The effect of Partial Rootzone Drying and Foliar Nutrition on water use efficiency and quality of Table Grape cultivars Crimson Seedless and Dauphine

by

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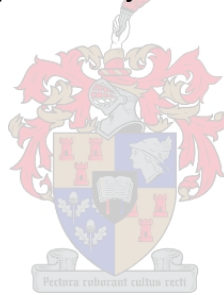
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I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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SUMMARY

The South African and international table grape industries are growing rapidly, which necessitates the production of high quality export fruit at competitive production costs. For this reason, alternative irrigation methods are required to utilise water optimally while still attaining good quality table grapes. An increase in agricultural productivity may be dependent on either the availability of more water for irrigation or an increase in the efficiency of water use.

The first aim of this study was to evaluate the effectiveness of the Partial Rootzone Drying (PRD) irrigation strategy in Crimson Seedless and Dauphine table grape production. This irrigation system is based on the drying of half of the vine roots, thereby allowing the plant to produce hormones like abscisic acid (ABA) in reaction to water stress. The hormone production in turn results in stomatal closure and the reduction of water loss via transpiration. The drying cycle is then repeated after 10 to 15 days on the other side of the vine, irrigating the previously dried roots. PRD will encourage a consistent production of the stress hormone abscisic acid (ABA), without actual water stress. This strategy reduces the amount of water used for irrigation, without an accompanying loss in fruit yield, as compared to conventional techniques. In this study, conventionally treated vines were irrigated according to historical block data and PRD-treated vines were irrigated at the same times.

The second aim of this study was to monitor the efficacy of a foliar nutrient, Croplife. This foliar nutrient allegedly improves the uptake of foliar applied nutrients, assists with transport of all minerals through the leaves and enables the plant to attain higher pest and disease resistance thresholds. Conventionally treated vines that did not receive foliar nutrient treatment were compared to vines that received foliar nutrients as prescribed by the manufacturer.

Vine cultivars Crimson Seedless and Dauphine, were grown under open hydroponic principles with drip and drip irrigation respectively in this experiment. For the hydroponic vines (Crimson Seedless), all vines were situated in the same row and 72 vines were divided into mini-plots of three vines. Treatments were then assigned to an equal number of plots at random. The same procedure was followed for the drip irrigated vines (Dauphine) but the vines were situated in two rows of equal length. Treatment

effects were followed from budburst until harvest, where after post-harvest analyses were conducted.

The first aim, namely to show that PRD is an effective irrigation strategy for table grape production in Crimson Seedless and Dauphine cultivars , has shown that vines did not exhibit signs of stress even though they received only half the conventional amount of water. This study was conducted over only one growth season and therefore no definite conclusions could be drawn about the long term effectiveness of PRD on table grapes. It did, however, confirm numerous results obtained from different studies on the use of PRD in wine grape production.

The results obtained in the second part of the study were inconclusive and could not show that Croplife is effective in improving the uptake and transport of applied foliar nutrients. Because Crimson Seedless is cultivated under open hydroponic principles, nutrients can be absorbed by the roots via the soil and micronutrients are also available from chemical sprays during the season. There was no evidence to indicate that the use of Croplife increased nutrient absorption and transport, neither did it supplement or detract form the observed effect of PRD.

Despite the limitations experienced during this study, it has shown that the use of PRD for table grape production may be a useful tool for improving water utilisation efficiency in future. The strategy will have to be developed systematically through experimentation to fully unlock the potential of the PRD management system for table grape production. This study provides a good starting point for future research required to elucidate numerous aspects of the PRD system and has clearly shown that established vineyards can be switched to a PRD system without a loss in table grape quality. It is envisaged that the advantages of this system could have a positive effect on the production of high quality fruit for the international market.

OPSOMMING

Die tafeldruif industrie in Suid-Afrika, en reg om die wêreld, groei teen 'n ongelooflike pas en word gekarakteriseer deur die produksie van hoë kwaliteit uitvoer gehalte teen laer produksie koste. Om hierdie rede word daar gesoek na alternatiewe besproeiingsmetodes, waar water optimaal, sonder oorbodige verbruik, vir goeie kwaliteit druiwe produksie gebruik kan word. 'n Toename in landbou produkte sal afhanklik wees van die beskikbaarheid van meer water vir besproeiing of die effektiewe gebruik van besproeiingswater.

Die eerste doel van hierdie studie was om die effektiwiteit van die besproeiings strategie Gedeeltelike Wortel Verdroging (GWV) op Crimson Seedless en Dauphine tafeldruiwe te toets. Hierdie besproeiings sisteem is gebaseer op die uitdroging van een helfte van die wingerd wortelstelsel wat toelaat dat plant stres hormone geproduseer word in reaksie op water stres, soos absissien suur (ABA), wat lei tot huidmondjiesluiting en verminderde waterverlies deur transpirasie. Die uitdrogings siklus word herhaal na 10 tot 15 dae aan die ander kant van die stok waar voorheen uitgedroogte wortels dan benat word. Hierdeur word 'n volhoubare produksie van die streshormoon ABA aangemoedig sonder werklike waterstres. Hierdie metode verminder die verbruik van water, sonder die verlies van opbrengs in vergelyking met konvensionele besproeiingsmetodes. In hierdie studie is kontrole stokke besproei volgens die geskiedenis van die blok, en GWV behandelde stokke was terselfdertyd besproei.

Die tweede doel van hierdie studie was om die effektiwiteit van die blaarvoeding, Croplife te moniteer. Hierdie blaarvoedingsproduk word beweer, verbeter die opname van voeding wat deur middel van blare toegedien word, verbeter die beweging van minerale deur die blare en stel die plant in staat om beter weerstand te bied teen peste en siektes. Sekere stokke het geen blaarvoeding ontvang nie en ander het 'n hoeveelheid, soos deur die maatskappy voorgeskryf, ontvang.

Twee tafeldruif kultivars, Crimson Seedless en Dauphine, wat besproei was onderskeidelik onder 'n oop hidroponiese stelsel (OHS) en onder drup besproeiing was gebruik in die studie. In die OHS blok is wingerdstokke gebruik in dieselfde ry en 72 stokke is in mini-plotte van drie stokke verdeel. Behandelings was dan ewekansig aan hierdie plotte toegedeel. Stokke onder mikro-besproeiing, is gebruik in twee rye van

dieselfde lengte en dieselfde prosedure is gevolg soos OHS stokke. Elke mini-plot bestaan uit drie stokke waarvan die middelste stok dien as die behandelings stok en die aangrensende twee stokke as bufferstokke. Behandelingseffekte was gemonitor vanaf bot tot oes waarna na-oes leeftyd ondersoek is.

Die eerste doelwit van hierdie studie, naamlik om die effektiwiteit van die besproeiings strategie Gedeeltelike Wortel Verdroging (GWV) te toets in 'n tafeldruif omgewing het bewys dat in beide Crimson Seedless en Dauphine die stokke nie gely het nie, al is die helfte van die water aan hierdie stoke toegedien. Die studie is ongelukkig slegs oor een groei seisoen beoefen, en geen definitiewe afleidings oor die effektiwiteit van GWV oor die langtermyn kan gemaak word nie. Dit het wel bevestig wat in verskeie wyndruif-studies gevind is ook waar is vir die twee tafeldruif kultivars. Meer studies in hierdie veld word verlang in die tafeldruifindustrie.

Die tweede doel, naamlik om te bewys dat Croplife effektief is in die verbetering van voedinginname deur die blare en die transport van nutriente is weifelend. Omdat die cultivar Crimson Seedless onder OHS groei is nutriente geredelik beskikbaar deur die wortels en is mikronutriente beskikbaar deur chemiese besproeiings praktyke gedurende die seisoen. Daar is geen duidelike resultate wat toon dat die gebruik van Croplife nutrient absorpsie verhoog en transport verbeter het in die plant nie. Dit het ook nie bewys dat die gebruik van Croplife die effektiwiteit van GWV positief of negatief beïnvloed nie.

Ongeag die beperkinge ondervind gedurende die studie is dit bevind dat die gebruik van GWV vir tafeldruif verbouing baie handig te pas kan kom in die toekoms vir verbeterde waterverbruikeffektiwiteit. Hierdie sal sistemies ontwikkel moet word, deur eksperimente, om die volle potensiaal daarvan te ontsluit, spesifiek vir tafeldruif produksie. Hierdie studie verskaf 'n beginpunt vir toekomstige navorsing om meer toegeligte verklarings van die bogenoemde aspekte, veral met die voordeel dat reeds gevestigde wingerde kan omgeskakel word tot die GWV besproeiings sisteem sonder 'n verlies in kwaliteit. Die voordele van die GWV sisteem kan in die toekoms moontlik 'n groot positiewe invloed op die produksie van hoër kwaliteit tafeldruiwe vir die internasionale mark hê.

This thesis is dedicated to
my parents Sandra and Piet van Zyl, my brother, Pieter and sister, Winell
and to all my friends, whom without their support this would never, had
been possible.

BIOGRAPHICAL SKETCH

Tinake van Zyl was born in Namibia on 30 November 1981. After matriculating at Bloemhof Girls High in 2000, she enrolled at Stellenbosch University and obtained a BScAgric degree in Viticulture and Oenology. In 2005, Tinake enrolled for an MScAgric degree in Viticulture.

ACKNOWLEDGEMENTS

"It is not the quantity of water applied to a crop, it is the quantity of intelligence applied which determines the result – there is more due to intelligence than water in every case" ALFRED DEAKIN 1890

PREFACE

This thesis is presented as a compilation of 5 chapters. Each chapter is introduced separately and is written according to the style of the journal South African Journal of Oenology and Viticulture.

Chapter 1   **General Introduction and Project Aims**

Chapter 2   **Literature Review**
An overview on Partial Rootzone Drying and Foliar Nutrition

Chapter 3   **Material and Methods**

Chapter 4   **Research results**

Chapter 5   **General discussion and final conclusions**

CONTENTS

Chapter 1

INTRODUCTION AND PROJECT AIMS

GENERAL INTRODUCTION AND PROJECT AIMS

1.1 INTRODUCTION

The table grape industry in South Africa is characterized by the production of high quality export fruit. Countries such as Chile and Australia compete in the same market window as South Africa. In order to remain competitive, it is therefore important that improved yields and high quality remain top priorities within the industry (Van Zyl, 2003). One of the main factors influencing the quality and yield of table grapes is the availability of water.

Due to the realization that limited water resources can no longer sustain continued development in dry countries like South Africa, increased agricultural productivity may become dependent on the availability of more water for irrigation or an increase in the efficiency of water use (Stoll *et al.,* 2000; Serman *et al.,* 2004). One method that strives to use water optimally is Partial Rootzone Drying (PRD). This irrigation strategy is designed to reduce water utilization in grapevines without a decline in yield, thus increasing water utilization efficiency (Du Toit *et al.*, 2003; Du Toit, 2004). It is generally believed that the reduction of irrigation volumes is accompanied by a reduction in yields and fruit size, but according to David (2003) this can be avoided if PRD is managed correctly.

Other factors that influence yield and fruit quality include soil properties and fertilization programs. One management system that strives to optimize all the factors involved in crop production is based on open-air hydroponic principles (OHP), which has specific application in table grape production (Van Zyl, 2003). Using OHP for table grape production is advocated as being one way to establish better quality fruit, with a higher yield, in a shorter period of time (Gurovich *et al.,* 1994). This has been demonstrated in many different crops, such as peppers, lettuce and tomatoes (Burt *et al.,* 1998) as well as chicory plants and cucumbers (Jensen, 1999). Although macronutrients are not usually applied in this way, there are also other ways of fertilizing crops, namely foliar nutrition. Elements such as nitrogen (N), potassium (K), magnesium (Mg), boron (B), copper (Cu), manganese (Mn), zinc (Zn) and especially calcium (Ca) can be applied via foliar sprays.

1.2 SPECIFIC PROJECT AIMS

The aims of this study were to monitor the effects of PRD and foliar nutrition products on table grape production. The influence of PRD and foliar nutrition products, especially on vegetative and reproductive vine growth, was monitored through the establishment of measurable parameters. Yield, fruit quality and vine growth were also measured.

The specific objectives for the study were as follows:

- Monitor the effects of water stress induced through PRD on Crimson Seedless and Dauphine.
- Investigate the effect of PRD and foliar nutrition on vegetative and reproductive growth in Crimson Seedless and Dauphine.
- Compare the effect of PRD and foliar nutrition on berry size, colour, sugar development and shelf life of Crimson Seedless and Dauphine to that of a conventionally managed irrigation system.
- Compare the mineral content of fruit and leaves when using PRD as irrigation management system in conjunction with, or without foliar nutrition to that of conventionally irrigated vines.

The following approaches were followed to achieve these goals:
1. The collection of all relevant background information on the specific vineyard blocks chosen for the project;
2. The determination of the soil status and root distribution of the chosen blocks;
3. The establishment of measurable parameters to determine the influence of PRD on vegetative and reproductive growth;
4. The determination of the influence of nutrient uptake by leaves on fruit quality;
5. The determination of the influence of PRD and nutritional products on post-harvest parameters.

The hypotheses for this study were:

PRD influences the vegetative and reproductive growth of Crimson Seedless and Dauphine by decreasing vegetative growth without influencing reproductive growth,

PRD increases water use efficiency and quality of Crimson Seedless and Dauphine.

Foliar nutrition improves plant water relations and the post harvest quality of Crimson Seedless and Dauphine.

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Chapter 2

LITERATURE REVIEW

An overview on Partial Rootzone Drying and Foliar Nutrition

2.1 GENERAL INTRODUCTION

2.1.1. SOUTH AFRICAN CLIMATE AND RAINFALL

South Africa is a semi-arid country: rainfall is distributed unevenly, both geographically and seasonally (van Zyl, 2003). The production of table grapes in South Africa is mostly limited to areas with low rainfall and humidity during the growing season and therefore, is highly dependent upon extensive irrigation practices.

Economic pressure on table grape production forces producers towards higher yields per hectare of finer quality fruit (van Zyl, 2003). More efficient water utilization on farm level can be achieved by changing from the relatively inefficient methods of irrigation, such as micro-irrigation, to less wasteful drip-irrigation systems (Yagev, 1977; Ahluwala *et al.,* 1998). The key to improving wine and table grape quality in irrigated vineyards is to achieve an appropriate balance between vegetative and reproductive development, since excessive shoot vigour may have undesirable consequences for fruit composition (Dry *et al.,* 1996; Dos Santos *et al.,* 2003). The reliance on intensive irrigation for viticultural production, and the fact that current water resources may no longer sustain continued development, implies that new vineyard development has become increasingly dependent on the development of different strategies such as regulated deficit irrigation (RDI) and partial rootzone drying (PRD).

As a developing country with a growing population and expanding agricultural and industrial outputs, South Africa is faced with water scarcity as one of its major obstacles for sustainable development (www.weathersa.co.za). There is well-founded concern that the unprecedented human, industrial and agricultural development of the past two centuries has caused changes in climate over and above natural variation. Climate models predict that the mean air temperature over South Africa may increase with an estimated 2°C over the next century. Higher temperatures may influence rainfall, lead to melting of ice caps and also increase CO_2 levels (www.weathersa.co.za). These changes could increase rainfall in some parts of the country, and cause a decrease in other parts. A reduction in rainfall amount or variability, or an increase in evaporation (due to higher temperatures) would further strain the already limited water resources. Not unlike other industries, crop production requires sustained water resources to

function. A reduction in plant water utilization could reduce the amount of water required for crop production, and thus help to alleviate the problem.

Previous studies examining changes in rainfall have found that parts of southern Africa have shown no increase in rainfall the past 77 years, whereas other have shown concerning decreases (Alexander, 2000). Table 1 shows clearly that monthly rainfall has decreased in the Western Cape over the last 3 decades, which is cause for concern.

Table 1: Changes in daily rainfall as supplied by the South African Weather Bureau for the Western Cape (www.weathersa.co.za)

AREA	YEARS	RAINFALL (mm/month)
Cape Town	1980-1990	59.53
	1990-2000	36.99
Malmesbury	1973-1987	29.9
	1988-2000	28.1
Stellenbosch	1975-1987	66.75
	1988-2000	63.8
Wynberg	1981-1990	92.32
	1991-2000	81.97

2.1.2 BACKGROUND ON THE SOUTH AFRICAN TABLE GRAPE INDUSTRY

In South Africa fruit is the second most important export commodity after metals and contributes significantly to the country's annual export income. Total area under vines for table grape production in 2001 totalled 11 150 hectares and reached even higher numbers in 2004 at 12 319 hectares, increasing by 1 169 hectares in only 3 years. Export has grown from 197 486 tons in the 2001/2002 season to 239 500 tons in the 2003/2004 season, which is a 42 014 ton (17.5%) increase (Deciduous Fruit Statistics, 2004). Grapes thus contribute a significant part of agriculture, totalling 28.5% of the total fruit export market in South Africa.

2.2 PARTIAL ROOTZONE DRYING

2.2.1 INTRODUCTION

In semi-arid countries many horticultural crops, including grapes, rely on irrigation for water. In Australia it was found that future expansion of the horticultural industry, especially into hotter regions, will require more water (Stoll *et al.*, 2000a) and this will also stand true for South Africa. In recent years water has increasingly become a limiting factor and the amount of water available for horticultural purposes has become restricted. Aggravating these water limitations, irresponsible water use for irrigation has a negative effect on the environment (Stoll *et al.*, 2000a).

Under intensive irrigation, grapevine cultivars grow vigorously and excessive growth needs to be controlled. Excessively vigorous vines are characterised by excessive amounts of vegetative growth relative to fruit production (Du Toit, 2004a). Controlling excessive growth leads to reduced canopy density, better bud fruitfulness and vine balance, decreased cost of maintenance and increased fruit quality (Dry *et al.,* 1996). The most common methods used to decrease excessive vegetative growth include rootstock selection, root restriction, pruning practices and probably the most successful, reduced water supply via irrigation management (Dry *et al.,* 1996). In regions with low growing-season rainfall, excessive vigour can successfully be controlled by judicious irrigation management, as found in studies on winegrapes in Australia (Dry *et al.,* 1996), and which also holds true for South Africa (Myburgh, 2005). In the table grape industry, the major concern is berry growth and hence, sufficient water availability. This largely constrains the number of suitable areas for table grape cultivation.

Regulated Deficit Irrigation (RDI) has been used in developing practical solutions to manipulate grapevine vegetative and reproductive growth in wine grape production (Goodwin and Macrae, 1990). In countries where water is a scarce commodity, such as Australia, RDI is widely practiced in the red wine industry (Dry *et al.,* 2001). This irrigation technique is most commonly achieved by applying a short period of water stress directly after berry set in order to control berry size and vegetative growth. In other words, it is an accurately controlled irrigation strategy to apply mild stress at a critical stage during the season (Dry *et al.,* 1996). Drawbacks of this technique can include excessive water stress that leads to major crop reduction or even defoliation in extreme situations (Dry *et al.,* 2001). Sometimes the inappropriate application of water

stress cannot be avoided because of an inability to re-schedule irrigation and application quantities when required, poor distribution, lack of uniformity of the irrigation system as well as poor management skills (Dry *et al.,* 2001).

PRD differs from RDI due to the fact that no physiological stress is imposed on the vine as measured via leaf water potential, yield and titrateable acidity formation in winegrapes (Campbell-Clause, 2001; Du Toit, 2004b).

2.2.2 PARTIAL ROOTZONE DRYING MANAGEMENT

In most plants, including grapevines, both leaf surfaces are covered with a cuticle which serves as a barrier that prevents excessive loss of moisture. Any gaseous exchange that occurs between the leaf and atmosphere must take place largely through the stomatal pores, located mostly on the upper and lower areas of the leaf surface (Loveys and Dry, 1998). The plant function most likely to be influenced by water deficit is stomatal conductance, and partial stomatal closure can lead to a decrease in transpiration (Dry *et al.,* 2001).

The mechanism regulating stomatal opening and closure is very important because it controls water loss and photosynthesis (Du Toit, 2004a). Variables such as temperature, light, wind, atmospheric carbon dioxide (CO_2) concentration, humidity and soil water availability influence stomatal aperture, with water availability and canopy management being important factors that can be manipulated (Loveys and Dry*,* 1998; Stoll *et al.,* 2000a). Plants are able to sense changes in environmental conditions such as ambient humidity, wind velocity, soil salinity and water availability. They accordingly adjust the rate at which carbon dioxide is assimilated and water vapour is lost from the leaves by regulation of stomatal aperture (Dry *et al.,* 1996).

From experience, scientists know that if water is withheld for any length of time growth slows and eventually ceases. If the drought condition continues, the plant will die. The only defence the vine has when faced with such water shortage is to close its stomata to conserve water (Loveys and Dry, 1998). By applying this knowledge, an irrigation system known as Partial Rootzone Drying (PRD) has been developed. As shown in Figure 1, the soil of half the root system is dried out slowly while the other half is kept wet by frequent irrigation. This gives the vine a false sense of water stress, because one root zone is constantly exposed to low soil water contents. After a certain

period (between 10 and 14 days) the sides of irrigated and non-irrigated are swapped to allow the initially irrigated side to dry out slowly. The principle of PRD is based on the fact that when one part of the root system is allowed to dry out over a period of time, root-derived signals to above-ground organs will be produced to induce a physiological response from the plant (Du Toit, 2004a).
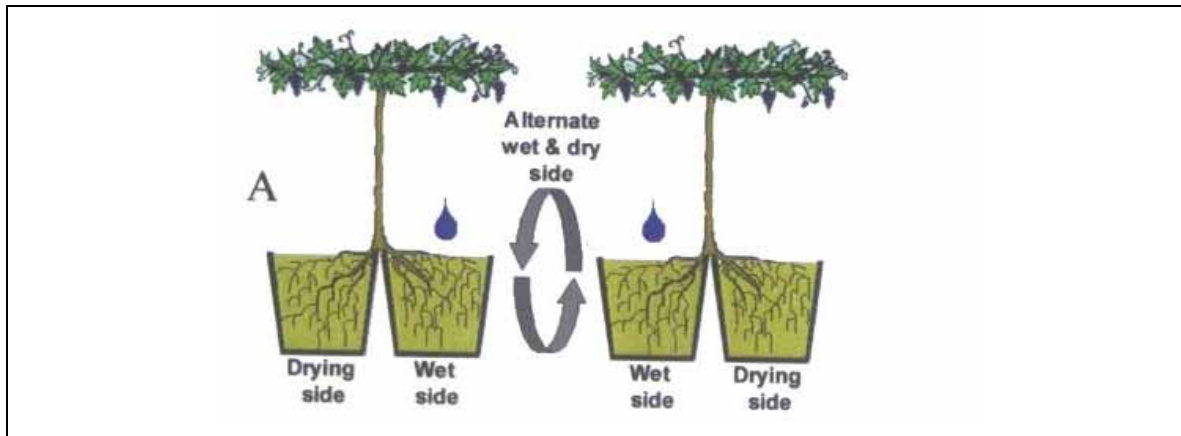
Figure 1: Implementation of partial rootzone drying (Du Toit, 2004b)

It has been shown that under such conditions, roots on the drying side perceive changes in soil water conditions and synthesise signals which are then transported in the xylem sap to the shoots (Gowing *et al.,* 1990). Much evidence has been accumulated that drying roots are the origin of abscisic acid (ABA), which is involved in the regulation of stomatal aperture (Dry *et al.,* 2000). The vine's response of stomatal closure when facing water shortage, is merely the protection of leaf tissue from excessive moisture loss, thus conserving water by reducing the transpiration rate (Du Toit, 2004b). It has been found that the PRD system sustains a continuous chemical signal from the drying soil without a loss of leaf water potential (Dry *et al.,* 1996, Dry and Loveys, 1998). The idea of using PRD as a tool to manipulate water deficit responses in this way has its origin in the observation that root-derived ABA was important in determining grapevine stomatal conductance (Stoll *et al.,* 2000b). Many studies confirmed that the amount of ABA in the xylem sap of plants can increase substantially as a function of reduced soil water availability, and that this increased delivery to shoots can increase ABA concentrations in different compartments of the leaf (Wilkinson and Davies, 2002). It has also long been apparent that ABA strongly promotes stomatal closure (Jones and Mansfield, 1970).

The question as to what the long term effect of using PRD will be on the develop root system of the vine, especially in young vineyards, does arise. For grapevines,

information on this subject is unavailable. Experiments have been conducted on potted young vines (Du Toit, 2004b), but no long term effects can be derived from this data as the vines were removed each year to determine components within the roots. Experiments have also been conducted on potted oilseed rape (*Brassica napus*), where the roots grew predominantly in wet areas (Wang *et al.,* 2005). In contrast to these findings, some literature shows that roots are also maintained and even grow significantly in dry compartments, which is interpreted as a means to preserve the water absorbing capacity in case of rewetting (Mingo *et al.,* 2004). Recently it has been shown that the root biomass of tomato plants may increase up to 55% under PRD as compared to a uniform control receiving the same total amount of water (Mingo *et al.,* 2004). However, these are annual plants and could differ substantially from perennial plants such as grapevines. These contrasting findings could also be ascribed to the differences in root growth between potted plants to those grown in the field. There are also differences in root growth peak times between different species of plants, where the growth peaks might fall outside the duration of the implementation of PRD.

2.2.3 ABSCISIC ACID (ABA)

Previously it was thought that the degree of stomatal opening was controlled directly by the water status of the leaf, that is, stomata close as the leaf wilts (Dry *et al.,* 1996). Although it is possible that the 'hydropassive' mechanism can come into play under severe water loss conditions, more recent research on winegrapes has shown that there is another regulatory mechanism for stomatal opening that operates well before there are any visible signs of water stress. This mechanism relies on the plant hormone, abscisic acid (Dry *et al.,* 1996). ABA is present in all plant tissues and its concentration is remarkably responsive to even the slightest water stress. The synthesis of ABA is stimulated by the dehydration of plant cells (Wright, 1977), including root cells. Leaf cells also synthesize ABA and leaf dehydration caused by severe soil water shortages massively increases bulk leaf ABA concentration, which often correlates well with stomatal closure (Wilkinson and Davies, 2002). The hormone induces an internal transduction cascade signal, involving plasmic calcium, which eventually reduces guard cell osmotic potential via loss of potassium and chloride ions to cause stomatal closure (Assmann and Shimazaki, 1999). With the application of PRD, one root zone is exposed to low soil water potentials. The root derived ABA is then transported to the leaves where stomata respond by reducing their aperture, thereby restricting water loss (Loveys and Dry, 1998). A direct consequence of this is a reduction in photosynthesis

as carbon dioxide and water vapour share a common stomatal pathway through the leaf surface (Loveys and Dry, 1998). The effects of PRD induced ABA are a possible reduction in shoot growth and partial stomatal closure (Dry and Loveys, 1999; Wilkinson and Davies, 2002). When only one side of the root zone is wetted and the 'wet' and 'dry' sides are not alternated, it has been shown that shoot growth rate will start to recover after a certain period of time (Dry and Loveys, 1999). This recovery is correlated with a reduced production of ABA in the 'dry' roots. A long-term effect on stomatal conductance and shoot growth in grapevines is therefore only possible if the signal originating from the 'dry' side can be sustained (Loveys and Dry, 1998). To maintain the long-term response, it is necessary to alternate the irrigated and non-irrigated sides so that a continuous chemical signal or a concentration of the signal maintains a physiological response – as demonstrated in studies on wine- grapes (Dry *et al.,* 2001).

Dry *et al.* (2001) found that the PRD system sustains the continuous chemical signal from drying soil without a loss of leaf water potential, which distinguishes this system from the RDI system. It has been found that stomata respond more to soil water potential than leaf water potential, and that shoot physiology is regulated independently of local osmotic influences, by signals that originate in the roots (Davies *et al.,* 1994).

2.2.4 CARBON ASSIMILATION

The geometric structure of a plant canopy determines its interaction with fluxes of energy. Canopy density is intimately related to crop productivity as the distribution of leaf and non-leaf surfaces influences light interception, and subsequent carbon assimilation and water loss (Schultz *et al.,* 2003). Water stress conditions in a vineyard reduce shoot growth, which may improve wine berry composition by limiting the number of sinks for carbohydrates (Smart *et al.,* 1990). The size of carbohydrate pools depends on extrinsic factors, such as nitrogen or water availability (Chaves, 1991). Extensive data in the literature suggest that leaf carbon assimilation can be limited by stomatal closure – either in response to a decrease in plant water potential or to an increase in the water vapour difference between the leaf and the air (Chaves, 1991). This influence is particularly important in deciduous woody species, such as the grapevine, where stored organic compounds are the dominant carbon sources for growth in the early spring (De Souza *et al.*, 2005). For grapevines, carbon discrimination ($\delta^{13}C$) in the grape berries can be used to characterize soil water availability in the vineyard (De Souza *et al.,* 2005; Gaudillére *et al.,* 2002). Stable carbon isotope uptake is discriminated by diffusion and photosynthesis at the carboxylation step (Farquhar *et al.,* 1980). The

gradient between the atmospheric CO_2 and the intercellular CO_2 concentration determines $\delta^{13}C$ and the main factor which affects this ratio is water stress (Farquhar *et al.,* 1989). Most CO_2 in the atmosphere contains carbon in the form of ^{12}C, but a fraction of CO_2 is also present in the stable isotope form of ^{13}C. During carboxylation, plants discriminate against ^{13}C present in ambient CO_2. Thus, the dry matter of plants contains a lower proportion of ^{13}C compared to that of ambient CO_2 (Thumma *et al.*, 1998). Farquhar and Richards, (1984) showed that ^{13}C discrimination is negatively related to transpiration efficiency in wheat. Thus, ^{13}C discrimination represents an integrated measure of transpiration efficiency of a plant over its life. There is a good correlation between $\delta^{13}C$ in berry pulp and leaf water potential. This may indicate that carbon isotope composition of this particular tissue can be a valuable index for the evaluation of plant water availability during the growing season (De Souza *et al.,* 2005).

In cases of water stress, stomatal control of CO_2 diffusion plays the most important role in controlling photosynthesis (Chaves, 1991). De Souza *et al.* (2005) found that deficit irrigation on two varieties of grapevines, Moscatel and Castelăo, promoted an increase in water utilization efficiency (yield/irrigated volume) as compared with full irrigation. This held true for either the short-term or the long-term as shown by the increase in ^{13}C found in plant tissues, especially in the berries. It was also found that the response to deficit irrigation varied with the grapevine variety and with the annual environmental conditions, differences between treatments being more marked under drier conditions. Contrary to previous findings, in a drier year, PRD induced higher leaf water potentials. This resulted from reduced leaf area and higher midday stomatal closure (De Souza *et al.*, 2005). This suggests that stomatal closure in PRD plants had only a marginal effect on plant water status compared with the induced growth reduction.

2.3 FOLIAR NUTRITION

The growing cost of fertilisers and increasing concern about groundwater pollution resulting from indiscriminate or excessive soil fertilisation, are problems that may be solved by more efficient fertiliser technologies (Swietlik and Faust, 1984). Foliar nutrition is one possibility for minimising this environmental hazard. It is used, with success, as replacement for soil application on a wide range of horticultural crops (Cook *et al.,* 1968). Factors that influence the uptake of these compounds include light, temperature and relative humidity as well as leaf age, surface and plant species (Swietlik and Faust,

1984; Eichert *et al.,* 2002). Light affects the absorption process itself, and high temperatures seem to increase absorption. Older leaves are more resistant to the uptake of foliar applied nutrients and a larger leaf surface enhances absorption (Swietlik and Faust, 1984). Numerous studies, mostly performed on fruit trees, have found that foliar nutrition applications increase growth of plants, while improving yield and fruit quality (Swietlik and Faust, 1984). This can be ascribed to the fact that foliar application of nutrients can supply essential elements directly to the foliage and fruit at times when rapid responses may be desired (Swietlik and Faust, 1984).

Nutrient foliar sprays are most commonly applied to correct micronutrient problems. Micronutrients such as zinc, boron, manganese and iron are required in small quantities by plants. Thus, foliar sprays can prevent or correct a shortage with relatively small amounts being absorbed by the foliage. In grapevines, however, Usha (2002) found that in certain parts of India the number of bunches per vine increased significantly in response to foliar application of boron. Also, fruit weight per bunch was significantly higher in Mg, B and Fe sprayed vines. Maximum fruit weight was observed in vines initially sprayed with Mg, followed by Fe and B. Foliar spray of urea, Zn and other nutrient combinations, however, failed to affect bunch weight significantly (Usha, 2002). Heavy metals such as zinc, manganese and iron are also readily fixed in most soils. Thus, they are not free to move or remain available in the soil as fertilizer (Boynton, 1954). Foliar spraying of zinc is commonly practiced because it is the most widely deficient micronutrient (Christensen, 2002). Neutral zinc (52% Zn) and zinc oxide (75% Zn) are the most economical and effective on a recommended label basis (Christensen, 2002). Boron can also be applied as a foliar spray, but it is most commonly applied to the soil via herbicide spray (Christensen, 2002). It has been shown that the application of manganese sulphate is the most efficient way to correct manganese deficiency, and that there are no advantages to using chelated manganese in a foliar spray (Christensen, 2002). Iron deficiency is the most difficult to correct because it is fixed in the tissue with little or no translocation to growing regions (Christensen, 2002). Literature contains conflicting reports whether iron chelates or inorganic salts are more effective, but iron chelates are the most widely used by growers (Christensen, 2002).

The use of foliar spray to apply macronutrients such as nitrogen, phosphorus, potassium, calcium and magnesium is more commonly used in the industry. Fertilization studies performed on nitrogen (^{15}N 10.74 atom% ^{15}N access) application in Germany

showed that no significant differences in nitrogen absorption from soil N supply and from foliar application could be found (Schreiber *et al.,* 2002). This does not mean, however, that foliar application can replace soil application in table grapes, as the cultivation of wine grapes and table grapes differ significantly. There are several weaknesses in the use of foliar macronutrients (Boynton, 1954). Firstly, the nutrient is most probably being supplied adequately via the soil. Secondly, absorption of the macronutrient would be insufficient to correct a long term deficiency, if at all. Thirdly, literature shows it to be an ineffective or impractical method to significantly supply macronutrients to grapevines (Christensen, 2002). It is commercial practice in the apple and citrus industries to apply nitrogen as urea - it is mostly used to supplement soil treatments as it sometimes takes up to six or more applications in one season to meet nitrogen requirements. Urea foliar application however has been tested on grapes with no measured benefit or increase in leaf nitrogen levels (Boynton, 1954; Conradie and Saayman, 1989; Christensen, 2002). In contrast to this, Beniwal *et al.* (1992) found that the use of foliar urea (0.5 – 1.5%) improved berry size, bunch weight and yield of Perlette table grapes. Beniwal *et al.* (1993) also found that post-harvest application of 0.5% urea decreased the loss of grapes during storage, but high concentrations of N contributed to the susceptibility of various physiological tissue disorders.

There have only been a few reports of significant responses on any crop to phosphorus foliar application (Boynton, 1954). A study performed in California over two years gave no positive responses and did not increase phosphorus levels in growing grapevine shoot tips (Cook *et al.,* 1968). The application of foliar potassium nitrate has been recommended in prune orchards as an interim corrective measure until soil application takes effect (Christensen, 2002). Research in grapes has shown no effect on potassium deficiencies or increases in foliar tissue potassium levels with the application of foliar potassium (Kasimatis and Christensen, 1976; Avenant *et al.,* 1997).

Calcium foliar spray application has mostly been evaluated for reducing fruit disorders such as waterberry in grapevines. Studies conducted on table grapes have shown increased success in curbing this disorder with the use of calcium nitrate as foliar spray, mostly due to increased nitrogen in the berry (Christensen, 2002). Magnesium sulphate sprays are recommended on grapevines as foliar spray to substitute soil application under a deficiency situation (Christensen, 2002).

2.4 SUMMARY OF CHAPTER

Ever increasing water shortages are making it necessary to find new and sustainable ways of irrigating vineyards with less water. The Partial Rootzone Drying principle has been shown to use less water and still deliver good quality grapes, but its application still has to be evaluated on table grapes in South Africa. The use of foliar nutrients, especially in the table grape industry, could be of great value in countering the effect of PRD on berry composition, therefore still using less water, without compromising the quality of the grapes.

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Chapter 3

MATERIAL AND METHODS

RESEARCH DESIGN

3.1 SITE SELECTION

Experimental sites were located in the Paarl region, South Africa. Vineyards of table grape cultivars Crimson Seedless and Dauphine were cultivated either under open hydroponic or drip irrigation systems, respectively.

The Dauphine block was situated on a south-facing mountain with a slope of 25%, whereas the Crimson Seedless block was situated on an even topography.

3.1.1 DAUPHINE

This cultivar was grafted on Richter 110 and planted in 1991. The vines were planted with a spacing of 3.5 x 1.5 m and covered approximately 0.38 ha. Drip irrigation was employed - two per vine in the intervine space and half the amount of drippers were used for PRD treatments. Irrigation started in November 2005 and stopped in March 2006 (Table 1, Appendix). PRD treatments were alternated every 10 to 14 days (Dry *et al.* 2000). Vines were pruned in the winter season with stronger canes on 10 buds and weaker canes being left with 8 buds. No suckering or yield control was done during summer canopy practices.

3.1.2 CRIMSON SEEDLESS

This cultivar was grafted on Ramsey and Richter 110 and planted in 2001. The vines were planted with a spacing of 3.5 x 1.5 m and covered approximately 1.17 ha. A dripper system was used with emitters delivering 8 L/h, two per vine in the intervine space and half the amount of drippers were used for PRD treatments. Irrigation started in November 2005 and ended in May 2006, excluding March 2006 (Table 2, Appendix). PRD treatments were alternated every 10 to 14 days (Dry *et al.* 2000). Vines were pruned in the winter season with stronger canes on 16 buds. No suckering or yield control was done during summer canopy practices. In this study, Crimson Seedless was grown under open hydroponic principles. This is based on classic hydroponic production principles but differs in that it lacks climatological control as the plants are cultivated in the outside environment (van Zyl, 2003). The soil is viewed only as an anchoring medium, and the plant is provided with all the essential nutrients via the irrigation system. The rationale behind this practice is that daily requirements can be met with

mixes representative of what the plant actually requires for that specific phenological stage (Van Zyl, 2003).

3.2 STATISTICAL LAYOUT WITHIN THE BLOCKS

The Crimson Seedless vines were grown hydroponically with all the vines situated in the same row. Seventy two vines were divided into 24 mini-plots, each consisting of three vines. The mini-plots were then randomly assigned to PRD treatment or no PRD treatment. There were 12 repeats of both PRD treatment and the control. The 24 plots were then equally divided into PRD with and without foliar nutrients, and control with and without foliar nutrients. Half of the experiment, in other words, the first twelve mini-plots that were in the row, received foliar nutrient as supplied by GDM technologies, whereas the last twelve mini-plots did not (Diagram 1, Appendix). The same procedure was followed in the Dauphine plots, but the vines were situated in two rows of equal length. Within the mini-plots, the centre vines were used as sample vines and the adjacent two vines served as buffer vines (Diagram 2, Appendix). Treatment effects were followed from budburst until harvest, thereafter post-harvest analysis was done to investigate post-harvest life.

The experimental design is a complete randomized design with six random replications. The treatment design is a split-plot design with the main plot factor being vines with nutrients and vines without nutrients. The sub-plot factors are vines with PRD and vines without PRD and the repeated measurements are the sub-subplot factors (before véraison (28/11/2005 and 27/12/2005 for both Crimson Seedless and Dauphine), 80% véraison (18/01/2006 for Crimson Seedless and 24/01/2005 for Dauphine), véraison (06/02/2006 for both Crimson Seedless and Dauphine) and harvest (23/02/2006 for Crimson Seedless).

3.3 SOIL COMPONENTS AND ROOT DISTRIBUTION

3.3.1. ROOT DISTRIBUTION
A soil pit was made in both the Crimson Seedless and Dauphine blocks to assess soil drainage, effective root depth and root distribution. The soil pit measured 1 m deep and 1.6 m wide, parallel to the row direction, 50 cm from the vine, within the vineyard with

one vine in the centre of the pit. A soil hammer was used to expose the roots. All the soil was carefully cleaned from the roots, which were then painted with white spraypaint. All the paint was removed from the soil to create a contrasting background for the white roots. White rope was used to provide the soil profile with a grid-like structure. Lines were placed at 20 cm intervals starting from the middle line, placed vertically along the vine trunk and photographed. Descriptions of the soil in different layers were noted and roots larger than 2 mm diameter were counted.

3.3.2 SOIL ANALYSES

Soil samples were taken at 20 cm intervals up to a depth of 1 m throughout the profile depth and sent to an independent laboratory, BEMLAB (Somerset-West, South Africa) for analyses (Tables 3, 4 and 5, Appendix).

3.4 GRAPEVINE PHYSIOLOGY

Assimilation of carbon dioxide and stomatal conductance were measured using a CIRAS$^®$ open photosynthesis system (CIRAS-1$^®$, PP systems, North America) with an infrared gas analyses instrument (IRGA). This instrument measures differential or absolute changes caused by leaf gas exchange and calculates photosynthesis from the loss/gain in CO_2 level. The open system design allows a constant airflow through the measuring chamber and minimizes the effect of the measurement on leaf gas exchange. To minimize the effect of the measurement chamber on leaf photosynthesis, the same photosynthetic active radiation (PAR), CO_2 concentration and relative humidity (RH) of ambient air had to be maintained during measurements. An internal light source provided ambient light intensity that was pre-determined by an average reading acquired by a ceptometer. Chamber CO_2 was controlled by the CIRAS$^®$ to a concentration equivalent to atmospheric CO_2 concentration. Chamber RH was controlled by the CIRAS to a value measured manually with a humidity sensor at atmospheric levels. The leaves were clamped in the leaf chamber before every measurement after every 20 s; the instrument was allowed to stabilize as determined by real time monitoring within the system. Photosynthesis and stomatal conductance was measured in mmol/m^2/s. Measurements were taken before véraison, at véraison and at 80% véraison with three readings per vine – apical, middle and basal leaves were used.

Midday stem water potentials were taken with a pressure bomb as described by Scholander *et al.* (1965). Time points again were before véraison, at véraison and at 80% véraison. Two leaves on every vine, basal and middle, were covered in foil, for twenty minutes, and measurements were then taken (Choné *et al.,* 2001). Leaves were sampled on cloudless days. Basal leaves were fully matured and located between the third and fifth nodes. Leaves in the middle of the canopy were also taken from shaded areas. Five leaves per treated vine were collected and immediately frozen and stored at -20°C for further macro- and micronutrient analyses. Leaves were sent to an independent laboratory, BEMLAB, for analyses on all macronutrients and micronutrients. Leaf temperature was measured at the same growth phases as mentioned above by a thermal infrared thermometer, Raytek Raynger® ST. Phenological stages of data collection are shown in figures 16 and 17 in Appendix.

3.5 BERRY MEASUREMENTS

Berry samples were taken from each treated vine before véraison, at 80% véraison and at harvest. Each sample comprised 20 berries, randomly chosen from each treated vine, at different positions within the bunch and within the canopy. Berry mass was determined by calculating the mean of 20 berries on an electronic balance. The berries were homogenised with a Braun® blender and centrifuged for ten minutes. Juice samples were analyzed using FT-IR spectroscopy (Foss Grape scan). Samples were filtered through a Filtration Unit (type 79500, FOSS Electric, Denmark) connected to a vacuum pump. The filter unit uses filter paper circles graded at 20 – 25 μm with diameter 185 mm (Schleicher & Schnell, reference number 10312714). The filtered musts were used for FT-IR spectral measurements. A Winescan FT120 equipped with a purpose built Michelson interferometer, was used to generate the FT-IR spectra (FOSS Electric A/S, Hillerød, Denmark). Instrument settings included: cell path length of 37 μm, sample temperature set to 40°C, and sample volume of 7 to 8 ml. The sample was pumped through the heat exchanger and the CaF_2-lined cuvette. Samples were scanned from 5011 to 926 cm^{-1} at 4 cm^{-1} intervals. Global calibrations were used for the FT-IR spectroscopic analyses. Analyses performed with FT-IR technology include pH, total acidity (TA), glucose, fructose and total soluble solids (TSS). The pH and TA were also determined using a Metrohm® 785 DMP Tritino automatic titrater, with sodium hydroxide (NaOH) at a dilution of 0.333 N. The TSS was also determined with a digital refractometer (Atago Pocket refractometer PAL-1) zeroed with distilled water.

Samples for the determination of carbon isotope composition from grape berries (one berry sampled randomly from each bunch and 10 random berries used from samples collected) were collected from each vine (De Souza *et al.,* 2003) at 80% véraison and at harvest. The samples were run on a Thermo Finnigan Delta Plus XP stable light isotope ratio mass spectrometer coupled via a Conflo III device to a Thermo 1112 Flash elemental analyser. The samples were run against in-house reference materials which have been calibrated according to international standards (VPDB for carbon and Air for nitrogen). The results are expressed relative to those standards. Carbon isotope composition is expressed as $\delta^{13}C = [(R_s - R_r)/ R_r] \times 1000$, where R_s is the $^{13}C/^{12}C$ ratio of the sample and R_r is the ratio of the reference material. The values are expressed as negative values as the R_s will always be smaller than R_r.

3.6 PRUNING MEASUREMENTS

The Crimson Seedless block was pruned with long bearers. Strong shoots were cut through the seventeenth bud, lateral shoots were cut to one bud and as many possible shoots were cut to short bearers. The Dauphine block was pruned with half-long bearers. Strong shoots were cut through the eleventh bud, weaker shoots were cut through the ninth bud and enough short bearers were left. Four representative shoots were taken from each treatment vine within the mini-plots in July 2006 for Crimson Seedless and August 2006 for Dauphine. These shoots were measured with a measuring tape, diameters were taken with a calliper and the first five lengths of the internodes were measured with a measuring tape. Internodes 3 and 5 were also measured separately. The average of each internode measurement was calculated. The mass of the shoots were taken with a spring balance (Salter Electro Samson) and average mass was calculated.

3.7 FOLIAR NUTRIENT APPLICATION

The foliar nutrient Croplife® was sprayed throughout the season at 135 ml per 200 L water until leaves were dripping wet, as prescribed by the GDM technologies company (Anon, 2001). This was repeated every 5-7 days until a week before harvest. The published content of the foliar nutrient solution is given in Table 3.1. The formulation is

protected by patent rights thus not all elements present in the foliar nutrient is made public. The main elements are nitrogen, phosphorous and potassium.

Table 3.1: Contents of foliar nutrient spray used, as given by GDM technologies

Elements present in Croplife		
Nitrogen	Chloride	Molybdenum
Phosphorous	Boron	Cobalt
Potassium	Iron	Strontium
Calcium	Manganese	Selenium
Magnesium	Copper	Bicarbonate
Sodium	Zinc	
Sulphur	Fluoride	

(GDM Technologies)

3.8 POST-HARVEST MEASUREMENTS

Crimson Seedless grapes were harvested on 23 February 2006 and placed in cold storage at -0.5°C for 7 weeks in 4.5 kg boxes. Samples were taken from each treatment, after 7 weeks of cold storage and again after 5 days at 15°C. Total soluble solids (TSS), titrateable acid (TA) and pH were analysed. This was to determine if the use of foliar nutrients had significant effects on TSS, TA and pH after harvest. The use of SO_2 sheets did not form part of the current study. These data are part of another study that did not investigate the effect of PRD on post-harvest life of table grapes. Data, however, of SO_2 sheets are included to simulate commercial practises. Treatments consisted of C (no foliar nutrient before harvest with SO_2 sheet), CA (no foliar nutrient before harvest with no SO_2 sheet), CB (foliar nutrient before harvest with SO_2 sheet) and CC (foliar nutrient before harvest with no SO_2 sheet).

3.9 IRRIGATION MEASUREMENTS

To determine irrigation efficiency and monitor the water balance of the PRD system, three $ECH_2O^®$ data loggers were placed within the Crimson Seedless block at 30-50 cm and two at 90-100 cm divided between control and PRD treatments. Decagon $ECH_2O^®$ probes were used to measure soil moisture to perform accurate long term moisture content monitoring. The probes measure the dielectric constant of the soil in order to

calculate its volumetric water content. This is done by calculating the rate of change of voltage applied to the sensor once it is buried in the soil. It has a high time resolution, making it possible to accurately monitor water use daily or hourly. Data were logged using an EM5 Decagon® data logger and downloaded every 3 months.

3.10 LITERATURE CITED

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Chapter 4

RESEARCH RESULTS

RESEARCH RESULTS

4.1 SOIL ANALYSES AND ROOT DISTRIBUTION

4.1.1 ROOT DISTRIBUTION OF CRIMSON SEEDLESS

Figure 4.1 shows the distribution of the roots and colour of the soil. Table 4.1 shows the description of the different soil layers of the Crimson Seedless block and number of roots larger than 2 mm diameter in each layer.
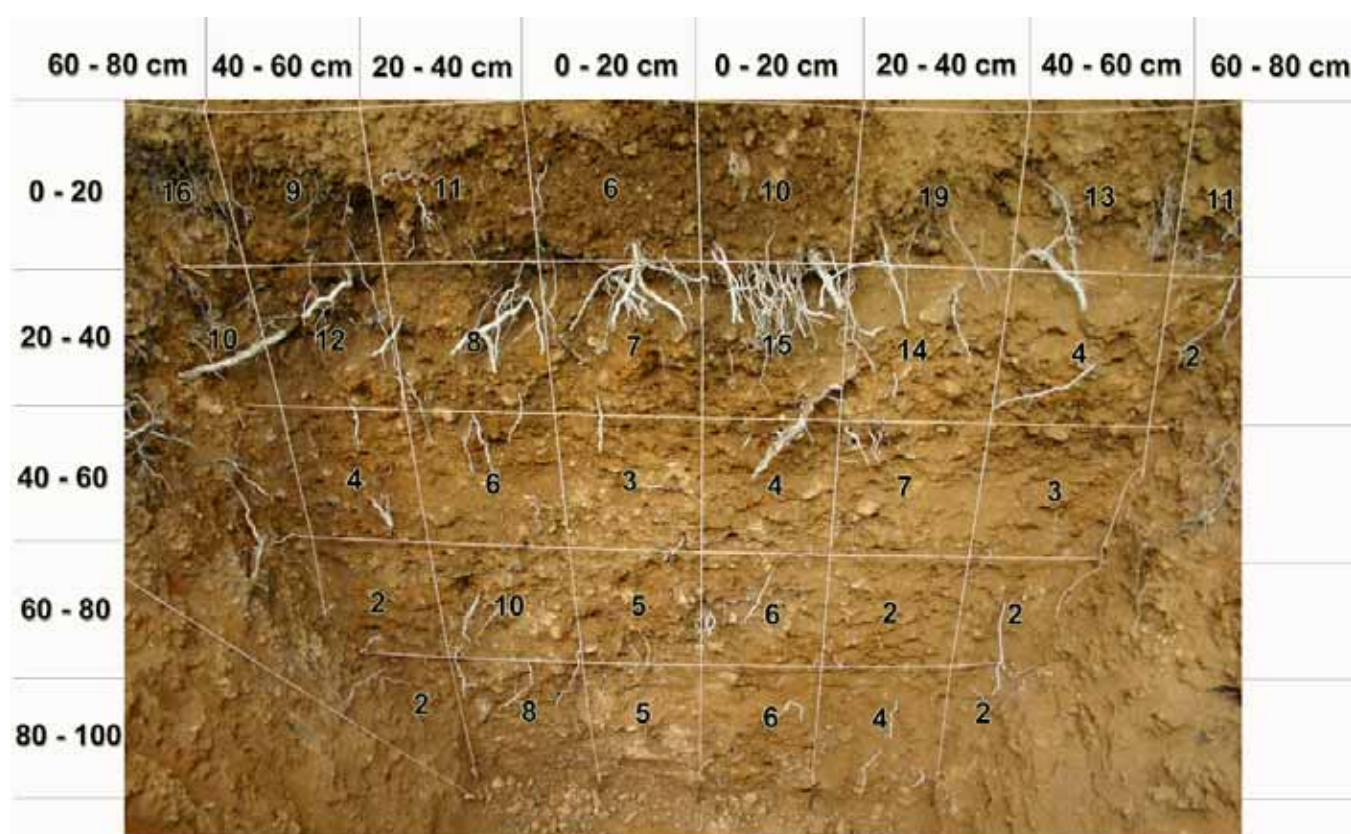
Figure 4.1: Root distribution and soil colour in Crimson Seedless block as investigated during December 2005. Numbers in the quadrants refer to the number of roots with a diameter exceeding 2 mm.

Table 4.1: Different soil layers and root distribution in the Crimson Seedless block

Roots >2mm	60-80	40-60	20-40	0-20	Vine	0-20	20-40	40-60	60-80	Code	Description
0-20	16	9	11	6		10	19	13	11	A	Loamy soil (Crumble structure)
20-40	10	12	8	7		15	14	4	2	B	Mottled clay, Brown/red colour, Compact structure
40-60		4	5	3		4	14	3			Easily penetrated by roots, Stony Shale/Red
60-80		2	10	5		6	2	2		C	Higher clay content, Brown/white colour, Penetrated by roots
80-100		2	8	11		6	7	2			
100-120											White clay, impenetrable barrier (110cm depth),Plough line

The soil in the Crimson Seedless block had a relatively high amount of clay (19.4%) which would explain the wetness found in the lower C layer. The impenetrable barrier also contributed to a water table on the plough line. The soil did, however, allow water to penetrate up to 100 cm. No chemical abnormalities were found in the soil analyses (Tables 3, 4 and 5).

4.1.2 ROOT DISTRIBUTION OF DAUPHINE

Table 4.2 shows the description of the different soil layers of the Dauphine block and number of roots larger than 2 mm diameter in each layer. Figure 4.2 shows the distribution of the roots in the soil.

Figure 4.2: Root distribution and soil colour in Dauphine block as investigated during September 2006

The root distribution throughout the soil profile was evenly spread up to a depth of 100 cm and across the 160 cm width of the profile. There was no apparent compaction in the soil. The soil consisted mainly of a sandy loam with less then 5% clay except for layer C with 12% clay content. Very few of the roots were larger than 2 mm and more fine roots are seen throughout the profile.

Figures 4.1 and 4.2 clearly show that the roots of vines grown under open hydroponic principles differ significantly from vines that are grown conventionally. The roots of OHP vines were spread out in the top layer of the soil and did not penetrate the soil deeper than 50 cm. Roots of vines grown under micro-sprinklers were evenly spread throughout the soil and visible up to a depth of 100 cm in the soil profile. This can be ascribed to the fact that the OHP roots receive all nutrients from the irrigation system and do not need to penetrate the soil in search of nutrients and water.

Table 4.2: Different soil layers and root distribution in the Dauphine block

Roots >2mm	60-80	40-60	20-40	0-20	Vine	0-20	20-40	40-60	60-80	Code	Description
0-20	7	6	1	1		7	3	3	4	A	Sandy loam, brown, Crumble structure
20-40	6	9	5	4		3	8	8	3	B	Sandy loam, brown, Crumble structure
40-60	5	6	6	5		5	6	6	3		Easily penetrated by roots, Crumble structure
60-80	7	7	8	9		7	8	5	3	C	Clay loam, red-brown, compact to Crumble structure
80-100	1	2	2	1			1	3	2		Penetrable by roots

4.2 WATER USE EFFICIENCY (WUE)

The mean mass of grapes harvested per vine and the water use efficiency of each vine, are shown in Table 4.3. PRD treatments received 50% less water than control treatment (specific amounts are shown in Table 2, Appendix). The mass of grapes harvested from each vine did not differ between treatments.

Water use efficiency did, however, differ significantly. The CrP (PRD with foliar nutrients added) treatment was found to have the highest WUE, having the highest mean and differing significantly from CrC (control treatment with foliar nutrients added) and CC (control) treatments. PRD treated vines alone induced a 42% increase in WUE compared to control irrigation, while in combination with Cr a 92% increase was observed ($P<0.05$). This outcome was expected, as PRD has been shown in many winegrape studies to have a high WUE (Dry *et al.*, 1996, 2001; Du Toit *et al.,* 2003; De

Souza *et al.,* 2003; Cifre *et al.,* 2004). Surprisingly, no significant differences were found between CP (PRD treatment) and control treatments. This may be due to large variation in yield per vine found during this particular year. With the use of foliar nutrient in combination with a PRD treatment (CrP), it seemed to be more efficient, thus contributing to using less water without crop loss. It must be kept in mind that with 50% reduction in irrigation water application, there is a 50% reduction in nutrients added via the OHP system to PRD treated vines. This may be a factor in the variable yields achieved in PRD vines. It stresses the importance of the combined effect of CrP, where some of the required nutrients were supplied via foliar application. CrC and CC treatments did not significantly differ from the CP treatment. There was, however, a large difference in the standard deviation between vines, indicating that, statistically, there were no differences in yield per vine between the different treatments. Drying of soil and irrigation effectivity, measured as volumetric water content by ECH_2O probes, are shown in Figure 1 of the Appendix.

Table 4.3: Yield and water use efficiency (WUE) per vine, respectively, for Crimson Seedless as measured during the 2006 season. CP = Partial Rootzone Drying, CC = Control, CrP = Partial Rootzone Drying with foliar nutrients, CrC = Control with foliar nutrients (means n = 6 ± s.e.; means with different letters are significantly different (P<0.05))

	CrP	CP	CrC	CC
Yield/vine (kg)	12.505[a]	9.292[a]	13.915[a]	12.893[a]
Std dev	±4.38	±3.39	±7.34	±2.51
Water applied (L/vine)	83	83	165	165
Water use efficiency (kg grapes/L)	0.15050[a]	0.11183[ab]	0.08417[b]	0.07833[b]

4.3 GRAPEVINE PHYSIOLOGY

4.3.1 INTRODUCTION

There are numerous studies on grapevine response to water deficit. Much of this research has focused on quantifying plant responses to water deficit, based on plant water potential. However, the nature of yield and quality losses for many fruits is dependent on the time when water deficits occur in relation to fruit development (Hardie and Considine, 1976). There is extensive evidence that water is a major factor limiting and regulating both quality and productivity in grapevine, with photosynthesis being primarily affected via the effects on stomatal closure (Jones *et al.,* 2002). This also affects the canopy temperature. Infrared measurement of canopy temperature can be used as an indicator of crop stress, canopy conductance or canopy transpiration, usually for irrigation scheduling purposes (Jones *et al.,* 2002). This study aims to correlate different parameters such as stomatal conductance, photosynthetic rate, leaf temperature and berry parameters and to discuss reactions to seasonal water deficit.

4.3.2 RESULTS AND DISCUSSION

4.3.2.1 Crimson Seedless

Analyses of transpiration rate in Crimson Seedless are shown in Table 4.4 and Figure 4.3. The plant function most likely to be influenced by water deficit is stomatal conductance, and partial stomatal closure can lead to a decrease in transpiration and possibly an increase in transpiration efficiency (Dry *et al.,* 2001). There were significant differences between treatments in vine transpiration rate as determined by the student t-tests. Split-split plot analyses of variance indicated that there was no main effect of treatments on the transpiration rate of Crimson Seedless (P=0.1345). Further analyses also indicated no main effects of either foliar nutrition (P=0.133), PRD (P=0.682) or an interaction between the two treatments (P=0.524) at a confidence level of 5%. This finding is in contrast with previous studies performed on winegrapes with PRD, which showed lowered transpiration rate throughout the season and thus lowered stomatal conductance (Stoll *et al.,* 2000; Du Toit *et al.,* 2003). However, in some instances (80% véraison) it may be judged that CrP and CrC treatments tended towards lower transpiration rates as compared to treatments without foliar nutrients (Figure 4.3). This finding is similar to results by Swietlik and Faust (1984) where foliar application

decreased transpiration. The nature of the stress was not defined but was not associated with visual observable injury.

Table 4.4: Split-split plot analyses of variance in transpiration rate of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (before véraison, 80% véraison and véraison)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	3.367	0.133
PRD	1	0.244	0.682
Croplife*PRD	1	0.592	0.524
Error	40	1.431	
Corrected total	71		
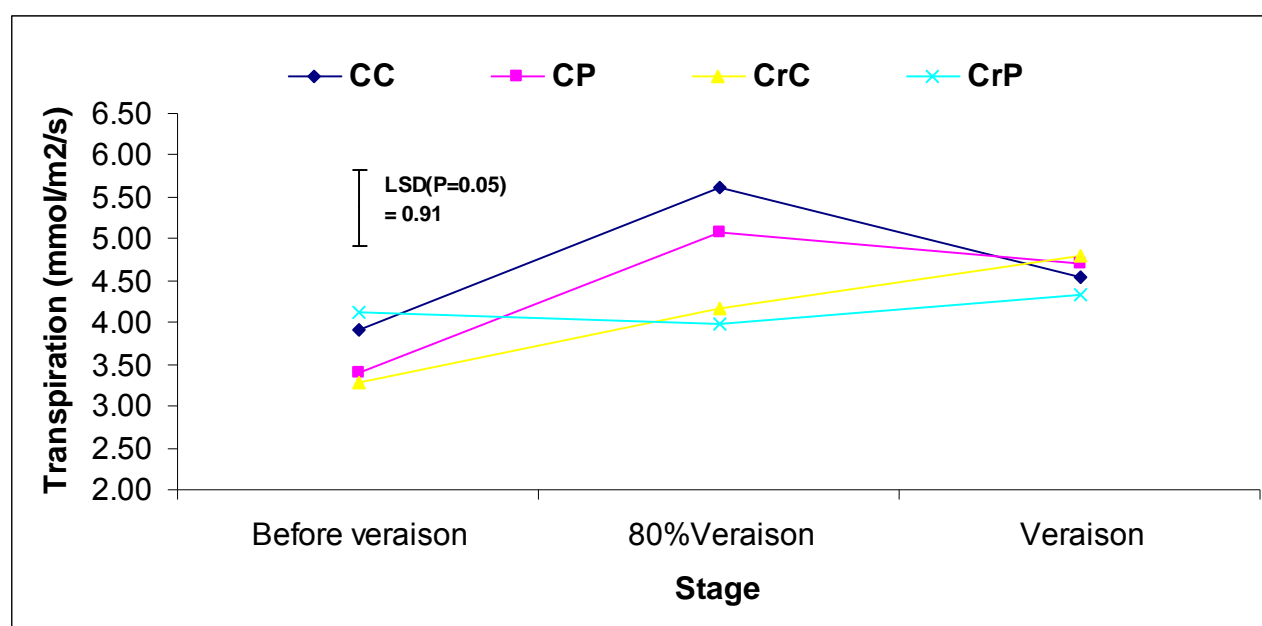
Figure 4.3: Transpiration rate of Crimson Seedless during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

Results for analyses of stomatal conductance of Crimson Seedless are shown in Table 4.5 and Figure 4.4. Early studies on PRD showed that chemical signals (ABA) produced in the drying roots reduced stomatal aperture (Dry *et al.,* 2001). Split-split plot analyses of variance indicated that there was a main effect of treatment to be found on

stomatal conductance in Crimson Seedless (P=0.0192). Further analyses also showed that this was indeed a foliar nutrient effect (P=0.0102) and not an irrigation effect (P=0.5946) or an interaction between PRD and foliar nutrients (P=0.4894) at a confidence level of 5%. Foliar nutrient treatments induced a lower stomatal conductance than that of the control treatment, especially at véraison (Figure 4.4). Swietlik and Faust (1984) also found that foliar nutrients decreased stomatal conductance, thus decreasing the transpiration rate (Figure 4.3). A lowered stomatal conductance as a result of PRD has been found in studies performed on wine grapes (Dry *et al.,* 1996; Dry and Loveys, 1998, 1999; Loveys *et al.,* 2000; Stoll *et al.,* 2000), but was not the case in this study. However, with the use of foliar nutrients (CrP) the PRD treatments did induce lowered stomatal conductance at 80% véraison and véraison, thus inducing lowered transpiration rates (Figure 4.3).

Table 4.5: Split-split plot analyses of variance of stomatal conductance of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (before véraison, 80% véraison and véraison)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	67650.6806	0.0102
PRD	1	2676.6806	0.5946
Croplife*PRD	1	4528.3472	0.4894
Error	40	9300.3917	
Corrected total	71		

Figure 4.4: Stomatal conductance of Crimson Seedless during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

Results for analyses on leaf photosynthetic rate (Pn) of Crimson Seedless are shown in Table 4.6 and Figure 4.5. There were no significant differences between treatments in vine Pn, as determined by the student t-tests. Split-split plot analyses of variance indicated no main effects of treatments on the Pn of Crimson Seedless (P=0.1601). Further analyses also highlighted no main effects of either foliar nutrition (P=0.2109), PRD (P=0.8492) or an interaction between the two treatments (P=0.7445) at a confidence level of 5%. These findings contradict results from studies performed on wine grapes with PRD, where reduced Pn has been found (Dry *et al.,* 2000; De Souza *et al.,* 2003). PRD did not have an effect on Pn in this study, and thus no effect on canopy development in Crimson Seedless. This indicates that a reduced canopy is not a result of the implementation of PRD on Crimson Seedless, which is preferred in table grape cultivars. This is of great value, as WUE has already been established as being increased by 42% with the use of PRD and 92% when foliar nutrients are added (Table 4.3), without decreasing foliage.

Table 4.6: Split-split plot analyses of variance in photosynthetic rate of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (before véraison, 80% véraison and véraison)). (P<0.05)

| Source	DF	Mean Sq	Pr >F
Croplife	1	43.245	0.2109
PRD	1	0.980	0.8492
Croplife*PRD	1	2.880	0.7445
Error	40	26.751	
Corrected total	71		

Figure 4.5: Leaf Photosynthetic rate (Pn) of Crimson Seedless during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

The results for leaf temperature of Crimson Seedless, measured with an infrared thermometer, are shown in Table 4.7 and Figure 4.6. A major function of transpiration is leaf cooling. Canopy temperature and its reduction relative to ambient air temperature is an indication of the efficiency of transpiration in cooling the leaves under a demanding environmental load. There were no significant differences in vine temperature between treatments as determined by the student t-tests. Split-split plot analyses of variance however, did show a main effect of treatments on the temperature of Crimson Seedless

(P=<0.0001). Further analyses indicated that the main effect was indeed of foliar nutrients (P=0.0253) and not due to PRD treatments (P=0.4602). Furthermore, no interaction between the two treatments (P=0.6757) was found at P<0.05. Direct measurement of leaf temperature has been related to crop water stress based on the fact that under stress-free conditions, the water transpired by the plants evaporates and cools the leaves. Conversely, in a water-deficit situation, little water is transpired and the leaf temperature increases (González-Dugo *et al.,* 2005).

Table 4.7: Split-split plot analyses of variance on the temperature of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (before véraison, 80% véraison and véraison)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	6.4201	0.0253
PRD	1	0.6613	0.4602
Croplife*PRD	1	0.2113	0.6757
Error	40	1.1893	
Corrected total	71		

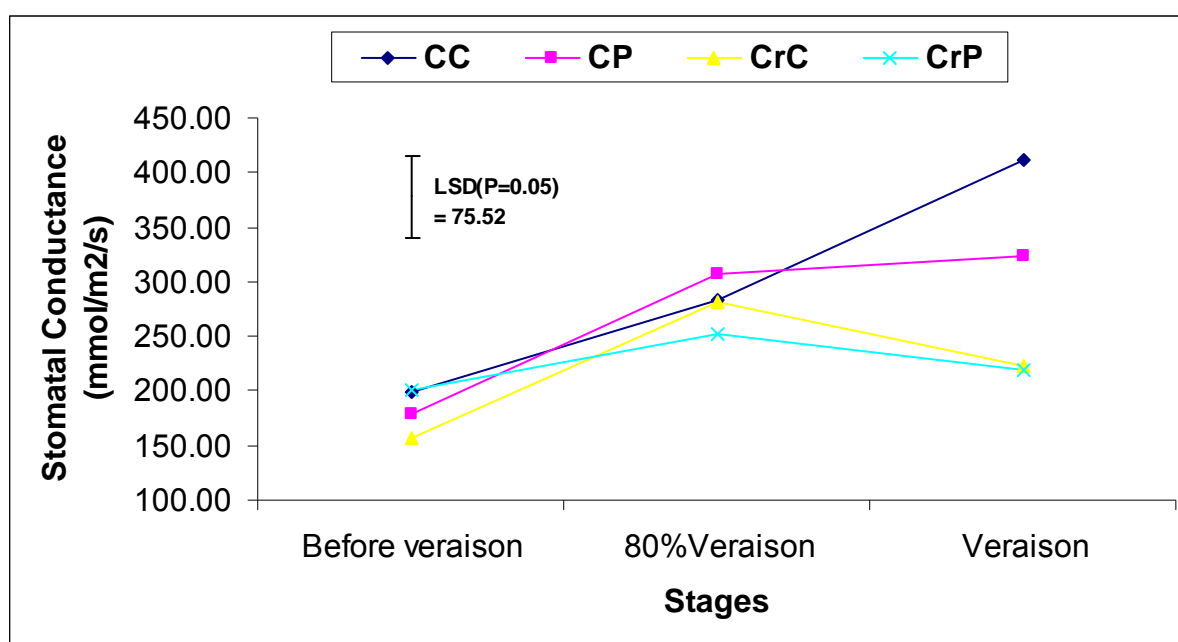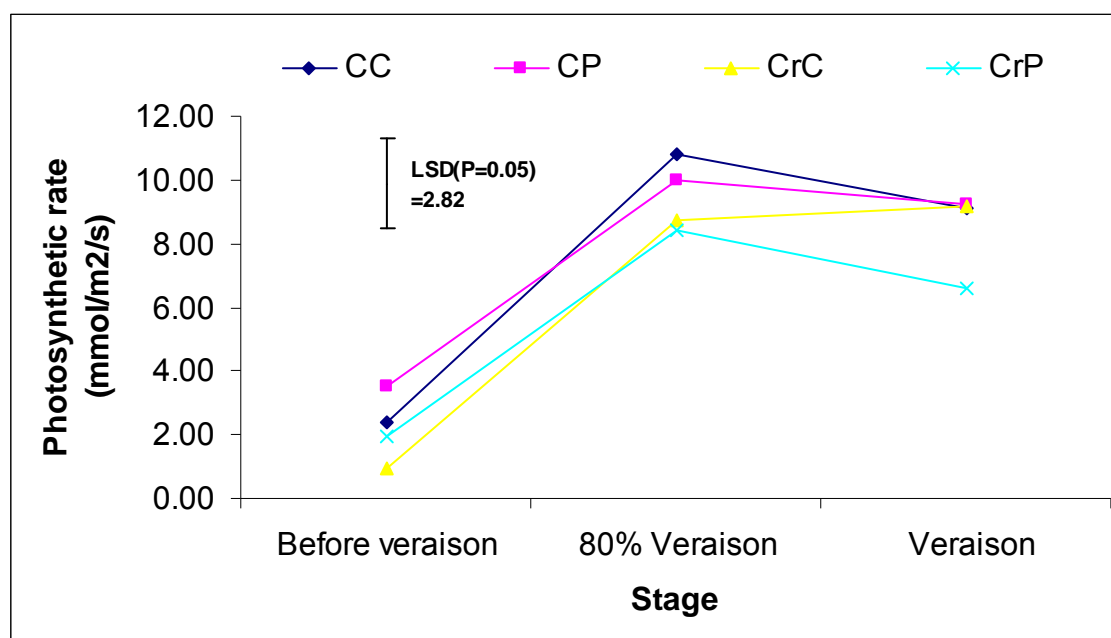**Figure 4.6:** Leaf canopy temperature in Crimson Seedless during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

To investigate the effect of PRD and foliar nutrients on plant water relations, stem water potentials (SWP) were measured at midday during the season of 2005/2006. The results are shown in Table 4.8 and Figure 4.7. The SWP technique was used because it has been shown to be a powerful tool in the assessment of water stress (Choné *et al.,* 2001). According to Choné *et al.* (2001), high degrees of stress occur at -1300 kPa and below, moderate stress is measured between -1000 and -1300 kPa and low degrees of stress are measured between -700 and -1000 kPa for winegrape cultivars. There are, however, no guidelines as to when stem water potential in table grapes reflects stress in the vine. For this study, a measurement below -1000 kPa was interpreted as an indication of water stress. There were no significant differences between treatments in stem water potential according to student t-tests. Split-split plot analyses of variance, however, indicated that there was a main effect between treatments in SWP of Crimson Seedless (P<0.0001). Further analyses also indicated that it was again a main effect of foliar nutrient treatment (P=0.0169) and not due to PRD treatments (P=0.3088). There was also no interaction between the two treatments (P=0.9326) at a confidence level of 5%. In Figure 4.7 a clear difference was observed between foliar nutrient treatments and control treatments at 80% véraison and full véraison. Swietlik and Faust (1984) showed that foliar nutrients decrease stomatal conductance, thereby decreasing transpiration and this has also been shown to be true in this study. These occurrences would decrease SWP giving an indication of slight water stress and this is clearly also shown in Figure 4.7, before véraison and at 80% véraison. The CP treatment did not induce stress (Figure 4.7). Similar findings have been found in previous studies performed on wine grapes for PRD treated wine grapevines (Dry *et al.,* 1996; Stoll *et al.,* 2000; Du Toit *et al.,* 2003; De Souza *et al.,* 2003). Because PRD treated vines are constantly provided with irrigation water, unlike deficit irrigation techniques where water is withheld, there is no effect on SWP and no water tension occurs in the vine. This differs from other deficit irrigation methods that significantly reduce leaf water potential relative to well-watered controls (Dry *et al.,* 1996). In studies performed on the table grape cultivar Thompson Seedless in Chilé, no differences were found in stem water potential with the implementation of PRD (Van Sch *et al.,* 2004).

Table 4.8: Split-split plot analyses of variance on stem water potential of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (before véraison, 80% véraison and véraison)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	186558.681	0.0169
PRD	1	31878.125	0.3088
Croplife*PRD	1	217.014	0.9326
Error	40	30002.917	
Corrected total	71		

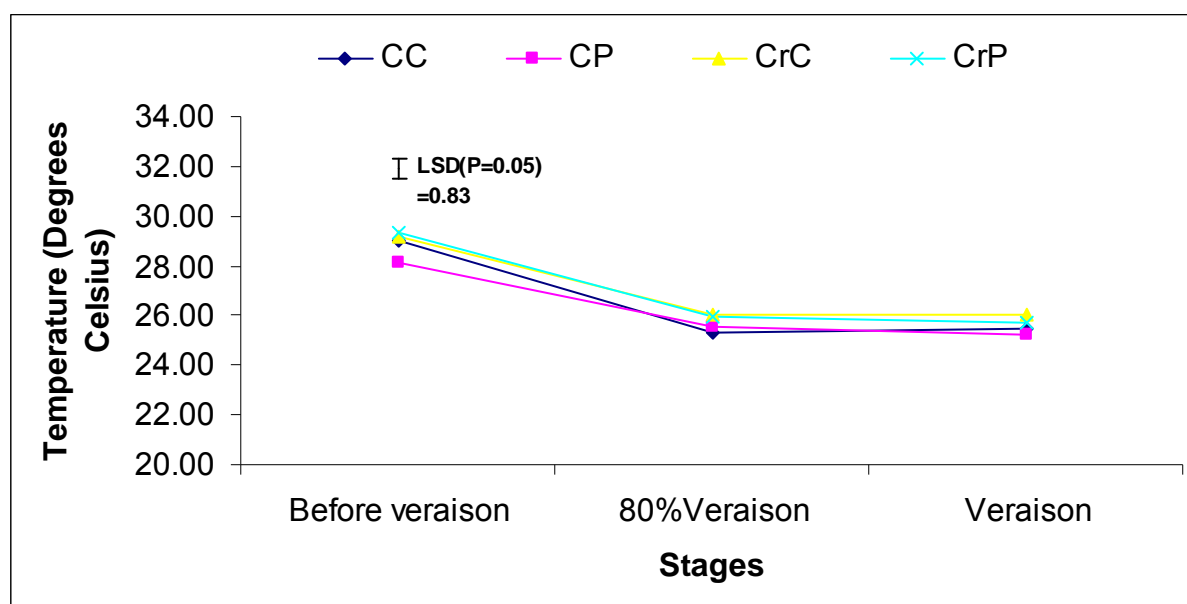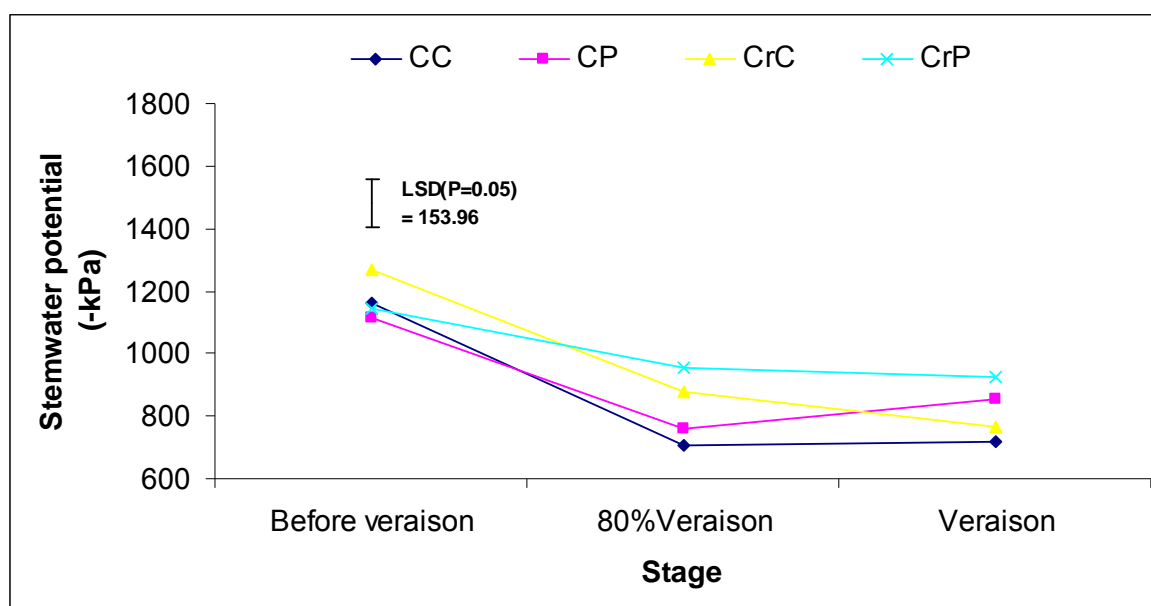**Figure 4.7:** Stem water potential at midday for Crimson Seedless during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

4.3.2.2 Dauphine

Analyses of transpiration rates of Dauphine are shown in Table 4.9 and Figure 4.8. There were no significant differences between treatments in vine transpiration rate as determined by the student t-tests. Split-split plot analyses of variance indicated a main effect of treatments on the transpiration rate of Dauphine (P<0.0001). There were, however, no main effects within treatments of either foliar nutrition (P=0.7959), PRD (P=0.1712) or an interaction between the two treatments (P=0.9897) at a confidence

level of 5%. This is similar to results obtained for Crimson Seedless where transpiration rate was not affected by either treatment. However, at 80% véraison a significant effect could be seen due to PRD (Figure 4.8), lowering the transpiration rate in Dauphine grapes. These results support results obtained from many studies performed on winegrapes that have shown lowered transpiration rates throughout the season with the implementation of PRD (Stoll *et al.,* 2000; Du Toit *et al.,* 2003).

Table 4.9: Split-split plot analyses of variance in transpiration rate of Dauphine measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (before véraison, 80% véraison and véraison)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	0.10427	0.7959
PRD	1	2.98493	0.1712
Croplife*PRD	1	0.01966	0.9105
Error	40	1.5372	
Corrected total	71		
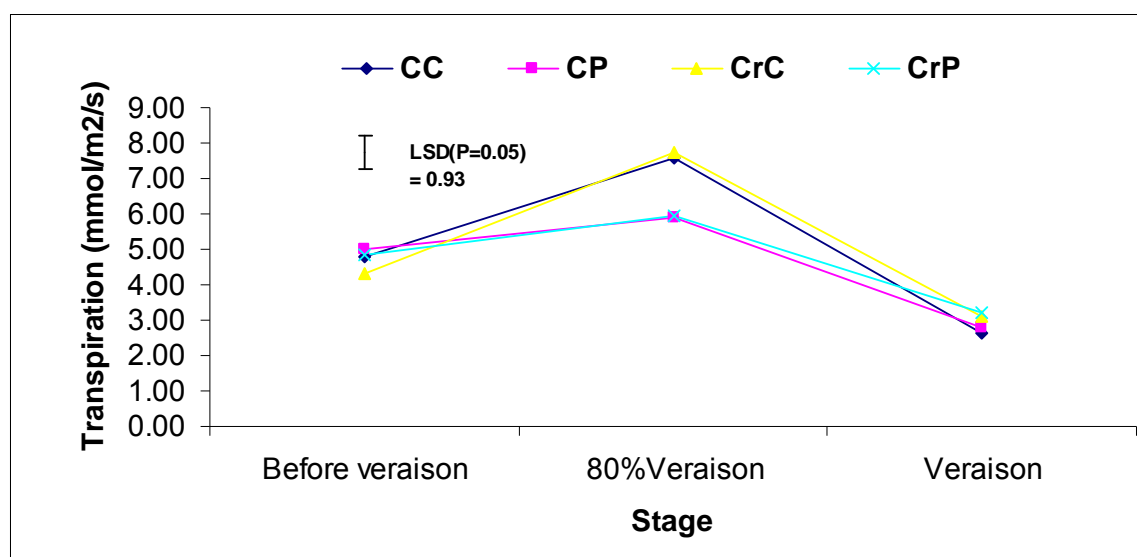
Figure 4.8: Transpiration rate of Dauphine during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

The measurements of stomatal conductance for Dauphine are shown in Table 4.10 and Figure 4.9. Differences were found between the treatments CrC and CP according to the student t-tests. This result was confirmed by the split-split plot analyses of

variance indicating a main effect (P=<0.0001) of treatment on stomatal conductance in Dauphine and a main effect in foliar nutrient treatments (P=0.0243). PRD also indicated a main effect (P=0.0186) but there was no interaction between the two treatments (P=0.9897) at a confidence level of 5%. The transpiration rates of PRD treatments were lower than control treatments (Figure 4.8) and thus a lowered stomatal conductance was anticipated. In the case of 80% véraison (Figure 4.9), treatments with foliar nutrients but without PRD had a high stomatal conductance because adequate amount of water is supplied to the vine. This is confirmed in Figure 4.8, where the transpiration rate of these treatments is a lot higher than PRD treatments at 80% véraison. With the application of foliar nutrients and adequate water supply, stomatal conductance is enhanced. PRD treatments have higher stomatal closure, which is expected because of the presence of the hormone ABA (Wilkinson and Davies, 2002).

Table 4.10: Split-split plot analyses of variance on stomatal conductance of Dauphine measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 levels of irrigation (+/- PRD) over 3 measuring times (0% véraison, 80% véraison and véraison)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	49849.031	0.0243
PRD	1	54752.920	0.0186
Croplife*PRD	1	1.531	0.9897
Error	40	9100.526	
Corrected total	71		
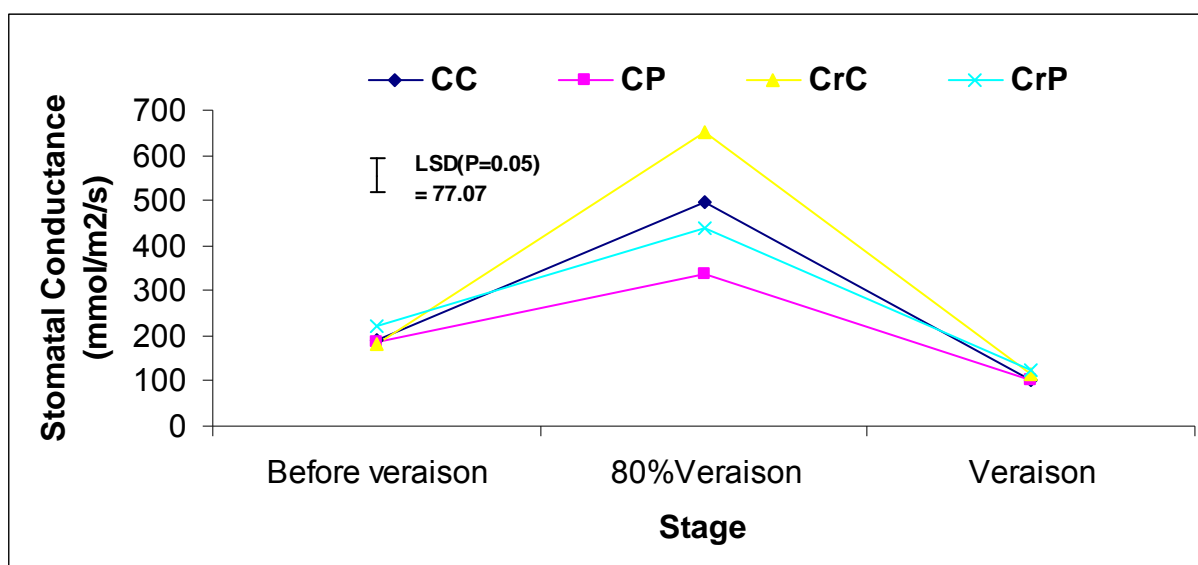
Figure 4.9: Stomatal conductance of Dauphine during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

Temperature analyses of Dauphine are shown in Table 4.11 and Figure 4.10. There were no significant differences in vine temperature between treatments as determined by the student t-tests. However, split-split plot analyses of variance indicated that there is a main effect (P<0.0001) of treatments on the temperature of Dauphine. Further analyses, however, showed only slight but non-significant effects of foliar nutrition (P=0.1073), with Croplife treated vines having lower leaf temperatures early in the season as compared to control. No effect of PRD (P=0.9636) or an interaction between the two treatments (P=0.4256) at P<0.05. As with Crimson Seedless, closure of stomata did not increase leaf temperature. There was a difference in mean temperature between Crimson Seedless and Dauphine, Crimson Seedless having lower average temperatures during the season than Dauphine. This could be due to the fact that the Crimson Seedless block had a longer period of shade from a mountain behind it, before midday when measurements were taken.

Table 4.11: Split-split plot analyses of variance in temperature of Dauphine measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (before véraison, 80% véraison and véraison)). ($P<0.05$)

| Source	DF	Mean Sq	Pr >F
Croplife	1	5.4175	0.1073
PRD	1	0.0042	0.9636
Croplife*PRD	1	1.2934	0.4256
Error	40	1.9958	
Corrected total	71		

Figure 4.10: Leaf Temperature of Dauphine during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates ($P=0.05$).

To investigate the effect of PRD and foliar nutrients on plant water relations in Dauphine, stem water potentials (SWP) were investigated during the season of 2005/2006 at midday, and the results are shown in Table 4.11 and Figure 4.13. For the purpose of this study measurement below -1000 kPa was interpreted as water stress. This cultivar was more stressed throughout the season than Crimson Seedless. This was expected as this block was not cultivated under the OHP system and less water was supplied to the vines. The vines, however, were not under severe stress. The student t-tests indicated no significant differences. The split-split plot analyses of variance indicated a main effect ($P<0.0001$) of treatments on the SWP of Dauphine.

Further analyses indicated a non-significant main effect of PRD treatment (P=0.0689), but not of foliar treatment (P=0.8005) nor an interaction between the two treatments (P=0.8692). The only case where PRD lowered SWP occurred at 80% véraison (Figure 4.13). This specific result contradicts many results obtained from winegrapes (Dry *et al.,* 1996; Stoll *et al.,* 2000; Du Toit *et al.,* 2003; De Souza *et al.,* 2003) and table grapes (Van Sch *et al.,* 2004) that indicated no decrease in SWP with the implementation of PRD. This could indicate that Dauphine is much more sensitive to water stress, but as the results is non-significant it can be ignored.

Table 4.11: Split-split plot analyses of variance on stem water potential of Dauphine measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (before véraison, 80% véraison and véraison)). (P<0.05)

| Source	DF	Mean Sq	Pr >F
Croplife	1	1031.337	0.8005
PRD	1	55694.531	0.0689
Croplife*PRD	1	437.587	0.8692
Error	40	15942.344	
Corrected total	71		

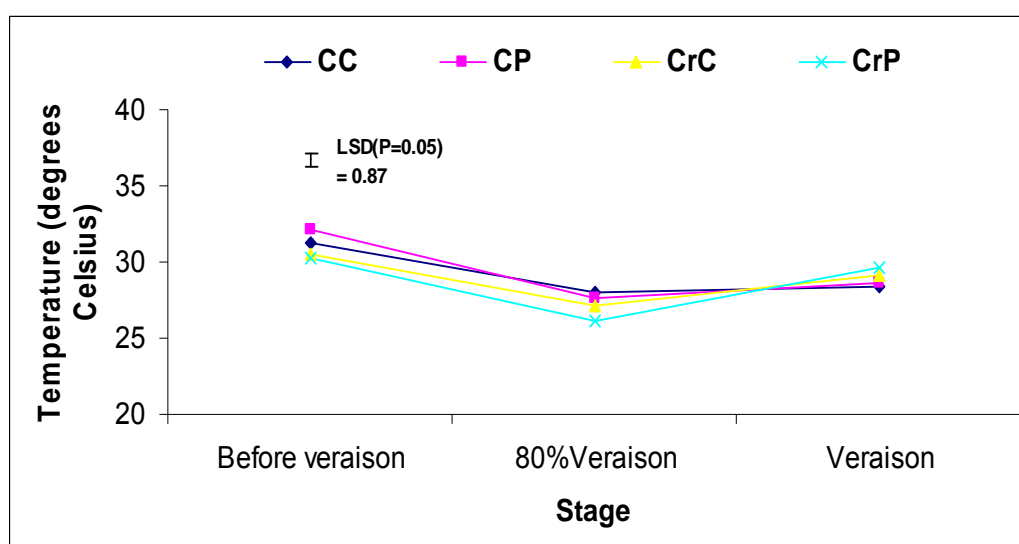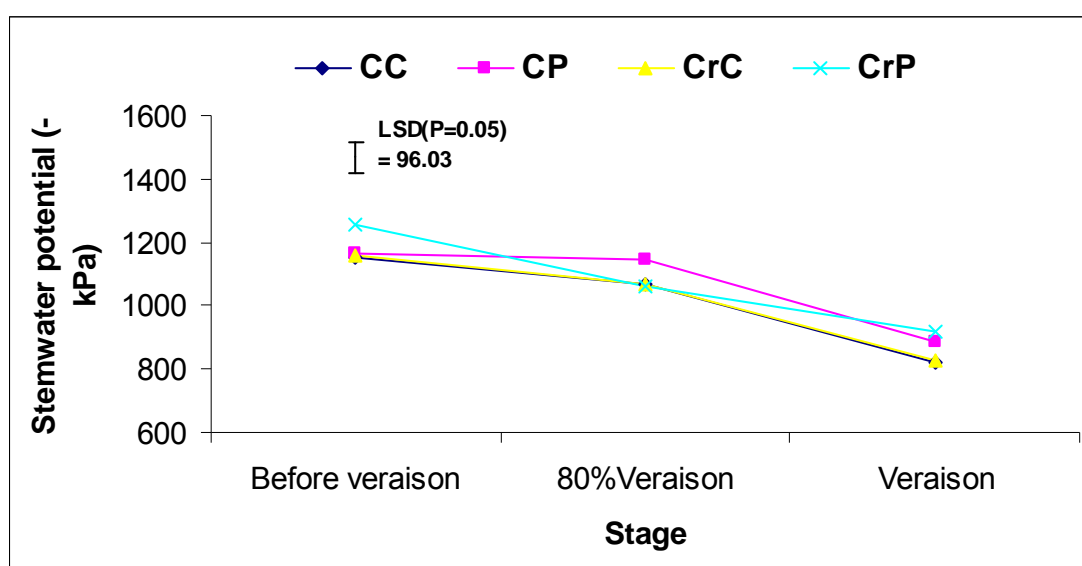**Figure 4.13:** Stem water potential of Dauphine during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

4.3.3 LEAF MEASUREMENTS

4.3.3.1 Crimson Seedless
4.3.3.1.1 Macronutrients

The levels for macronutrients nitrogen (N), phosphorous (P), potassium (K), calcium (Ca) and magnesium (Mg) present in the leaves of Crimson Seedless are shown in Table 4.12 and Figure 4.14. There were no significant differences between treatments in the percentage of macronutrients N, P, K and Ca in leaves of Crimson Seedless as determined by the student t-tests. There was, however, a difference in treatments CC and CP according to the student t-tests for the element Mg. Split-split plot analyses of variance indicated main effects in N ($P<0.0001$), K ($P=0.0042$), Ca ($P=0.0028$) and Mg ($P=0.0025$) but not for P ($P=0.1090$). Further analyses indicated no main effect of foliar nutrition in all elements except N ($P=0.0220$). PRD also had no main effect on any of the elements except Mg ($P=0.0011$) – also confirmed by the student t-test and no interaction between the two treatments for any of the elements were found. At both sampling periods (harvest and post-harvest) the percentage of Mg was higher in leaves of vines undergoing the PRD treatment (Figure 4.14) compared to control vines. The fact that potassium levels did increase significantly in PRD vines was another indication that vines did not undergo significant water stress, as photosynthates were not replaced by increased potassium deposits. Because the Crimson Seedless vines used in this study were grown on open hydroponic principles, there was no guarantee that the provided foliar nutrient was the only source of absorbed elements.

Table 4.12: Split-split plot analyses of variance of leaf macro-elements of Crimson Seedless, measured twice during the season at harvest and post-harvest (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD)). Each value represents 5 replicates ($P<0.05$).

Source	N		P		K		Ca		Mg	
	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F
Croplife	0.0910	0.0220	0.0033	0.2218	0.0144	0.4140	0.0972	0.1834	0.0008	0.4062
PRD	0.0315	0.1593	0.0014	0.4220	0.0808	0.0616	0.0560	0.3079	0.0168	0.0011
Croplife*PRD	0.0032	0.6480	0.0007	0.5767	0.0876	0.0526	0.0108	0.6510	0.0030	0.1226

Figure 4.14: Analysis of macronutrients in the leaves Crimson Seedless. Treatments consisted of CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition) during the season 2005/2006, with 5 leaves per vine at harvest and post-harvest (P=0.05).

4.3.3.1.2 Micronutrients

Levels of micronutrients sodium (Na), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and boron (B) present in the leaves of Crimson Seedless are shown in Table 4.13 and Figure 4.15. There were no significant differences between treatments in the percentages of Na, Mn, Fe, Cu, Zn and B in the leaves of Crimson Seedless according to the student t-tests. Split-split plot analyses of variance indicated no main effects of treatments for any of the elements except Cu (P=0.0327). Further analyses indicated no main effects of foliar nutrition except for the element Fe (P= 0.0271). PRD also had only a main effect on the element Fe (P= 0.02201), but not on any of the other elements, also there was no interaction between the two treatments for any of the elements at a confidence level of 5%. It can be concluded that the use of foliar nutrition enhanced the absorption of Fe in the leaves (Figure 4.15), but overall there were no real differences between foliar treated and untreated vines. Foliar nutrient sprays are commonly used to correct micronutrient problems because they are required in relatively small quantities by grapevines. It is commonly found that plants obtain sufficient micronutrients from chemical sprays (Christensen, 2002). However, as with the macro-elements, it cannot be ruled out that the absorbed elements have been obtained from the soil as the vines

were grown under open hydroponic principles and nutrients are added weekly, sometimes as often as daily. PRD treated vines did not suffer from a lack of micro-nutrients, although 50% less water and thus 50% less nutrients were applied to these vines. This result may imply that with the OHP system formula, excessive amounts of nutrients are added to the vine.

Table 4.13: Split-split plot analyses of variance of leaf micro-elements of Crimson Seedless, measured twice in the season at harvest and post-harvest (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD)). Each value represents 5 replicates (P<0.05).

Source	Na		Mn		Fe		Cu		Zn		B	
	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F
Croplife	2914.08	0.425	34400.52	0.050	16688.02	0.027	188.02	0.426	85.33	0.629	243.00	0.175
PRD	65.33	0.904	238.52	0.864	4700.52	0.022	540.02	0.184	385.33	0.309	161.33	0.264
Croplife*PRD	5376.33	0.282	275.52	0.854	5440.02	0.188	165.02	0.456	102.08	0.598	14.08	0.739
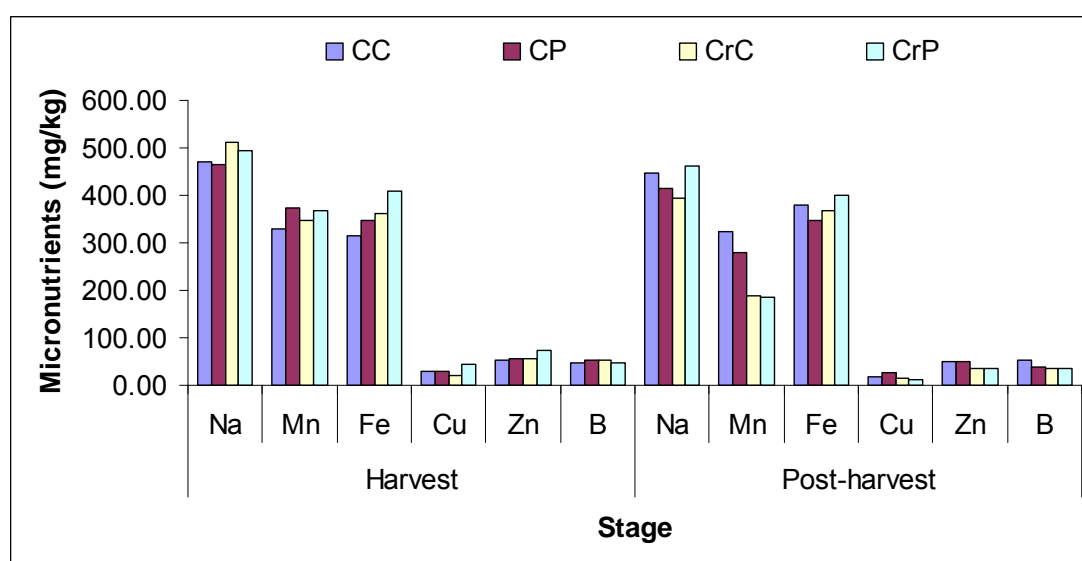
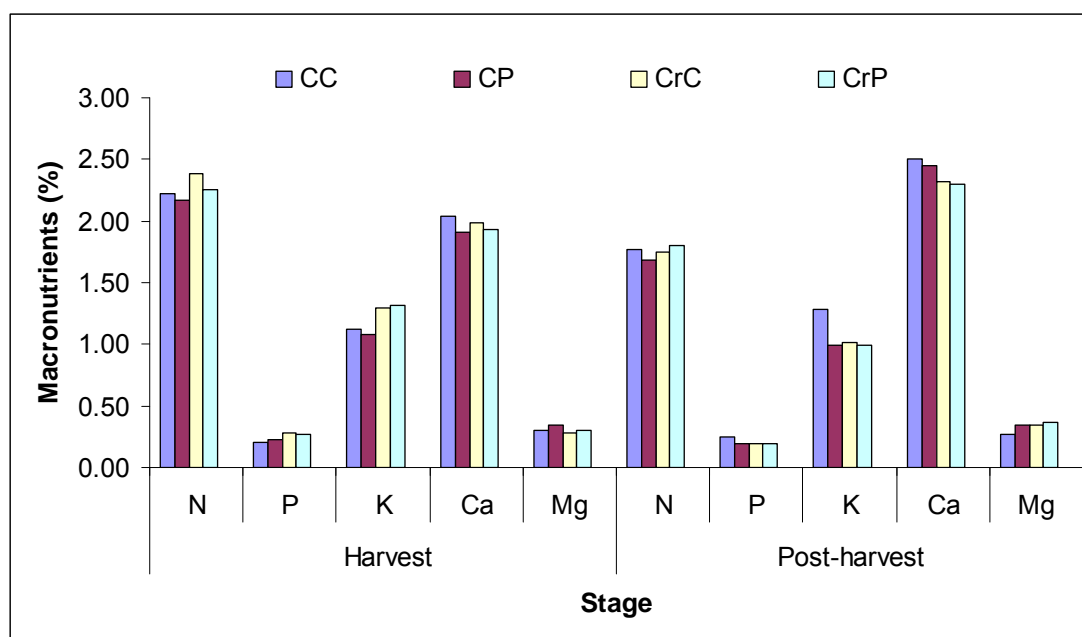**Figure 4.15:** Analysis of micronutrients in the leaves of Crimson Seedless. Treatments consisted of CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition) during the season 2005/2006, measured in Crimson Seedless with 5 leaves per vine at harvest and post-harvest (P=0.05).

4.3.3.2 Dauphine

4.3.3.2.1 Macronutrients

The levels for macronutrients nitrogen (N), phosphorous (P), potassium (K), calcium (Ca) and magnesium (Mg) present in the leaves of Dauphine are shown in Table 4.14 and Figure 4.16. There were no significant differences between treatments in the percentage of N, K, Ca and Mg in leaves of Crimson Seedless as determined by the student t-tests. There was, however, a significant difference in phosphorous levels between foliar nutrition and control treatments according to the student t-tests. Split-split plot analyses of variance indicated main effects of N ($P<0.0001$), P ($p=0.0004$), K ($P<0.0001$), Ca ($P=0.0004$) and Mg ($P=0.0025$). Further analyses also indicated a main effect of foliar nutrition for elements P ($P=0.0001$), K ($P=0.0108$) and Ca ($P= 0.0158$) but not for elements N ($P=0.6780$) and Mg ($P=0.8584$). The PRD treatment had no main effect on any of the macronutrients of Dauphine and there was no interaction between the two treatments except for Mg ($P=0.0291$) at a confidence level of 5%. In treatments where foliar nutrition was applied, P levels were higher (Figure 4.16) as demonstrated by the student t-tests and higher mean values. This finding indicates that P, and also possibly K (Figure 4.16), are more readily absorbed by the leaves from foliar treated vines than the other elements. It is thus possible that foliar nutrient sprays increase the absorption of selected elements in the absence of OHP. Interestingly, the Ca levels decreased with the addition of foliar nutrition and Mg levels decreased with the combination of foliar nutrition and PRD (Figure 4.16).

Table 4.14: Split-split plot analyses of variance of leaf macro-elements of Dauphine, measured twice in the season at harvest and post-harvest (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD)). Each value represents 5 replicates ($P<0.05$).

Source	N		P		K		Ca		Mg	
	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F
Croplife	0.0027	0.6780	0.0151	0.0001	0.0667	0.0108	0.3727	0.0158	0.0001	0.8584
PRD	0.00003	0.9631	0.0002	0.5513	0.0042	0.4877	0.0514	0.3393	0.0026	0.3768
Croplife*PRD	0.0216	0.2465	0.00005	0.7858	0.0072	0.3650	0.00005	0.9754	0.0173	0.0291
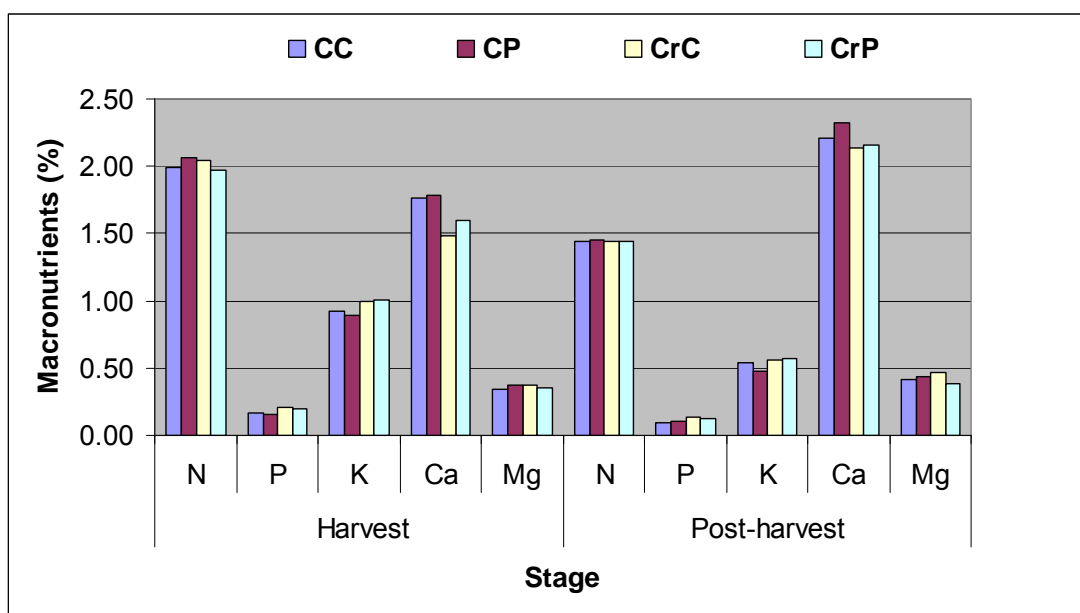
Figure 4.16: Macronutrients measured in the leaves of Dauphine. Treatments consisted of CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition) during the season 2005/2006, measured in Dauphine with 5 leaves per vine at harvest and post-harvest (P=0.05).

4.3.3.2.2 Micronutrients

Levels of the micronutrients sodium (Na), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and boron (B) present in the leaves of Dauphine are shown in Table 4.15 and Figure 4.17. There were no significant differences between treatments in the percentages of micronutrients in leaves for Mn, Fe and Cu according to the student t-tests. There were, however, differences in Na (between the combination of treatments and treatments without foliar nutrients), Zn (between the combination of treatments and treatments without foliar nutrients and foliar nutrient treatments and non-foliar nutrient treatments without PRD) and B (between foliar nutrient treatment and treatments without, both without PRD) levels according to the student t-tests. Split-split analyses of variance indicated main effects of treatments on micronutrient absorption in leaves of Dauphine in elements Na (P=0.0083), Fe (P=0.0008) and B (P=0.0237), but not in elements Mn (P=0.1028), Cu (P=0.5362) and Zn (P=0.1387). Further analyses indicated a main effect of foliar nutrition on the leaf contents of Na (P=0.0001) and Zn (0.0031), but none of the other elements. In studies conducted by Zhang and Brown (1999) and Ferrandon and Chamel (1988) in pistachio and pea plants, respectively, it was found that foliar-applied Zn was very poorly translocated across the cell membranes into the symplast. Furthermore, a linear relationship between the concentration of foliar-applied Zn and the amount of Zn recovered in plants was found

(Zhang and Brown, 1999). It is thus possible that Zn absorption is improved by the application of foliar sprays. Na can be absorbed from other sources such as insecticides and soil nutrition (Swietlik and Faust 1984). It can also be readily absorbed from foliar nutrients, as demonstrated by this experiment. The PRD treatment had no main effect on any of the elements, neither did the combination of the two treatments except for the element B ($P=0.0018$). Boron levels decreased with the application of foliar nutrition (Figure 4.17).

Table 4.15: Split-split plot analyses of variance of leaf micro-elements of Dauphine, measured twice in the season at harvest and post-harvest (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD)). Each value represents 5 replicates ($P<0.05$).

| Source	Na		Mn		Fe		Cu		Zn		B	
	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F	Mean sq	Pr>F
Croplife	103509.19	0.0001	9464.08	0.190	3570.75	0.156	93.52	0.541	438.64	0.003	63.92	0.260
PRD	3024.19	0.426	7600.33	0.239	225.33	0.715	196.02	0.379	39.17	0.324	2.47	0.822
Croplife*PRD	28.52	0.938	15123.00	0.102	243.00	0.704	77.52	0.578	0.286	0.932	625.83	0.002
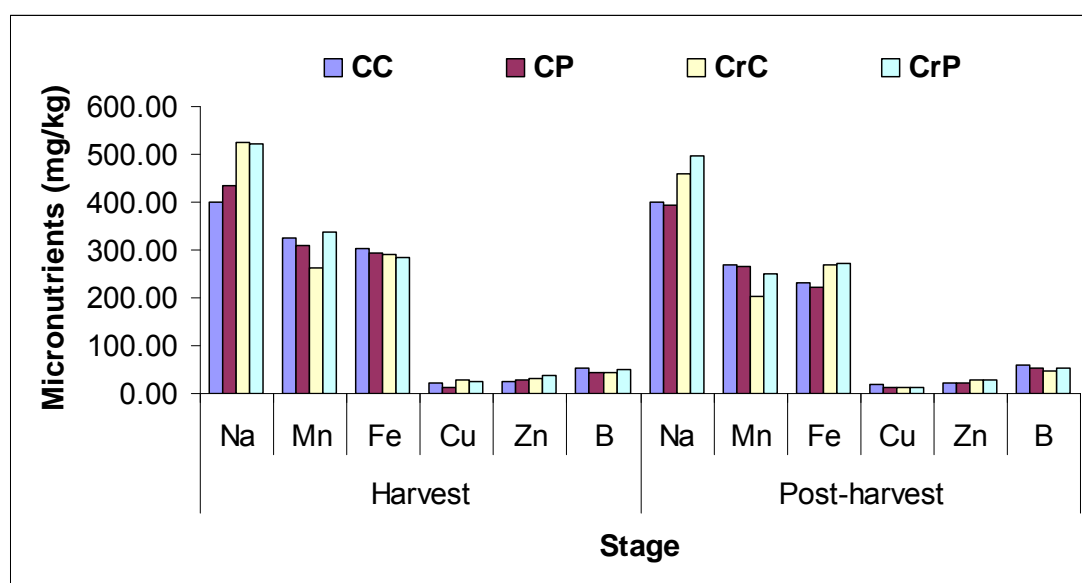
Figure 4.17: Micronutrients measured in the leaves of Dauphine. Treatments consisted of CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition) during the season 2005/2006, measured in Dauphine with 5 leaves per vine at harvest and post-harvest; bars represent means of 2 replicates; ($P=0.05$).

4.4 BERRY MEASUREMENTS

4.4.1 INTRODUCTION

The aim of the grape producer is to produce grapes that have a specific composition that qualifies the grapes as high quality and are able to compete in the market with grapes produced in countries such as Chile and Australia (Van Zyl, 2003). One of the main factors influencing the quality and yield of table grapes is the availability of water. An increase in quality and yield may be established with specific techniques or the manipulation of techniques such as PRD and the use of foliar nutrients. Increases in berry yield and quality with the use of foliar nutrients have been achieved in India (Usha, 2002). Fruit weight per bunch was shown to be significantly higher in Mg, B and Fe sprayed vines, with maximum fruit weight achieved in vines sprayed with Mg, followed by Fe and B (Usha, 2002).

4.4.2 RESULTS AND DISCUSSION

4.4.2.1 Crimson Seedless
4.4.2.1.1 Pre-harvest analyses

The accumulation of total soluble solids (TSS) for Crimson Seedless for the season 2005/2006 is shown in Table 4.16 and Figure 4.18. There were no significant differences between treatments in the accumulation of berry sugars according to the student t-tests. Split-split plot analyses of variance indicated a main effect of treatments on TSS of Crimson Seedless (P=<0.0001). Further analyses, however, indicated no main effects of either foliar nutrition (P=0.4522), PRD (P=0.9834) or an interaction between the two treatments (P=0.7451). All treatments achieved the desired sugar content at the same time at harvest and there were no differences in sugar accumulation. However, in some instances treatment CrP (80% véraison) and treatment CrC (véraison) tended towards a lower TSS (Figure 4.18) before harvest. It was expected that PRD treatments would achieve an earlier harvest as higher sugar accumulation was evident in PRD treated winegrapes (Du Toit, 2004), but this was not the case.

Table 4.16: Split-split plot analyses of variance in total soluble solids of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (80% véraison, véraison and harvest)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	1.6501	0.4522
PRD	1	0.0013	0.9834
Croplife*PRD	1	0.3068	0.7451
Error	40	2.8635	
Corrected total	71		
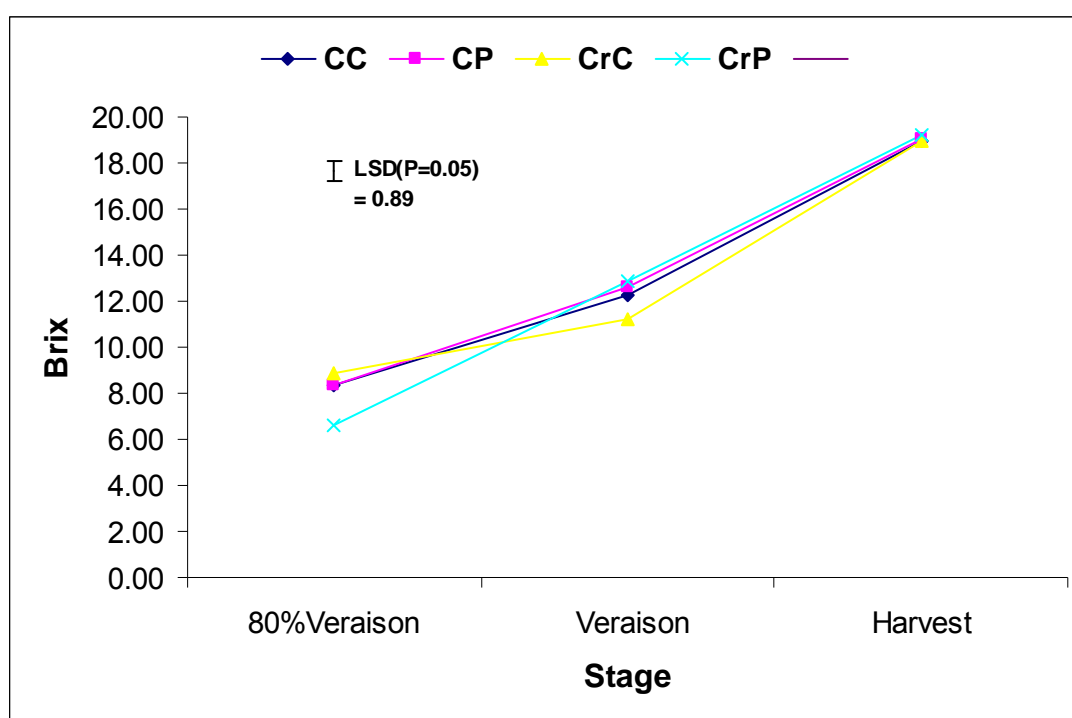
Figure 4.18: Sugar accumulation (°Brix) of Crimson Seedless during the season 2005/2006 by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

The degradation of titratable acidity (TA) for Crimson Seedless for the 2005/2006 season is shown in Table 4.17 and Figure 4.19. There were no significant differences between treatments in berry TA as determined by the student t-tests. Split-split plot analyses of variance indicated that there was a main effect of treatments on TA of Crimson Seedless (P<0.0001). Further analyses indicated a main effect of foliar

nutrition (P=0.0298), but not PRD (P=0.2326) or an interaction between treatments (P=0.0838) at P<0.05. The effect of foliar nutrition was clearly seen at véraison (Figure 4.19), as indicated by lower TA values for these treatments. All treatments did, however, reach the desired TA at harvest and no differences in acid degradation were measured.

Table 4.17: Split-split plot analyses of variance in titratable acidity of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (80% véraison, véraison and harvest)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	2.2649	0.0298
PRD	1	0.6555	0.2326
Croplife*PRD	1	1.4028	0.0838
Error	40	0.4462	
Corrected total	71		
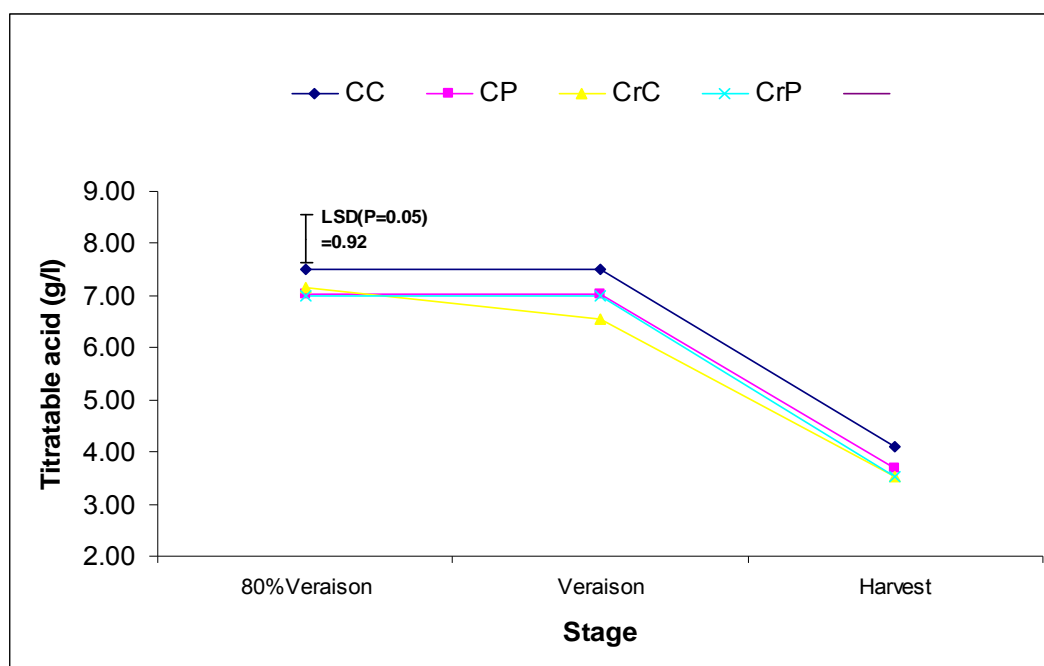
Figure 4.19: Acid degradation of Crimson Seedless during the season 2005/2006 as affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

The TA to TSS ratio for Crimson Seedless is shown in Table 4.18 and Figure 4.20. There were no significant differences between treatments in the TA:TSS ratio according

to the student t-tests. Split-split plot analyses of variance indicated a main effect of treatments on the TA:TSS ratio of Crimson Seedless (P<0.0001). Further analyses, however, indicated no main effects for either treatments foliar nutrition (P=0.9775), PRD (P=0.6653) or an interaction between the two treatments (P=0.3470) at a confidence level of 5%. All the treatments reached approximately the same ratio at harvest and no treatments differed statistically from one another. The ratio for the CrC treatment was lower at véraison because of lower TA (Figure 4.19) and TSS (Figure 4.18) values.

Table 4.18: Split-split plot analyses of variance on the ratio of TSS and TA of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (80% véraison, véraison and harvest)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	0.00002	0.9775
PRD	1	0.0051	0.6653
Croplife*PRD	1	0.0242	0.3470
Error	40	0.0267	
Corrected total	71		
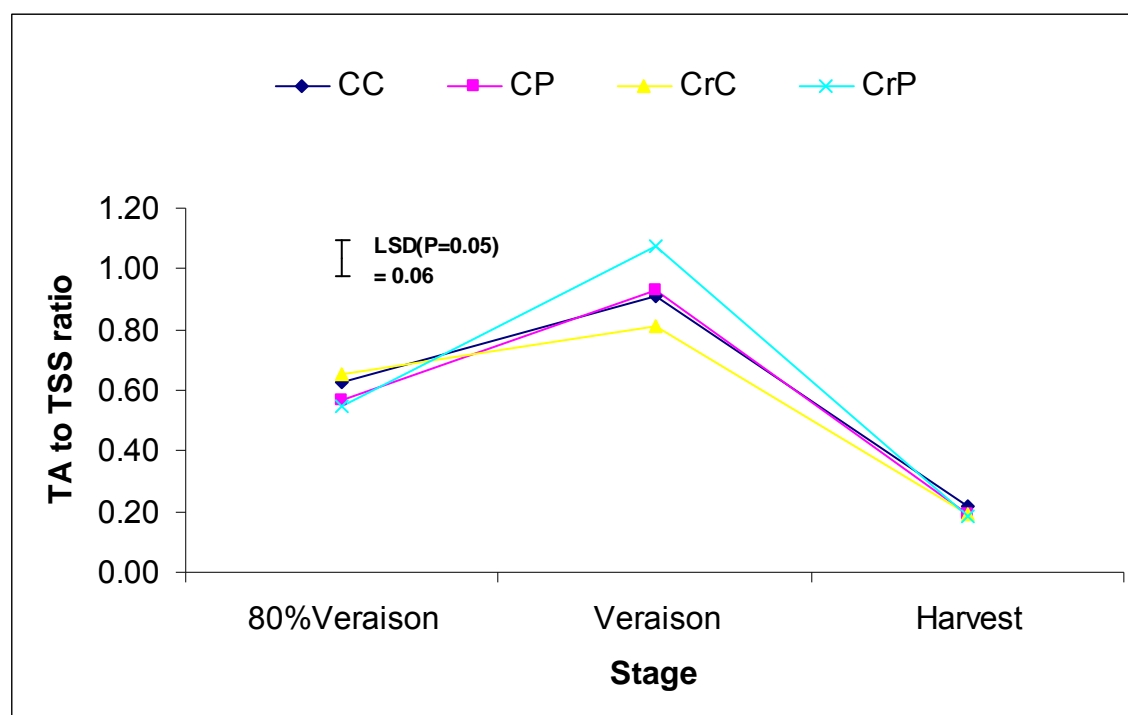
Figure 4.20: The ratio of TA:TSS in Crimson Seedless for the season of 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition); (P=0.05).

The change in berry mass for the cultivar Crimson Seedless for the season 2005/2006 is shown in Table 4.19 and Figure 4.21. There were no significant differences between treatments in grape size according to the student t-tests. Split-split plot analyses of variance indicated a main effect of treatments on berry size (P<0.0001). There were, however, no main effects foliar nutrition (P=0.1823), PRD (P=0.3946) or of an interaction between the two treatments at P<0.05. It can be argued that PRD treatments without foliar nutrients had smaller berries than the other treatments indicating a general lowered mass effect (Figure 4.21).

Table 4.19: Split-split plot analyses of variance in grape mass of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 3 measuring times (80% véraison, véraison and harvest)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	2.8053	0.1823
PRD	1	1.1280	0.3946
Croplife*PRD	1	1.3415	0.3536
Error	40	1.5228	
Corrected total	71		
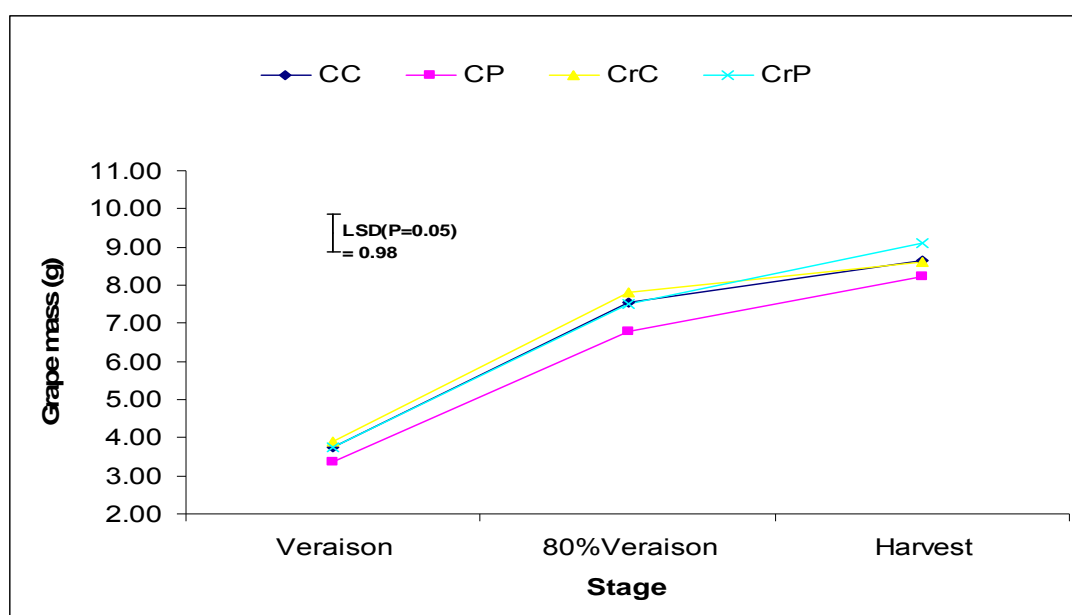
Figure 4.21: Berry mass development (g) of Crimson Seedless during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC

(Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of a sample volume of 10 berries (P=0.05).

The ratio of C12/C13 for Crimson Seedless is shown in Table 4.20 and Figure 4.22. According to Deloire *et al.* (2004), values that are more negative indicate lower vine stress. The range for the treatments in our study (-24 to -27) is considered to be non-stressed or low stress for wine grapes (Deloire *et al.,* 2004). Significant differences were found between control treatments and foliar nutrient treatments according to the student t-tests. Split-split plot analyses of variance also indicates a main effect between treatments for the ratio of C12/C13 of Crimson Seedless (P=0.0054). Further analyses indicated both foliar nutrition (P=0.0002) and PRD (P=0.0051) had an effect, with no interaction between the two treatments (P=0.6362). PRD treatments showed higher accumulated stress compared to control treatments, which was expected. However, the accumulated stress levels lay between -24 and -27 and vines were thus considered unstressed or minimally stressed. The use of foliar nutrient also increased C12/C13 values, indicating significant increases in stress due to foliar application. However, data shows that these vines fall within the category un-stressed or low-stressed and none of the vines showed visual signs of stress during this period.

Table 4.20: Split-split plot analyses of variance on the C12/C13 ratio of Crimson Seedless measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 2 measuring times (80% véraison and harvest)). (P<0.05)

| Source	DF	Mean Sq	Pr >F
Croplife	1	16.7088	0.0002
PRD	1	7.9381	0.0051
Croplife*PRD	1	0.1850	0.6362
Error	20	0.8018	
Corrected total	47		
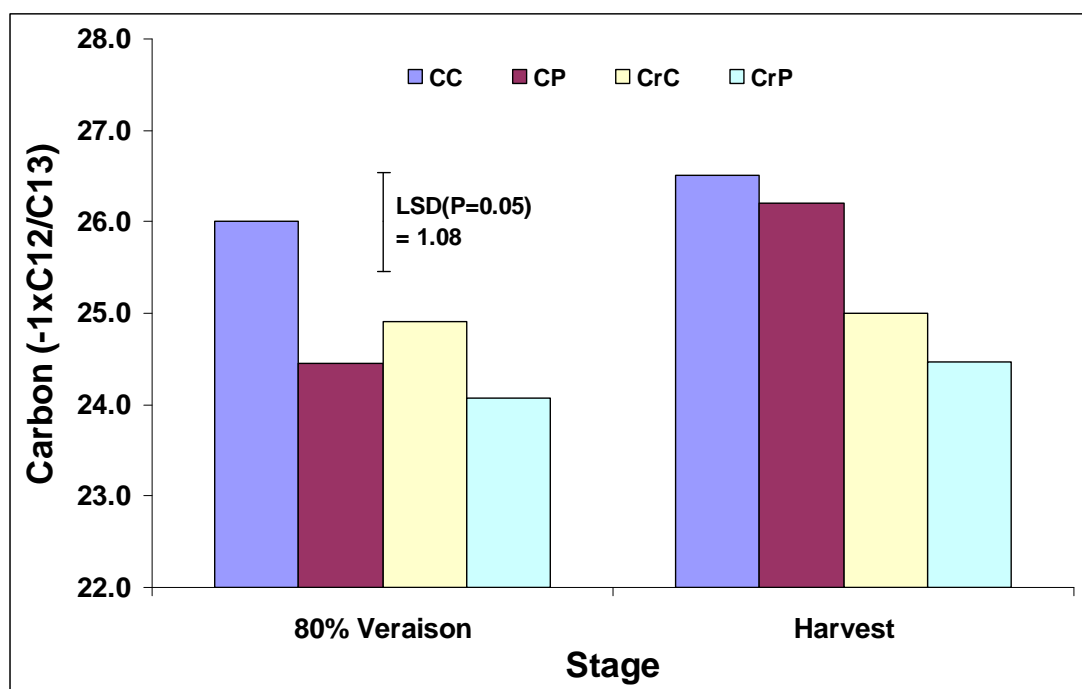
Figure 4.22: Differences in carbon discrimation on Crimson Seedless during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each bar represents the mean of 2 replicates (P=0.05).

4.4.2.1.2 Post-harvest analyses

During post-harvest analysis, only grapes with and without foliar nutrients were compared, as well as the influence of SO_2 sheets. Treatments consisted of C (no foliar nutrient with SO_2 sheet), CA (no foliar nutrient with no SO_2 sheet), CrB (foliar nutrient with SO_2 sheet) and CrC (foliar nutrient with no SO_2 sheet). The effects on TSS in Crimson Seedless grapes following cold storage for seven weeks at -0.5ºC (equivalent to "just out of the container") and after an extra five days at 15ºC (equivalent to "on the shelf") are shown in Figure 4.23. According to the student t-tests, there was a significant difference between the C treatment and the other three treatments. The degree of decreased TSS for treatment C is very small (Figure 4.23) and thus not of great importance.
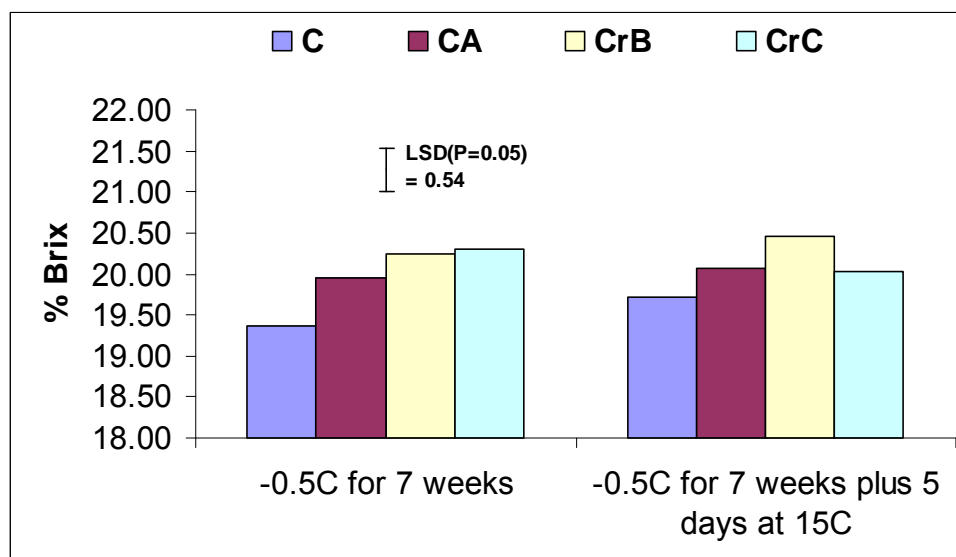
Figure 4.23: Total soluble solids of Crimson Seedless post-harvest for the 2005/2006 season affected by treatments C (no foliar nutrient with SO2 sheet), CA (no foliar nutrient with no SO2 sheet), CrB (foliar nutrient with SO2 sheet) and CrC (foliar nutrient with no SO2 sheet). Bars represent means of 6 replicates. (P=0.05).

The effects on TA in Crimson Seedless grapes following cold storage for seven weeks at -0.5ºC and after an extra five days at 15ºC are shown in Figure 4.24. According to the student t-tests, there was a significant difference between treatment CrC and the other three treatments. Treatment CrC did not degrade TA levels during cold storage as much as the other three treatments (Figure 4.24). After 5 days at 15°C and the subsequently higher rates of respiration treatment CrC again did not degrade TA as much as the other three treatments. Treatment CrB also had higher TA levels than treatments without foliar nutrition. This could be an indication that adding foliar nutrition before harvest increases the shelf life of the grapes, with regards to the degradation of TA during cold storage.
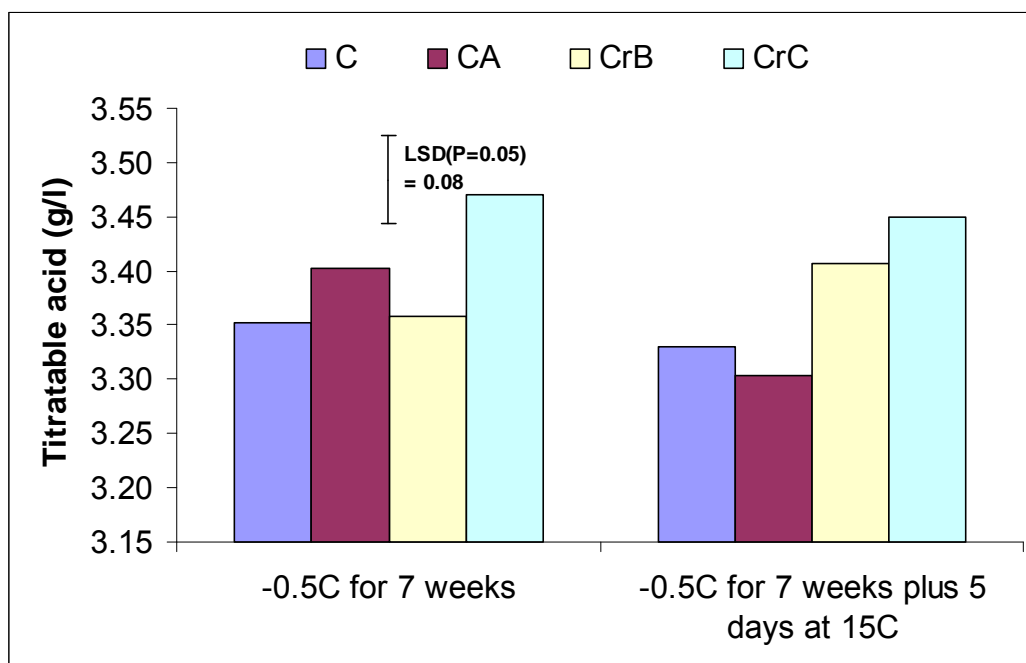
Figure 4.24: Effects of titratable acidity in Crimson Seedless post-harvest for the 2005/2006 season by treatments C (no foliar nutrient with SO2 sheet), CA (no foliar nutrient with no SO2 sheet), CrB (foliar nutrient with SO2 sheet) and CrC (foliar nutrient with no SO2 sheet). Bars represent means of 6 replicates. (P=0.05).

The post-harvest TA to TSS ratios in Crimson Seedless are shown in Figure 4.25. According to the student t-tests there were significant differences between treatment CrB and treatments CrC and C. This was expected due to the influences of the treatments on TSS (Figure 4.23) and TA (Figure 4.24), respectively.
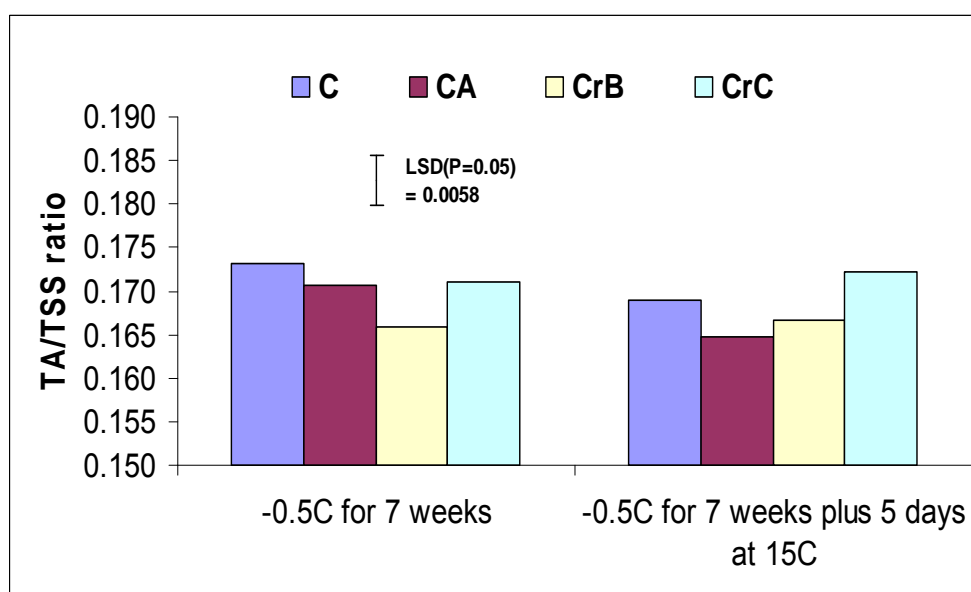
Figure 4.25: The ratio of titratable acidity towards total soluble solids in Crimson Seedless post-harvest for the 2005/2006 season by treatments C (no foliar nutrient with SO2 sheet), CA (no foliar nutrient with no SO2 sheet), CrB (foliar nutrient with SO2 sheet) and CrC (foliar nutrient with no SO2 sheet). (P=0.05)

4.4.2.2 Dauphine

4.4.2.2.1 Pre-harvest analyses

The accumulation of total soluble solids (TSS), for Dauphine for the season 2005/2006 is shown in Table 4.21 and Figure 4.26. There were no significant differences between treatments in berry TSS accumulation according to the student t-tests. Split-split plot analyses of variance indicated that there was a main effect of treatments on TSS accumulation during the season (P=0.0005). This was attributed mainly to near significant effects of foliar nutrient application (P=0.1015). The PRD treatment (P=0.482) or an interaction between the two treatments (P=0.9324) was not significant (P<0.05).

Table 4.21: Split-split plot analyses of variance in total soluble solids of Dauphine measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 2 measuring times (80% véraison and véraison)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	18.6405	0.1015
PRD	1	3.9480	0.4382
Croplife*PRD	1	0.0466	0.9324
Error	19	6.2949	
Corrected total	46		
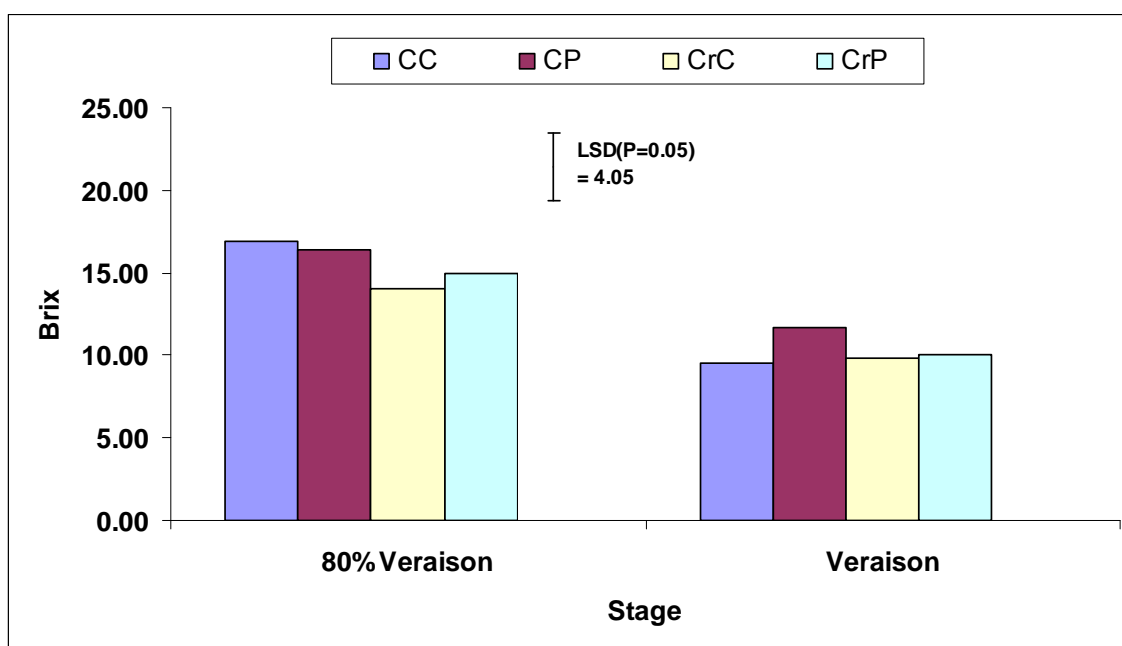
Figure 4.26: Sugar accumulation (°Brix) of Dauphine during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

The degradation of titratable acidity for Dauphine for the season 2005/2006 is shown in Table 4.22 and Figure 4.27. There were no significant differences between treatments in TA degradation according to the student t-tests. There was a main effect of treatments on the degradation of TA as shown by the split-split plot analyses of variance (P=0.0100). The main effect could not be attributed to the foliar nutrient treatments (P=0.2440) or to PRD treatments (P=0.3907). There was also no interaction between the two treatments (P=1.000). Foliar nutrient treatments had higher TA values at 80% véraison (Figure 4.27).

Table 4.22: Split-split plot analyses of variance in titratable acidity of Dauphine measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 irrigation regimes (+/- PRD) over 2 measuring times (80% véraison and véraison)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	2.2533	0.2440
PRD	1	1.2033	0.3907
Croplife*PRD	1	0.0000	1.0000
Error	20	1.5635	
Corrected total	47		
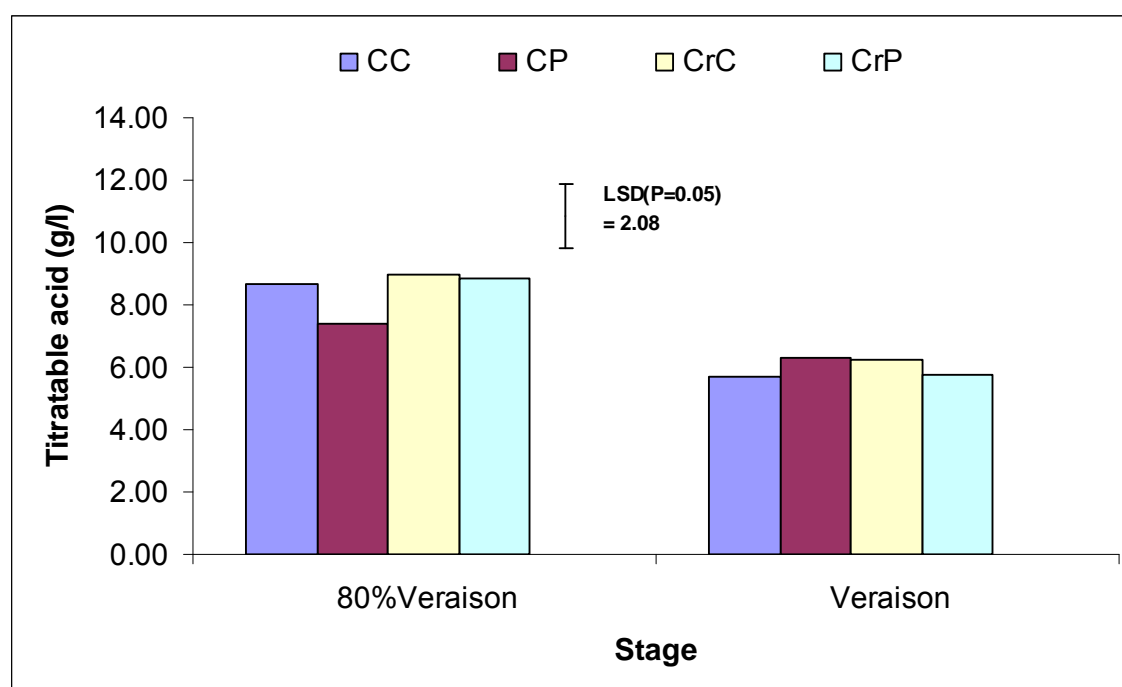
Figure 4.27: Acid degradation of Dauphine during the season 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition). Each value represents the mean of 6 replicates (P=0.05).

The ratio between TA and TSS for Dauphine is shown in Table 4.23 and Figure 4.28. There were no significant differences between treatments for the TA:TSS ratios according to the student t-tests. Split-split plot analyses of variance indicated a main effect of treatments for Dauphine (P=0.0001). Further analyses indicated a main effect for foliar nutrition treatments (P=0.0436). The PRD treated Dauphine vines, however, showed no effect (P=0.2076) and no interaction between the two treatments (P=0.8848) at a confidence level of 5%.

Table 4.23: Split-split plot analyses of variance on the ratio of TSS and TA of Dauphine measured throughout the season (Split-split plot analyses of variance included 2 levels of nutrients (+/- Croplife) and 2 levels of irrigation (+/- PRD) over 2 measuring times (80% véraison and véraison)). (P<0.05)

Source	DF	Mean Sq	Pr >F
Croplife	1	0.0628	0.0436
PRD	1	0.0229	0.2076
Croplife*PRD	1	0.0003	0.8848
Error	19	0.0134	
Corrected total	46		
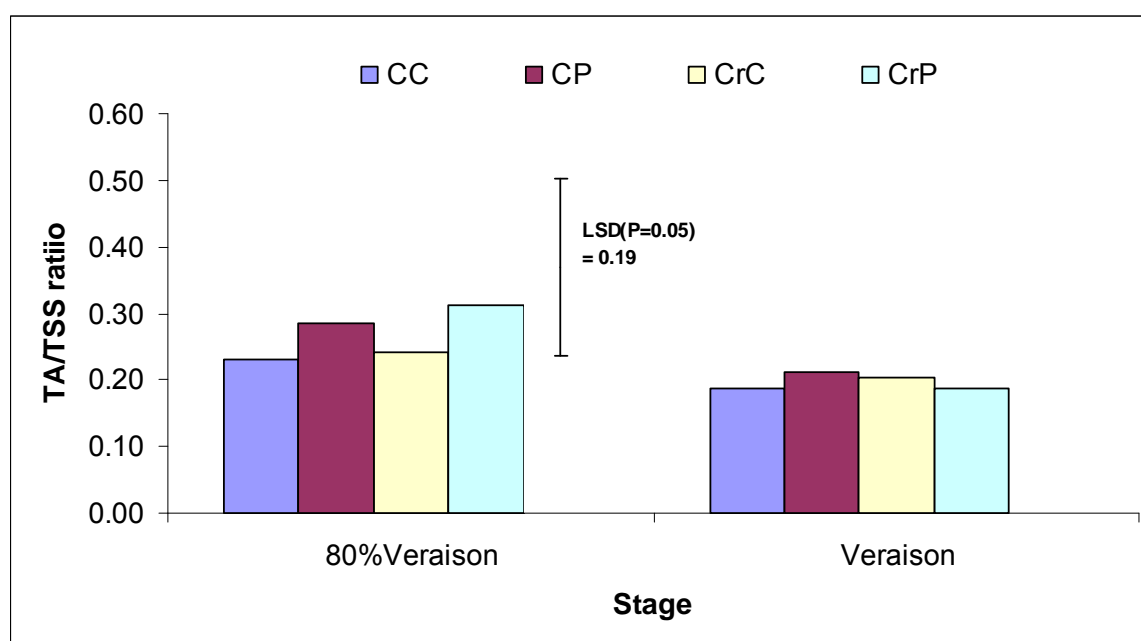
Figure 4.28: Ratio of titratable acidity and total soluble solids of Dauphine during the season of 2005/2006 affected by treatments CC (Control without foliar nutrition), CP (PRD without foliar nutrition), CrC (Control with foliar nutrition) and CrP (PRD with foliar nutrition); (P=0.05).

4.5 PRUNING MEASUREMENTS

4.5.1 INTRODUCTION

Vegetative growth exhibits higher sensitivity to water deficit than gaseous exchange and fruit growth (Dos Santos *et al.,* 2003). Research has shown that in plants growing in drying soil, shoot growth can be limited as a result of hydraulic insufficiency i.e., decreased shoot water status and thus chemical signalling via the xylem between the roots and shoots (Davies *et al.,* 1994). There is evidence suggesting that shoot growth can decline due to root-to-shoot signalling mechanisms even in the absence of an unaltered tissue water condition (Davies and Zhang, 1991; Dodd *et al.,* 1996; Bacon *et al.,* 1998). Studies performed by Dry *et al.* (1996) on wine grapes showed that with the implementation of PRD, there was an accompanying 29% decline in shoot mass and less vegetative growth was observed. These findings are supported by a study by Du Toit *et al.* (2003) on Cabernet Sauvignon where main shoot growth was reduced by 34% and lateral shoot growth by 74%. It is also apparent from the aforementioned study, that sensitivity to PRD differs between cultivars. Merlot was less affected by PRD and showed a 20% reduction in length of main shoot growth and 31% reduced growth in lateral shoots (Du Toit *et al.,* 2003). Table grape cultivars may also be affected differently to wine grape cultivars.

On the other hand, excessive water supply can result in a high canopy density which may negatively affect fruit quality (Myburgh, 2005). This may be due to competition for assimilates in growing shoots and berries and effects on fruit microclimate, namely reducing light penetration in the cluster zone (Crippen and Morrison, 1986; Dokoozlian and Kliewer, 1996). Vegetative growth can be managed through deficit irrigation such as regulated deficit irrigation (RDI), where irrigation volumes are either reduced or withheld for specified periods of time (McCarthy, 1997; Battilani, 2000). The PRD irrigation system has also proven to allow control of plant growth and transpiration, without severe water stress periods that can occur in RDI (Dry *et al.,* 1996; During *et al.,* 1997; Loveys *et al.,* 2000).

4.5.2 RESULTS AND DISCUSSION

4.5.2.1 Crimson Seedless

Average pruning mass, shoot diameter and internode length for Crimson Seedless for 2006 are shown in Table 4.24. From these results, no statistically significant differences could be found between any of the treatments for the aforementioned parameters. According to Dry *et al.* (1996), the main component of shoot growth affected by PRD is node number per shoot and internode length is often not altered at all. The results from this study indicate that the use of PRD did not cause a reduction in shoot growth and also that the use of foliar nutrients did not increase growth in the cultivar Crimson Seedless. These findings are in contrast to the results obtained on the effects of PRD on winegrapes, where PRD lowered shoot growth during the growing season (Dry *et al.,* 1996; Stoll *et al.,* 2000; Du Toit *et al.,* 2003). Similar results were expected in this study, but it is possible that cultivar genetics played a much larger role than expected. This effect is also seen between winegrape cultivars that behave differently with regards to shoot growth under PRD irrigation (Du Toit *et al.,* 2003). The results obtained in our study may be seen as a positive outcome for table grape production, as a reduction in shoot growth is not desired.

Table 4.24: Pruning measurements of mean mass, diameter and internode lengths for Crimson Seedless taken during the winter of 2006. CP = Partial Rootzone Drying, CC = Control, CrP = Partial Rootzone Drying with foliar nutrients, CrC = Control with foliar nutrients (means n = 4; means with different letters are significantly different (P<0.05))

	CP	CC	CrP	CrC	LSD
Mass (g)	0.5917^a	0.5433^a	0.4700^a	0.4617^a	0.2165
Diameter (mm)	9.6667^a	9.5167^a	9.4000^a	9.4000^a	1.3498
All internodes (cm)	83.800^a	82.350^a	79.567^a	77.517^a	11.263
Third internodes (cm)	9.1667^a	9.0667^a	8.2500^a	8.0167^a	1.6272
Fifth internodes (cm)	10.9833^a	10.7167^a	10.2667^a	10.0667^a	1.7921

4.5.2.2 Dauphine

Average pruning mass, shoot diameter and internode length for Dauphine for 2006 are shown in Table 4.25. From these results no statistically significant differences can be found in mean mass and diameter measurements. The results also indicate that the use of PRD did not cause a reduction in shoot growth and that the use of foliar nutrients did not promote growth in the cultivar Dauphine. These findings are in contrast to the results obtained on the effects of PRD on winegrape varieties such as Cabernet Sauvignon and Shiraz, where PRD minimized shoot growth (Dry *et al.,* 1996; Stoll *et al.,* 2000; Du Toit *et al.,* 2003). As with Crimson Seedless, cultivar genetics may explain this occurrence. There were, however, significant differences between treatments CP and CrC at the third internode. According to Dry *et al.* (1996) internode length is not particularly affected by the use of PRD. There is also no reason to suspect that the use of foliar nutrients in conjunction with PRD will shorten internode length, thus this phenomenon could be attributed to vine variation.

Table 4.25: Pruning measurements of mean mass, diameter and internode lengths for Dauphine taken during the winter of 2006. CP = Partial Rootzone Drying, CC = Control, CrP = Partial Rootzone Drying with foliar nutrients, CrC = Control with foliar nutrients (means n = 4; means with different letters are significantly different (P<0.05))

	CP	CC	CrP	CrC	LSD
Mass (g)	0.31833^a	0.31167^a	0.27333^a	0.26000^a	0.0702
Diameter (cm)	8.5208^a	8.4750^a	8.2375^a	8.1875^a	0.4954
All internodes (cm)	73.900^a	73.542^a	71.650^a	71.292^a	0.7173
Third internodes (cm)	9.1667^a	9.0667^{ab}	8.2500^{ab}	8.0167^b	0.9766
Fifth internodes (cm)	11.0417^a	11.0208^a	10.8542^a	10.6042^a	1.7124

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Chapter 5

GENERAL DISCUSSION AND FINAL CONCLUSIONS

DISCUSSION AND CONCLUSIONS

5.1 CONCLUSIONS

There are currently very limited guidelines available for the cultivation of table grapes under a Partial Rootzone Drying (PRD) system. This type of irrigation management as a system for table grape production has never been evaluated under South African conditions, making it difficult to determine whether the system has similar advantages to those associated with wine grape production. Findings of PRD in wine grapes include better fruit quality without yield loss and the effective use of water (Du Toit 2004; Dos Santos *et al.,* 2003) which are critical factors in the cost-effectiveness and marketability of table grape production. In South Africa there are no existing table grape vineyards managed under the PRD system. It was therefore impossible to do a comparative study to determine its effect on table grape production.

The aims of the current study were to determine the potential effect of water stress, induced by PRD, and the effects of a foliar nutrient on vine performance. This was performed as a case study where the influence of PRD and foliar nutrients on vegetative and reproductive vine growth was monitored. The effects of PRD and foliar nutrients on yield and quality were determined with the aforementioned aims taken into account.

In order to achieve these goals, the relative background information was collected for two cultivars on a farm in the Paarl region of the Western Cape, South Africa. The two cultivars used in the study were Crimson Seedless, a red seedless cultivar, and Dauphine, a white, seeded cultivar. The Crimson Seedless block was approximately 5 years old and cultivated under Open Hydroponic Principles (OHP). The Dauphine block was approximately 15 years old and previously under micro-irrigation which was changed to drip-irrigation. Soil analyses were done on both blocks to establish soil texture and wetness. The layout of the treatments within the blocks of the two cultivars was done statistically to ensure an even spread of measuring points throughout the plots. The soil type and root distribution of both cultivars was investigated. The Crimson Seedless block showed a wet layer in the C layer of the soil. This could be a result of poor soil preparation, where the implement used formed a plough line.

The first hypothesis for this study stated that PRD influences the vegetative and reproductive growth of two table grape cultivars, Crimson Seedless and Dauphine by decreasing vegetative growth without influencing reproductive growth. According to shoot measurements it became evident that vegetative growth was not decreased by the implementation of PRD, which differs from studies performed on wine grapes where vegetative growth was decreased (Dry *et al.,* 1996; Stoll *et al.,* 2000; Du Toit *et al.,* 2003). Vegetative parameters measured during the growing season for Crimson Seedless indicated no significant influences for any of the measurements throughout the season. These findings are contradictory to many wine grape and other plant studies that show great influences on stomatal conductance and transpiration rate, as well as photosynthetic rate (Dry *et al.,* 1996; Stoll *et al.,* 2000; De Souza *et al.,* 2003; Du Toit *et al.,* 2003; Wakrim *et al.,* 2005). Some measurements such as transpiration and stem water potential were influenced at only 80% véraison by PRD. Other measurements such as stomatal conductance and photosynthetic rate were influenced at full véraison. For the cultivar Dauphine however, all measurements were influenced at 80% véraison by either PRD or PRD in conjunction with Croplife. These results appear to be similar to those obtained by Du Toit *et al.* (2003) in studies on wine grapes where stomatal conductance is lowered and thus water loss via transpiration is decreased. Stem water potential results also indicated that PRD treated vines experienced slightly higher stress conditions, although not severe stress. At véraison however, only stem water potential of Dauphine was influenced – again indicating higher stress levels for PRD treated vines, although again, not at a high level.

A second hypothesis for this study stated that PRD would increase water use efficiency (WUE) and quality of Crimson Seedless and Dauphine table grapes. It was shown in this study that there was a 50% water-savings effect without a decline in grape quality, as also found in studies performed on wine grapes (Dry *et al.*, 1996, 2001; Du Toit *et al.,* 2003; De Souza *et al.,* 2003; Cifre *et al.,* 2004). PRD treated vines alone induced a 42% increase in WUE compared to control vines, while in combination with Croplife a 92% increase in WUE was observed. This may have positive implications for the production of table grapes in the future – without compromising the quality of the grapes, significantly less water could be consumed during their production.

The third and final hypothesis for this study stated that foliar nutrition improves plant water relations and the post harvest quality of Crimson Seedless and Dauphine table

grapes. In the cultivar Crimson Seedless the use of Croplife decreased stomatal conductance, which has also been seen in crops such as corn (Harder *et al.,* 1982), but had no effect on the transpiration of the vines at véraison. The use of the foliar nutrient also decreased stem water potential in PRD treated vines, further indicating higher stress levels in these vines. Similar observations were made in studies on apple seedlings (Swietlik *et al.,* 1982). There were no significant indications that the use of foliar nutrition increased nutrient absorption via the leaves of the vines. In addition, there were no observable effects when foliar nutrition was combined with PRD. The use of foliar nutrition did, however, improve the post-harvest quality of grapes by slowing the degradation of titratable acidity within the berries, without significantly affecting other parameters. In the cultivar Dauphine the use of Croplife increased water stress in PRD treated vines prior to véraison. This could be a result of the change in irrigation system as this cultivar was previously micro-irrigated prior to the onset of the experimental period. At the beginning of the growing season vines were affected negatively in the rapid growth phase. It was also found by Swietlik and Faust (1984) that foliar nutrients decreased stomatal conductance, thus decreasing the transpiration rate and stem water potential which, in turn, resulted in a water stressed environment. This cultivar differed in its response to foliar nutrition when compared to Crimson Seedless. No effects were found in the other measurements used as indicators for the effect of foliar nutrition on grapevine physiology. Leaf analysis indicated that phosphorus was more readily absorbed in this cultivar and higher phosphorous levels were detected in vines treated with foliar nutrients. The micronutrients sodium, zinc and boron were also absorbed more readily by vines treated with the foliar nutrient, Croplife. These elements are all mobile or partially mobile elements and can be absorbed through leaves (Swietlik and Faust*,* 1984). Results for the absorption of macronutrients and micronutrients with the application of foliar nutrition cannot be seen as conclusive. This is because the Crimson Seedless was cultivated on an open hydroponic principle system and any nutrients could also have been obtained from the soil, with micronutrients also possibly obtained from chemical sprays (Christensen, 2002).

Total soluble solids (TSS) and titratable acidity (TA) were measured during fruit evaluation. For Crimson Seedless there were no differences between treatments for TSS or TA. Grape mass was also not influenced by either PRD or foliar nutrient application. This indicated that PRD did not have a negative influence on the development of the grape berries, which is contrary to findings in many wine grape

studies (Dry *et al.*, 1996, 2001; Du Toit *et al.,* 2003; De Souza *et al.,* 2003; Cifre *et al.,* 2004). Carbon analyses showed that PRD did have a water stress effect on berries and this effect was amplified with the use of foliar nutrients. However, the stress levels measured in the berries are not considered as high or even mild stress, and thus the use of PRD and foliar nutrition did not significantly stress vines. The treatments imposed very low levels of stress on the vines, which may be considered negligible. The data confirms that stem water potential measurements can be considered as an accurate indication of water stress in grapevines. To conclude, PRD and foliar nutrients did not improve grape quality but more importantly, they did not influence these parameters negatively.

For Dauphine there were no differences between treatments for TSS or TA. It is however difficult to draw conclusions from these results due to missing harvest data. It does seem, however, that PRD or foliar nutrients combined with PRD did not improve grape quality as measured by TSS and TA up until véraison, but neither did it influence it negatively.

There were no differences in pruning mass, diameter and node lengths between treatments for Crimson Seedless, indicating that PRD did not reduce vegetative growth, nor did foliar nutrient application increase it. For Dauphine there were also no differences in pruning mass or shoot diameter between treatments, but there were differences between lengths of the third internodes. The treatment CP (only PRD treatment with no foliar nutrients) had the longest third internode length. Previous wine grape studies indicate that vegetative growth decreased with the implementation of PRD (Dry *et al.,* 1996; Du Toit *et al.,* 2003), but this was not the case for these two table grape cultivars. A possible explanation for this outcome could be the amount of water supplied. In a table grape scenario a lot more water is supplied throughout the season as compared to wine grapes. Even if only half the normal amount was applied, it still remains considerably more than what wine grapes receive. Water is also applied whenever there is an indication that soil is reaching its refill point, and the soil is then filled to field capacity again. In an Open Hydroponic System (OHS) situation, water is also readily supplied as the soil is considered only as an anchor medium and not as a source of water or nutrients. Fertilizer programmes for table grapes also differ significantly from those of wine grapes, with more nutrients being readily available to the OHS vine.

This study presents a foundation for future research on some key aspects of PRD irrigation and foliar nutrient application. PRD could be a useful tool for grape production in a country like South Africa which has limited water resources, while still producing quality grapes for an industry that is market driven and internationally competitive.

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Appendix

Diagram 1: Outlay of Crimson Seedless treatments

Treatments without foliar nutrients (PRD and C)

Treatments with foliar nutrients (PCr and CCr)
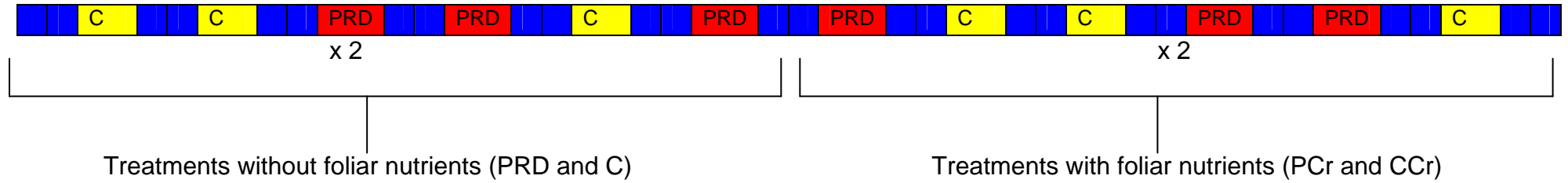
Diagram 2: Outlay of Dauphine treatments

Treatments without foliar nutrients (PRD and C)

Treatments with foliar nutrients (PCr and CCr)
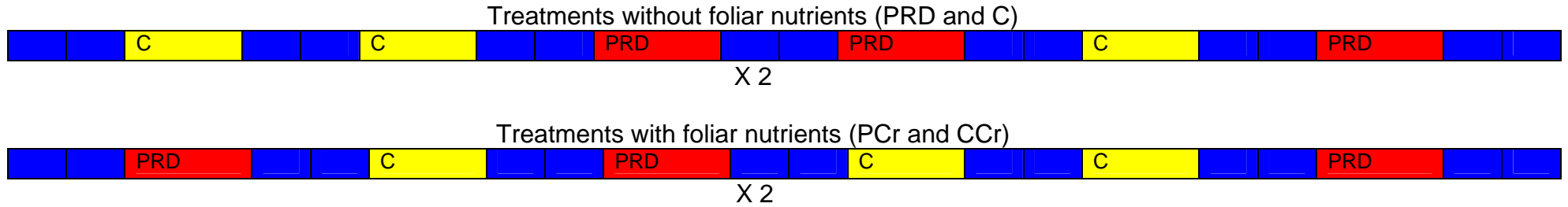
Two buffer vines

PRD   PRD treatment

C   Control treatments

Table 1: Irrigation schedule for Dauphine for the season 2005/2006

Date	Pulse/day (min)
2005/11/16	60
2005/11/18	180
2005/11/23	60
2005/11/30	120
2005/12/05	120
2005/12/12	180
2005/12/19	180
2005/12/21	180
2005/12/26	120
2005/12/29	240
2006/01/02	120
2006/01/04	180
2006/01/09	180
2006/01/11	120
2006/01/16	120
2006/01/18	120
2006/01/22	120
2006/01/24	240
2006/01/30	180
2006/02/06	60
2006/02/08	60
2006/02/13	180
2006/02/16	60
2006/02/20	180
2006/02/22	240
2006/02/27	120
2006/03/01	120
2006/03/06	180
2006/03/08	180
2006/03/13	240
2006/03/15	180
2006/03/20	180
2006/03/22	180
2006/03/27	180

Table 2: Irrigation schedule for Crimson Seedless 2005/2006 season

Date	Pulse/day (min)	Date	Pulse/day (min)	Date	Pulse/day (min)
2005/11/01	30	2006/01/03	30	2006/02/27	30
2005/11/02	30	2006/01/04	30	2006/02/28	30
2005/11/03	30	2006/01/05	30	2006/03/03	30
2005/11/07	30	2006/01/06	30	2006/03/06	30
2005/11/08	30	2006/01/09	30	2006/03/07	30
2005/11/09	30	2006/01/10	30	2006/03/08	30
2005/11/10	30	2006/01/11	30	2006/03/09	60
2005/11/14	30	2006/01/12	30	2006/03/10	60
2005/11/15	30	2006/01/13	30	2006/03/14	60
2005/11/16	30	2005/01/16	30	2006/03/15	30
2005/11/17	30	2006/01/17	30	2006/03/16	30
2005/11/18	30	2007/01/18	30	2006/03/17	60
2005/11/21	30	2008/01/19	30	2006/03/20	30
2005/11/22	30	2006/01/20	30	2006/03/23	30
2005/11/23	30	2006/01/23	30	2006/03/24	30
2005/11/24	30	2006/01/24	30	2006/03/27	60
2005/11/25	30	2006/01/25	30	2006/03/28	30
2005/11/28	30	2006/01/26	30	2006/03/29	60
2005/11/29	30	2006/01/27	30	2006/03/30	30
2005/11/30	30	2006/01/30	30	2006/03/31	30
2005/12/01	30	2006/01/31	30	2006/04/03	30
2005/12/02	80	2006/02/01	30	2006/04/04	30
2005/12/05	30	2006/02/02	30	2006/04/05	30
2005/12/06	30	2006/02/03	30	2006/04/06	30
2005/12/07	60	2006/02/06	30	2006/04/07	30
2005/12/08	30	2006/02/07	30	2006/04/10	30
2005/12/12	30	2006/02/08	30	2006/04/11	30
2005/12/13	30	2006/02/09	30	2006/04/12	30

Date	Pulse/day (min)	Date	Pulse/day (min)	Date	Pulse/day (min)	Date	Pulse/day (min)
2006/02/10	30	2006/04/13	30	2006/05/02	30	2006/05/19	30
2006/02/13	30	2006/04/18	60	2006/05/03	30	2006/05/22	30
2006/02/14	30	2006/04/19	60	2006/05/04	30	2005/05/24	30
2006/02/15	30	2006/04/20	30	2006/05/05	30	2005/05/26	30
2006/02/16	30	2006/04/21	30	2006/05/08	30		
2006/02/17	30	2006/04/24	30	2006/05/09	30		
2006/02/20	30	2006/04/25	30	2006/05/10	30		
2006/02/23	30	2006/04/26	30	2006/05/11	30		
2006/02/24	30	2006/04/27	30	2006/05/12	30		
2006/02/25	30	2006/04/30	30	2006/05/15	30		
2006/02/26	30	2006/05/01	30	2006/05/17	30		

PRD treated vines received half of the amount of water given to control vines.

Soil analysis of Crimson Seedless 2005/2006 season

Table 3: General analysis of soil profile

| pH (KCL) | Resist (ohm) | H+ (cmol/kg) | Stone (vol%) | P Bray II (mg/kg) | Exchangeble cations (cmol(+)/kg) | | | | | mg/kg | | | | % |
					K	Na	K	Ca	Mg	Cu	Zn	Mn	B	C
5.5	1060	0.54	40	58	59	0.1	0.15	4.87	1.08	15	6	10	0.4	0.6
5.2	1550	0.54	38	50	38	0.12	0.1	3.55	0.85	9.2	3	7.1	0.3	0.5
5	1290	0.59	42	51	36	0.1	0.09	3.04	0.99	5.04	1	5	0.2	0.2
4.9	1620	0.54	34	59	29	0.1	0.07	2.66	0.89	5.68	1	3.3	0.1	0.2
4.8	1370	0.69	35	29	27	0.13	0.07	2.67	0.95	4.43	1	1.6	0.1	0.2

Table 4: Base saturation of soil profile

Na%	K%	Ca%	Mg%	T-value (cmol/kg)
1.5	2.23	72.19	16.07	6.74
2.36	1.88	68.76	16.53	5.16
2.16	1.89	63.09	20.6	4.81
2.33	1.73	62.36	20.9	4.26
2.91	1.51	59.18	21.1	4.51

Table 5: Mechanical analysis of soil profile

| Clay% | Silt% | Fine sand% | Med sand | Coarse sand | Stone% | Classific | Waterholdingcapacity | | |
							10kPa%	100kPa%	mm/m
17.4	16	37.9	11.5	17.2	37.9	SaLm	19.01	11.64	73.7
20.4	14.8	35.9	11.1	17.8	41.9	SaKlLm	17.88	11.18	67
21	20	33.2	10.4	15.4	34.5	SaKlLm	21.44	13.8	76.4
19.4	22.2	32.9	10.6	14.9	35.2	SaLm	21.48	13.83	76.5
17.8	24.2	33.9	9.7	14.4	0.6	SaLm	33.62	21.51	121.1

Fertigation programme – Crimson Seedless

Table 6: Irrigation details for Crimson Seedless 2005/2006 season

Fenological stages	Date	Days	L/vine/day	m3/ha/day	m3/area/day	Hrs/day	Min/day
Budswel - 10cm shoot	15 Sept - 28 Sept 2005	14	1.2	4.6	22.2	00:30	30
10cm shoot - start of flowering	29 Sept - 23 Oct 2005	25	2.3	9.2	44.4	01:00	60
Start of flowering - fruit set	24 Oct - 09 Nov 2005	17	3.2	12.8	61.8	01:23	83
Fruit set- beginning of veraison	10 Nov - 19 Dec 2005	40	6.4	25.6	123.6	02:46	167
Beginning of veraison - veraison	20 Dec - 26 Dec 2005	7	9.6	38.4	185.5	04:10	250
Veraison - beginning of harvest	27 Dec - 25 Jan 2006	30	10.4	41.6	200.9	04:31	271
Harvest	26 Jan - 12 Feb 2006	18	8.0	32.0	154.6	03:28	209
End of harvest - leaf fall	13 Feb - 17 Mar 2006	33	4.8	19.2	92.7	02:05	125
Leaf fall	18 Mar - 29 Apr 2006	43	4.0	16.0	77.3	01:44	104
1 May winter rest	30 Apr - 30 May 2006	31	1.6	6.4	30.9	00:41	42
31 May winter rest	31 May - 14 Aug 2006	76	0.1	0.3	1.4	00:01	2
Budswel	15 Aug - 14 Sept 2006	31	0.6	2.4	11.6	00:15	16

Table 7: Total kg product per stage for entire area – Tank A for Crimson Seedless 2005/2006 season

Date	Vita NS	MAP	MOP-SOL	MgSO4	Vita K	Fe EDTA	MnSO4	ZnSO4	CuSO4	Solubor	NaMo
15 Sept - 28 Sept 2005		31	15	101	41	0.97	0.43	0.42	0.06	0.64	0.021
29 Sept - 23 Oct 2005		58	54	210	64	2.04	0.86	0.71	0.13	1.31	0.042
24 Oct - 09 Nov 2005		18	27	57	19	0.51	0.18	0.17	0.13	0.21	0.011
10 Nov - 19 Dec 2005		84	140	280	93	2.69	0.95	0.95	0.17	1.17	0.056
20 Dec - 26 Dec 2005		22	68	11	36	0.61	0.28	0.22	0.15	0.24	0.010
27 Dec - 25 Jan 2006		84	150	128	166	2.39	0.84	0.88	0.16	0.95	0.044
26 Jan - 12 Feb 2006		55	77	51	97	1.22	0.44	0.42	0.08	0.53	0.027
13 Feb - 17 Mar 2006	47	38	72	172	45	1.03	0.31	0.31	0.07	0.47	0.022
18 Mar - 29 Apr 2006	78	63	72	287	134	1.72	0.57	0.52	0.10	0.73	0.037
30 Apr - 30 May 2006	31	25	39	115	43	0.69	0.23	0.21	0.04	0.29	0.015
31 May - 14 Aug 2006	21	34	53	136	24	3.03	1.07	1.05	0.20	1.30	0.065
15 Aug - 14 Sept 2006	21	17	15	86	31	0.90	0.39	0.31	0.06	0.60	0.020

Table 8: Kg product in 5000L concentrate per stage (14% for Crimson Seedless)

Date	Vita NS	MAP	MOP-SOL	MgSO4	Vita K	Fe EDTA	MnSO4	ZnSO4	CuSO4	Solubor	NaMo
15 Sept - 28 Sept 2005		31	15	101	41	0.97	0.43	0.42	0.06	0.64	0.021
29 Sept - 23 Oct 2005		58	54	210	64	2.04	0.86	0.71	0.13	1.31	0.042
24 Oct - 09 Nov 2005		18	27	57	19	0.51	0.18	0.17	0.03	0.21	0.011
10 Nov - 19 Dec 2005		84	140	280	93	2.69	0.95	0.95	0.17	1.17	0.056
20 Dec - 26 Dec 2005		22	68	11	36	0.61	0.28	0.22	0.05	0.24	0.010
27 Dec - 25 Jan 2006		84	150	128	166	2.39	0.84	0.88	0.16	0.95	0.044
26 Jan - 12 Feb 2006		55	77	51	97	1.22	0.44	0.42	0.08	0.53	0.027
13 Feb - 17 Mar 2006	47	38	72	172	45	1.03	0.31	0.31	0.07	0.47	0.022
18 Mar - 29 Apr 2006	39	31	36	143	67	0.86	0.29	0.26	0.05	0.37	0.018
30 Apr - 30 May 2006	31	25	39	115	43	0.69	0.23	0.21	0.04	0.29	0.015
31 May - 14 Aug 2006	21	34	53	136	24	3.03	1.07	1.05	0.20	1.30	0.065
15 Aug - 14 Sept 2006	21	17	15	86	31	0.90	0.39	0.31	0.06	0.60	0.020

Table 9: Tank A 5000L fertigation programme for Crimson Seedless 2005/2006 season

Fenological stages	Date	L/Hr	L/dayCaNO3	L/1000L	EC mS/cm	Concentr%
Budswel - 10cm shoot	15 Sept - 28 Sept 2005	714	357	16.1	0.68	3.8
10cm shoot - start of flowering	29 Sept - 23 Oct 2005	200	200	4.5	0.40	7.7
Start of flowering - fruit set	24 Oct - 09 Nov 2005	211	294	4.8	0.14	2.4
Fruit set- beginning of veraison	10 Nov - 19 Dec 2005	45	125	1.0	0.15	12
Beginning of veraison - veraison	20 Dec - 26 Dec 2005	171	714	3.9	0.16	2.7
Veraison - beginning of harvest	27 Dec - 25 Jan 2006	37	167	0.8	0.12	10.6
Harvest	26 Jan - 12 Feb 2006	80	278	1.8	0.14	5.6
End of harvest - leaf fall	13 Feb - 17 Mar 2006	73	152	1.6	0.15	7.5
Leaf fall	18 Mar - 29 Apr 2006	134	233	3.0	0.23	6.4
1 May winter rest	30 Apr - 30 May 2006	232	161	5.2	0.32	5.1
31 May winter rest	31 May - 14 Aug 2006	2018	66	45.2	2.91	5.4
Budswel	15 Aug - 14 Sept 2006	618	161	13.9	0.56	3.4

Table 10: Kg/ha/stage fertigation programme for Crimson Seedless 2005/2006 season

Fenological stages	Date	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo	Cl
Budswel - 10cm shoot	15 Sept - 28 Sept 2005	7.0	1.8	5.1	7.6	2.0	4.3	26.1	27.5	30.1	3.3	27.2	1.7	1.6
10cm shoot - start of flowering	29 Sept - 23 Oct 2005	14.1	3.2	11.1	15.6	4.2	8.1	55.0	55.5	51.2	6.9	55.6	3.4	5.6
Start of flowering - fruit set	24 Oct - 09 Nov 2005	3.7	1.0	4.5	4.0	1.1	2.3	13.7	11.6	12.5	1.7	9.0	0.9	2.8
Fruit set- beginning of veraison	10 Nov - 19 Dec 2005	19.9	4.7	22.6	21.9	5.6	11.1	72.3	61.0	68.9	8.9	49.9	4.6	14.5
Beginning of veraison - veraison	20 Dec - 26 Dec 2005	1.5	1.2	10.1	1.1	0.2	1.7	16.3	17.7	16.0	2.6	10.3	0.8	7.0
Veraison - beginning of harvest	27 Dec - 25 Jan 2006	12.3	4.7	29.9	12.5	2.6	9.8	64.2	54.2	63.8	8.4	40.5	3.6	15.5
Harvest	26 Jan - 12 Feb 2006	5.2	3.1	16.5	4.8	1.0	5.1	32.7	28.4	30.4	4.1	22.5	2.2	8.0
End of harvest - leaf fall	13 Feb - 17 Mar 2006	12.6	2.1	11.4	11.1	3.5	7.6	27.8	20.1	22.7	3.5	19.9	1.8	7.5
Leaf fall	18 Mar - 29 Apr 2006	21.0	3.5	19.2	18.5	5.8	14.9	46.3	36.8	37.8	5.5	31.0	3.0	7.5
1 May winter rest	30 Apr - 30 May 2006	8.6	1.4	7.7	7.6	2.3	5.6	18.5	14.7	15.1	2.2	12.4	1.2	4.0
31 May winter rest	31 May - 14 Aug 2006	10.2	1.9	7.6	10.0	2.7	5.1	81.5	69.0	75.8	10.5	55.2	5.3	5.5
Budswel	15 Aug - 14 Sept 2006	5.8	1.0	4.3	5.1	1.7	4.1	24.3	24.8	22.8	3.0	25.5	1.6	1.6

Table 11: Leaf analysis for Crimson Seedless 2005/2006 season

2006/02/24	%							mg/kg			
Nr	N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn	B
C1	2.63	0.25	1.35	2	0.25	431	158	387	13	31	68
C2	2.37	0.39	1.39	2.28	0.26	619	404	434	39	80	63
C3											
C4	2.34	0.31	1.3	2.07	0.31	579	492	387	79	123	57
C5	2.5	0.24	1.32	1.53	0.26	420	291	416	18	48	48
C6	2.22	0.24	1.5	1.77	0.29	426	264	451	24	44	45
C7											
C8	2.2	0.25	1.14	2.04	0.34	485	341	436	16	56	45
C9	2.37	0.32	1.26	2.21	0.35	554	516	302	17	68	45
C10	2.32	0.25	1.25	2.02	0.27	503	319	320	16	51	50
C11	2.3	0.29	1.22	1.97	0.32	476	368	346	37	55	43
C12	2.13	0.25	1.18	1.87	0.29	549	394	303	19	58	44
C13	2.22	0.26	1.31	2.03	0.35	520	289	393	14	37	42
C14	1.99	0.18	0.82	1.88	0.29	439	291	317	29	52	44
C15	2.18	0.27	1.2	1.39	0.36	479	437	290	30	70	66
C16	2.18	0.23	1.15	1.7	0.31	513	425	398	22	61	49
C17	2.05	0.3	1.49	2.56	0.31	614	608	324	79	111	54
C18	2.25	0.19	1.17	2.01	0.26	394	309	296	12	46	48
C19	2.21	0.18	1.13	1.81	0.26	454	212	289	9	34	42
C20	2.21	0.25	1.13	2.29	0.33	424	490	297	25	63	59
C21	2.44	0.19	0.84	2.06	0.26	427	249	253	18	46	56
C22	2.19	0.14	0.78	1.79	0.39	417	301	340	50	35	43
C23	2.4	0.15	0.88	1.61	0.42	525	233	438	8	28	35
C24	2.08	0.28	1.29	2.57	0.33	417	358	336	56	70	62

Table 12: Leaf analysis for Crimson Seedless 2005/2006 season

2006/03/27	%							mg/kg			
Nr	N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn	B
C1	1.61	0.17	1.09	2.15	0.29	436	211	492	14	38	24
C2	1.67	0.25	1.18	2.39	0.3	479	211	467	18	43	46
C3	1.88	0.18	0.79	3.07	0.45	475	139	490	10	32	32
C4	1.84	0.22	1.21	1.92	0.37	485	243	452	16	47	34
C5	1.93	0.18	1.16	2.01	0.34	305	118	361	8	23	33
C6	1.81	0.23	1.36	2.51	0.29	405	227	444	15	39	46
C7	1.83	0.19	0.99	2.02	0.39	529	140	405	10	26	47
C8	1.72	0.16	0.69	2.22	0.38	426	164	299	9	25	28
C9	1.78	0.18	1.09	2.35	0.35	347	167	309	13	33	33
C10	1.71	0.18	0.77	2.66	0.39	315	147	279	10	26	41
C11	1.75	0.21	0.92	2.05	0.31	446	201	315	13	36	27
C12	1.78	0.18	0.79	2.39	0.4	485	281	296	19	47	36
C13	1.52	0.29	1.45	2.49	0.32	714	487	556	25	71	36
C14	1.59	0.17	0.81	2.55	0.34	354	261	312	29	48	28
C15	1.72	0.18	1.06	2.1	0.35	444	256	346	22	41	33
C16	1.4	0.14	0.85	2.23	0.26	399	221	280	42	48	39
C17	1.72	0.19	1.18	2.61	0.25	424	349	254	14	48	43
C18	1.77	0.22	1.42	2.36	0.24	380	295	287	17	47	44
C19	1.58	0.19	1.26	2.44	0.25	449	346	362	33	61	37
C20	1.77	0.23	0.85	2.86	0.31	338	350	361	28	55	40
C21	1.94	0.25	1.17	2.61	0.24	350	242	378	12	39	61
C22	2.06	0.33	1.24	2.53	0.33	367	230	442	13	38	92
C23	2.03	0.23	1.17	2.42	0.4	419	253	395	19	43	43
C24	1.59	0.2	1.22	2.52	0.4	533	338	386	22	67	43

Table 13: Leaf analysis for Dauphine 2005/2006 season

2006/02/24	%							mg/kg			
Nr	N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn	B
D1	2.1	0.19	0.83	1.57	0.52	411	247	201	9	31	52
D2	2.28	0.19	1.2	1.68	0.42	372	199	171	9	27	48
D3	1.9	0.19	0.88	1.5	0.31	458	354	217	11	37	58
D4	1.92	0.14	1.31	1.46	0.34	346	210	213	11	25	53
D5	1.67	0.15	0.95	1.23	0.23	445	230	223	35	21	44
D6	2.05	0.19	0.98	1.53	0.37	522	349	289	21	31	46
D7	1.9	0.26	0.86	2.05	0.41	698	511	297	67	47	52
D8	2.09	0.23	1.12	1.52	0.33	624	353	354	20	43	49
D9	2.22	0.27	1.16	1.36	0.4	737	381	346	20	46	33
D10	2.16	0.23	1.02	1.34	0.38	730	278	434	14	36	39
D11	1.95	0.18	0.87	1.54	0.36	476	248	340	20	37	43
D12	1.86	0.19	0.84	1.74	0.31	459	242	364	77	35	41
D13	2.11	0.14	0.82	2.12	0.54	450	358	281	17	24	53
D14	2.17	0.16	0.76	2.28	0.47	447	366	253	8	30	39
D15	2.08	0.14	0.89	1.64	0.32	400	351	226	18	21	41
D16	1.9	0.15	0.81	2.01	0.31	333	339	265	7	29	49
D17	1.73	0.12	0.82	1.55	0.23	318	260	238	7	21	53
D18	2	0.14	1.09	1.7	0.28	401	363	289	14	29	51
D19	2.01	0.18	1	1.58	0.27	403	247	296	21	22	63
D20	1.79	0.14	0.95	1.63	0.34	520	434	312	29	39	46
D21	1.95	0.24	0.93	2.07	0.32	407	408	336	56	75	87
D22	2.13	0.15	0.9	1.55	0.4	429	307	373	9	27	41
D23	2.21	0.18	0.98	1.55	0.36	383	133	273	9	24	45
D24	2.26	0.15	0.97	1.59	0.41	531	227	428	9	27	34

Table 14: Leaf analysis for Dauphine 2005/2006

2006/03/27	%							mg/kg			
Nr	N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn	B
D1	1.42	0.14	0.47	2.35	0.65	445	230	257	11	27	51
D2	1.31	0.12	0.49	2.53	0.43	387	256	178	8	36	48
D3	1.31	0.1	0.49	2.91	0.38	420	297	255	9	18	73
D4	1.29	0.12	0.68	2.05	0.31	522	281	281	10	25	53
D5	1.47	0.14	0.55	2.26	0.36	461	237	195	23	24	66
D6	1.43	0.16	0.78	1.63	0.31	606	319	249	22	35	49
D7	1.55	0.13	0.5	2.05	0.39	519	243	229	11	24	51
D8	1.53	0.12	0.47	2.23	0.44	474	214	256	10	28	54
D9	1.55	0.15	0.64	1.64	0.37	544	188	287	11	26	42
D10	1.49	0.13	0.58	1.97	0.57	504	177	296	10	28	32
D11	1.52	0.11	0.5	2.05	0.45	449	149	368	9	34	40
D12	1.4	0.11	0.64	2.09	0.39	410	135	394	12	23	46
D13	1.47	0.1	0.4	2.46	0.47	442	405	209	42	27	63
D14	1.6	0.11	0.35	3.12	0.52	317	320	192	25	24	60
D15	1.48	0.1	0.45	2.25	0.35	329	386	154	16	23	50
D16	1.28	0.09	0.38	2.34	0.34	348	252	143	9	17	57
D17	1.38	0.1	0.54	2.1	0.32	335	310	185	6	16	66
D18	1.28	0.09	0.59	2.27	0.33	419	354	224	40	30	69
D19	1.54	0.1	0.56	2.37	0.48	382	208	290	8	21	43
D20	1.44	0.11	0.48	2.19	0.46	447	258	255	10	24	52
D21	1.41	0.1	0.55	2.19	0.48	422	155	225	10	19	40
D22	1.59	0.1	0.57	1.89	0.42	401	188	247	6	22	51
D23	1.48	0.1	0.63	2.1	0.51	447	172	275	9	21	55
D24	1.44	0.1	0.6	1.96	0.43	479	201	311	8	28	37

Table 15: Grape analysis at harvest for Crimson Seedless 2005/2006 season

	mg/100g fresh mass					%	g/fruit
Nr	N	P	K	Ca	Mg	Water %	Fruit mass
C1	102	20.84	210	14.5	8.7	78.98	6.9
C2	99	19.52	190	13.7	7.9	80	5.2
C3	107	22.35	223	13.7	8.9	78.1	6.1
C4	106	21.96	196	12.9	8.7	78.35	6.6
C5	88	18.81	194	12.8	8.3	78.34	6.1
C6	98	19.26	169	12.7	8.5	79	6.7
C7	109	21.64	191	17.7	10	80.32	6.4
C8	99	21.56	218	11.9	8.5	78.86	6.1
C9	102	21.02	198	13	8.7	77.94	6.3
C10	91	21.12	186	11.2	8	80.79	6.9
C11	116	21.02	187	15.7	9	77.69	4.6
C12	64	17.69	170	12.4	7.7	81.82	5.8
C13	105	25.48	224	16.8	9.1	79.26	6
C14	107	22.28	173	15.7	9.2	78.66	5.4
C15	85	19.56	162	15.9	8	78.65	5.8
C16	74	20.64	196	13.7	8.8	78.28	6.6
C17	86	21.67	200	14.6	8.4	78.64	6.1
C18	100	21.97	195	13.5	8	79.68	5.6
C19	104	21.85	177	12	7.4	79.78	6.3
C20	100	22.09	192	17.4	8.5	79.72	7.7
C21	114	22.56	187	13.4	8	79.73	7.1
C22	109	24.17	200	20.1	9.9	80.48	6.6
C23	114	22.8	199	14.9	9.5	80.07	7.1
C24	92	20.01	198	16.7	9.1	80.4	7.4

Table 16: Phenological stages of data collection for Crimson Seedless

Date	Phenological stage
28 November 2005	Before véraison
18 January 2006	80% véraison
6 February 2006	Véraison
23 February 2006	Harvest

Table 17: Phenological stages of data collection for Dauphine

Date	Phenological stage
27 November 2005	Before véraison
24 January 2005	80 % Véraison
6 February 2006	Véraison

Figure 1: ECH$_2$O data on volumetric water content in the Crimson Seedless block for season 2005/2006