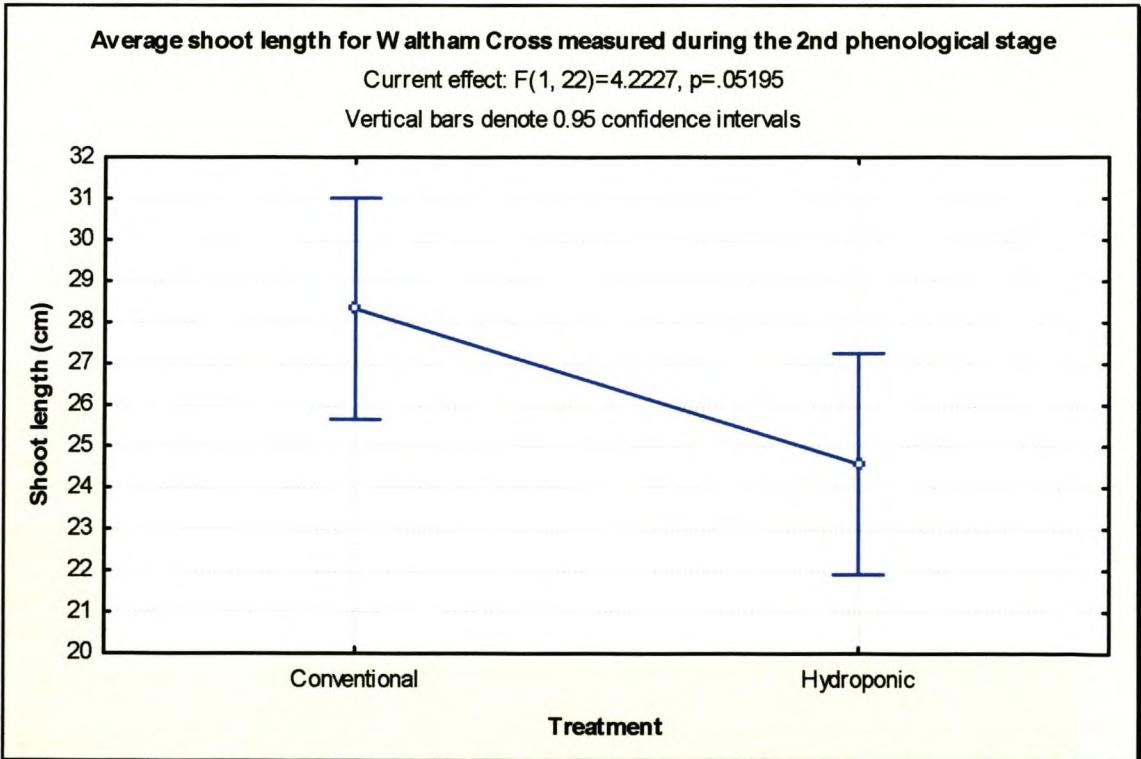

Figure 5.5: Statistically determined results for shoot length in WC grown conventionally and hydroponically.

5.3.2 PRUNING MASS

The average pruning mass for conventionally grown DBH was significantly higher than that for the OHS-treated DBH during the 2001 season, but the opposite result emerged in the 2002 season (see Table 5.3). When comparing the two seasons for conventionally grown DBH (Fig. 5.6), there is a significant increase in pruning mass for 2001. There is also a difference between the two seasons of OHS-grown DBH. Although the 2002 season showed a higher pruning mass than 2001, the difference was not as pronounced as in the conventional system.

For WC (Fig. 5.7), the average pruning mass for both treatments was not significant. The conventionally grown treatment showed an increase in pruning mass from 2001 to 2002, whereas the OHS treatment showed a decline in pruning mass from the 2001 season to the 2002 season. There was no significant difference between the two different treatments in 2001 and 2002.

Table 5.3: The average pruning mass (kg/vine) for DBH and WC treated conventionally and hydroponically.

| Cultivar	Treatment				p value
	Conventional		Hydroponic		
	2001	2002	2001	2002	
Dan ben Hannah	2.82	1.94	1.99	2.53	< 0.01
Waltham Cross	2.24	2.68	2.61	2.21	0.25
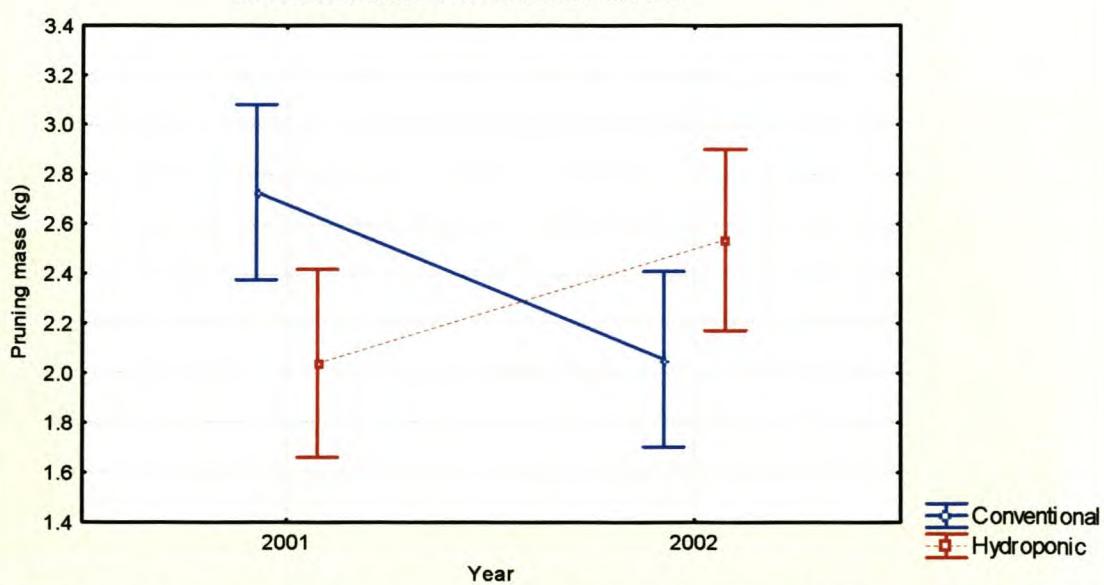
Figure 5.6: Pruning mass for conventionally and hydroponically grown DBH determined statistically.
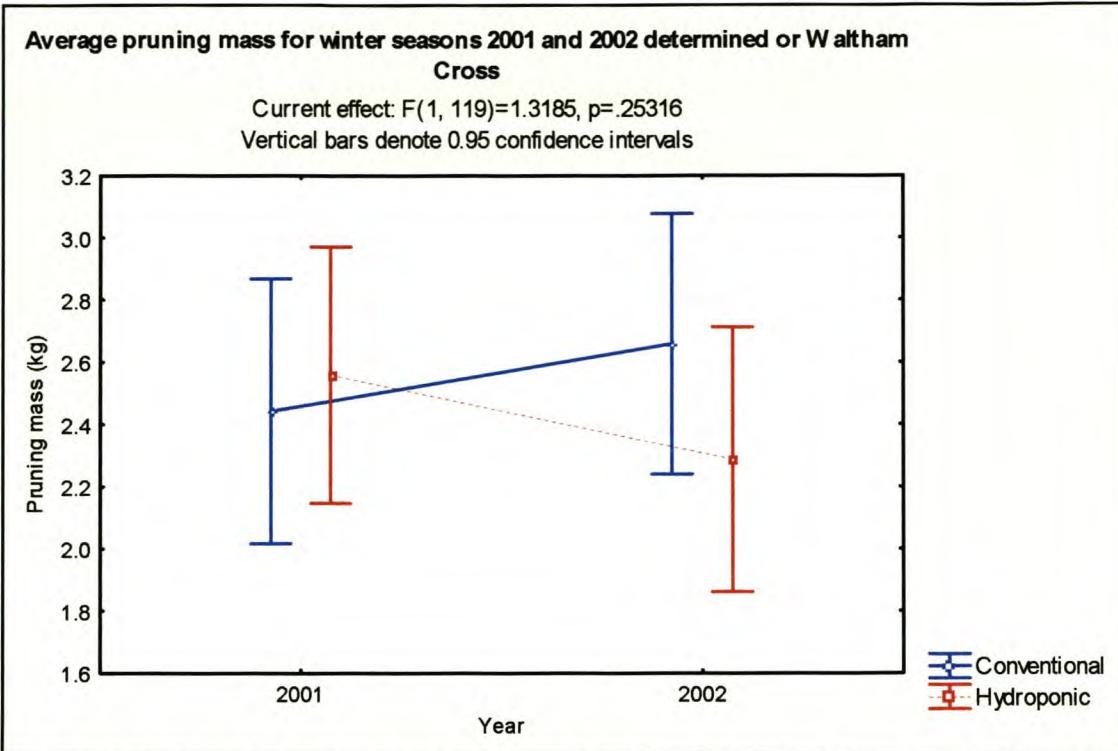
Figure 5.7: Pruning mass for conventionally and hydroponically grown WC determined statistically.

5.3.3 BUD FERTILITY AND BUD MITE INFECTION

For DBH, the determination of bud fertility showed significant differences between the conventional and OHS treatment (Fig. 5.8). The overall bud fertility was lower for the OHS treatment, with more than 16 bud positions on a cane. The OHS treatment reached the highest percentage of bud fertility (55%) at bud position nine. The conventionally grown DBH displayed 60% and 62% bud fertility at positions 12 and 17 respectively. The number of buds allocated during pruning for both conventionally and OHS-treated DBH was between eight and ten (Chapter 3 and Table 5.1). Thus, for the conventionally grown DBH, bud positions 12 and 17 were not allocated during pruning.

The overall percentage of bud fertility for OHS-grown WC was higher than for the conventional treatment (Fig. 5.9). The highest percentage of bud fertility for conventionally grown WC was 80% at bud position nine. For the OHS treatment of WC, the percentage of bud fertility was higher than 80% for bud positions 11, 13, 14 and 15, and even reach 100% fertility at bud position 11. According to the producer, six to eight buds are allocated during pruning for WC (Chapter 3), but an average of eight to nine buds was determined for both conventionally and OHS-treated WC. Nevertheless, bud positions 11 and 13 to 15 were not allocated in the OHS-treated WC.

Average bud fertility percentage for Dan ben Hannah
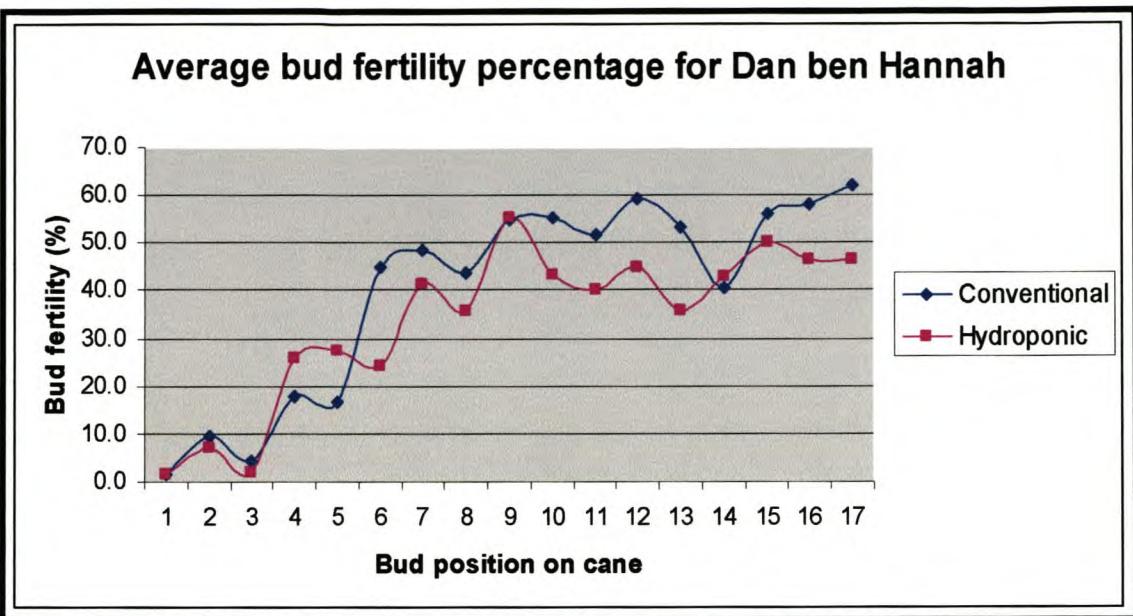
Figure 5.8: Average percentage of bud fertility at 17 different bud positions for conventionally and hydroponically grown DBH.

**Average bud fertility percentage for Waltham Cross**
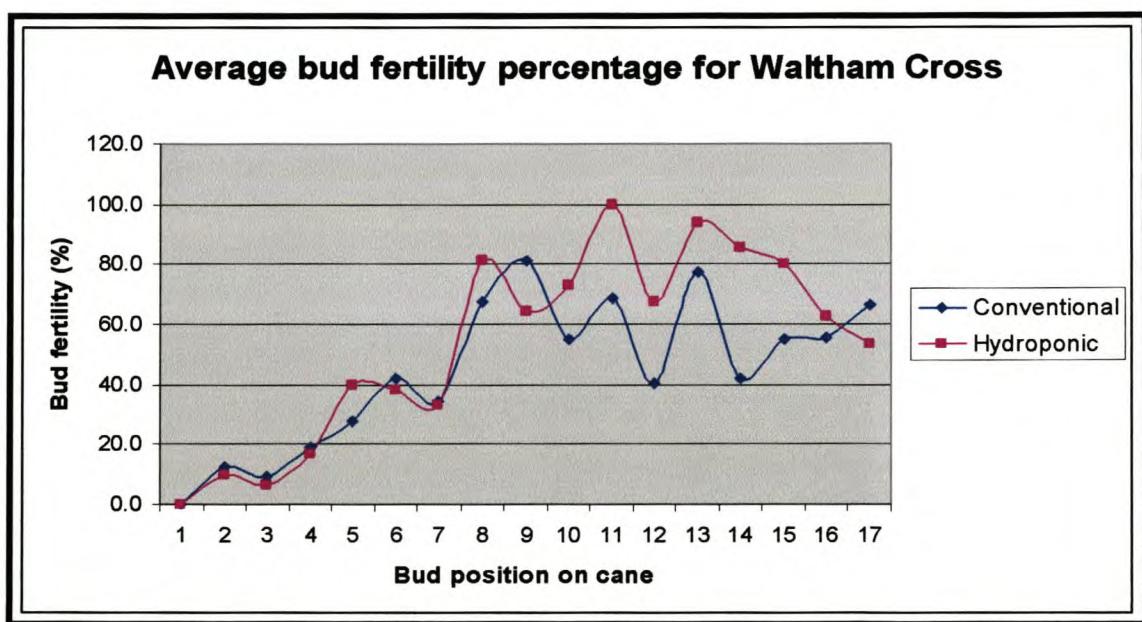
Figure 5.9 Average percentage of bud fertility at 17 different bud positions for conventionally and hydroponically grown WC.

For both OHS-treated DBH and WC, the percentages of bud mite infection were higher than that for the conventional treatment (Figs. 5.10 and 5.11). The difference was more significant for DBH than for WC. A high infection percentage of above 40% was detected for both DBH and WC under OHS. Both cultivars under conventional treatment rendered lower infection percentages, with the highest infection measured at between 30 and 35%.
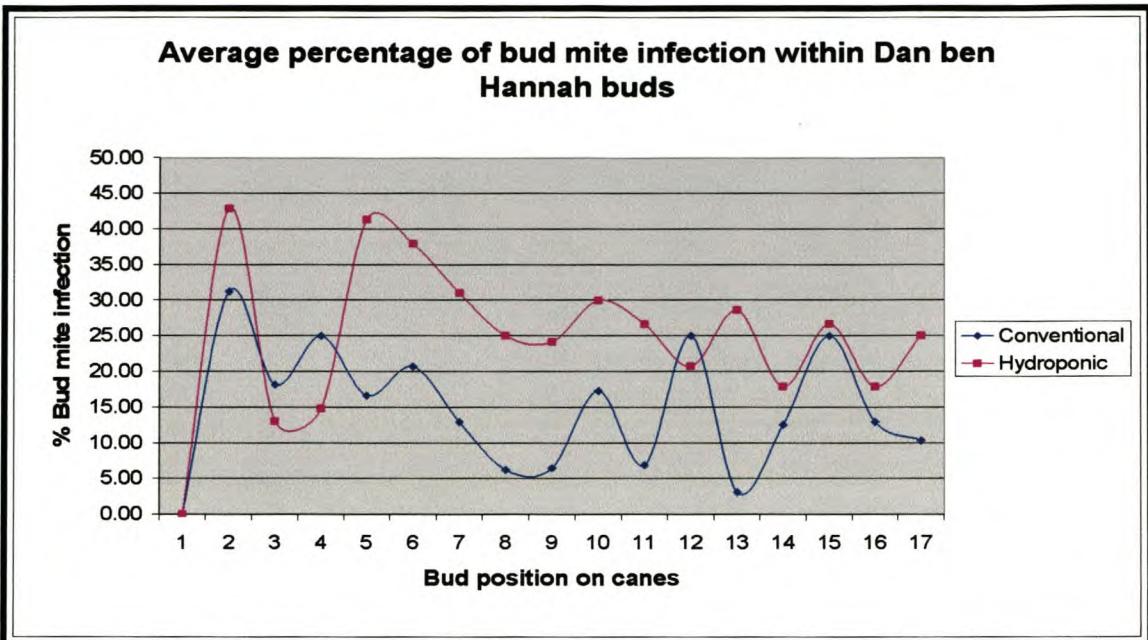
Figure 5.10: Average percentage of bud mite infection at 17 different bud positions for conventionally and hydroponically grown DBH.
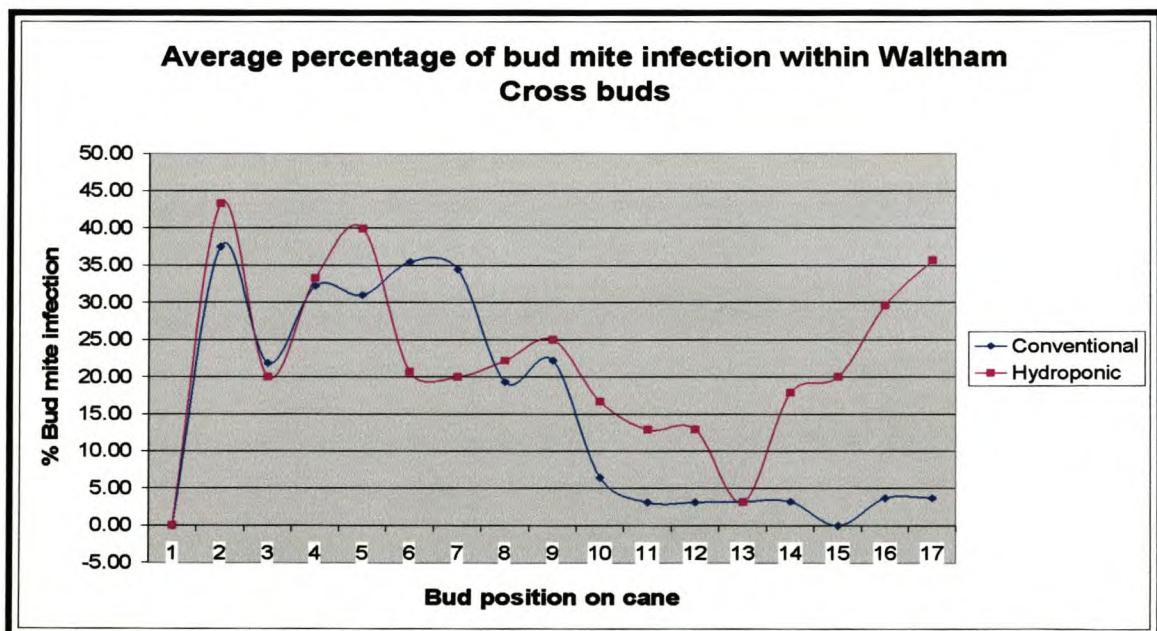
Figure 5.11: Average percentage of bud mite infection at 17 different bud positions for conventionally and hydroponically grown WC.

5.3.4 LIGHT INTENSITY IN THE GRAPEVINE CANOPY

The overall light intensity in the grapevine canopy was higher during both the phenological stages in conventionally grown DBH than in OHS-treated DBH when the measurements were performed (Fig. 5.12). The light intensity for both cultivars dropped as the season progressed. Table 5.4 shows the average values of light intensity, as well as the statistically determined p values, for both treatments of DBH.

Table 5.4: Light intensity results for both DBH and WC at two different phenological stages.

Phenological stage : Fruit set – Harvest	Dan ben Hannah		Waltham Cross		p value
	Conventional	Hydroponic	Conventional	Hydroponic	
Average light intensity $\mu E.m^{-2}.s^{-1}$ at fruit set	208.47	127.64	202.00	221.78	0.59
Average light intensity $\mu E.m^{-2}.s^{-1}$ at harvest	121.55	62.14	168.84	259.65	0.19

There was no significant difference in light intensity between conventionally and OHS-grown WC at the fourth phenological stage (Fig. 5.13). However, the difference became significant in stage seven, when conventionally grown WC gave a higher light intensity than the OHS-grown WC. However, the light intensities observed for both treatments of WC never fell below 170 $\mu E.m^{-2}.s^{-1}$, which was significantly higher than that observed for DBH. Table 5.4 shows the average light intensity for WC and the calculated p values.
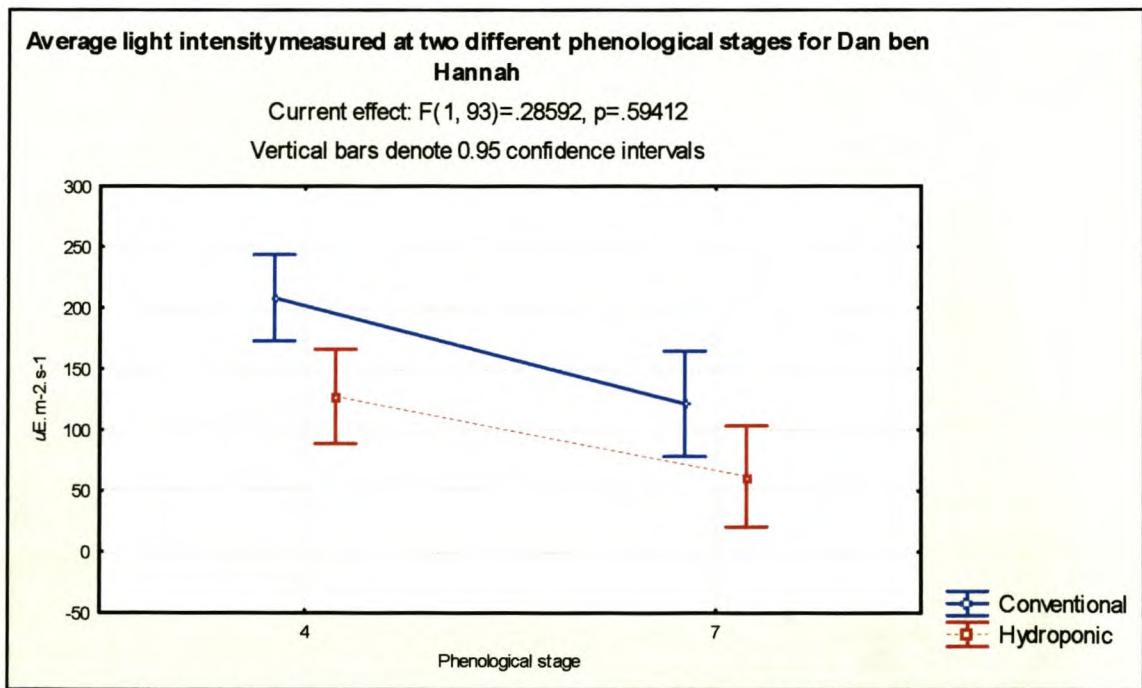
Figure 5.12: Light intensity results determined and statistically analysed for conventionally and hydroponically grown DBH.
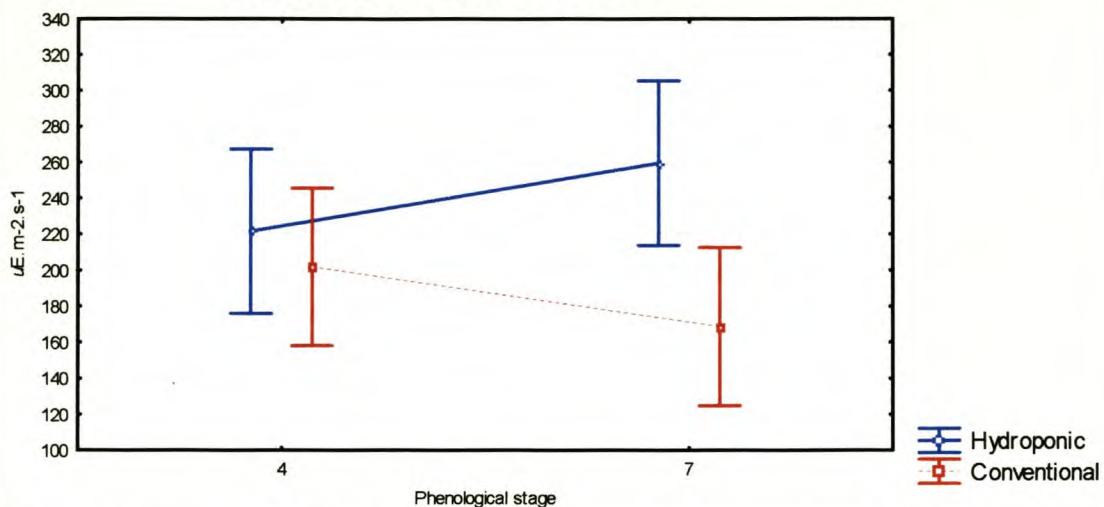
Figure 5.13: Light intensity determined and statistically analysed for conventionally and hydroponically grown WC.

5.3.5 STARCH CONTENT OF CANES

The starch content of conventionally and OHS-treated DBH and WC is presented in Table 5.5. There was no significant difference between the conventionally and OHS-grown vines in both cultivars.

Table 5.5: The average starch content (mg/g dry mass) determined for conventionally and hydroponically grown DBH and WC.

Starch content	Dan ben Hannah			Waltham Cross		
	Conventional	Hydroponic	p value	Conventional	Hydroponic	P value
mg/g dry mass	21.502	20.726	0.70	22.188	23.422	0.41

5.4 DISCUSSION

5.4.1 VEGETATIVE PARAMETERS VISUALLY MEASURED OR COUNTED FOR BOTH DAN BEN HANNAH AND WALTHAM CROSS

Overall, the vegetative measurements showed slightly more vigorous growth for OHS-treated DBH if the shoot lengths were compared to the conventionally treated cultivars (Table 5.1). This was also confirmed by the average internode lengths, which were slightly longer than the norm. The vegetative growth of grapevines increases with water application (Myburgh, 1996). A rainy 2001/2002 season from August 2001 until the end of November 2001 (Chapter 3) might also have contributed

to the more excessive vegetative growth. The excessive vegetative growth could also be due to suboptimal nutrient mixes. N, in particular, plays a critical role in vegetative growth. More than twice the amount of N was given to the OHS-treated cultivars (Chapter 3, Figures 3.8 & 3.9) than to the conventionally treated ones during the growing season. However, the OHS-treated WC showed less vigorous growth earlier in the season than the conventionally treated WC, and the vegetative growth for both treatments was more in balance during the season.

Bud burst was also slightly earlier in the OHS-treated vines, finally resulting in harvest dates that were four days and three days earlier in the OHS-treated DBH and WC respectively.

5.4.2 PRUNING MASS

During the winter season of 2001, the pruning mass for both OHS-treated cultivars was much lower than for the conventional treatments. The reason for this might be that the vines were not yet fully adapted to the new irrigation systems and therefore underwent mild stress. However, the pruning mass for the OHS-treated DBH increased in the 2002 winter season and was more in balance with the conventional treatment. The pruning mass for the conventionally treated DBH declined from 2001 to 2002, maybe due to suboptimal fertiliser applications on a sandy soil.

The pruning mass for the OHS treated WC declined from 2001 to 2002. This decline might be a result of the constant changes to the OHS fertiliser and irrigation programmes.

5.4.3 BUD FERTILITY AND BUD MITE INFECTION

Bud fertility can be negatively affected by a dense canopy, resulting in shoots that do not bear any grapes. The measured bud fertility showed an overall higher bud fertility near the apical ends of the shoots, thus from bud position 10 onwards. The actual bud fertility was lower for all the treatments because no more than 10 buds were allocated per bearer during winter pruning. Bud mite infection was generally higher in the OHS-treated cultivars, especially when the bud fertility was lower near the basal ends of the canes. Thus, bud mite infection had a directly negative effect on bud fertility.

5.4.4 LIGHT INTENSITY IN THE GRAPEVINE CANOPY

The average light intensity for the OHS-grown DBH confirmed a denser canopy because of the rapid shoot growth during the season. For optimal photosynthesis, the light intensity should be about 800 $\mu E.m^{-2}.s^{-1}$ in the bunch zone of the canopy. If the light intensity is lower than 100 $\mu E.m^{-2}.s^{-1}$, bud fertility will be affected negatively. This threshold level was not reached in the OHS-grown DBH vines at harvest, whereas the conventionally grown vines barely exceeded the threshold. The situation in the case of WC was more positive, as shoot growth was not so rapid, and the OHS-

grown vines therefore had a higher light intensity in the canopy at harvest than DBH. The increase in light intensity in the OHS treated WC as the season proceeded could have been due to plant stress caused by suboptimal irrigation and fertilisation.

5.4.5 STARCH CONTENT OF CANES

Starch is known to be the main reserve compound in the storage tissues in the grapevine (Hunter *et al.*, 1995). At the beginning of the season, vines are dependent on their reserves for initial budding and shoot growth. There were no significant differences between the starch contents of DBH and WC under either treatment. The reserves were therefore high enough for even budding at the beginning of the 2001/2002 season.

5.5 CONCLUDING REMARKS

Overall vine growth was more vigorous, especially in the OHS-treated vines, most likely due to excessive water. This was proved by the visual measurement of vegetative parameters, pruning mass, bud fertility and light penetration in the bunch zone of the vine. The more dense canopy of the OHS-treated vines, especially DBH, could induce problems with bud fertility in later seasons. General canopy management practices were performed twice in a season (Chapter 3, Tables 3.1 and 3.2), but this might not be optimal for the OHS-treated vines, for which more than one suckering action might be necessary during the growth season. A topping action once every season stimulated lateral shoot growth, which resulted in an even more dense canopy.

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Chapter 6

RESEARCH RESULTS

The effective uptake of nutrients and its effect on the fruit quality of grapes cultivated under conventional and open air hydroponic systems

RESEARCH RESULTS

6.1 INTRODUCTION

The effectiveness of the uptake of water and nutrients is determined in terms of how much of each is provided to a plant, what is mobilised through the root system towards the shoots, and how much of the water and nutrients ends up in the leaves and the fruit. Because of a number of factors, including application at the wrong phenological stage, nutrients applied to the soil do not always reach the intended organs, such as the bunches.

The fruit quality of table grapes can be influenced in various ways. Too much water at the wrong time may result in berry split, or nutrient deficiencies within the berries may cause a weaker skin structure, leading to excessive berry rot. Wrong canopy management may result in a canopy that is too dense, which has an influence on bud fertility and induces uneven ripening and berry size.

This chapter will describe nutrient uptake and its effect on fruit quality for both DBH and WC treated conventionally and hydroponically. To this end, leaf blade and petiole analyses at two different phenological stages, fruit analyses after storage, storage ability, seed status, berry skin analyses, anthocyanin analyses of DBH skins, total production over five seasons and Fosscan analyses were used to compare the conventionally and OHS-treated DBH and WC vines.

To determine if there were any differences between the two treatments for the two cultivars, an ANOVA analysis (Statistica 6.0) was used to compare averages between the two groups. A significance level of 0.1 was used as a guideline, as described by Nelsen (2002).

6.2 MATERIALS AND METHODS

6.2.1 LEAF BLADE AND PETIOLE ANALYSES

Leaf blade and petiole analyses were done on both DBH and WC. Samples were collected at two different phenological stages in the growing season. Leaf and petiole samples were taken from leaves opposite bunches and the leaf blades were immediately separated from the petiole. These samples were sent to Bemlab in Somerset West for both macro- and microelement analyses. The standard ranges used for the amount of nutrients in the leaf blades and petioles are summarised in Chapter 2, Table 2.6. Fruit set standards were used for leaf blade and petiole analyses done on the 12th of November 2001, whereas the véraison standards were used for analyses done on the 23rd of January 2002.

6.2.2 FRUIT ANALYSES

Fruit analyses were performed directly after harvest. One hundred berries from each of the four treatments were randomly taken from various bunches and sent to Bemlab in Somerset West for both macro- and microelemental analyses. Bunch stems from DBH under both treatments were also sent to Bemlab for elemental analysis.

6.2.3 ASSESSING THE STORAGE ABILITY OF THE GRAPES

The harvest was scheduled according to the Capespan standards for table grapes. The standards for DBH were: minimum total soluble solids (TSS) of 16, or a sugar/acid ratio of 19:1 and a minimum TSS of 14.5. For WC, the standards were: minimum TSS of 15.5, or a sugar/acid ratio of 21:1 and a minimum TSS of 13.5. During the harvest, 10 boxes of each treatment per cultivar were analysed at Hortech Laboratories in Stellenbosch. The packaging material consisted of the standard 4.5 kg boxes, with non-perforated bags, poly cotes and SO_2 sheets. The 40 boxes were marked and stored at -0.5°C for five weeks. After five weeks, the boxes were kept at 15°C for one week to mimic the typical shelf life of export table grapes. The boxes were subsequently weighed on an electronic scale, after which the fruit were analysed. After opening the boxes, the bunches in each box were counted and inspected for brown stems on a scale from 1 (green) to 5 (brown) as a measure of stem dryness. The amount of moisture in each box was determined visually and the results were compiled on a scale of 1 (dry), 2 (condensation) and 3 (free water).

The loose berries, SO_2-damaged berries, *Botrytis*-infected berries and split berries were taken from each individual box and weighed on the same electronic scale. The results were determined as the percentage of loose berries for a certain box weight and subsequently analysed statistically.

6.2.4 SEED STATUS

A total of six bunches from each treatment were used to determine the seed status. Sixty randomly selected berries per bunch were opened and the total number of seeds were counted. The results were statistically analysed, showing the average number of seeds per berry for each of the four treatments.

6.2.5 SKIN ANALYSES

Grape skin analyses were performed with a scanning electron microscope at the Department of Oceanography at the University of Cape Town. These analyses were performed on the grapes which had been stored at Hortech for five weeks at -0.5°C, as discussed in 6.2.3. Berry samples were taken for each cultivar and its two treatments. Cross-sectional cuts were made through all the berries so that a section of the berry skin was maintained on the outside and part of the pulp was maintained on the inside. These samples were glued onto copper discs and frozen with liquid N.

The samples were inserted into the microscope one by one and photographed at different levels of magnification.

6.2.6 SKIN COLOUR ANALYSES FOR DAN BEN HANNAH

Ten randomly selected bunches from each of the four treatments were stored at -20°C until they were used. All the berries on the bunch were sampled, and a random sample of 25 berries per treatment was removed for further analyses. After determination of the volume of the berries, the skins were separated from the pulp by gentle squeezing the berries between the thumb and forefinger. Any pulp adhering to the skins was removed. Skins were rinsed in distilled water, blotted dry, and the fresh mass was determined (Hunter *et al.*, 1991). Skins were subsequently frozen using liquid N and then ground into a fine powder. The samples were kept frozen at -80°C until used.

A total of 0.25 g of frozen skin material was extracted in 7.5 mL methanolic 0.1% HCl solution (pH 3.5) at room temperature, using a horizontal shaker operating at 250 rpm for 15 minutes. After centrifugation at 15 000 rpm for 15 minutes, the supernatant was decanted and the process was repeated twice. The supernatants were combined and acidified to pH 1.0 using 1 M HCl. The solution was then made up to 100 mL with extraction solvent (pH 1.0) and left in the dark at room temperature for approximately one hour. The samples were then taken out and the absorbencies of the total anthocyanins were determined at 520 nm and 420 nm respectively, using 1 mm quartz cells (Hunter *et al.*, 1991).

6.2.7 USING THE FOSSCAN 2000 TO DETERMINE ADDITIONAL INFORMATION

Four bunches from each treatment were hand pressed to extract the juice. Four bottles containing 100 mL of grape juice from each of the four treatments were filtered to separate all the solid grape material from the juice. The results for the 16 samples were determined with Foss Grapescan 2000 (Foss Electric, Denmark). Two individual programs were used, namely winescan and mustscan.

6.3 RESULTS

6.3.1 LEAF BLADE AND PETIOLE ANALYSES

6.3.1.1 Dan ben Hannah

Leaf blade and petiole analyses were done separately for both DBH and WC. Tables 6.1 and 6.2 show the analyses for DBH, for which the leaf blade and petiole samples were taken between fruit set and véraison (12 November), and then again just prior to harvest (23 January).

The leaf blade samples taken during the fourth phenological stage show definite toxicities for the micronutrients Mn, Cu and Zn in both the conventional and OHS

treatments. Of the macroelements, K was normal in the conventional treatment, but high in the OHS treatment. Nitrogen levels in the OHS treatment were higher than normal, due to the high percentage of N fertiliser applied, as discussed in Chapter 3, and Ca was lower than normal for the conventionally grown vines. The P levels were also higher for the OHS treated vines. For the second set of leaf blade samples, taken at harvest, all low, high and toxic levels of nutrients subsided into normal levels, except for the micronutrient Cu, which were still high in both treatments. At harvest, the Ca levels in OHS-grown vines were lower than in the conventional vines (Table 6.1).

The analysis of the petiole samples for both the conventionally and OHS-treated DBH is shown in Table 6.2.

Table 6.1: Leaf blade analyses for DBH.

Nutrient	Date					Legend
	2001/11/12	2002/1/23	2001/11/12	2002/01/23		
	Treatment					
	Conventional		Hydroponic			
	%					Deficient
N	2.46	2.39	2.51	2.48		Low
P	0.46	0.3	0.51	0.3		High
K	1.11	0.93	1.27	1.03		Toxic
Ca	1.37	1.93	1.56	1.82		
Mg	0.41	0.49	0.46	0.52		
	mg/kg					
Na	223	304	257	314		
Mn	353	169	439	133		
Fe	90	98	87	103		
Cu	180	34	228	30		
Zn	85	36	142	35		
B	49	56	64	62		

Table 6.2: Petiole analyses for DBH.

Nutrient	Date				
	2001/11/12	2002/1/23	2001/11/12	2002/01/23	
	Treatment				
	Conventional		Hydroponic		
	%				
N	0.94	0.75	1.35	1.08	Deficient
P	0.75	0.64	0.8	0.7	Low
K	2.35	2.28	2.94	2.8	High
Ca	0.99	1.41	1.03	1.32	Toxic
Mg	0.3	0.56	0.31	0.58	
	mg/kg				
Na	372	606	302	425	
Mn	71	49	70	42	
Fe	31	29	26	34	
Cu	31	13	35	21	
Zn	44	62	47	61	
B	33	35	35	39	

The situation was very different in the petiole analyses. Potassium levels were toxic throughout all véraison analyses, whereas Ca and Mg levels were normal in all the samples taken throughout the season. Nitrogen was toxic in the OHS treatment between fruit set and véraison, but only high at harvest. Phosphorus levels were higher than normal in all the treatments, except for the conventional vines at harvest. Of the microelements, Cu was toxic in both treatments earlier in the season, but returned to normal at harvest. Zinc levels were high for both treatments between fruit set and véraison, but became toxic at harvest.

6.3.1.2 Waltham Cross

The toxicity in the leaf blades and petioles of WC was higher than in DBH, especially for the microelements (Table 6.3). Nitrogen levels in conventionally and OHS treated vines were higher than normal between fruit set and véraison. The N levels returned to normal at harvest for both treatments. Potassium levels were slightly higher than normal at harvest for both WC treatments, and Ca levels were lower for both treatments earlier in the season, although normal at harvest. In addition, the Ca levels in OHS-grown WC were lower at harvest than in conventionally grown vines.

For the micronutrients, the leaf blade analyses showed higher levels of Mn earlier in the season for both treatments. Copper and Zn levels were toxic between fruit set and véraison for both treatments. At harvest, the conventional treatment showed high levels of Cu and Zn, although these were no longer toxic, but this was not the case in the OHS-grown WC.

In the petiole analyses, the macroelements did not show significant differences in terms of deficiencies and toxicities, except for K toxicity at harvest in both treatments. Nitrogen levels were slightly higher than normal between fruit set and véraison in conventionally grown vines, but returned to normal at harvest. Calcium was slightly lower than the conventional treatment early in the season for OHS-treated vines, but also returned to normal during harvest. Zinc showed high and toxic levels in both leaf blade and petiole analyses of the conventionally treated vines, and the toxic levels of Zn remained in the OHS-treated vines from early to later in the season. Iron was lower than normal between fruit set and véraison for both treatments, while Cu was higher than normal for both treatments at phenological stage four (Table 6.4).

Table 6.3: Leaf blade analyses for WC.

Nutrient	Date			
	2001/11/12	2002/1/23	2001/11/12	2002/01/23
	Treatment			
	Conventional		Hydroponic	
	%			
N	2.88	2.12	2.85	2.08
P	0.22	0.17	0.39	0.25
K	0.86	1.18	0.97	1.08
Ca	1.46	1.63	1.25	1.55
Mg	0.24	0.30	0.25	0.28
	mg/kg			
Na	155	256	148	255
Mn	320	143	329	178
Fe	81	79	83	78
Cu	126	24	170	37
Zn	80	45	81	60
B	42	55	37	54

Deficient
Low
High
Toxic

Table 6.4: Petiole analyses for WC.

Nutrient	Date					Legend
	2001/11/12	2002/1/23	2001/11/12	2002/01/23		
	Treatment					
	Conventional		Hydroponic			
	%					Deficient
N	1.05	0.86	0.95	0.89		Low
P	0.29	0.19	0.52	0.52		High
K	1.63	3.00	1.77	2.90		Toxic
Ca	1.17	1.31	0.99	1.47		
Mg	0.41	0.67	0.35	0.82		
	mg/kg					
Na	259	491	252	533		
Mn	59	44	66	52		
Fe	19	40	26	25		
Cu	23	8	28	12		
Zn	42	62	62	77		
B	31	39	29	36		

6.3.2 FRUIT ANALYSES

Table 6.5 shows the fruit analyses done for both cultivars under conventional and OHS treatment after five weeks of storage. For DBH, the levels of the macroelements were slightly higher in the OHS treatment, except for Ca, which was lower, and Mg, which was the same. The levels of microelements were the same in both treatments of DBH, except for the Na level, which was higher in the conventional treatment, and Fe, which was higher in the OHS treatment.

In the WC analysis, the levels of the macroelements, P and K were higher in the fruit from the OHS treatment. Nitrogen levels was lower, and there were no significant differences for Ca and Mg. The levels of microelements were basically the same in both treatments, except for the Fe level, which was higher in the OHS treatment.

Table 6.5: Fruit analysis of DBH and WC after five weeks of storage.

Element	Cultivar			
	Dan ben Hannah		Waltham Cross	
	Treatment			
	Conventional	Hydroponic	Conventional	Hydroponic
	mg/100 g fresh mass			
N	72	93	78	72
P	23.36	24.06	17.31	22.99
K	190	205	195	248
Ca	12.0	9.5	11.0	11.1
Mg	8.4	8.3	7.0	8.3
	mg/kg fresh mass			
Na	13.4	9.6	13.1	15.6
Mn	0.6	0.5	0.4	0.4
Fe	2.3	3.0	1.6	3.1
Cu	0.9	0.8	0.6	0.6
Zn	0.6	0.5	0.5	0.9
B	3.2	3.4	2.7	2.6

Figure 6.1 (DBH) and Figure 6.2 (WC) show the fruit analyses with regard to physical appearance. The results show important differences in the rachis framework, berry size and berry colour.

Both cultivars under the OHS treatment displayed a more compact rachis framework. This compactness led to more compact bunches. DBH showed a visually more intense berry colour and more even sized berries than the OHS-treated vines, whereas WC showed more even berry size in the conventionally grown vines. The overall berry colour of OHS-treated WC was more yellow than in the conventional treatment. Conventionally grown vines showed visual skin browning symptoms.
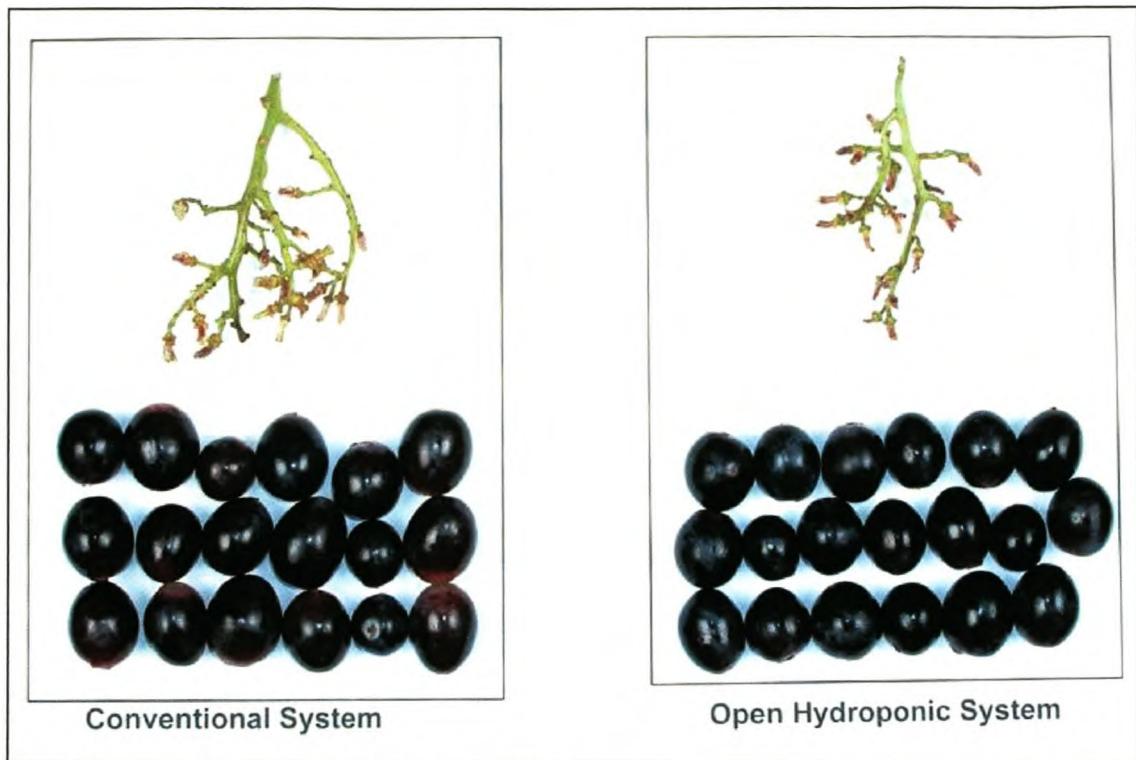
**Figure 6.1:** Berry size, colour and rachis framework of DBH.
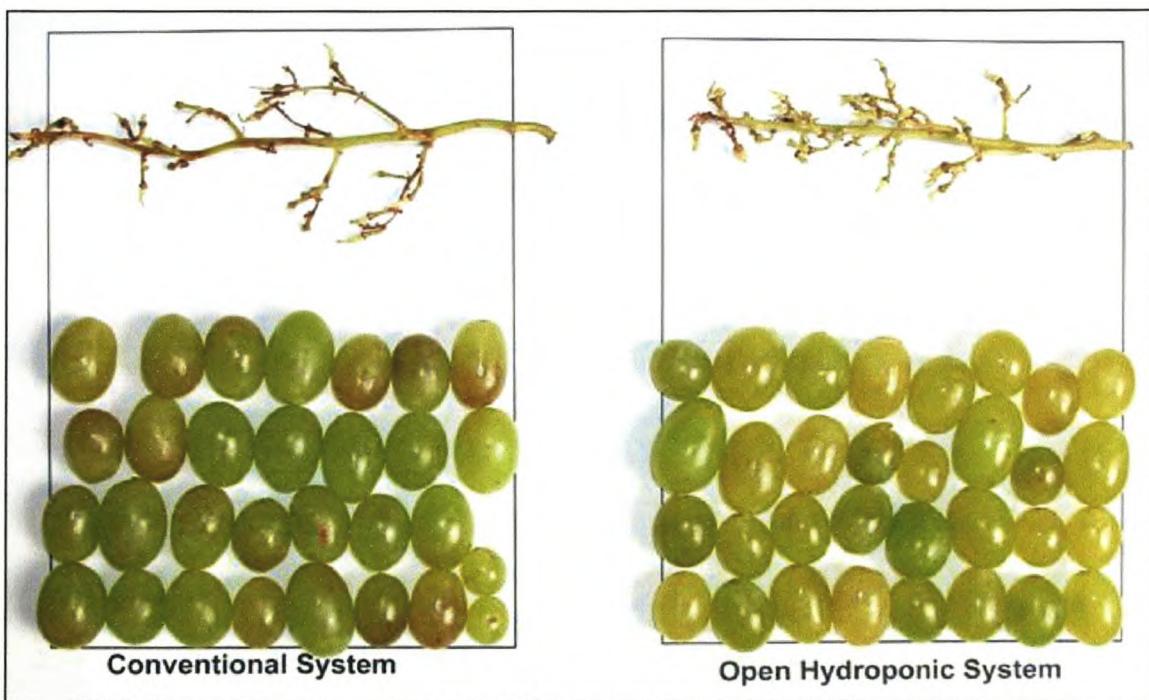
Figure 6.2: Berry size, colour and rachis framework of WC.

As can be seen from the above results, the Ca levels, especially for OHS-treated DBH, were lower in both the leaf blade and fruit analyses. Ca is important for providing strength to berry skins in the developing stage. A nutrient analysis was done on the rachis of both conventionally and OHS-treated DBH. The results are shown in Table 6.6. No difference was found for the macronutrient contents in the

rachis analysis. The microelement levels showed higher levels of Na in the conventional treatment, and higher Fe levels in the OHS treatment of DBH.

Table 6.6: Analysis of the bunch stems of DBH (Date: 2002/04/10).

Element	Treatment	
	Conventional	Hydroponic
	%	
N	0.45	0.60
P	0.68	0.52
K	2.54	2.70
Ca	0.80	0.82
Mg	0.10	0.09
	mg/kg	
Na	515	385
Mn	16	23
Fe	61	123
Cu	23	20
Zn	23	25
B	18	23

6.3.3 ASSESSING THE STORAGE ABILITY OF THE GRAPES

In DBH, there was not a significant difference in the average percentage of loose berries, SO_2 damage and berry split between the conventional and OHS treatment (Table 6.7). The same was the case for the percentage of loose berries, SO_2 damage, berry split and skin browning in both treatments of WC (Table 6.9). However, in both cultivars there was a significant difference in the percentage of *Botrytis* infection. Figures 6.3 and 6.4 show the statistically significant differences in *Botrytis* infection in DBH and WC respectively.

The difference in the average amount of stem browning in both cultivars under conventional and OHS treatment was not significant, neither was the amount of moisture present in the cartons after storage (Table 6.7).

Table 6.7: Average and p values for DBH and WC after five weeks of storage. The shaded values are statistically significant and are shown in Figures 6.3 and 6.4.

Criteria	Dan ben Hannah			Waltham Cross		
	Conventional	Hydroponic	p	Conventional	Hydroponic	p
Percentage (%)						
Loose berries	0.83	0.81	0.96	3.04	2.03	0.36
SO₂ damage	15.92	15.74	0.96	0.62	0.30	0.25
Botrytis infection	0.26	0.94	**0.05**	1.67	8.13	**<0.01**
Berry split	1.49	1.49	0.31	0.90	2.90	0.88
Skin browning	-	-	-	0.08	0.04	0.45
Scale : 1=Green and 5=Brown						
Stem browning	3.0	2.7	0.26	1.7	1.4	0.20
Scale : 1=Dry, 2=Condensation, 3=Free Water						
Moisture	1.2	1.0	0.15	1.0	1.1	0.33

Figure 6.5 shows a magnified picture of conventionally grown DBH with berry split and SO₂ damage. The SO₂ damage can be observed as bleached areas at the split site on the berry.
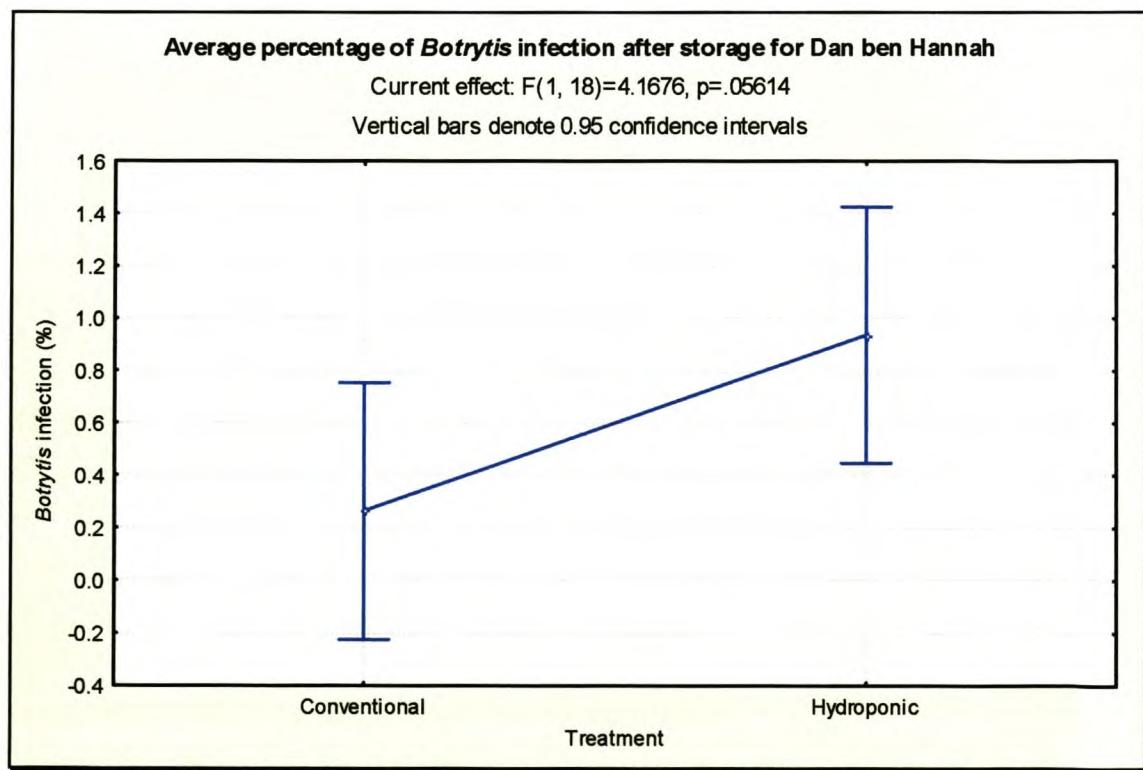

Figure 6.3: The average percentage of *Botrytis* infection in DBH after a five-week storage period.
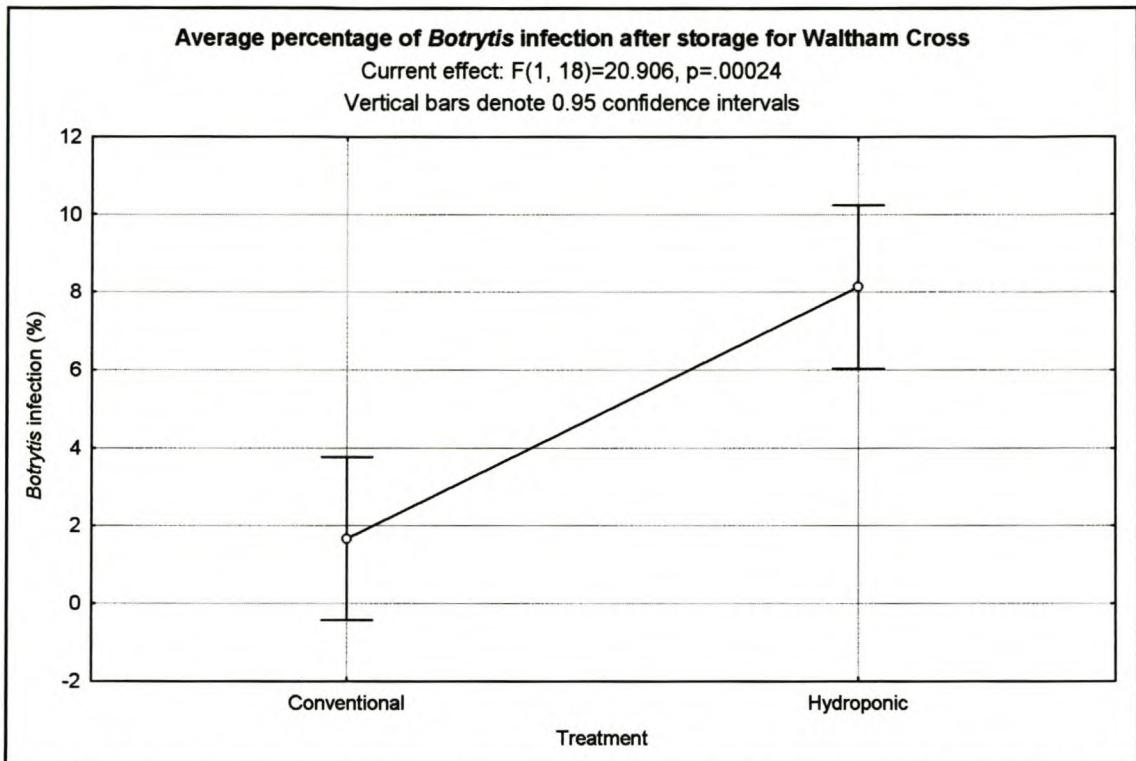
Figure 6.4: The average percentage of *Botrytis* infection in WC after five weeks of storage.

Figure 6.5: Berry split and SO_2 damage in conventionally grown DBH after five weeks of storage.

Figure 6.6 shows a magnified picture of conventionally grown WC with skin browning symptoms. Calcium is essential as a binding agent to ensure structure and stability in the cell walls and cell membranes, and to retain the permeability of the cell membranes. A shortage of Ca often causes breakdown of the cell membrane, which results in ageing and browning in table grapes (Strydom *et al.*, 1999). However, the fruit analyses done on WC showed no difference in the average level of Ca between the two treatments.

Figure 6.6: Berry skin browning of conventionally grown WC after five weeks of storage.

6.3.4 SEED STATUS
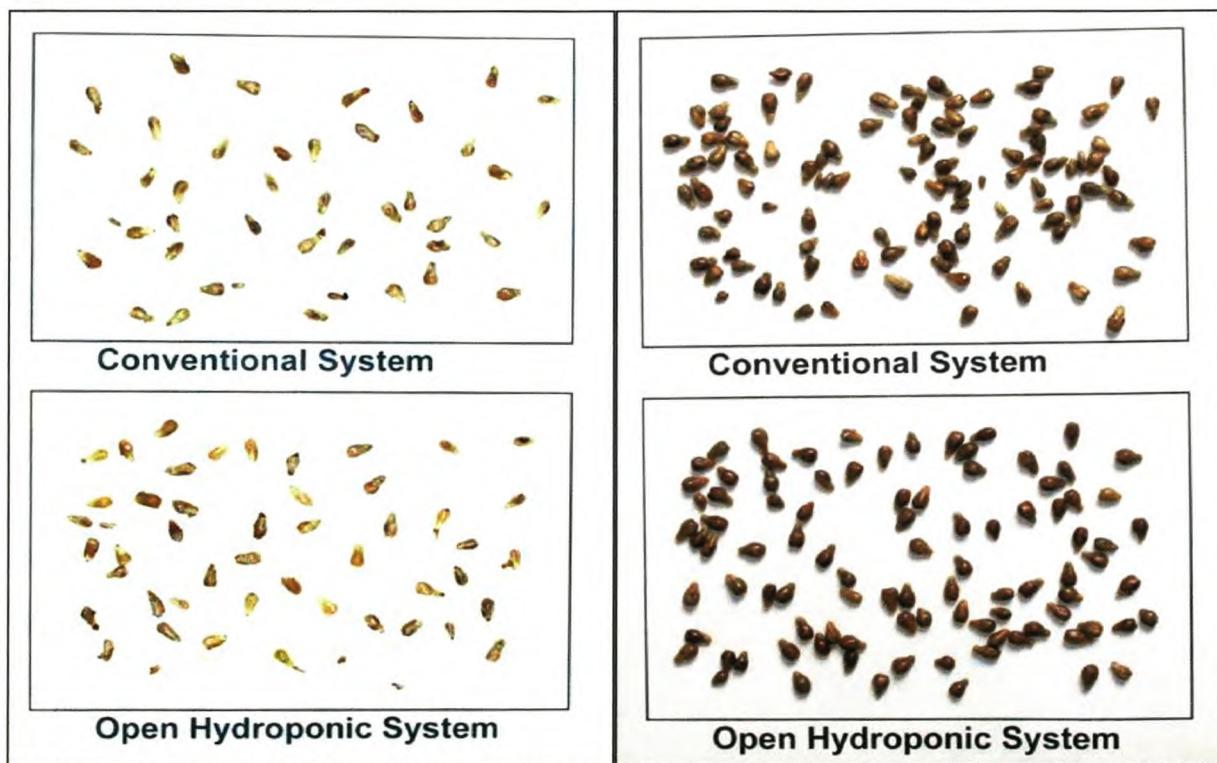
Figure 6.7: Seed status of DBH (on the left) and WC (on the right), showing no significant differences in colour, shape and size between the conventional and hydroponic treatment.

No distinctive difference was found in the seed status of conventionally and OHS-treated DBH and WC (Fig. 6.7). Hydroponically treated DBH shows a few smaller seeds than those from the conventional system. Seed colour, size, evenness and shape were basically the same for both treatments of DBH and WC. Tables 6.8 and 6.9 show the averages and p values that were statistically determined in this regard. The only significant difference in seed size (in WC) is shown in Table 6.9 and is graphically represented in Figure 6.8.

Table 6.8: Average number of seeds per berry in conventionally and hydroponically grown DBH

Criteria	Average		p value
	Conventional	Hydroponic	
Number of seeds per berry	2.070	1.993	0.71

Table 6.9: Average number of seeds per berry in conventionally and hydroponically grown WC.

| Criteria	Average		p value
	Conventional	Hydroponic	
Number of seeds per berry	1.463	1.270	0.01
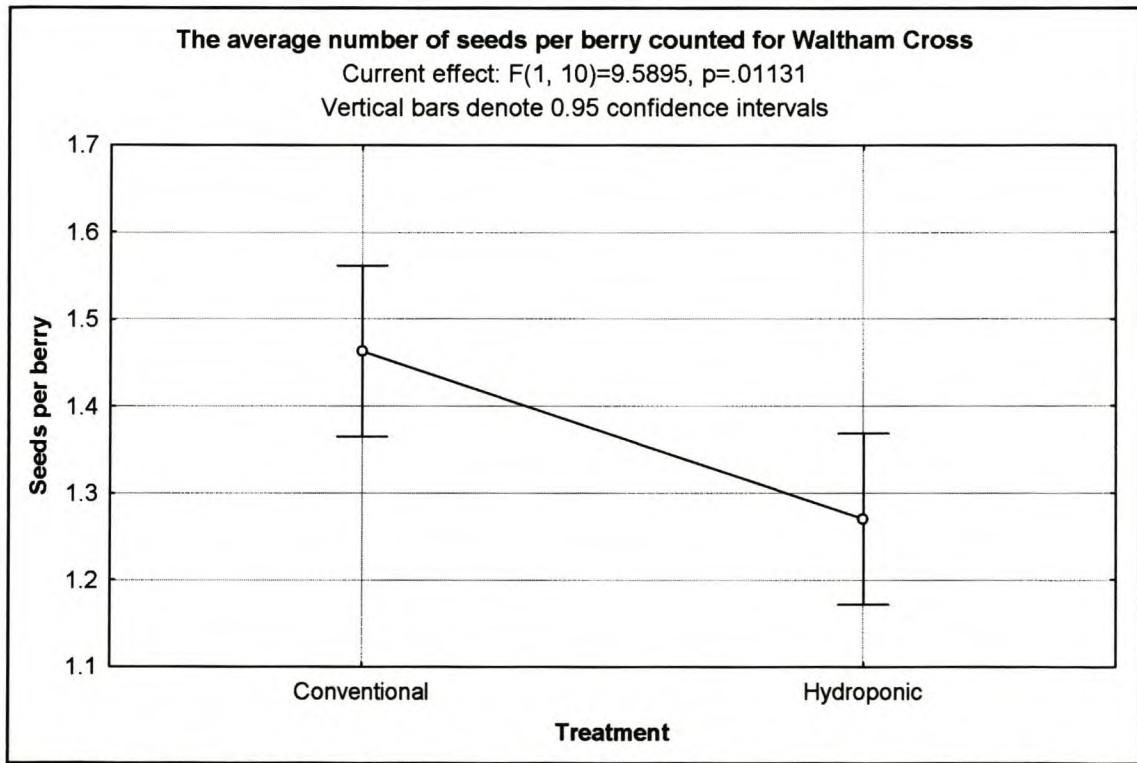
Figure 6.8: The significant difference for the number of seeds per berry in conventionally and hydroponically grown WC.

6.3.5 SKIN ANALYSES

The skin analyses of conventionally grown were done at a magnification of 600. They showed no distinct pericarp due to the preparation methods used for the grape skin material. Three layers of hypodermal cells and a distinct mesocarp, with larger cells and cell walls, are visible (Fig. 6.9). Skin analyses done on OHS-treated DBH (500x magnification) showed that no waxy layer was present, also due to the preparation of the material, and only a distorted epidermal cell layer. Two layers of hypodermal cells are visible, but these cells are also distorted and have broken cell walls. Very large mesocarp or pulp cells can be seen on the inside of the hypodermal layer (Fig. 6.10).

The cells of the conventionally treated DBH were more intact, with clearly visible cell walls. The cells of the OHS-treated DBH were much bigger, particularly the mesocarp cells, which also showed degradation of the cell walls.
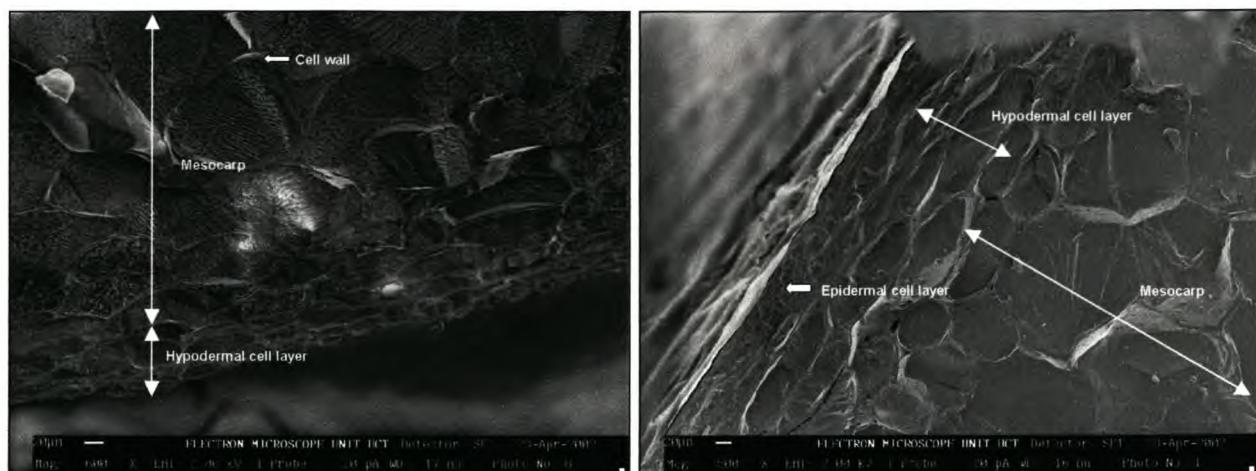

Figure 6.9: Conventionally grown DBH on the left and hydroponically grown DBH on the right.

Skin analyses were done on conventionally and OHS-treated WC at a magnification of 500. Conventionally treated WC showed a distinct pericarp with its waxy layer on the outside and a layer of small epidermal cells underneath. Three layers of hypodermal cells were visible on the inside of the epidermal cells (Fig. 6.10). Hydroponically treated WC showed no trace of a waxy layer, and no epidermal cells were visible. Only two layers of hypodermal cells were present (Fig. 6.10). The situation in the mesocarp cells was the same as for DBH. The OHS-treated berries had larger, disrupted cells with thin cell walls.
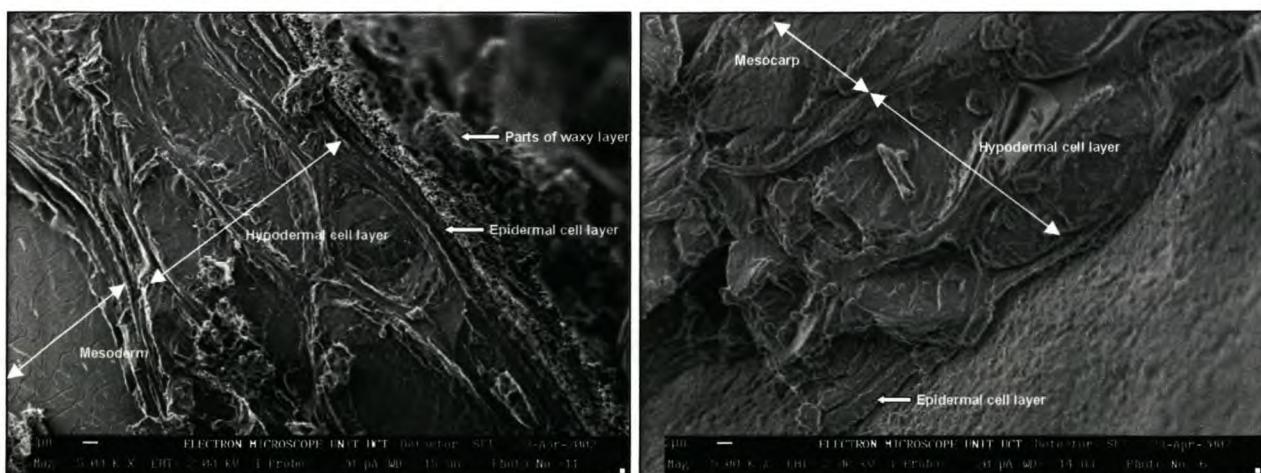

Figure 6.10: Conventionally grown WC on the left and hydroponically grown WC on the right.

6.3.6 SKIN COLOUR ANALYSES FOR DAN BEN HANNAH

The absorbance of the anthocyanin content in the grape skins of the conventionally and OHS-treated DBH was measured (Table 6.10). The OHS treatment showed significantly higher absorbance by the anthocyanin level at both 420 and 520 nm (Figs. 6.11 and 6.12).

Table 6.10: The absorbance levels of anthocyanins for conventionally and hydroponically treated vines as measured by the method of Hunter *et al.* (1991).

| Absorbance	Treatment		p value
	Conventional	**Hydroponic**	
420 nm	0.094	0.138	< 0.01
520 nm	0.376	0.602	<0.01
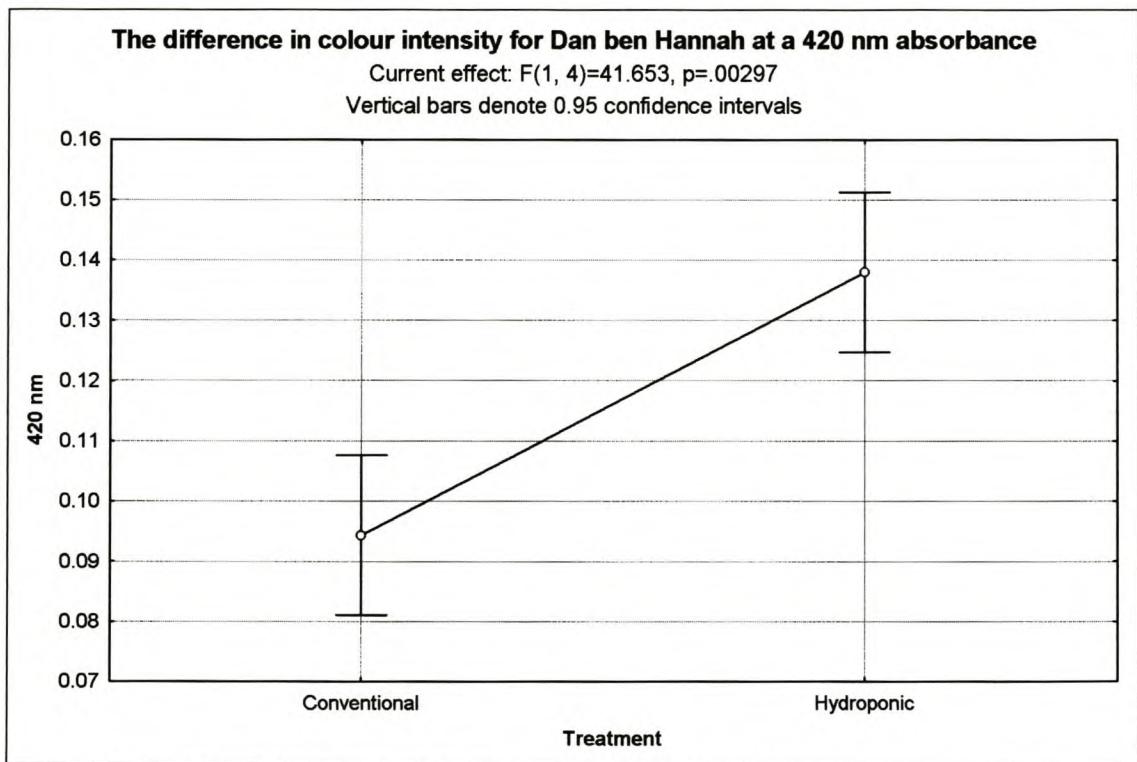
Figure 6.11: The difference in colour intensity of DBH at 420 nm.

Figure 6.13 shows the significant difference in colour between conventionally and OHS-treated DBH. The conventionally grown DBH shows a lighter, more red colour, especially where the berry meets the rachis. The OHS-treated DBH is nearly black in colour. This visual difference was confirmed by extracting the total anthocyanins from the berry skins and subjecting them to Fosscan, which showed a higher total anthocyanin content for the OHS-treated DBH (section 6.3.7).
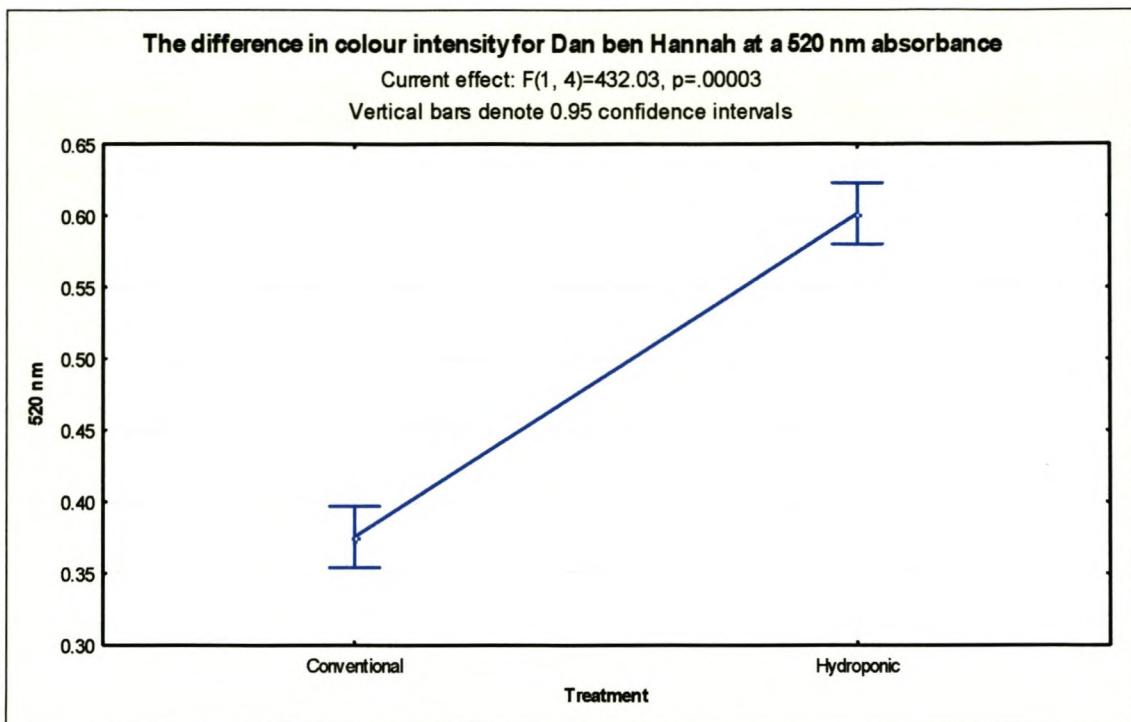
**Figure 6.12:** The difference in colour intensity or DBH at 520 nm.

Conventional System

Open Hydroponic System
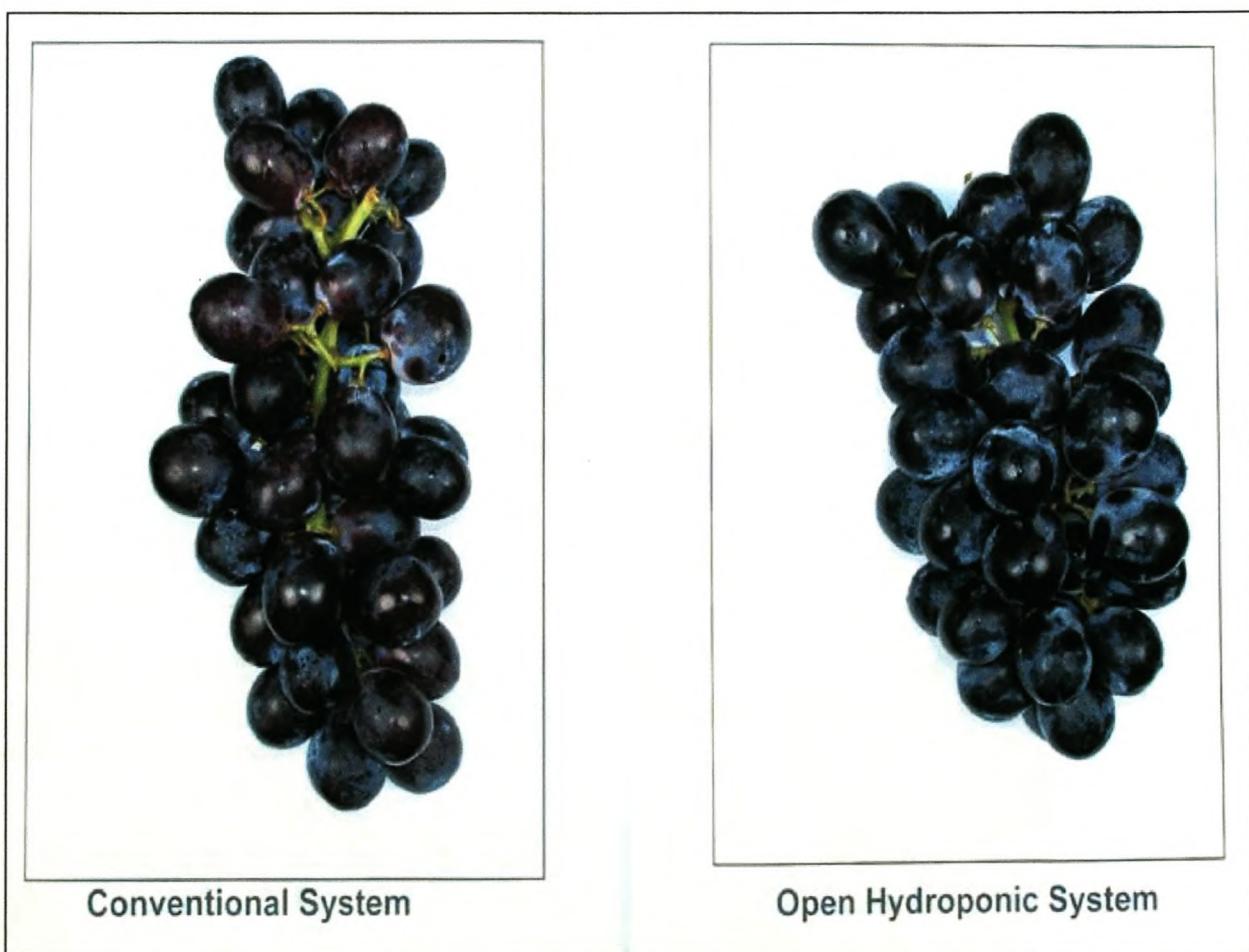
Figure 6.13: The difference in colour and compactness of DBH bunches from both treatments harvested on the same day.

6.3.7 USING THE FOSSCAN 2000 TO DETERMINE ADDITIONAL INFORMATION

The mustscan program of Fosscan 2000 was used to determine the pH, total acid, tartaric acid and malic acid in both the conventional and hydroponic treatment of both cultivars. There was no significant difference between the conventional and OHS treatment of both cultivars, as shown by the average and p values in Table 6.11.

Table 6.11: Average mustscan analyses determined for both cultivars using Fosscan 2000.

Criteria	Dan ben Hannah			Waltham Cross		
	Conventional	Hydroponic	p	Conventional	Hydroponic	p
pH	3.20	3.25	0.13890	3.44	3.36	0.20720
Total acid g/L	6.72	6.29	0.16091	6.40	6.40	0.99613
Tartaric acid g/L	2.89	3.95	0.07824	3.76	3.72	0.87102
Malic acid g/L	4.50	4.23	0.39209	2.93	4.34	0.22859

Fosscan 2000 was used to determine other interesting factors relating to the conventional and hydroponic treatment of both cultivars. The winescan program was used to determine sugar content, anthocyanins, phenol index, sanitary index, etc. of DBH and WC grape juice for both treatments. The results are shown in Table 6.12 as an interesting addition to the results for fruit quality.

Table 6.12: Average winescan analyses determined for both cultivars with Fosscan 2000.

Criteria	Dan ben Hannah		Waltham Cross	
	Conventional	Hydroponic	Conventional	Hydroponic
Glucose-fructose g/L	143.25	137.25	141.75	148.5
Brix	7.45	7.70	7.325	7.75
Density	1.059	1.05675	1.05825	1.06125
Polyphenol index	22.575	16.85	11.9	13.375
OD 280	11.9	11.025	12.05	11.4
OD 520	5.0	4.4	3.75	3.775
Colour intensity	6.2	5.05	4.05	4.425
Anthocyanins	134	153.75		
Ammonia	47.5	75.5	76.25	87.50
Alpha amino nitrogen	144.75	176.5	168	211.25
Total assimilable nitrogen	192.25	252	244.25	298.75
Potassium	1963	1943.5	2036.75	2146

Sanitary index				
Grey rot	9.0	10.25	11.0	9.25
Acid rot	5.75	5.5	4.75	3.5
Yeast activity	6.25	6.75	6.75	6.5
Lactic activity	0.25	0.25	1.0	1.0

6.3.8 TOTAL PRODUCTION IN THE PAST FIVE YEARS

The yield data for the past five seasons were collected to provide a better understanding of the influence of the change from conventional production to OHS production. For both cultivars, the 2000/2001 season showed a significant drop in production which might be due to the system change (Table 6.13). The DBH yield improved during the 2001/2002 season, but was still not as good as the 1997/1998, 1998/1999 and 1999/2000 seasons. WC recovered quickly, however, and in the 2001/2002 season had the best production for the past five years. However, these results were influenced because conventionally and OHS treated grapes were not harvested separately.

Table 6.13: Total yield of the past five seasons for DBH and WC.

Season	Dan ben Hannah		Waltham Cross	
	Total yield	Yield /ha	Total yield	Yield /ha
	4.5 kg units			
1997/1998	25993	9779	21117	5768
1998/1999	23472	8831	21902	5982
1999/2000	19850	7462	21093	5763
2000/2001	18112	6809	16050	4385
2001/2002	18628	7008	24899	6801

6.4 DISCUSSION

6.4.1 LEAF BLADE AND PETIOLE ANALYSES

The toxicity levels of nutrients in the leaf and petiole analyses are concerning factors in both DBH and WC treated conventionally and hydroponically. Although the toxicity levels generally decreased in both cultivars as the season proceeded, it is clear that the nutrients applied conventionally and hydroponically were imbalanced.

The exceptionally toxic levels of Cu and Zn in both cultivars treated conventionally and hydroponically must be considered dangerous to the plant. Foliar sprays earlier in the season might be responsible for the high Cu, Zn and Mn levels. These elements leave a residue on the leaf surface which then becomes embedded in the cuticula of the leaves. These elements will not wash out when the leaves are

prepared for analyses. This toxicity could result in visual symptoms, which were not present in this study, and could affect the functioning of other elements.

The parameter used in the USA and Australia is nitrogen availability taken in the petioles instead of the leaf blades during the flowering stage. However, guidelines vary according to cultivar, soil type and cultivation method. The total N in the leaf blades might vary by 10% between vines to which it was under applied and excessively applied, and by up to 100% in the petioles (Conradie, 2001).

The annual N requirement for a production of 25 tonnes per hectare is 97 kg/ha (Chapter 2, Table 2.8) (Conradie, 2001). During the 2000/2001 season, 87 kg N/ha, 103 kg Ca/ha (Ca nitrate flakes) and 28 kg N/ha, 23 kg Mg/ha (Mg nitrate), were applied to the OHS-treated DBH (Chapter 3, Table 3.8). Only 52 kg N/ha and 52 kg K/ha were given to the conventionally grown DBH post harvest (Chapter 3, Table 3.8). The conventionally grown WC received a total of 243 kg N/ha in the southern part of the block and 58 kg N/ha in the northern block during the season. The OHS-treated WC received 94 kg N/ha, 111 kg Ca/ha (Ca nitrate flakes), and 27 kg N/ha, 22 kg Mg/ha (Mg nitrate) during the 2000/2001 season (Chapter 3, Table 3.9). During the 2001/2002 season, both OHS-treated cultivars received 89 kg Ca/ha and 106 kg Ca/ha alone and at least 56 kg/ha of another N-bonded fertiliser (Chapter 3). It is therefore clear why the leaf blade and petiole analyses of DBH show high N values. However, the situation in WC can only be explained by the influence of the different soil fertilities of the northern and southern parts of the WC block (Chapter 3).

Calcium, which is critical for the cell structure in the berry skins, was lower at harvest in the leaf blades of both cultivars treated hydroponically than in the conventional system. There could be several reasons for the lower Ca, one of which might that Ca was only taken up by the vine during the early stages of the growing season and that not enough Ca was applied during this time. Another reason could be that the Ca was not in a form that made it available to be absorbed by the plant's root system. Calcium has antagonistic interactions with other elements in the soil, such as ammonium (Chapter 2). Because ammonium phosphate was applied (Chapter 3, Tables 3.5 and 3.6) during irrigation, this might have had an effect on the Ca uptake. However, the amount of Ca in the fruit is more important than that in the leaf blade because of its importance for cell wall structure to produce better quality fruit.

6.4.2 FRUIT ANALYSES

As seen in the previous section, the results show that the levels of certain nutrients were higher in OHS-treated DBH and WC, and others we re lower.

Calcium was lower in the OHS-grown DBH than in the conventional treatment, resulting in a weaker cell structure in the berry skins.

The N level in the fruit of OHS-treated DBH was higher than in the conventional DBH. Nitrogen induces strong vegetative growth, which is associated with lower yield and poorer fruit quality (Conradie, 2001). *Botrytis* infection was found in the OHS-

treated grapes after storage, and this might be due to poorer fruit quality induced by excessive N fertilisation.

The toxic levels of the microelements in the leaf blade and petiole analyses did not show in the fruit analyses of any of the four treatments. The rachis structure was more compact, with shorter laterals and pedicels, in the OHS-treated bunches of both cultivars, which explained the more compact bunches (Fig. 6.1 to 6.2).

The more yellow berry colour in OHS-treated WC and the darker colour of OHS-treated DBH show that these cultivars were ready for harvest a few days earlier than the conventionally grown cultivars. This was also proven by the starting dates of the phenological stages, according to which the OHS-treated DBH could have been harvested four days earlier than the conventionally treated vines, and the OHS-treated WC three days earlier.

6.4.3 ASSESSING THE STORAGE ABILITY AND SEED STATUS OF THE GRAPES

High N levels in the fruit induce poorer fruit quality because *Botrytis* infection may appear more readily (Conradie, 2001), although the N levels in the OHS-treated WC fruit were lower. Irrigation during ripening will increase the risk of infection by diseases such as *Botrytis* (Van Zyl, 1984), and canopies that are more dense will increase the risk of disease infection due to the lower evaporative potential in the fruit zone (English *et al.*, 1990). This was the case in the OHS-treated DBH (chapters 3 and 5).

The significantly higher level of *Botrytis* infection in both OHS-treated cultivars could also be the result of the lower Ca levels in the berry skins, which affect cell structure. The other possible reason for the higher infection is related to the fact that the bunches of the OHS-treated cultivars were more compact than those of the conventional treatment. Airflow inside the bunches would have been limited and, once one berry had become infected, the disease would spread to the other berries more quickly than in the conventional system.

There were no significant differences between any of the other factors involved in determining storage capacity, such as loose berries, SO_2 infection and berry split, in the OHS and conventional treatments.

The number of seeds per berry in OHS-treated WC was significantly lower than in the conventional treatment, which might be as a result of plant stress, although there was an average of one seed per berry in both treatments. Loose berries after storage were not a problem.

6.4.4 SKIN AND SKIN COLOUR ANALYSES

The skin analyses were performed with a scanning electron microscope and confirm that the cell structure of the berry skins disintegrated during storage in both OHS-treated cultivars, probably because of the lack of Ca. The disintegrated skin cells

probably also contributed to the higher *Botrytis* infection in the OHS-grown cultivars, as the weaker cell walls could be penetrated more easily.

The OHS-treated DBH and WC show a more intense red and yellow colour respectively than in the conventional treatments. This result confirms that the OHS-treated DBH and WC ripen earlier than under the conventional treatment.

6.4.5 TOTAL PRODUCTION IN THE PAST FIVE SEASONS

From the total production of DBH and WC, it can be seen that the initial change to drip irrigation might have had a very negative effect on the yield. The DBH showed a better yield in the 2001/2002 season and the WC, however, produced its highest yield in five years. These results might be the effect of the system change, where the vine roots were still adapting to the new system. However, because the conventionally and OHS treated grapes for both cultivars were harvested together, parameters such as the climate might have also played a role in the yield decline of 2000/2001.

6.4.6 USING THE FOSSCAN 2000 TO DETERMINE ADDITIONAL INFORMATION

Fosscan 2000 was used only to determine the differences between the treatments. Because Fosscan 2000 is only calibrated for wine and wine grapes, it will not be discussed in detail.

Fosscan 2000 confirmed that the colour intensity was higher in the OHS-grown cultivars. The total amount of anthocyanins was also shown to be higher in the OHS-treated DBH. The sugar content (Brix) was higher in the OHS-treated WC. All these results confirm the earlier ripeness of the OHS-treated DBH and WC in comparison to the conventional treatments.

6.5 CONCLUDING REMARKS

This chapter has pointed out the critical role played by nutrients in overall vine growth and fruit quality. There is no doubt that the excessive levels of N, in combination with the lower Ca levels, had a negative effect on fruit quality. The pathway followed by the nutrients was followed from the soil and through the vine, where they are metabolised in the leaf blades, petioles and bunches. From the development of the phenological stages it became clear that both OHS-treated cultivars were ripe for harvest a few days before the conventional vines. The anthocyanin assay proved this phenomenon, as the colour intensity of DBH treated hydroponically was higher. This was also confirmed by Fosscan.

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Chapter 7

GENERAL DISCUSSION AND CONCLUSIONS

GENERAL DISCUSSION AND CONCLUSIONS

The cultivation of table grape cultivars under Open Hydroponic Systems (OHS) employs an intensive management system for which very limited guidelines currently are available. The OHS system for table grape production has never been evaluated systematically and it is therefore difficult to determine if the system holds the number of possible advantages that have been advocated. These include higher yields and better quality, both of which are critical factors in the cost-effectiveness and marketability of table grape production.

In South Africa, there are very few existing vineyards under OHS production. Moreover, virtually no existing OHS sites and table grape production blocks lend themselves optimally to a comparative study of OHS production parameters and advantages. Optimally, vineyards have to be established under OHS for comparison with other types of production systems under comparative conditions, together with systematic experimentation with regard to individual parameters. This should ideally exclude the management of the system as a variable factor.

The aims of this study were to monitor the usefulness and impact of OHS on table grape production. This was done within the framework of a case study, in which the influence of OHS, specifically on vegetative and reproductive vine growth, was monitored through the establishment of measurable parameters. The effect of OHS on yield and quality was determined with the above-mentioned aims taken into account.

In order to achieve these goals, all the relative background information was collected for two cultivars grown under OHS, with micro-irrigation as a control. The two cultivars identified for this study were Dan Ben Hannah (DBH), a black, seeded cultivar, and Waltham Cross (WC), a white, seeded cultivar. The DBH block was approximately 22 years old when one hectare was changed from conventional micro-irrigation to OHS in August 2000. The same approach was followed for the WC block, which was 16 years old when the system change took place. Thus, some of each cultivar was already under OHS cultivation for approximately five months when this project started at the beginning of 2001. Old soil maps, as well as irrigation and fertiliser programmes, were obtained from the production manager. The soil maps provided information on the soil types identified in the blocks prior to the establishment of the above-mentioned cultivars. The conventionally treated vines were irrigated and fertilised according to historical block data. The OHS-treated vines were irrigated and fertilised according to programmes established by one consultant for the 2000/2001 season, and by a different consultant for the 2001/2002 season. These soil maps, irrigation and fertiliser programmes were studied and recorded as a base description of the blocks and to establish an experimental layout for the intended project. The layout of the two cultivar blocks with their different treatments was done statistically to ensure an even spread of measuring points through the blocks. All measurements within the different treatments were done at these

measuring points. A total number of 96 vines were used as measuring points for each of the four treatments. Diseased vines and vines close to roads were excluded from the study to ensure more accurate experimental data. Ten chosen phenological growth stages were monitored throughout the season in OHS-treated vines and compared with the conventionally treated vines. At the end of the 2001/2002 growth season, all relevant climatic parameters were collected for the specific production unit

An important project aim was to determine the influence of OHS on root development and root distribution, as well as the influence of the soil status on the vine roots. This study showed that vine roots can adapt relatively quickly (within two growing seasons) from a micro-irrigation system with an extensive wetted area to a smaller wetted OHS drip area. Active vine roots tended to develop in the shallower soil layer beneath the drippers. From soil pits prepared and studied in the various blocks it became clear that the soil maps that were initially drawn up for the area were incorrect, as a different soil type, namely Tukulu, with differences in the clay content, were found in the blocks. This complicated the subsequent analysis of some of the data, since soil type influences the root system, soil pH, soil density and the soil nutrient status.

Another complicating factor regarding this study was the fact that a change occurred in the fertiliser and irrigation programmes from one season to another, especially in the OHS-treated vines. This was because the production unit switched to a different consultant. From the fertilisation data it became clear that there were differences from one season to another in the elemental levels of nutrients applied, specifically for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and sulphur (S). These factors, in conjunction with a rainy 2001/2002 season, led to excessive vegetative growth, especially in the DBH grown under OHS. The excessive vegetative growth had an influence on the amount of light penetrating the vine canopy, with a greater effect on the OHS-treated DBH, as shown by shoot length measurements. The OHS-treated WC had a higher light intensity within the grapevine canopy than the conventionally treated vines throughout the season. A denser vine canopy may lead to a higher risk of disease infection within the block due to a higher humidity factor, which might have an effect on the storage ability of the grapes. The denser canopy also tends to have a negative influence on bud fertility, as shown by the OHS-treated DBH, which had a lower bud fertility percentage than the conventionally treated vines.

Nutrient uptake and fruit quality were also investigated by means of leaf blade, petiole and fruit analyses, as well as in terms of storage ability, grape skin analyses and colour analyses. Leaf blade and petiole analyses were done between fruit set and véraison for both cultivars treated conventionally and hydroponically, and again just prior to harvest. Micronutrient toxicities were revealed in the leaf blade analyses for both treatments of DBH and WC which were caused by residue embedded in the cuticula of the leaves. The N levels were higher in the OHS-treated DBH than in the

conventional treatment caused by the difference in the clay contents of the soil, although the N levels returned to normal towards harvest for both treatments of WC. The fruit analyses correlated with the leaf blade analyses and showed a higher N content for the OHS-treated DBH grapes, but a lower Ca content than in the conventionally treated grapes. In WC, the fruit analyses showed a normal N and Ca content for both treatments. However, the fruit analyses did not show any micronutrient toxicities in the grapes. The cold storage data showed a higher level of *Botrytis* infection in both cultivars treated hydroponically than in the conventionally treated cultivars. The higher *Botrytis* infection was caused by a combination of factors, which will be discussed below. Higher N levels in the fruit might induce *Botrytis* infection to appear more rapidly, causing poorer fruit quality. Calcium is an important macronutrient for the cell structure of the berry skin. The OHS-treated DBH showed a lower Ca content in the fruit analysis, which might have contributed to a higher *Botrytis* infection due to a poorer skin cell structure. Another factor that contributed to the higher *Botrytis* infection was the compact rachis structure of the OHS-treated grapes, which caused the bunches to be more compact. This phenomenon was present in both OHS-treated cultivars, but could not be explained on the basis of the results obtained from the elemental analyses of the rachis structure.

One of the advantages of OHS that was shown in this study was the ability to manipulate grapevine phenology for earlier ripeness. Both OHS-treated grapes ripened a few days earlier than the conventionally treated grapes, based on the skin colour analyses for DBH and the Fosscan Brix value for WC. This kind of advantage might have a positive influence for the production of table grapes for a specific market window.

Another advantage arising from this project is the rapid adaptation ability of relatively old vines from one system to another in terms of yield and production. Within two growth seasons, the total yield of both OHS-treated cultivars correlated with the conventionally treated cultivars. The white, seeded cultivar produced more grapes per hectare (6 801 4.5 kg units) in the 2001/2002 season than in the previous three seasons (5 763 to 5 982 4.5 kg units), excluding the first season after the system change, as a result of the adaptation effect on the yield.

This thesis presents a starting point for future in-depth research on every individual aspect affecting OHS production. This study, with its limitations, shows that, with the correct management protocols in place, OHS could be a useful tool for future production management to be market driven and internationally competitive to meet the higher demand for better quality table grapes.