The effect of irrigation and canopy management on selected vegetative growth and reproductive parameters of *Vitis vinifera* L. cv. Shiraz in the Breede River Valley

by

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Declaration

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Date: 20 December 2013

Summary

The objective of the study was to determine combined effects of irrigation and canopy management practices on grapevine water status, growth, yield and juice characteristics. The field study was carried out with Shiraz/110R grapevines in the Breede River Valley. Grapevines were drip irrigated at 30%, 60% and 90% plant available water (PAW) depletion, respectively. For each PAW level, grapevines had (i) suckered, vertical shoot positioned (VSP), (ii) non-suckered, VSP and (iii) sprawling canopies. Treatments were replicated three times in a randomised block design and applied during the 2011/12 and 2012/13 seasons.

Irrigation applied at low PAW depletion levels, *i.e.* high frequency irrigation, required substantially higher irrigation volumes compared to high depletion levels, *i.e.* low frequency irrigation. Low frequency irrigation increased grapevine water constraints compared to high frequency irrigation. Sprawling canopy grapevines experienced more water constraints than VSP grapevines. Grapevines irrigated at 90% PAW depletion experienced strong water constraints. Low frequency irrigation seemed to accelerate berry ripening compared to high frequencies, probably due to smaller berries and lower yields. Sprawling canopies consistently enhanced berry ripening due to more sunlight interception by the leaves. Berry ripening of VSP grapevines was slower, but inconsistent between seasons.

Level of PAW depletion and canopy management practice did not affect number of leaves per primary shoot. Low frequency irrigation reduced number of leaves per secondary shoot. Leaf number per shoot contributed more to total leaf area than leaf size. Level of PAW depletion did not affect number of shoots per grapevine. Suckering reduced number of shoots per grapevine. Low frequency irrigation reduced total leaf area per grapevine compared to high frequency irrigation. Effects of canopy management practice were more pronounced in the case of high frequency irrigation compared to low frequency irrigation. At pruning, primary cane length was not affected by level of PAW depletion or canopy management practice. Secondary cane mass and diameter were not affected by canopy management practice. Multiple linear regression showed that cane mass was a function of cane length and diameter.

Low frequency irrigation reduced berry mass compared to high frequency irrigation, irrespective of canopy management practice. However, at harvest there was no difference in berry mass between 30% and 60% PAW depletion. Low irrigation frequencies tended to accelerate TSS accumulation compared to high irrigation frequencies. Sprawling canopy grapevines enhanced berry ripening, particularly at lower irrigation frequencies, compared to VSP grapevines. Sugar content per berry tended to incline until it reached a plateau which was more prominent at high irrigation frequencies than low frequencies. The plateau was reached earlier for sprawling canopy grapevines compared to VSP grapevines. At harvest, TTA was higher where grapevines were harvested earlier. Due to enhanced ripening, low frequency irrigation resulted in higher TTA at harvest than high frequency irrigation. Lighter crop load in relationship to higher leaf area resulted in higher TTA at harvest. Level of PAW depletion and canopy management practice did not affect pH.

Bunch numbers per grapevine showed no clear trends that could be related to water constraints experienced by grapevines. With regards to canopy management, suckered VSP grapevines reduced bunches per grapevine compared to non-suckered VSP and sprawling canopy grapevines. Bunch mass followed trends similar to berries per bunch. Yield was substantially reduced by low irrigation frequencies compared to high frequencies. Suckered VSP grapevines tended to reduce yields compared to non-suckered grapevines. However, the effect diminished where grapevines were irrigated at 90% PAW depletion. Yield losses due to sunburn showed no clear trends that could be related to level of PAW depletion. Grape damage due to sour rot seemed to be more prominent at high frequency irrigation, particularly for non-suckered grapevines. Total yield loss percentage was primarily a function of sunburn rather than sour rot.

Opsomming

Die doelwit van hierdie studie was om die gekombineerde effek van besproeiing en lowerbestuurspraktyke op wingerd waterstatus, groei, opbrengs en druiwesap eienskappe te bepaal. Die veld studie is uitgevoer met Shiraz/110R wingerdstokke in die Breede Rivier Vallei. Wingerdstokke was d.m.v. drupbesproeiing teen 30%, 60% en 90% plant beskikbare water (PBW) ontrekking, onderskeidelik besproei. Vir elke PBW ontrekkingspeil, was wingerdstokke (i) gesuier en vertikale lootposisionering toegepas, (ii) ongesuier en vertikale lootposisionering toegepas en (iii) geen lowerbestuur toegepas nie (lowers wat oophang). Behandelings is drie keer in ‘n ewekansige blokontwerp herhaal en tydens die 2011/12 en 2012/13 seisoene toegepas.

Besproeiing wat teen ‘n lae PBW ontrekkingspeil toegedien is, d.w.s. hoë frekwensie besproeiing, vereis aansienlik hoër besproeiings volumes i.v.m. hoë besproeiing ontrekkingspeile, d.w.s. lae frekwensie besproeiing. Wingerdstokke wat oopgehang het meer watertekorte as vertikaal lootgeposisioneerde wingerdstokke ervaar. Wingerdstokke wat teen 90% PBW ontrekking besproei was, het sterk watertekorte ervaar. Dit het voorgekom of lae frekwensie besproeiing korrelrypwording versnel het i.v.m. hoë frekwensie besproeiing. Dit was heelwaarskynlik a.g.v. kleiner korrels en laer opbrengste. Wingerdstokke wat oophang het, het konsekwent korrelrypwording versnel a.g.v. meer sonligonderskepping deur die blare. Korrelrypwording van vertikaal lootgeposisioneerde wingerdstokke was stadiger, maar teenstrydig tussen die seisoene.

Plant beskikbare water ontrekkingspeil en lowerbestuurspraktyke het geen invoeld gehad op die aantal blare per primêre loot nie. Lae frekwensie besproeiing het die aantal blare per sekondêre loot verminder. Die hoeveelheid blare per loot het ‘n groter bygedra gemaak i.v.m. blaar grootte. Plant beskikbare water ontrekkingspeil het geen invloed gehad op die aantal lote per wingerdstok nie. Suier verminder die aantal lote per wingerdstok. Lae frekwensie besproeiing verminder die totale blaar oppervlak i.v.m. hoë frekwensie besproeiing. Die effek van lowerebestuurspraktyke is duideliker sigbaar by hoë frekwensie besproeiing i.v.m. lae frekwensie besproeiing. Primêre lootlengte was nie deur PBW ontrekkingspeil of lowerbestuurspraktyke beïnvloed nie. Sekondêre lootmassa en -deursnit is nie deur lowerbestuurspraktyk beïnvloed nie. Meervoudige lineêre regressie het getoon dat lootmassa ‘n funksie van lootlengte en -deursnit was.

Lae frekwensie besproeiing het korrelmassa verminder ongeag die lowerbestuurspraktyk i.v.m. hoë frekwensie besproeiing. Daar was egter geen verskil in korrelmassa by oes tussen 30% en 60% PBW ontrekking nie. Lae frekwensie besproeiing was geneig om suiker akkumulasie te versnel i.v.m. hoë frekwensie besproeiing. Wingerdstokke wat oopgehang het, het veral by lae frekwensie besproeiing korrelrypwording versnel i.v.m. vertikaal lootgeposisioneeide wingerdstokke. Suikerinhoud per korrel het geneig om toe te neem totdat dit ‘n plato bereik het. Hierdie plato was meer prominent by hoë frekwensie besproeiing i.v.m. lae frekwensie besproeiing. Wingerdstokke wat oopgehang het, het ook hierdie plato vroeër bereik i.v.m. vertikaal lootgeposisioneerde wingerdstokke. By oes was die totale titreerbare suur (TTS) hoër vir wingerdstokke wat vroeër geoes was. As gevolg van versnelde rypwording was TTS van wingerdstokke wat teen lae frekwensie besproei is hoër i.v.m. hoë frekwensie besproeiing. ‘n Ligter oeslading in verhouding tot ‘n hoër blaaroppervlak het ook gelei tot hoër TTS by oes. Plant beskikbare water ontrekkingspeil en lowerbestuurspraktyke het geen invloed op die pH gehad met oes nie.

Die hoeveelheid trosse per wingerdstok het nie duidelike tendense gewys wat verbind kon word met watertekorte wat deur die stokke ervaar is nie. Gesuierde vertikaal lootgeposisioneerde wingerdstokke het die hoeveelheid trosse per stok verminder i.v.m. die ongesuierde vertikaal lootgeposisioneerde wingerdstokke en wingerstokke wat oopgehang het. Trosmassa het dieselfde tendense as korrels per tros gevolg. Lae frekwensie besproeiing het opbrengs aansienlik verminder i.v.m. hoë frekwensie besproeiing. Gesuierde vertikaal lootgeposisioneerde wingerdstokke het geneig om opbrengste te verminder i.v.m. ongesuierde vertikaal lootgeposisioneerde wingerdstokke. Hierdie effek het egter verdwyn waar wingerdstokke teen 90% PBW ontrekking besproei was. Druif skade a.g.v. suurvrot was meer prominent by hoë frekwensie besproeiing, veral vir ongesuierde vertikaal lootgeposisioneerde wingerdstokke. Total opbrengs verlies, uitgedruk as ‘n persentasie, was hoofsaaklik ‘n funksie van sonbrand eerder as ‘n funksie van suurvrot.

This thesis is dedicated to my family

Hierdie tesis is opgedra aan my familie

Biographical sketch

Robert Stolk was born on 3 December 1988 in Pretoria. He started his school career at Akasia Primary School near Pretoria and matriculated at Swellendam High School in 2006. In 2007 he enrolled for a BScAgric-degree majoring in Viticulture and Oenology at the University of Stellenbosch and obtained his degree in 2010. In 2011 he enrolled for the MScAgric-degree in Viticulture at the same University.

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Preface

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

Chapter 1	**General Introduction and project aims**
Chapter 2	**Literature review**
	The effect of irrigation and canopy management practice on grapevine growth, yield and juice characteristics
Chapter 3	**Determination of spatial variability in a vineyard to be used for a field experiment**
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Chapter 1

General introduction and project aims

1. GENERAL INTRODUCTION AND PROJECT AIMS

1.1 INTRODUCTION

South Africa, being located in a semi-arid part of the world, is a relatively dry country with climates varying from desert and semi-desert in the north-western part to sub-humid in the south-eastern part (NWRS, 2004). This correlates with the rainfall pattern of South Africa, with the highest rainfall occurring in the east and south-eastern part of the country. In comparison with the mean annual rainfall of 860 mm occurring over the world, South Africa receives just more than half of that at a mean annual of 450 mm. The Western Cape, where 95% of the total of 100 568 hectares of wine grape vineyards of the South African wine industry are planted, has a mean annual rainfall of 348 mm which is unevenly distributed as a result of high mountain ranges (Floris & Uren, 2012). Furthermore, these areas have high evaporation rates and irrigations are usually necessary to compensate for the inadequate water supply stored in the soil from winter rain (Van Zyl & Weber, 1981; NWRS, 2004).

In 2011, approximately 55% of the vineyards were irrigated or established under drip irrigation in comparison with about 23% in 1996 (Van Wyk & Van Niekerk, 2012). Partial wetting of the soil volume, *i.e.* the soil surface and/or soil depth, by using drip irrigation contributes to water savings (Van Zyl & Van Huyssteen, 1988). In agriculture, water savings play an important role for development in the future, *i.e.* expansion of the area under irrigated vineyards with the same volume of water allocated to a farmer, as future allocations will become less (Van Zyl & Weber, 1981; Petrie *et al.,* 2004). Water savings could also be achieved by low irrigation frequencies, *i.e.* high levels of plant available water (PAW) depletion, compared to high irrigation frequencies (Lategan, 2011). This could be due to a reduction in vegetative growth which leads to a restriction in evaporation losses (Myburgh, 2011 and references therein), more particularly in transpiration losses (Schultz, 2003). Differences in vegetative growth could also lead to differences in the amount of labour inputs required for certain canopy management practices and the costs of applying these practices. There has already been some research to quantify labour inputs of applying different canopy management practices (Volschenk & Hunter, 2001a; Volschenk & Hunter, 2001b; Archer & Van Schalkwyk, 2007).

However, there has not been research on the combined effects of irrigation and canopy management practices. Therefore, the combined effect of irrigation and canopy management practice on vegetative growth, canopy management labour inputs and the costs thereof needs investigation.

1.2 PROJECT AIMS

This study formed part of a larger research project, initiated and funded by the Water Research Commission of South Africa, Project number K5/2080//4 (Water Research Commission, 2012), and co-funded by Winetech, the Agricultural Research Council and the Technology and Human Resources Programme (THRIP) development programme of Department of Trade and Industry and the National Research Foundation. The aim of the project is to evaluate the possibility of reducing vigorous growth of vineyards, thereby minimizing the canopy management inputs and costs, by means of deficit irrigation.

The aims of this particular study were:

(i) To apply three different level of PAW depletion in combination with three different canopy management practices to drip irrigated Shiraz grapevines in the Breede River Valley region;

(ii) To determine the effect of different levels of PAW depletion, different canopy management practices and combinations thereof on vegetative growth of irrigated grapevines;

(iii) To determine the effect of different levels of PAW depletion, different canopy management practices and combinations thereof on plant water status of irrigated grapevines;

(iv) To determine the effect of different levels of PAW depletion, different canopy management practices and combinations thereof on yield response of irrigated grapevines.

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Chapter 2

Literature review

The effect of irrigation and canopy management practice on grapevine growth, yield and juice characteristics

2. THE EFFECT OF IRRIGATION AND CANOPY MANAGEMENT PRACTICE ON GRAPEVINE GROWTH, YIELD AND JUICE CHARACTERISTICS

2.1 INTRODUCTION

The majority of the grape production regions around the world are found between the 30 and 50° N and 30 and 40° S latitudes (Williams *et al.*, 1994). These regions are known for their Mediterranean type climates with mild to cold, wet winters and warm to hot, dry summers to which the grapevine (*Vitis vinifera*) is adapted to (Williams *et al.*, 1994). Under these climatic conditions, *i.e.* low summer rainfall and high evaporation demands (Williams *et al.*, 1994; Patakas *et al.,* 2005), soil water from winter rain is often inadequate to provide for the grapevine's water requirements throughout the summer (Van Zyl & Weber, 1981; Schultz, 1997). It is inevitable that grapevines are prone to experience water constraints (Van Zyl & Weber, 1981; Williams *et al.*, 1994), and irrigations are usually necessary to compensate for the reduction of vegetative growth and production caused by water constraints (Patakas *et al.,* 2005). With water being a scarce resource, future irrigation water allocations could be restricted even more than the current restrictions (Zyl & Weber, 1981; Petrie *et al.*, 2004). Therefore, finding a balance between yield (economically viable for the producer) and wine quality (to compete in international world markets) is of great importance (Mehmel, 2010).

Canopy management practices, such as suckering, shoot positioning, leaf removal, lateral removal and topping may affect yield and wine quality (Hunter *et al.*, 1991; Hunter, 2000; Volschenk & Hunter, 2001b). Other canopy management practices such as winter and summer pruning, as well as improving a trellis system may also affect yield and wine quality (Freeman *et al.,* 1980; Smart *et al.*, 1990; Archer & Van Schalkwyk, 2007). The effect of canopy management practice on yield also plays an important role in economically viable practices.

Knowledge regarding the effect of irrigation on yield and wine quality, as well as the effect of canopy management practice on yield and wine quality, is readily available. However, knowledge of how irrigation and canopy management practice will interact with one another and affect yield and wine quality is limited.

The objective of this literature review is to discuss the effect of irrigation and canopy management practice on grapevine water status, vegetative growth, yield and its components, as well as juice characteristics.

2.2 GRAPEVINE WATER STATUS

Upon an imbalance between water uptake and water loss through transpiration, and the degree to which this imbalance occur gives arise to plant water status (Smart, 1974). When the loss through transpiration exceeds water uptake, regardless of the water availability, diurnal patterns of water constraints appear (Hardie & Considine, 1976; Williams *et al.,* 1994). This diurnal pattern generally has no lasting effect, however, water constraints due to decreasing soil water content over longer periods of time result in the plant being unable to recover at night (Van Zyl, 1987). Water loss through transpiration creates a negative pressure in the plant which pulls water from the roots to the leaves (Scholander *et al.*, 1965). This negative pressure can be measured by using a pressure chamber as described by Scholander *et al.* (1965). When using a leaf in the measurement, it is cut off, placed inside the chamber and sealed with the cut on the petiole to the outside. The negative pressure experienced by the leaf retracts and holds water to the inside. When applying pressure that exceeds the negative pressure inside the leaf, the water is forced to the surface of the cut. The pressure at which this occurs equals the water with holding capacity of the leaf, is that at which point the surface of the cut is just wetted by the liquid (Scholander *et al.*, 1965). This measurement is then referred to as leaf water potential (Ψ_L).

Grapevine water status can be influenced by environmental and plant factors (Smart & Coombe, 1983). Environmental factors influencing grapevine water status include solar radiation, cloud cover, relative humidity, temperature, wind and soil water status (Smart & Coombe, 1983). Solar radiation provides energy for transpiration and low amounts limit transpiration of grapevine leaves (Smart & Coombe, 1983). Interruption in solar radiation can reduce grapevine water constraints indirectly (Myburgh, 2011a). Cloud cover lowers grapevine water indirectly by reducing solar radiation (Smart & Coombe, 1983). Low relative humidity and high temperatures induce stomatal resistance which reduces transpiration (Smart & Coombe, 1983). An increase in wind velocity causes an increase in transpiration rates by increasing vapor pressure deficit (Smart & Coombe, 1983). A decrease in soil water content gives rise to a decrease in grapevine water status (Smart & Coombe, 1983). Plant factors influencing grapevine water status include node position of leaves, as well as total and exposed leaf area (Smart & Coombe, 1983). Leaves on node positions seven to fourteen have higher transpiration rates (Smart & Coombe, 1983). A higher total leaf area and/or exposed leaf area increases transpiration rates (Smart & Coombe, 1983). All the above mentioned environmental and plant factors influence Ψ_L indirectly by influencing stomatal resistance and/or transpiration.

Grapevine water status can be determined using three different measurements, *i.e*. pre-dawn leaf water potential (Ψ_{PD}), midday Ψ_L and midday stem water potential (Ψ_S) (Williams & Araujo, 2002). Midday Ψ_L has been used as an indicator of plant water status since the development of the pressure chamber (Williams & Araujo, 2002 and references therein) with consistent readings between leaves uniformly exposed to solar radiation. However, due to a lack in correlation with soil water status, Ψ_{PD} and Ψ_S are often used to measure plant water status in the field (Williams & Araujo, 2002 and references therein; Van Leeuwen *et al.*, 2009). A better correlation between Ψ_{PD} and soil water status is based on the assumption that grapevine water status will be in equilibrium with soil water status before dawn since no transpiration, due to a lack of solar radiation, occurred during the night (Williams & Araujo, 2002 and references therein). However, this equilibrium will be between Ψ_{PD} and the wettest soil layer explored by the roots (Van Leeuwen *et al.*, 2009). A better correlation between Ψ_S and soil water status is based on the assumption of enabling a leaf to come in to equilibrium with the grapevine stem by excluding al environmental factors affecting grapevine water status (Williams & Araujo, 2002 and references therein), while the rest of the grapevines is still exposed to the prevailing atmospheric conditions (Van Leeuwen *et al.*, 2009). For a measure of grapevine water status to be considered a sensitive indicator of water constraints, it must be responsive to soil water status (Williams & Araujo, 2002 and references therein).

Although Ψ_{PD}, Ψ_L and Ψ_S of Malagouzia grapevines were responsive to soil water status, greater treatment differences were found for Ψ_S compared to Ψ_{PD} and Ψ_L (Patakas *et al.*, 2005). This suggested that Ψ_{PD}, Ψ_L and Ψ_S are considered to be sensitive indicators of grapevine water status. Williams and Araujo (2002) found that Ψ_{PD}, Ψ_L and Ψ_S of Chardonnay grapevines were all similarly significantly correlated with soil water content. Lategan (2011) concluded that Ψ_L of Shiraz grapevines was insensitive to soil water status, whereas Ψ_{PD} and Ψ_S were responsive to soil water status. Choné *et al.* (2001) concluded that Ψ_L of Cabernet Sauvignon grapevines was insensitive to soil water status under the conditions of their study, whereas Ψ_{PD} and midday Ψ_S were responsive to soil water status. In addition, midday Ψ_S detected subtle treatment differences which Ψ_{PD} could not. Therefore, under the conditions of their study, Ψ_S was most responsive to soil water status. Since Ψ_{PD} and midday Ψ_S were responsive to soil water status they were both considered to be sensitive indicators of grapevines water status. The difference between Ψ_{PD} and midday Ψ_S could be due to the Ψ_{PD} responding to the wettest soil layer while rehydrating during the night, but not able to supply enough water to keep up with evaporative demand during the day (Van Leeuwen *et al.*, 2009).

Myburgh (2011b) reported that Ψ_{PD} and Ψ_L of Pinotage and Sauvignon blanc grapevines were responsive to soil water status, therefore, sensitive indicators of grapevine water status. Similar results were reported for Grenache and Syrah grapevines (Schultz, 1997). Pre-dawn leaf water potential of Cabernet franc, Syrah and Shiraz responded to soil water content (Hardie and Considine, 1976; Pellegrino *et al.*, 2004; Pellegrino *et al.*, 2005). Girona et al. (2006) reported that midday Ψ_L of Pinot noir grapevines was responsive to soil water status. Olivo (2009) and Van Leeuwen (2009) found that Tempranillo and Merlot grapevines, respectively, were responsive to soil water status. Therefore, midday Ψ_S is considered to be a sensitive indicator of grapevine water status. All of the above mentioned authors concluded that plant water potential decreased as water constraints, *i.e.* less soil water availability, increased.

One day after irrigation, midday Ψ_L, Ψ_{PD} and midday Ψ_S showed no difference between Malagouzia grapevines irrigated daily to 100%, 50% and 80% of the crop water requirements or evapotranspiration (ET_c), respectively (Patakas *et al.*, 2005). However, thirteen days after irrigation, midday Ψ_L still showed no difference between treatments, whereas Ψ_{PD} of grapevines irrigated to 50% and 80% of daily ET_c was -0.25 MPa lower compared to daily irrigation to 100% of ET_c. Similar to $\Psi_{PD,}$ midday Ψ_S of grapevines irrigated to 50% and 80% of daily ET_c was -0.5 MPa en -0.6 MPa lower, respectively, compared to grapevines daily irrigation to 100% of ET_c.

Chardonnay/5C grapevines that received no irrigation had lower Ψ_{PD}, Ψ_L and Ψ_S compared to irrigation to 0.5 and 1.0 fraction of estimated full ET_c, five days after irrigation (Williams & Araujo, 2002). The same trend occurred between irrigation to 0.5 and 1.0 fraction of estimated full ET_c. However, no difference in Ψ_{PD}, Ψ_L and Ψ_S occurred between irrigation to 0.5 and 1.0 fraction of estimated full ET_c, one day after irrigation. The dryland treatment also had lower Ψ_{PD}, Ψ_L and Ψ_S compared to the treatments irrigated to 0.5 and 1.0 fraction of estimated full ET_c, one day after irrigation.

On 20 February 2007, Ψ_{PD} and Ψ_S showed statistical differences between Shiraz grapevines irrigated at 35% PAW depletion compared to grapevines irrigated at 90% PAW depletion, before irrigation back to field capacity (Lategan, 2011). However, on the same day, midday Ψ_L showed no statistical difference between grapevines irrigated at 35% PAW depletion compared to grapevines irrigated at 90% PAW depletion.

There are fewer reports on grapevine water status responses to canopy management practises than responses to soil water status and irrigation strategies. However, it was shown that there were no differences in Ψ_{PD} in Pinotage grapevines irrigated at 50% PAW depletion and trained onto a six-strand hedge and a two-tier hedge, respectively, in the Breede River valley (Myburgh, 2011b). Water status of Sauvignon blanc grapevines under the same conditions. When irrigation was applied at 75% PAW depletion, Ψ_{PD} in Pinotage and Sauvignon blanc also did not differ, irrespective of trellis system. Similar to Ψ_{PD}, trellis system did not affect Ψ_L (Myburgh, 2011b).

Under comparable soil and atmospheric conditions, grapevine water status can also differ between cultivars (Winkel & Rambal, 1993; Medrano *et al*., 2003; Schultz, 2003). Leaf water potential in isohydric plant species remain more or less constant during the day, and does not respond to changes in soil water status (Schultz, 2003 and references therein). In contrast, Ψ_L in anisohydric grapevines follow a distinct diurnal pattern, and decreases as the soil water decreases. In this regard it was shown that Shiraz showed anisohydric behaviour, *i.e.* Ψ_L decreased during the day and was lower in grapevines experiencing water constraints. In contrast, Grenache showed near-isohydric behaviour, *i.e.* Ψ_L did not fall significantly below the minimum Ψ_L in watered grapevines (Schultz, 2003). During the pre- and post-véraison periods, Ψ_L in Shiraz in a sandy soil irrigated at 75% PAW depletion tended to be higher than in Merlot and Sauvignon blanc in the same soil in the Olifants River valley (Myburgh, 2011e).

Since Ψ_S seems to be a better indicator of grapevine water constraints, threshold values for water constraint classes of Ψ_S are useful to determine grapevine water status as proposed by Lategan (2011) adapted from Ojeda et al. (2002) and Van Leeuwen et al. (2009). These classes are no stress (≥-1.3 MPa), weak stress (-1.3 MPa to -1.7 MPa), medium stress (-1.7 MPa to -1.9 MPa), strong stress (-1.9 MPa to -2.0 MPa) and severe stress (<-2.0 MPa).

2.3 VEGETATIVE GROWTH

Vegetative growth of grapevines could be measured by six parameters, *i.e.* root growth, trunk and cordon growth, shoot growth, leaf area and secondary shoot growth (Smart & Coombe, 1983; Smart, 1985). However, pruning mass of dormant winter canes are often used to quantify shoot growth of the previous growing season (Williams *et al.*, 1994). Grapevines with high vigour generally have longer primary shoots, larger leaf areas and longer secondary shoots (Smart, 1985), as well as higher cane mass compared to grapevines with low vigour. It is well documented that higher soil water availability increases vigour of grapevine vegetative growth, irrespective of cultivar (Smart & Coombe, 1983; Van Zyl, 1984; Smart, 1985; Stevens *et al.*, 1995; Pellegrino *et al.*, 2005; Van Leeuwen *et al.*, 2009; Mehmel, 2010; Lategan, 2011; Myburgh, 2011d; Fernandes de Oliveira, 2013). Furthermore, different canopy management practices reduce grapevine vigour by altering either one or all of the parameters used to define grapevine vegetative growth (Van Zyl & Van Huyssteen, 1980; Smart *et al.*, 1990; Archer & Strauss, 1991; Hunter, 2000; Volschenk & Hunter, 2001a; Wolf *et al.*, 2003; Archer & Van Schalkwyk, 2007).

Vegetative growth can also be related to the level of plant available water (PAW) depletion. The latter is usually defined as the difference in the soil water content between field capacity and permanent wilting point, unless specified otherwise. Van Zyl (1984) showed that shoot growth rates of Colombar grapevines was lower for grapevines irrigated at 75% PAW depletion, *i.e.* drier soil conditions, compared to grapevines irrigated at 30% PAW depletion, *i.e.* wetter soil conditions. Pruning mass increases of 137%, 110% and 42% for Chenin blanc, Shiraz and Cabernet Sauvignon grapevines, respectively, was due to irrigation compared to a non-irrigated control (Smart & Coombe, 1983). Higher water stress indices, *i.e.* the integration of daily soil water availability over specific periods, between shoot growth initiation and cessation resulted in lower pruning mass per grapevine (Stevens *et al.*, 1995). Final leaf area and internode length of first order secondary shoots was not affected by mild and medium water deficits compared to a control of well-watered Shiraz grapevines (Pellegrino *et al.*, 2005). However, severe water deficit reduced final leaf area and internode length compared to mild and medium water deficits, as well as a well-watered control. Cane mass of Cabernet Sauvignon increased at two different localities with an increase in soil water availability (Mehmel, 2010). A single drip line increased average cane mass of grapevines over two seasons by 1.3 ton per hectare (t/ha) compared to a non-irrigated grapevines in one locality. In the same locality, a double drip line increased average cane mass of grapevines over two seasons by 2.7 t/ha compared to non-irrigated grapevines and 1.4 t/ha compared to the single drip line. In the other locality, similar trends occurred. An average cane mass increase of 1.0 t/ha was obtained where irrigation was applied at 30% PAW depletion compared to irrigation at 90% PAW depletion (Lategan, 2011). Merlot grapevines showed an average increase of 0.4 t/ha over four seasons where grapevine were irrigated five times during the season in the grapevine row compared to non-irrigated grapevines (Myburgh, 2011d). Total leaf area per grapevine of Cannonua grapevines increased from 2.73 m^2/grapevine to 4.02 m^2/grapevine prior to harvest as total irrigation volume increased from 80 mm to 250 mm (Fernandes de Oliveira, 2013). However, no increase in total leaf area occurred as total irrigation volume increased from 80 mm to 144 mm.

Where the same quantity of irrigation water was applied to Chenin blanc grapevines on different trellis systems, *i.e.* bush vines, Perold, lengthened Perold and slanting trellis, differences in pruning mass occurred (Van Zyl & Van Huyssteen, 1980). The slanting trellis system had the highest pruning mass compared to the other trellis systems. However, the lengthened Perold trellis system tended to have higher pruning mass compared to bush vines and the Perold trellis system. The Ruakura Twin Two Tier (RT2T) trellis system reduced total cane mass of Cabernet franc grapevines by 0.6 kg/grapevine compared to a standard vertically shoot positioned (VSP) trellis system (Smart *et al.*, 1990). The RT2T reduced total cane mass by dividing the canopy and reducing canopy height. This was probably due to a reduction in mass per cane with an increase of 46 shoots per grapevine compared to the standard VPS trellis system. Narrow plant spacing of Pinot noir grapevines increased the cane mass per hectare compared to wider plant spacing by increasing the plant density (Archer & Strauss, 1991). All canopy management treatments, *i.e.* suckering and topping, leaf removal at different stages of berry development and in different halves of the canopy, as well as lateral shoot removal at different stages of berry development and in different halves of the canopy, reduced total remaining leaf area of Sauvignon blanc grapevines compared to a non-manipulated control (Hunter, 2000). However, lateral removal, irrespective of stage of development and position in the canopy, reduced total remaining leaf area the most. Cane mass (kg) per meter cordon was reduced by enlarging cordon length per grapevine of a vertical trellis, either by removing alternate vines or by changing it into a modified Lyre trellis system (Volschenk & Hunter, 2001a). Mechanical pruning reduced cane mass of Cabernet Sauvignon grapevines compared to spur pruned grapevines at Nietvoorbij near Stellenboch (Archer & Van Schalkwyk, 2007). The same trend occurred in Chardonnay, Chenin blanc, Sauvignon blanc, Pinotage, Merlot and Cabernet Sauvignon grapevines at Elsenburg near Stellenbosch. However, this trend only occurred in Chardonnay and Chenin blanc, to a lesser extent, near Robertson. In Colombar, Sauvignon blanc, Ruby Cabernet and Shiraz no difference was found in cane mass between spur pruned and mechanically pruned grapevines near Robertson.

Although literature regarding the interactive effects of irrigation and seasonal canopy management practices are very limited, the interactive effects of irrigation and pruning level has been investigated (Freeman *et al.*, 1979; McCarthy *et al.*, 1983). Pruning mass increased for irrigated compared to non-irrigated Shiraz grapevines (Freeman *et al.*, 1979). Furthermore, pruning mass decreased as pruning level, *i.e.* node per grapevine, increased for non-irrigated grapevines. However, pruning mass stayed consistent as pruning level increased in the case of irrigated grapevines. It should be noted that these trends were not evident after four years' time. Irrigation treatments consisting of no irrigation, replacement of 0.2 of weekly Class A Pan evaporation (E) and replacement of 0.4 of E, had significantly increased pruning mass of Shiraz grapevines (McCarthy *et al.*, 1983). Canopy management practice of topping six to eight nodes above the second bunch, followed by an application of 500 ppm ethephon, had significantly increased pruning mass. However, the interaction of these two practices had no significant effects (McCarthy *et al.*, 1983).

2.4 YIELD AND ITS COMPONENTS

Grape berry development can be divided into three stages during berry growth (Dokoozlian, 2000). Stage I of berry growth occurs immediately after bloom and is characterized by rapid berry growth through cell division and enlargement. Stage II of berry growth is characterized by a lag phase in which growth slows down (Dokoozlian, 2000). Berry ripening begins at commencement of Stage III of berry growth which is characterized by the resumption of rapid growth (Dokoozlian, 2000). During Stage I berries are firm and organic acids accumulate while the sugar content stays low. During Stage II berries still remain firm while organic acid levels reach their maximum. During Stage III berry softening begins, the berry loses chlorophyll, berry colour starts to change for red varieties, sugar accumulation begins while organic acids are metabolized and called véraison (Dokoozlian, 2000).

It is well documented that soil water availability influences berry size, *i.e*. a reduction in size as the soil dries out, irrespective of grapevine cultivar (Hardie & Considine, 1976; Van Zyl, 1984; Williams *et al.*, 1994; McCarthy, 1997; Schultz, 1997; Ojeda *et al.*, 2002; Petrie *et al.*, 2004; Van Leeuwen *et al.*, 2009; Lategan, 2011; Myburgh, 2011d; Frenandes de Oliveira *et al.,* 2013). Although grapevines that experience water deficit during the post-véraison period reduced berry mass compared to irrigated grapevines (Hardie & Considine, 1976; Petrie *et al.*, 2004; Lategan, 2011), the most sensitive period for water deficit is between post-flowering and véraison (Hardie & Considine, 1976; Williams *et al.*, 1994; McCarthy, 1997; Lategan, 2011). The latter period corresponds with Stage I and Stage II of berry growth and development (Dokoozlian, 2000). However, at Stage I berry size is determined and subsequently the effect of water deficit in this particular stage is irreversible (Ojeda *et al.*, 2002; Lategan, 2011). Furthermore, the double-sigmoid growth curve of berry development will not be affected by water constrains (Williams *et al.*, 1994).

Colombar grapevines irrigated at low frequencies enhanced sugar accumulation compared to high frequency irrigation (Van Zyl, 1984). In contrast, Myburgh (2011a) reported no difference in juice TSS of Shiraz grapevines irrigated at high and low irrigation frequencies in the Lower Olifants River region. Furthermore, it was reported that sugar accumulation in Merlot berries was not slower for non-irrigated grapevines compared to grapevines irrigated at low frequencies near Wellington (Myburgh 2011d). Previous research showed that the number of berries per bunch of non-irrigated Cabernet Sauvignon grapevines was lower compared to irrigated grapevines near Wellington (Mehmel, 2010). Furthermore, in one season, data showed an increase in bunch mass with an increase in irrigation. However, in another season, bunch mass only increased between non-irrigated and irrigated grapevines (Mehmel, 2010). In both seasons bunch mass did not differ between irrigated and non-irrigated grapevines near Philadelphia (Mehmel, 2010). Bunches per grapevine varied a lot between seasons and localities and there were no clear trends between differences in irrigation (Mehmel, 2010).

Yields of Cabernet Sauvignon grapevines increased where irrigation was applied compared to non-irrigated grapevines near Wellington (Mehmel, 2010). However, an increase in irrigation water applied did not increase yield. Yields of Shiraz grapevines increased where irrigation was applied at 30% PAW depletion compared to 90% PAW depletion (Lategan, 2011). In the case of two different trellis systems, *i.e.* a six-strand hedge and a tow-tier trellis system, yields increased where irrigation was applied at 50% RAW depletion before and after véraison compared to irrigation at 75% RAW depletion before and after véraison (Myburgh, 2011c). Since yield is a function of berry mass, berry numbers per bunch, bunch mass and bunch numbers, it is evident that a reduction in yield will primarily be a result of a reduction in berry size (Petrie *et al.*, 2004).

Canopy management practices is applied to alter the number of leaves and the amount of shoots and fruit in a certain amount of space to achieve a desired canopy microclimate (Smart *et al.*, 1990). These practices include pruning, suckering, shoot positioning, leaf removal and using improved training systems (Smart *et al.*, 1990). Practices such as different training systems did not seem to affect berry mass (Swanepoel *et al.*, 1990; Wolf *et al.*, 2003). However, canopy management practices such as mechanical pruning, minimal pruning and no pruning reduced berry mass compared to spur pruning (Archer & van Schalkwyk, 2007).

In Cabernet Sauvignon grapevines the number of bunches per grapevine were more or less the same, irrespective of soil water status (Mehmel, 2010). The number of bunches of spur pruned grapevines was higher for grapevines experiencing less water constrains compared to grapevines experiencing more water constraints (Petrie *et al.*, 2004). In a study on alternative pruning methods, bunch mass was higher for spur pruned grapevines compared to mechanical, minimal and no pruned grapevines (Archer & Van Schalkwyk, 2007). However, the latter trend was due to less shoots per vine on the spur pruned grapevines compared to the other pruning treatments, which reduced bunch mass.

Grapevines that were subjected to no canopy management enhanced sugar accumulation compared to shoot positioning, suckering and shoot positioning (Volschenk & Hunter, 2001). Therefore, harvest date of sprawling canopy grapevines could be brought forward. The yield of Shiraz grapevines increased as the number of nodes at pruning increased (Freeman, *et al.*, 1979). In the case of Chenin blanc grapevines, a Perold, a lengthened Perold and a slanting trellis system increased the yield compared to bush vines (Van Zyl & Van Huyssteen, 1980). Closer in-row spacing of Pinot noir grapevines increased yield compared to wider in-row spacing (Archer & Strauss, 1991). This was probably due to more grapevines per hectare contributing to yield. No canopy manipulation and lateral removal, during any stage of berry development, reduced yield of Sauvignon blanc grapevines compared to suckering and topping, as well as leaf removal during any stage of berry development (Hunter, 2000). However, suckering, topping and leaf removal at berry set and pea size lead to the highest yields.

In vigorous growing vineyards, the disease levels are often high (Savage & Sall, 1984), as wide and dense canopies present problems in disease control due to reduced air movement and increased relative humidity inside these canopies (Creasy & Creasy, 2009). The incidence of sour rot was higher for no canopy management Chenin blanc grapevines compared to other canopy management practices such as shoot positioning, suckering and shoot positioning, shoot positioning and defoliation, shoot positioning and topping and combinations thereof (Volschenk & Hunter, 2001). The severity of the incidence was also higher for the no canopy management treatment compared to the other treatments. Chenin blanc is known to generally have more compact bunches (Goussard, 2008). Therefore, the high severity of sour rot in the Chenin blanc bunches could have been attributed to the more compact bunches (Savage & Sall, 1984; Ferreira & Marais, 1987).

2.5 JUICE CHARACTERISTICS

Berry total soluble solids (TSS) concentration at harvest depends on the decision of determining harvest date. Date of harvest can either be determined by berry maturity level (Ashley, 2004; Lategan, 2011) or according to a predetermined harvest date (Volschenk & Hunter, 2001b; Ashley, 2004). However, using either way, sugar accumulation differences between treatments can be identified. Juice TTA at harvest seemed to be higher where grapevines were harvested earlier in the first season (Lategan, 2011). This earlier harvest date is indirectly linked to less irrigation volumes applied and drier soil conditions (Lategan, 2011). However, in the following two seasons, different levels of PAW depletion did not affect juice TTA in the latter study. Suckering and shoot positioning carried out on Chenin blanc grapevines had higher TTA levels at harvest compared to a control with no canopy management, but only tended to be higher compared only shoot positioned grapevines (Volschenk & Hunter, 2001). In the latter study, the different canopy management treatments did not affect juice pH at harvest. In one of three seasons, level of PAW depletion had no effect on juice pH (Lategan, 2011). Furthermore, juice pH was not affected where Shiraz grapevines were irrigated at low and high frequencies in the Lower Olifants River region (Myburgh, 2011a).

2.6 CONCLUSIONS

Three different measures of grapevine water status, *i.e.* pre-dawn leaf water potential (Ψ_{PD}), midday leaf water potential (Ψ_L) and midday stem water potential (Ψ_S) have been shown to be responsive to soil water status. According to Williams & Araujo (2002) and references therein, for a measure of grapevine water status to be reckoned as a sensitive indicator of water constraints, it must be responsive to soil water status. Therefore, Ψ_{PD}, Ψ_L and Ψ_S can be considered as sensitive indicators of grapevine water status. However, Ψ_L has been reported to be insensitive to soil water status. Grapevine water status measured one day after irrigation showed no difference between treatments compared to thirteen days after irrigation where lower soil water status had lower potentials. Irrigation diminished effects of water constraints on grapevine water status compared to non-irrigated grapevines. Before irrigation back to field capacity, Ψ_{PD} and Ψ_S showed statistical differences between irrigation at 30% PAW depletion and irrigation at 90% PAW depletion, whereas Ψ_L showed no statistical differences. This showed that Ψ_S was most sensitive to soil water status.

It is evident that vegetative growth is reduced by water constraints, irrespective of cultivar, locality or way of determination of vegetative growth. Furthermore, vegetative growth can be reduced by altering the grapevine canopy. Such a reduction could either be achieved by wider plant spacing, accompanying growth by a larger trellis system, increasing the number of shoots per grapevine or reducing grapevine leaf area. Interactions of irrigation and canopy management practice no significant effect or no greater increase compared to either or both independently. Furthermore, it must be noted that the majority of research carried out on canopy management were pruning levels, plant spacing or changes in trellising system. Little work has been done on seasonal canopy management and the interaction thereof with irrigation.

Berry mass is reduced by water constraints, particularly during the post-flowering (Stage I of berry development) period. However, the canopy management practice influences shoot and bunch density which reduces berry size. Bunch numbers does not seem to be affected by soil water status. By reducing shoot density through canopy management practices such as suckering, reduces bunch numbers. Bunch mass is reduced where soil water content is low and seems to be a function of berry mass. Higher shoot densities seems to decrease bunch mass. Since yield is a function of berry mass, berry numbers per bunch, bunch mass and bunch numbers, it is evident that a reduction in yield will primarily be a result of a reduction in berry size. The incidence of sour rot is higher for grapevine canopies receiving no canopy management compared to suckering and/or vertically shoot positioned grapevine canopies. Sour rot also seems to be a function of bunch compactness.

Harvest date is affected by sugar accumulation if yield is harvested at a certain maturity level. Juice TTA at harvest seemed to be higher were grapevines were harvested earlier. However, earlier harvest dates are affected by irrigation (enhanced in drier soils) or canopy management practice (lower bunch density). Juice pH does not seem to be affected by irrigation or canopy management.

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Chapter 3

Determination of spatial variability in a vineyard to be used for a field experiment

3. DETERMINATION OF SPATIAL VARIABILITY IN A VINEYARD TO BE USED FOR A FIELD EXPERIMENT

3.1 INTRODUCTION

In the Western Cape, spatial variability, particularly of soil conditions is generally high. Therefore, soil conditions can vary considerably over short distances. This variation can influence grapevine growth and yield within vineyards. However, grape growers usually accept this variability, and manage vineyards as if they are homogenous (Bramley & Hamilton, 2004). However, in the case of field trials, soil variation is likely to affect grapevine growth and yield responses, particularly to nutrition and irrigation treatments. Due to this, variability within vineyards should be as low as possible where field trials are carried out.

Since spatial variability is almost inevitable, covariants such as trunk circumference and cane mass at pruning can be measured before treatments are applied (Boshoff, 2010). These covariants can be used in statistical analysis to compensate for natural spatial variability within a field trial. Aerial imagery can also be used to determine variability within an experiment vineyard (Strever, 2003).

The objective of this study was to determine if the variability between experiment plots of a proposed field experiment was within acceptable limits.

3.2 MATERIALS AND METHODS

3.2.1 Experiment vineyard

The study was carried out during the 2010/11 season in an eleven-year-old commercial Shiraz/110R vineyard situated on the flood plain of the Poesjenels River, on the farm Wansbek located about 23 km southwest of Robertson in the Breede River Valley region. The vineyard is at a latitude of 33˚54’ S on a southeast facing slope of less than 1˚ at an altitude of 201 m above sea level. The region has a semi-arid climate, and based on the growing degree days (GDD) from September until March (Winkler, 1962), the specific locality is in a class V climatic region (Le Roux, 1974). Lategan (2011) previously described the soil as a Valsrivier form or a Cutanic Luvisol with an orthic A horizon and pedocutanic B horizon overlaying a horizon consisting of unconsolidated material without signs of wetness. During soil preparation, the soil was cross ripped to a depth of 0.8 m before establishing the vineyard (Van Huyssteen, 1983). Grapevines were planted 2.5 m × 1.2 m in a northwest/southeast row direction and trained onto a four-strand lengthened Perold trellis system (Booysen *et al*., 1992). The grapevines were not suckered and the shoots were tucked into the trellis wires. Irrigation was applied by means of 3.5 L/h UniRAM® drippers at a spacing of 1.0 m.

3.2.2 Experiment plot layout

The proposed experiment plots comprised of two rows of six grapevines each, with two buffer grapevines at each end and a buffer row on each side to minimise overlapping treatment effects. Each experiment plot covered 122 m^2.

3.2.3 Quantification of growth vigour

In each of the 30 proposed experiment plots (Fig. 3.1), one grapevine was selected at a fixed position, *i.e.* the second grapevine in the first experiment row, for detailed vegetative growth measurements. The latter entailed measuring the cane length, diameter and mass of primary and secondary shoots at pruning on 12 July 2011. On each plot, the total number of shoots were counted, and the total cane mass determined by weighing at pruning. All grapevines in the proposed experiment plots were pruned to two bud spurs. Spur spacing was managed at winter pruning by allocating to Five spurs were allocated to each of the two cordon arms, *i.e.* ten spurs per grapevine at *ca.* 12 cm spur spacing. The trunk circumferences were measured with a flexible measuring tape approximately 30 cm above the soil surface on each grapevine in all the proposed experiment plots.

3.2.4 Aerial images

Two aerial images of the Shiraz block used in the study were taken on 9 February 2011. One was a near-infrared (NIR) image, whereas the second was a colour photograph. The latter consisted of three standard colour channels *viz.* red, green and blue (RGB). The resolution of the images was approximately 0.5 m.

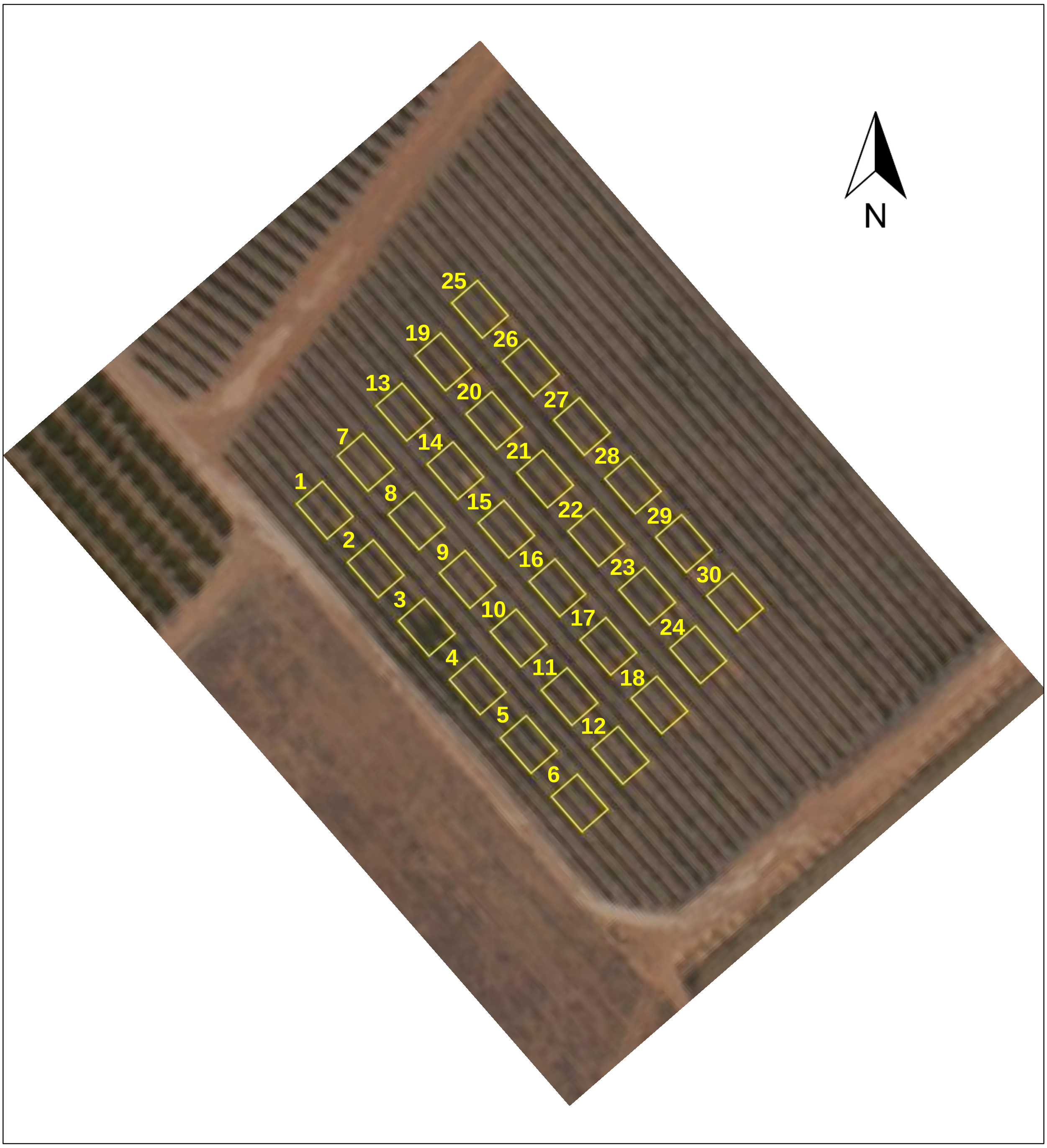

Figure 3.1 Layout of proposed experiment plots for the field trial near Roberson.

3.2.5 Image analysis

ImageJ (Ver. 1.46) image analysis software was used to convert the image and extract data. The software was used to split the colour photograph into its three colour channels (red, green, blue). Of these three colour images, only the red channel was used for further processing. A ratio vegetation index (RVI) image (Pearson & Miller, 1972) was defined as follows:

$$RVI = \frac{NIR}{R} \tag{3.1}$$

where R is the value for the red colour of the RGB photograph. This resulting image was used to determine differences in vigour between the proposed experiment plots before treatments were applied.

The resulting RVI image was then rotated until the grapevines rows were horizontal. Following this, the image was calibrated by using the known distance of the amount of grapevines in a row and assigning the length to the amount of pixels covered by a line stretching from the one end of that same row to the other end. With a set scale, a mask could be created to cover the area of a proposed experiment plot. This mask was then used to determine the mean RVI for a complete experiment plot as indicated in Figure 3.1. The mask included the canopies of the 12 experiment grapevines, as well as the soil background between the two rows and half the distance between rows on either side.

The relationships between measured vegetative growth per experiment plot, *i.e.* pruning mass and trunk circumference, and results obtained from the aerial images were obtained by means of simple linear regression. This was done to validate the processed image data by means of measured vegetative growth variables.

3.2.6 Statistical analysis

One way Analysis of Variance (ANOVA) was carried out to test for block differences (n=30). The data were also subjected to normality and Levene's tests. STATGRAPHICS® was used to calculate linear regression.

3.3 RESULTS AND DISCUSSION

3.3.1 Ratio vegetative index values

In February 2011, visual observation revealed that the grapevines showed no nutrient or water stress symptoms. Furthermore, there were no disease and/or pest infections. This indicated that the grower followed an effective disease and pest control programme. The RVI values obtained from the aerial images are presented in Table 3.1. The mean and the standard deviation of the RVI values were 1.541 and ±0.113, respectively.

Table 3.1 Ratio vegetation index (RVI) determined shortly before harvest in February 2011 of Shiraz/110R grapevines determined at pruning in July 2011.

Plot number	RVI (NIR/R)	Plot number	RVI (NIR/R)	Plot number	RVI (NIR/R)
1	1.518	11	1.605	21	1.556
2	1.588	12	1.478	22	1.532
3	2.050	13	1.537	23	1.554
4	1.647	14	1.517	24	1.461
5	1.598	15	1.513	25	1.459
6	1.482	16	1.542	26	1.516
7	1.431	17	1.596	27	1.515
8	1.509	18	1.411	28	1.519
9	1.438	19	1.567	29	1.551
10	1.560	20	1.556	30	1.405

3.3.2 Growth vigour

Number of canes and cane mass per grapevine, as well as dimensions of primary canes determined at pruning are presented in Table 3.2. Vegetative growth variables of secondary canes are presented in Table 3.3. Mean trunk circumference and cane mass per grapevine are presented in Table 3.4.

3.3.3 Normality of vegetative growth

The one way ANOVA showed that there were no significant differences in vegetative growth between proposed experiment plots (data not shown). Normality tests showed deviation from normality. Due to this, Plot 3 (Fig. 3.1) was identified as an outlier. The deviation from normality of Plot 3 was due to a leak in the irrigation system. The leak was repaired before the trail commenced. According to Levene's test of homogeneity, variances were homogenous (data not shown). Following removal of the outlier from the data set, the statistical analysis procedure was repeated with n=29. Having done this, normality tests showed no deviation from normality.

Table 3.2 Mass and number of primary canes per grapevine, as well as primary cane dimensions of Shiraz/110R grapevines determined at pruning in July 2011 near Robertson.

Plot no.	Cane mass per grapevine (kg)	Number of canes per grapevine	Primary canes		
			Mass (g)	Length (cm)	Diameter (mm)
1	1.1	29	31.7	88.9	5.56
2	0.9	34	24.2	78.8	5.22
3	2.1	41	39.5	108.9	5.46
4	1.2	40	23.7	78.6	5.09
5	1.2	35	17.6	60.2	4.94
6	1.0	35	20.2	72.0	4.79
7	0.8	27	21.1	73.4	5.03
8	0.8	28	29.5	90.3	5.34
9	1.0	32	21.7	75.7	5.04
10	1.1	25	28.6	96.1	5.07
11	0.9	34	24.2	78.8	5.22
12	0.8	33	21.7	75.2	5.48
13	0.9	37	24.6	77.8	5.60
14	0.9	33	39.5	108.9	5.46
15	0.9	34	23.8	82.4	5.24
16	1.2	35	27.2	86.1	5.39
17	1.1	38	25.1	83.6	5.32
18	0.9	30	21.7	75.8	5.25
19	0.9	45	23.5	73.8	5.39
20	0.9	28	25.9	73.7	5.42
21	0.7	34	24.2	78.8	5.22
22	1.0	31	22.9	72.9	5.23
23	1.1	38	25.1	80.9	5.22
24	1.0	32	26.9	80.4	5.25
25	0.7	48	14.1	53.1	4.87
26	1.0	42	15.0	63.8	4.85
27	0.9	37	20.8	72.2	5.26
28	0.9	33	17.1	65.9	5.00
29	1.0	31	21.2	79.6	4.80
30	0.8	32	24.4	76.8	5.52
Mean	1.0	34	24.2	78.8	5.22
Standard deviation	±0.2	±6	±6.0	±12.5	±0.24

Table 3.3 Number of secondary canes per grapevine, as well as secondary cane dimensions of Shiraz/110R grapevines determined at pruning in July 2011 near Robertson.

Plot no.	Number of secondary canes per grapevine	Mass (g)	Length (cm)	Diameter (mm)
1	31	5.6	37.5	3.49
2	20	3.9	28.2	3.61
3	53	7.8	43.7	4.22
4	40	4.2	26.1	3.87
5	20	3.2	22.5	3.71
6	16	1.9	18.9	3.15
7	16	1.6	16.0	3.18
8	13	5.1	36.1	3.69
9	14	2.6	21.1	3.31
10	22	8.0	50.7	3.87
11	20	3.9	28.2	3.61
12	12	2.3	23.2	3.17
13	20	2.1	17.6	3.42
14	15	7.8	43.7	4.22
15	17	4.9	29.0	3.74
16	32	2.4	23.5	3.34
17	20	4.3	54.4	3.62
18	20	5.0	27.4	4.26
19	27	3.3	23.9	3.73
20	24	3.8	27.3	3.78
21	20	3.9	28.2	3.61
22	11	4.0	26.8	3.59
23	21	3.6	26.1	3.74
24	26	3.8	27.9	3.65
25	8	1.7	14.5	3.12
26	14	3.0	24.1	3.66
27	7	0.8	9.2	3.09
28	15	3.2	21.7	3.67
29	10	7.5	47.4	3.59
30	14	2.6	21.2	3.66
Mean	20	3.9	28.2	3.61
Standard deviation	±10	±2.0	±11.4	±0.32

Table 3.4 Trunk circumference and total cane mass per grapevine of Shiraz/110R grapevines determined at pruning in July 2011.

Plot number	Trunk circumference (mm)	Cane mass per grapevine (kg)
1	176	1.1
2	173	0.9
3	188	2.1
4	177	1.2
5	177	1.2
6	166	1.0
7	166	0.8
8	178	0.8
9	175	1.0
10	176	1.1
11	173	0.9
12	167	0.8
13	172	0.9
14	162	0.9
15	175	0.9
16	183	1.2
17	173	1.1
18	175	0.9
19	168	0.9
20	171	0.9
21	174	0.7
22	162	1.0
23	156	1.1
24	170	1.0
25	151	0.7
26	161	1.0
27	164	0.9
28	156	0.9
29	177	1.0
30	176	0.8
Mean	171	1.0
Standard deviation	±8	±0.2

3.3.4 Relationship between measured growth and aerial imagery

The RVI increased with an increase in cane mass if the outlier is ignored (Fig. 3.2A). A similar relationship was reported for Cabernet Sauvignon grapevines (Dobrowski *et al.*, 2003). Although the relationship was significant, the correlation coefficient was relatively low (R^2=0.26). This was probably due to relatively little variation in cane mass at pruning (0.7 to 1.2 kg/grapevine). Therefore, the corresponding RVI values only ranged between 1.41 and 1.65. However, if the outlier is included the relationship between RVI and cane mass becomes more significant, as indicated in the following equation:

$$y = 0.3922x + 1.1576 \qquad (R^2 = 0.747;\ p < 0.0001;\ s.e. = 0.058) \qquad (3.2)$$

These results suggested that the RVI is more likely to respond to substantial differences in grapevine vegetative growth.

In contrast to cane mass, RVI could not be related to grapevine trunk circumference if the outlier was ignored (Fig. 3.2B). However, if the outlier was included the RVI still could not be related to trunk circumference as indicated in the following equation:

$$y = 0.0058x + 0.5447 \qquad (R^2 = 0.180;\ p = 0.0196;\ s.e. = 0.104) \qquad (3.3)$$

This indicated that the leak in the irrigation system did not have any effect on trunk circumference in the case of Plot 3. Therefore, it can be assumed that the effect of excessive water due to the leak was of a temporary nature. This also indicated that grapevine shoot growth would be more responsive to soil water status than trunk circumference under the given conditions.

3.4 CONCLUSIONS

Aerial imagery showed that abnormal growth occurred in one of the proposed experiment plots. The reason for this deviation was not due to natural variation. Therefore, the cause of the problem could be rectified before the field trial commenced. Furthermore, results indicated that RVI could be related to grapevine cane mass if the latter showed relatively large variability. Under the given conditions, the RVI could not be related to grapevine trunk circumference. This was due to a lack of variation in trunk circumference between plots. This study showed that the vegetative growth did not differ between plots to the extent that natural spatial variation would affect canopy management treatments of the proposed field trial.

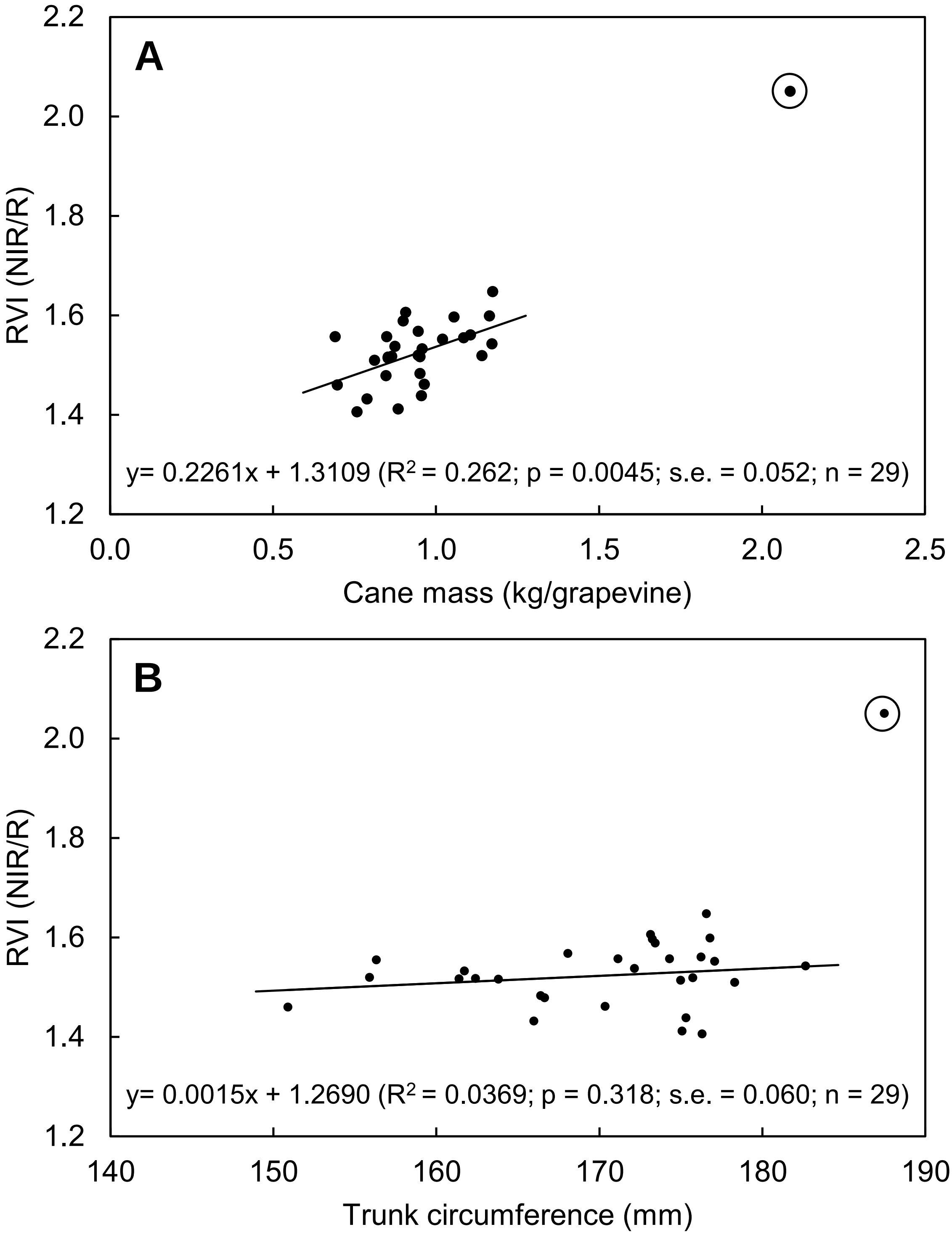

Figure 3.2 Relationship between ratio vegetative index (RVI) and (A) cane mass per grapevine and (B) trunk circumference of Shiraz/110R near Robertson.

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Chapter 4

Research results

The effect of irrigation and canopy management practice on selected vegetative growth parameters

4. THE EFFECT OF IRRIGATION AND CANOPY MANAGEMENT ON SELECTED VEGETATIVE GROWTH PARAMETERS

4.1 INTRODUCTION

Grapevines are usually cultivated in regions with a Mediterranean climate, *i.e.* mild to cold, wet winters and warm to hot, dry summers (Williams *et al.*, 1994). In these regions, stored winter rain is often inadequate to provide for the grapevines' water requirement throughout the summer (Van Zyl & Weber, 1981). Furthermore, these regions are known for high evaporative demand and without irrigation grapevines are prone to experience water constraints (Van Zyl & Weber, 1981; Williams *et al.*, 1994). However, with population increases occurring, it is inevitable that water availability for agriculture will decrease and that water will become a scarce resource (Sepaskhah & Ghahraman, 2004). With water being a scarce resource, the already limited supply of irrigation water could be restricted further in future allocations of irrigation water (Van Zyl & Weber, 1981; Petrie *et al.*, 2004). It is evident that irrigation water should be used more efficiently. Irrigation water use efficiency (WUE) can be defined as the amount of irrigation applied to produce a unit of fresh mass (grapes) (Myburgh, 2003). However, water use efficiency should be improved by either producing the same yields with less irrigation water, or by producing higher yields with the same volume of water. In the case of producing the same yields with less irrigation water, expansion of area under irrigated vineyards could be achieved without reducing the water use efficiency (Petrie *et al.*, 2004).

Water saving can be achieved by reducing evaporation losses. Evaporation losses from the soil surface could be reduced by low frequency irrigation compared to high frequency irrigation (Myburgh, 2011b and references therein). Furthermore, water saving can also be achieved by reducing excessive transpiration losses. A reduction in these transpiration losses can be achieved by a decrease in stomatal conductance caused by water constraints (Schultz, 2003). Furthermore, a reduction in leaf area, *i.e.* a reduction in the amount of stomata present, could also reduce excessive transpiration losses. Leaf area can either be reduced by reducing irrigation water (Mehmel, 2010), or by canopy management, *i.e.* removing secondary shoots and/or leaf removal (Hunter, 2000). Reducing leaf area induces favourable canopy microclimate conditions for berry ripening especially in the bunch zone (Myburgh, 2011c), which may have a prominent positive impact by increasing yield and/or quality (Iland, 1989).

The objective of this study was to determine the combined effects of irrigation and canopy management practices on irrigation volumes, phenological development, canopy composition and water status of grapevines.

4.2 MATERIALS AND METHODS

4.2.1 Experiment vineyard

Details of the experiment vineyard were discussed in Chapter 3. Refer to Chapter 3, section 3.2.1.

4.2.2 Experimental layout

Grapevines were drip irrigated at three levels of plant available water (PAW) depletion in combination with three canopy management practises (Table 4.1). The three PAW depletion levels were 30%, 60% and 90%, respectively. The three canopy management practises consisted of (i) suckering and vertical shoot positioning (VSP), (ii) only VSP and (iii) sprawling canopy. Irrigation at 30% PAW depletion, in combination with suckering and VSP served as the control treatment (T1). In winter, all grapevines were pruned to two bud spurs. Following this, grapevines were suckered at approximately 30 cm shoot length. Shoots were positioned at the end of flowering, as well as throughout the season. Shoot topping was carried out when they extended *ca.* 30 cm above the top trellis wire. In the case of the sprawling canopies, no shoots were positioned, and only the ones that attached to the trellis wires remained vertical. However, vertical shoots were also topped *ca.* 30 cm above the top trellis wire, whereas horizontal shoots were topped *ca.* 60 cm inside the work row. Treatments were applied from bud break in September until harvest in March during the 2011/12 and 2012/13 seasons (Table 4.1). All the treatments were replicated three times in a randomised block design. Experimental plots comprised of two rows of six grapevines each, with two buffer grapevines at each end and a buffer row on each side to minimise overlapping treatment effects (Fig. 4.1). Each experimental plot covered 122 m^2.

Table 4.1 The effect of plant available water (PAW) depletion and canopy management practice, *i.e.* suckering and/or vertical shoot positioning (VSP) applied to Shiraz/110R grapevines during the 2011/12 and 2012/13 growing seasons near Robertson.

Treatment	PAW depletion	Canopy management practice	
		Suckered	VSP
T1	30%	Yes	Yes
T2	30%	No	Yes
T3	30%	No	No
T4	60%	Yes	Yes
T5	60%	No	Yes
T6	60%	No	No
T7	90%	Yes	Yes
T8	90%	No	Yes
T9	90%	No	No

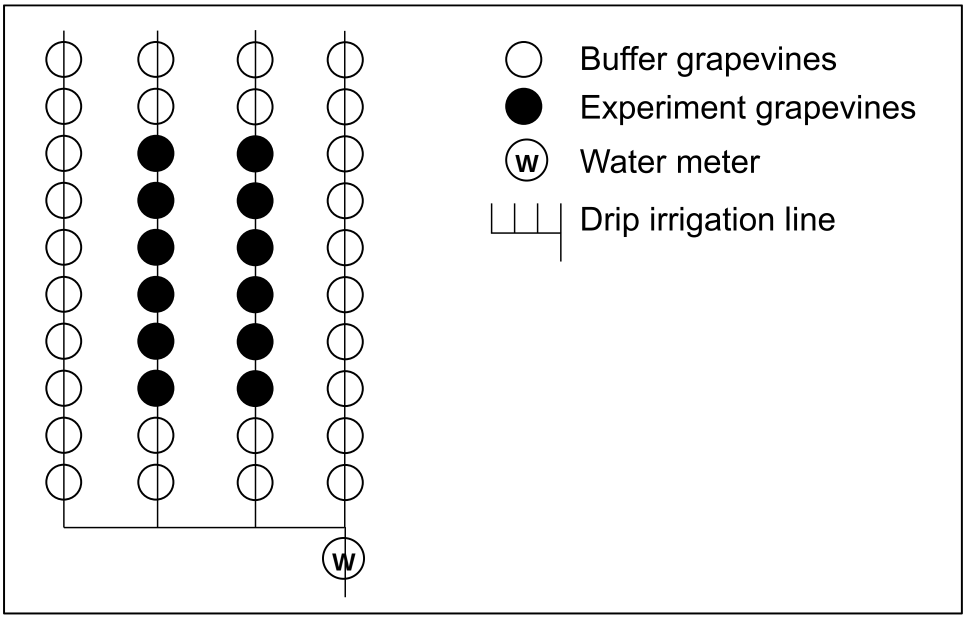

Figure 4.1 Schematic illustration of an experiment plot.

4.2.3 Atmospheric conditions

Air temperature (T), relative humidity (RH), net solar radiation (R_s) and wind speed (U_2) were recorded hourly by means of an automatic weather station (Campbell Scientific, Utah) approximately 110 m from the experiment vineyard. The daily reference evapotranspiration (ET_o) was calculated by means of a modified Penman-Monteith equation (Allen *et al*., 1998). Rainfall was recorded weekly at the experiment vineyard using a standard rain gauge. Data collected between 2005 and 2013 at this particular weather station were considered to be representative of the long-term means (LTM) for this locality.

4.2.4 Irrigation volumes and soil water content

Soil water content (SWC) was measured at 20, 30, 60 and 90 cm soil depths according to the neutron scattering technique using a neutron probe (HYDROPROBE 503DR, CPN®, California). The neutron scattering technique generally measures soil water in a sphere with a radius of *ca.* 25 cm (Hillel, 1998). A previous study, carried out in the same vineyard (Lategan, 2011), showed that the majority of the roots occurred to a depth of *ca.* 70 cm. Hence, this was considered to be the root zone depth. Therefore, SWC was measured up to 30 cm below the root zone to monitor if drainage losses occurred.

Neutron probe access tubes were installed in the grapevine row of all experimental plots. Neutron counts were calibrated against gravimetric SWC and converted to volumetric SWC in a field calibration carried out in the same vineyard by Lategan (2011). Soil water content was measured once a week during September and October. From November until harvest in February and March, SWC was measured at least twice a week, as well as before and after irrigation. After harvest, SWC was measured weekly until the first winter rainfall. Subsequently, SWC was measured monthly until the end of August. Total PAW, *i.e.* water retained between field capacity (matric potential of -0.01 MPa) and permanent wilting point (-1.5 MPa), was determined in a previous study (Lategan, 2011). Water meters were used to measure irrigation volumes of the different treatments, and converted to millimetres per hectare.

4.2.5 Vegetative growth

4.2.5.1 Monitoring of phenological development

Phenological stages, *i.e.* budburst (stage 4), flowering (stage 23), fruit set (stage 27) and véraison (stage 36) were visually identified according to the modified Eichhorn and Lorenz (E-L) system by Coombe (1995), and their dates recorded.

4.2.5.2 Spur spacing and numbers

The total number of spurs was counted for each experimental plot at pruning in winter to calculate the number of spurs per grapevine. Spur spacing was obtained by dividing the number of spurs per grapevine by the cordon length.

4.2.5.3 Leaf area

To determine leaf area, five shoots were randomly selected prior to harvest in the 2011/12 season. For unbiased sampling, an elastic band marked at five intervals, was stretched along the bunch zone of the experiment grapevines (Howell *et al*., 2013). Shoots opposite the markings on the elastic band were selected. To obtain more representative samples ten shoots were randomly selected in the 2012/13 season. For this purpose, the elastic band was marked at ten intervals. To obtain the primary and secondary leaves used for the determination of leaf area, the leaf petioles were cut as close as possible to the lamina. The leaf area per primary and secondary shoot was determined by using an electro-mechanical area meter (Model 3100, Li-Cor, Nebraska).

4.2.5.4 Cane measurements at pruning

Cane length and diameter of primary and secondary shoots were determined at pruning. For this purpose, shoots were randomly selected as discussed above. The number of nodes per primary shoot was counted to calculate internode length. Shoot length was measured with a flexible tape. Shoot diameter was measured at the bottom, in the middle and at the top of primary and secondary shoots using a Vernier calliper. Following this, the primary and secondary shoots were weighed separately.

4.2.6 Grapevine water status

4.2.6.1 Midday stem water potentials

Grapevine water status was quantified by determining the water potentials in mature leaves on primary shoots by means of the pressure chamber technique (Scholander *et al.*, 1965), according to the protocol described by Myburgh (2010). Midday stem water potential (Ψ_S) was measured in one leaf per plot in all the treatments at various stages during the growing season. Leaves were covered in aluminium bags (Choné *et al.*, 2001; Myburgh, 2010) for at least one hour before measurements were carried out.

4.2.6.2 Diurnal grapevine water potential

Diurnal leaf water potentials (Ψ_L) were measured in the 2012/13 season shortly before the grapes were harvested. The diurnal leaf water potential was measured in all three replications of all the treatments. On 25 February 2013, Ψ_L was measured every two hours from 04:00 until 02:00 the next morning. Measurements were completed within 30 minutes by using two pressure chambers. Both pressure chambers were custom built, and their pressure gauges calibrated against a precision gauge. Total diurnal leaf water potential (Ψ_T) was calculated using the trapezoidal rule (Larson *et al.*, 1994) as described by Myburgh and Howell (2006). This was done to determine if there were differences when insignificant, but consistent trends were accumulated over a period of time.

4.2.7 Statistical analysis

The data were subjected to an analysis of variance. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means that differed at $p \leq 0.05$ were considered to be significantly different. STATGRAPHICS® was used for the analyses of variance, and to calculate linear regression.

4.3 RESULTS AND DISCUSSION

4.3.1 Atmospheric conditions

In both seasons, R_s was lower than the LTM, except in December 2011 (Fig. 4.2). This was probably due to the frequently observed overcast conditions. Mean monthly maximum air temperature (T_x) varied between the 2011/12 and 2012/13 seasons (Fig. 4.3). In the 2011/12 season, T_x was comparable to the LTM, except in January and April (Fig. 4.3). At this stage, there is no clear explanation for the latter trends. In the 2012/13 season, T_x was lower in October compared to the 2011/12 season. This was probably due to above average rainfall and frequently overcast conditions which decreased the R_s (Figs. 4.2 & 4.4). In the 2012/13 season, T_x was higher in November and December than in 2011/12. The absence of rainfall in November 2012, and relatively low rainfall and wind in December 2012, probably resulted in higher T_x. In December 2012, visual observations revealed that more cloud cover occurred than in December 2011 which could have caused R_s in December 2012 to be lower than December 2011 (Fig. 4.2). In both seasons, minimum air temperature (T_n) was comparable to the LTM, except in December (Fig. 4.3).In both seasons, maximum relative humidity (RH_x) was comparable to the LTM (Fig. 4.5). In 2011/12, minimum relative humidity (RH_n) tended to be lower in the first part of the season compared to the LTM. This was probably due to lower than average rainfall (Fig. 4.4). In both seasons, daily U_2 was lower up to harvest compared to the LTM (Fig. 4.6). Reference evapotranspiration (ET_o) was comparable to the LTM, except in October and December 2012 (Fig. 4.7). In October 2012, the lower ET_o was due to relatively high rainfall which caused lower R_s and higher RH_n (Figs. 4.2 & 4.5). In contrast, lower ET_o in December 2012 was a result of lower R_s and lower U_2 (Figs. 4.2 & 4.6).

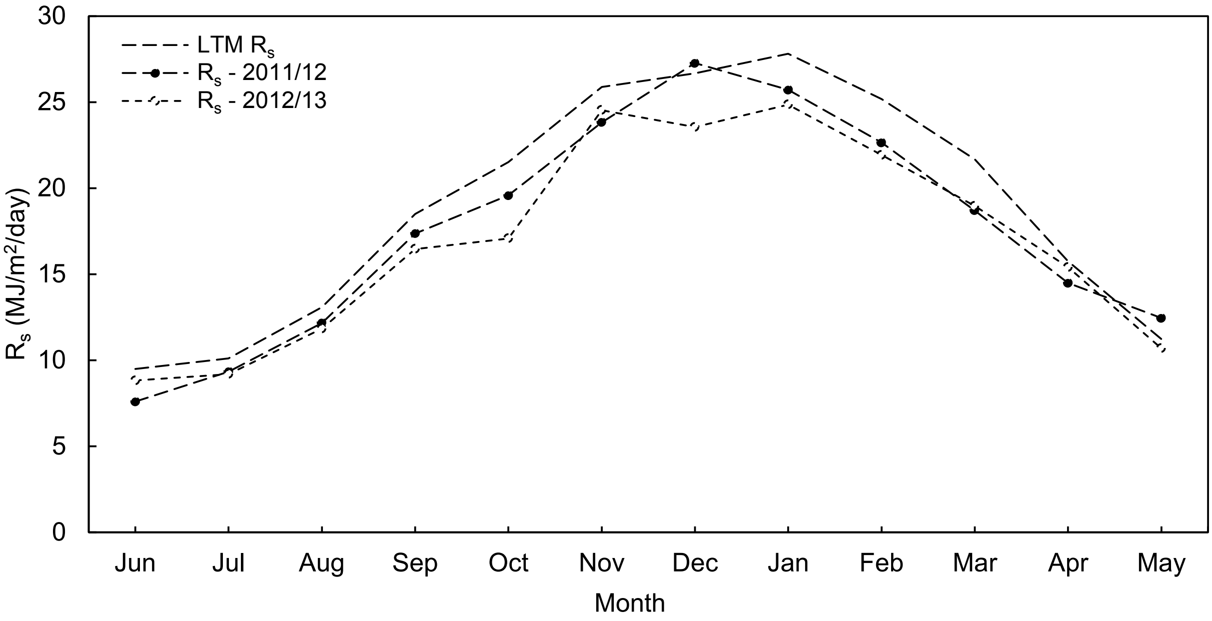

Figure 4.2 Daily net solar radiation (R_s) during the 2011/12 and 2012/13 seasons compared to the long term mean (LTM) near Robertson.

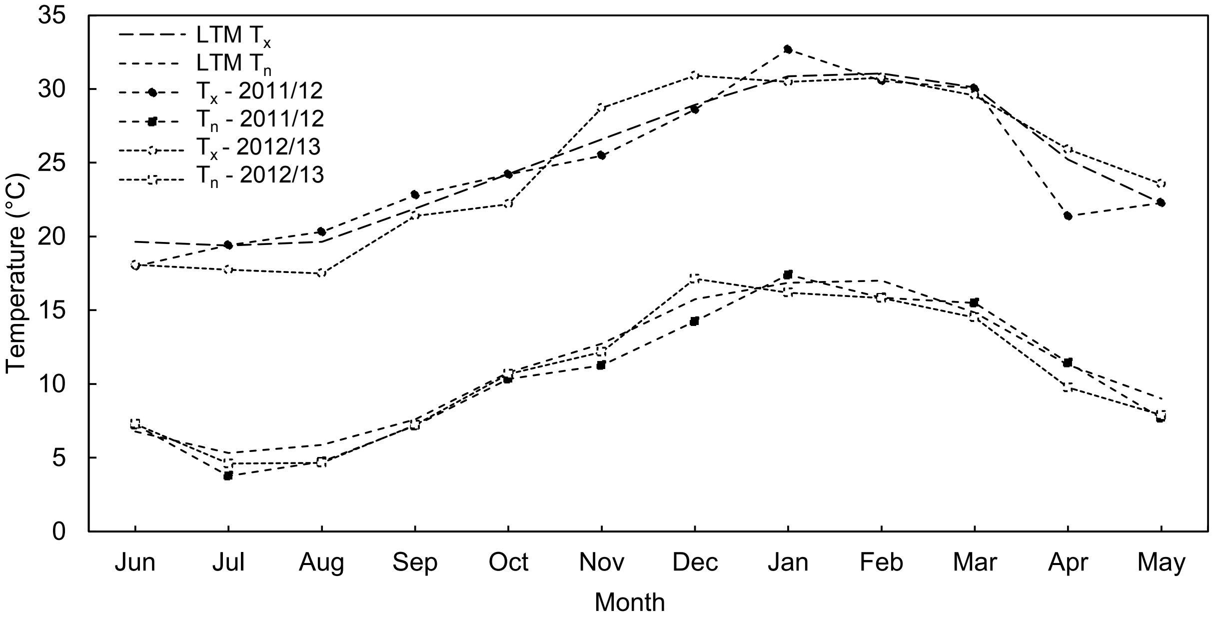

Figure 4.3 Monthly mean daily maximum (T_x) and minimum (T_n) temperatures during the 2011/12 and 2012/13 seasons compared to the long term mean (LTM) near Robertson.

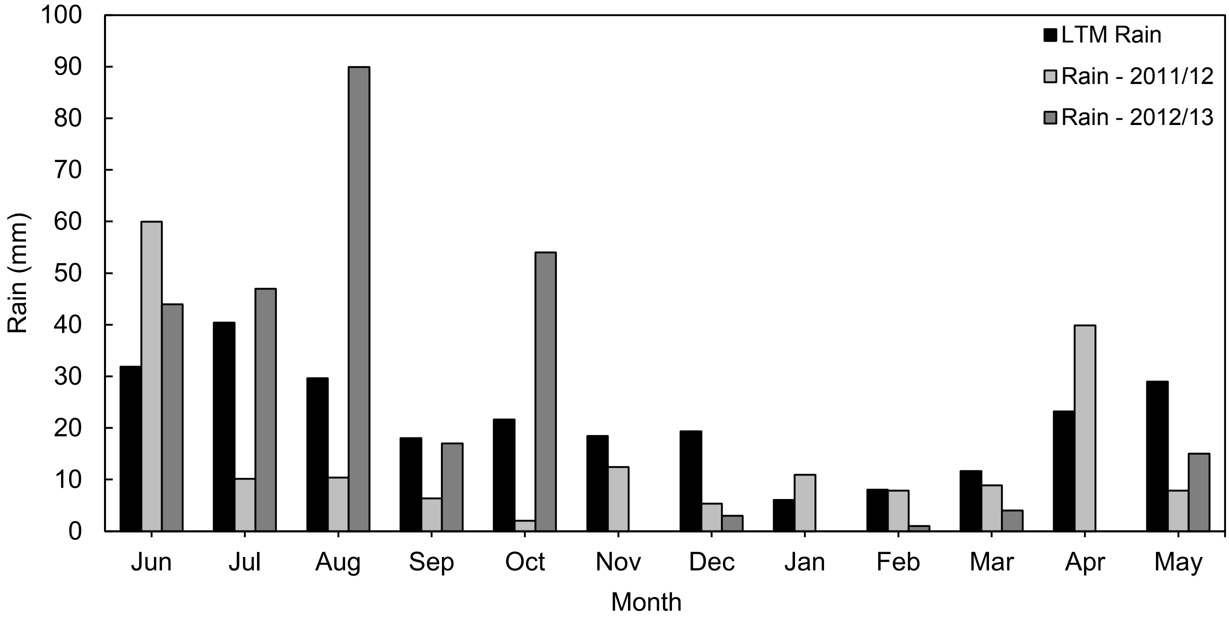

Figure 4.4 The amount of rain during the 2011/12 and 2012/13 seasons compared to the long term mean (LTM) near Robertson.

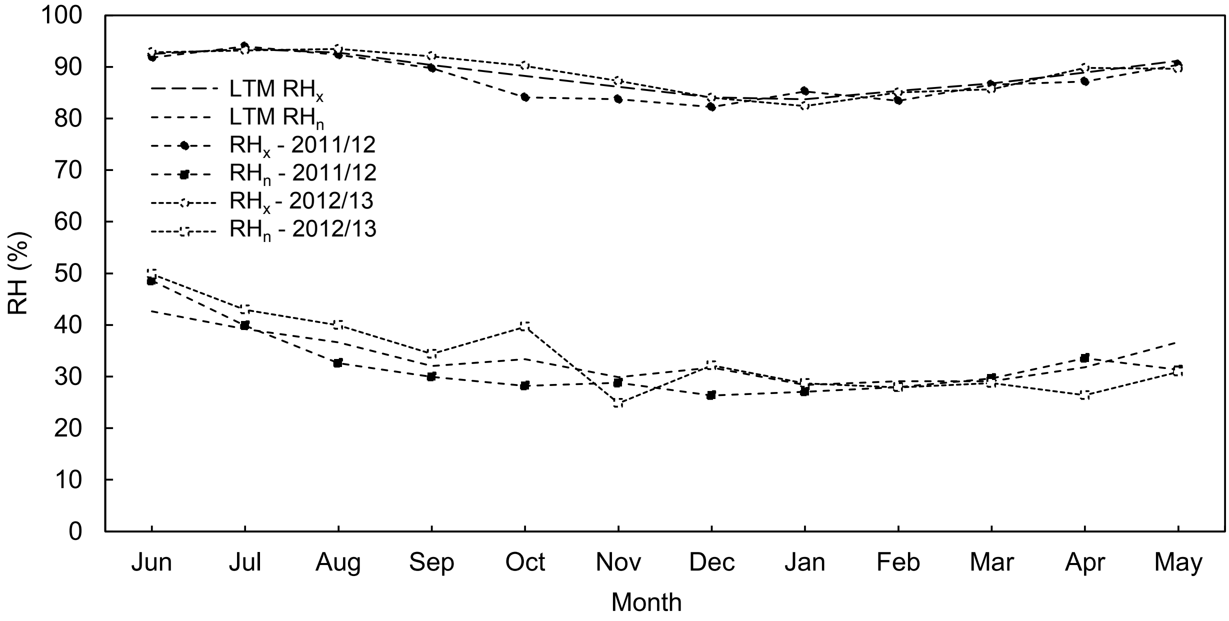

Figure 4.5 Maximum relative humidity (RH_x) and minimum relative humidity (RH_n) during the 2011/12 and 2012/13 seasons compared to the long term mean (LTM) near Robertson.

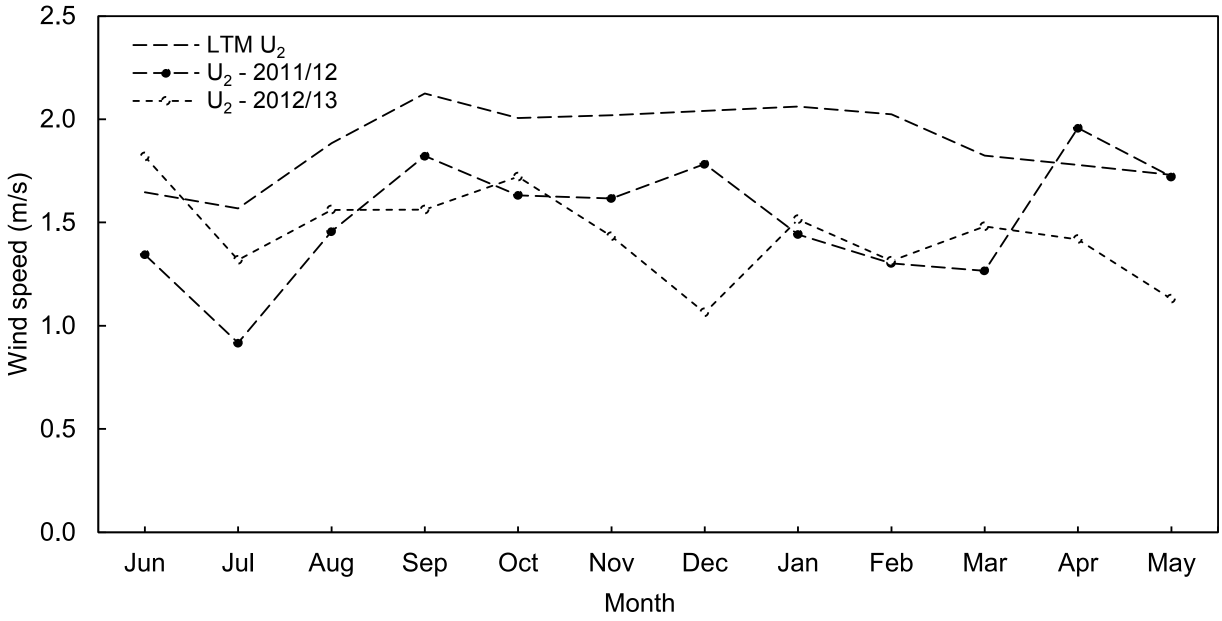

Figure 4.6 Wind speed (U_2) during the 2011/12 and 2012/13 seasons compared to the long term mean (LTM) near Robertson.

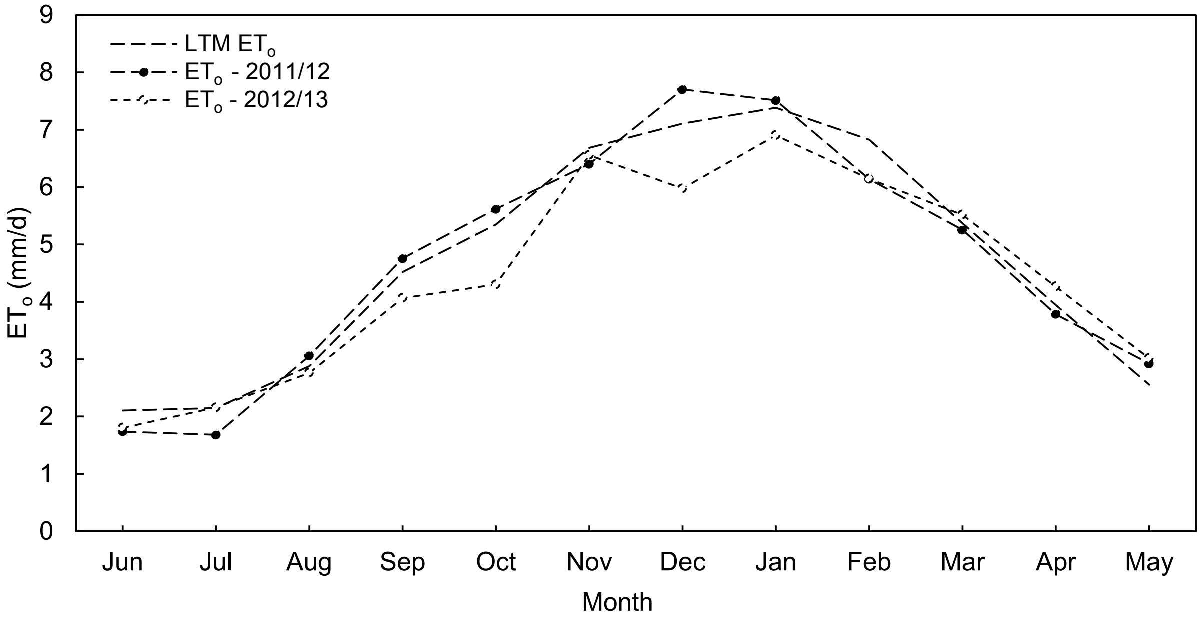

Figure 4.7 Reference evapotranspiration (ET_o) during the 2011/12 and 2012/13 seasons compared to the long term mean (LTM) near Robertson.

4.3.2 Irrigation volumes and soil water content

In the 2011/12 season, irrigation applied pre-harvest decreased as the level of PAW depletion increased (Table 4.2). In the case of 30% and 60% depletion levels, grapevines with sprawling canopies (T3 & T6) required less irrigation compared to suckered (T1 & T4) and non-suckered VSP (T2 & T5) grapevines. Since grapes of the sprawling canopies reached the target sugar content earlier (Table 4.5), irrigation was reduced earlier than for grapes of the suckered and non-suckered VSP canopies. Consequently, T3 and T6 grapevines received slightly more post-harvest irrigation (Table 4.2) before irrigation of all treatments was terminated on 26 April 2012. In the case of the 90% PAW depletion level, canopy management practice did not affect the volume of irrigation applied in the pre- and post-harvest periods.

Table 4.2 The effect of plant available water (PAW) depletion and different canopy management practices on irrigation volumes of Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

PAW depletion and canopy Management practice	Irrigation applied (mm)		
	Pre-harvest	Post-harvest	Total
T1 - 30% - Suckered VSP	535.9	34.2	570.1
T2 - 30% - Non-suckered VSP	535.9	34.2	570.1
T3 - 30% - Sprawling canopy	501.3	68.8	570.1
T4 - 60% - Suckered VSP	425.6	29.7	455.3
T5 - 60% - Non-suckered VSP	425.6	29.7	455.3
T6 - 60% - Sprawling canopy	402.7	52.6	455.3
T7 - 90% - Suckered VSP	151.4	52.3	203.8
T8 - 90% - Non-suckered VSP	151.4	52.3	203.8
T9 - 90% - Sprawling canopy	151.4	52.3	203.8

The mean SWC in the root zone, *i.e.* the 0 to 75 cm soil layer, for each of the PAW depletion levels is presented in Fig. 4.8. The SWC at which irrigations were applied were generally close to the three different target PAW depletion levels. Furthermore, the mean SWC in the 75 to 105 cm soil layer indicated that almost no over irrigation occurred in the 2011/12 season.

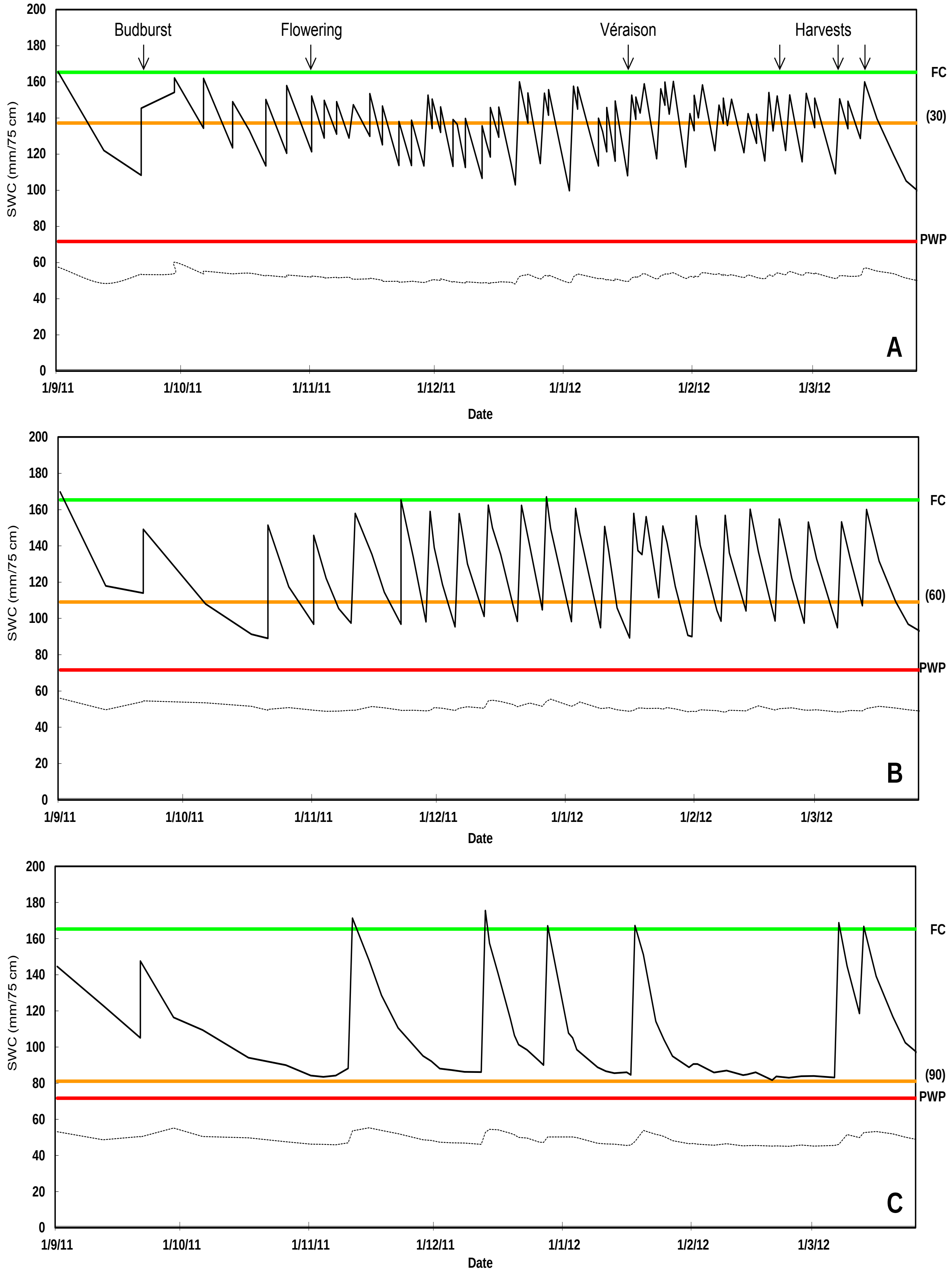

Figure 4.8 Variation in mean soil water content (SWC) in the root zone (0 to 75 cm) where irrigation was applied at (A) 30%, (B) 60% and (C) 90% plant available water depletion (PAW) where three different canopy management practices were applied to Shiraz/110R in a field trial near Robertson during the 2011/12 season. FC and PWP are field capacity and permanent wilting point, respectively, whereas values in brackets designate PAW depletion levels. Dashed line indicates mean SWC in the 75 to 105 cm soil layer.

Similar to the 2011/12 season, irrigation applied pre-harvest decreased as the level of PAW depletion increased in the 2012/13 season (Table 4.3). In the case of the 30% depletion level, grapes on the T1 grapevines ripened earlier compared to the T2 and T3 grapevines (Table 4.5). This was probably due to the fact that the T1 grapevines bore less bunches than T2 and T3. The latter aspect will be discussed in section 5.2.3.1. Consequently, T1 grapevines received more post-harvest irrigation than T2 and T3 (Table 4.3) before irrigation of all treatments was terminated on 12 March 2013. In the case of 60% PAW depletion, different rates of berry ripening also resulted in variation of harvest dates and different pre-harvest irrigation volumes (Tables 4.3 & 4.5). Although T6 grapevines were harvested earlier, they received one irrigation less than T4 and two less than T5. In the case of the 90% PAW depletion level, canopy management practice did not affect the volume of irrigation applied in the pre- and post-harvest periods.

Table 4.3 The effect of plant available water (PAW) depletion and different canopy management practices on irrigation volumes of Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

PAW depletion and canopy Management practice	Irrigation applied (mm)		
	Pre-harvest	Post-harvest	Total
T1 - 30% - Suckered VSP	557.3	72.0	629.3
T2 - 30% - Non-suckered VSP	594.3	37.0	631.3
T3 - 30% - Sprawling canopy	594.3	37.0	631.3
T4 - 60% - Suckered VSP	356.6	58.0	414.6
T5 - 60% - Non-suckered VSP	376.6	58.0	434.6
T6 - 60% - Sprawling canopy	337.6	58.0	395.6
T7 - 90% - Suckered VSP	156.3	69.1	225.4
T8 - 90% - Non-suckered VSP	156.3	69.1	225.4
T9 - 90% - Sprawling canopy	156.3	69.1	225.4

The mean SWC in the root zone, *i.e.* the 0 to 75 cm soil layer, for each of the PAW depletion levels is presented in Fig. 4.9. In contrast to the 2011/12 season, at times the SWC at which irrigations were applied were less than the target PAW depletion levels, particularly in the case of 30% and 60% PAW depletion. This was due to logistical problems, *e.g.* when striking farm workers prevented access to the field trial on various occasions. A further problem was that SWC was measured less frequently, *i.e.* not before and after all irrigations as was the case in the 2011/12 season.

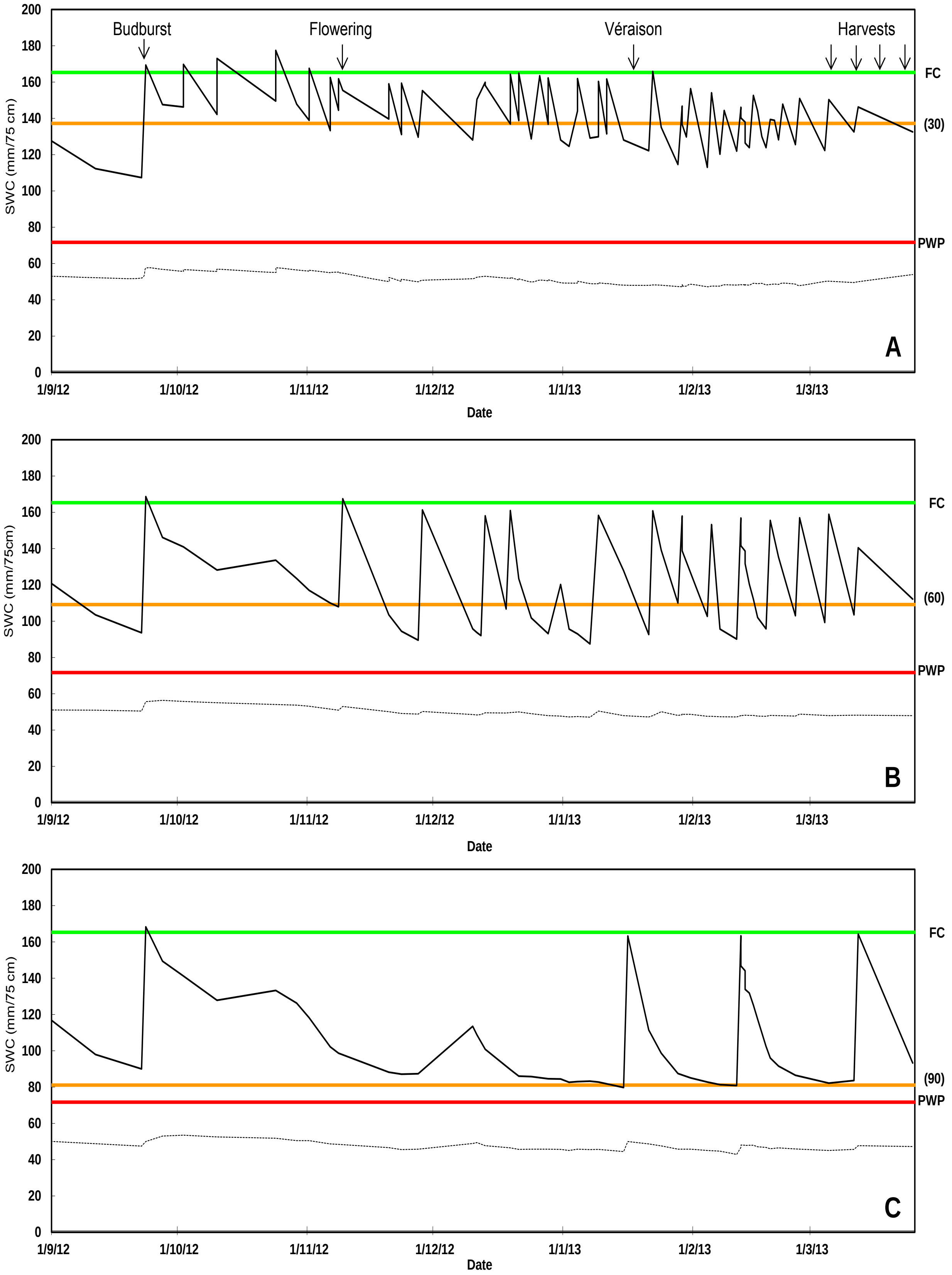

Figure 4.9 Variation in mean soil water content (SWC) in the root zone (0 to 75 cm) where irrigation was applied at (A) 30%, (B) 60% and (C) 90% plant available water depletion (PAW) where three different canopy management practices were applied to Shiraz/110R in a field trial near Robertson during the 2012/13 season. FC and PWP are field capacity and permanent wilting point, respectively, whereas values in brackets designate PAW depletion levels. Dashed line indicates mean SWC in the 75 to 105 cm soil layer.

However, the mean SWC in the 75 to 105 cm soil layer indicated that almost no over irrigation occurred in the 2012/13 season.

4.3.3 Phenological development

Visual observations revealed that the different PAW depletion/canopy management practice combinations did not affect phenological development compared to the control during both seasons (Table 4.4). This suggested that the differences in atmospheric conditions, as discussed above, had no pronounced effects on grapevine phenology. However, in the 2012/13 growing season, cooler air temperature, rainfall and lower R_s in October probably delayed flowering and fruit set by five and four days, respectively, compared to 2011/12 (Fig 4.2, 4.3 & 4.4). The latter response could be attributed to the way plants deal with solar radiation and soil water resources, as well as practices that cloud affect the environment, which play a role in phenological development (Mariani *et al.*, 2013). Determination of air temperature, which drives the Italian PHEnology Network (IPHEN) model, relies on the assumption that many factors interact on different scales (Mariani *et al.*, 2013). Some these factors include: net radiation flux, cold and warm air advections, and energy released by precipitations due to the change of the state of water. In a study with cotton, it was shown that date of flowering was controlled by air temperature and photoperiod (Wery, 2005 and references therein). However, it was also shown that the effect of water deficits could only be linked to an increase in canopy temperature through stomatal closure. Therefore, it seems that an indirect effect generally reduces the duration of flowering. Likewise, external effects might have influenced grapevine flowering and fruit set under the given conditions. Since flowering is considered to be at full bloom according to the modified E-L system (Coombe, 1995), the period prior to flowering, *i.e.* from stages 15 to 23, could have been influenced by the prevailing atmospheric conditions. In the 2012/13 season, lower R_s and T_x, as well as higher rainfall in October compared to the LTM and the 2011/12 season, could have prolonged the flowering period instead of reducing its duration (Figs. 4.2, 4.3 & 4.4).

Table 4.4 Dates of phenological stages of Shiraz/110R grapevines recorded in the 2011/12 and 2012/13 growing seasons near Robertson.

Season	Budburst (Stage 4)*	Flowering (Stage 23)*	Fruit set (Stage 27)*	Véraison (Stage 36)*
2011/12	21 Sep.	1 Nov.	10 Nov.	16 Jan.
2012/13	20 Sep.	6 Nov.	14 Nov.	17 Jan.

*According to the modified Eichhorn and Lorenz (E-L) system (Coombe, 1995).

2011/12 season: Irrigation at 90% PAW depletion enhanced berry ripening to such an extent that the target sugar content of 24°B was reached earlier than for grapevines irrigated at 30% and 60% depletion (Table 4.5). Maturity could either be delayed by severe water constraints or excessive irrigation throughout the season (Petrie *et al.*, 2004 and references therein). However, Colombar grapevines irrigated at 75% PAW depletion with micro-sprinklers ripened 15 days earlier compared to grapevines that were irrigated at 10% PAW depletion (Van Zyl, 1984). The latter delay was probably related to berry size and the dilution effect of the sugar concentration with an increase in berry volume (Van Leeuwen *et al.*, 2009). Treatment effects on berry mass and volume will be discussed in section 5.2.1.1. In the case of 30% and 60% PAW depletion, grapevines with sprawling canopies (T3 & T6) enhanced berry ripening compared to suckered VSP (T1 & T2) and non-suckered VSP (T4 & T5) grapevines. This trend was probably due to T3 and T6 grapevines being exposed to more incoming R_s during the day compared to T1, T2, T4 and T5 grapevines. In this regard, it was previously shown that canopy management increased sunlight penetration in Chenin blanc/99 Richter grapevines (Volschenk & Hunter, 2001). Furthermore, Williams *et al.* (1994) reported that canopies with increased sunlight interception increased sugar accumulation rates.

2012/13 season: Harvest dates showed similar trends as in the 2011/12 season, except that in the case of VSP grapevines, suckering enhanced the rate of berry ripening compared to non-suckered grapevines irrigated at 30% and 60% depletion (Table 4.5). This trend was probably due to a higher leaf area per grapevine in relation to crop load enhancing berry ripening (Kliewer & Dokoozlian, 2005). Leaf area per grapevine will be discussed in section 4.3.4.2.

Table 4.5 The effect of plant available water (PAW) depletion and different canopy management practices on harvest dates of Shiraz/110R grapevines during the 2011/12 and 2012/13 growing seasons near Robertson.

Treatment	PAW depletion	Canopy management practice	Harvest date	
			2011/12	2012/13
T1	30%	Suckered VSP	12 March	18 March
T2	30%	Non-suckered VSP	12 March	25 March
T3	30%	Sprawling canopy	6 March	25 March
T4	60%	Suckered VSP	12 March	18 March
T5	60%	Non-suckered VSP	12 March	25 March
T6	60%	Sprawling canopy	6 March	12 March
T7	90%	Suckered VSP	24 February	5 March
T8	90%	Non-suckered VSP	24 February	5 March
T9	90%	Sprawling canopy	24 February	5 March

4.3.4 Vegetative growth

4.3.4.1 Spur spacing and numbers

The different irrigation/canopy management practice combinations did not affect the number of spurs per grapevine or the spur spacing (data not shown). On average, there were ten spurs per grapevine, spaced *ca*. 12.2 cm apart.

4.3.4.2 Leaf area

2011/12 Season: Level of PAW depletion did not affect the number of leaves per primary shoot (Table 4.6). Within a specific PAW depletion level, canopy management practice also had no effect on the number of leaves per primary shoot. This was probably due to shoots of all treatments being topped to the same height, *i.e.* approximately 30 cm above the top trellis wire. The number of leaves per normally developed and underdeveloped shoot did not differ in shaded and exposed canopies (Cloete *et al.*, 2006). The number of leaves per primary shoot of the shaded canopy treatment was comparable to the leaf numbers of non-suckered VSP grapevines in this study, whereas the leaf numbers of the exposed canopy treatment was comparable to that of the suckered VSP grapevines. In the case of secondary shoots, level of PAW depletion did not affect number of leaves per shoot, except for a tendency towards less leaves per secondary shoot where irrigation was applied at 90% PAW depletion. It was previously reported that the number of leaves per secondary shoot of dryland Cabernet Sauvignon grapevines was lower compared to irrigated grapevines (Mehmel, 2010). Leaf numbers on secondary shoots also seemed to be sensitive to mild water deficits (Fereres, 2012). Therefore, a reduction in the number of leaves on secondary shoots could be possible when grapevines experience strong water deficits. Where grapevines were irrigated at 30% and 60% PAW depletion, respectively, canopy management practice had no effect on the number of leaves per secondary shoot. However, in the case of irrigation at 90% PAW depletion, suckered VSP grapevines (T7), had more leaves per secondary shoot compared to non-suckered VSP grapevines (T8). Visual observation revealed that this trend was probably due to more secondary shoots forming on the suckered VSP grapevines in response to topping when shoot growth extended about 30 cm above the top trellis wire. This trend towards increasing secondary shoot~~s~~ growth following topping is in agreement with previous findings (Jackson & Lombard, 1993 and references therein). Level of PAW depletion did not affect total leaf numbers on primary plus secondary shoots, except that the non-suckered grapevines irrigated at 90% depletion (T8) had lower leaf numbers (Table 4.6). Canopy management practice had no effect on total number of leaves per shoot.

Leaf area per primary shoot tended to decrease with an increase in PAW depletion level (Table 4.6). Leaf area per primary shoot also showed almost no response where Cabernet Sauvignon grapevines were subjected to water constraints (Mehmel, 2010). Canopy management practices applied in this study also had no effect on the leaf area per primary shoot. This was in contrast to results obtained where canopy manipulations included selective leaf removal (Hunter, 2000). The level of PAW depletion did not affect the leaf area per secondary shoot, except for a tendency towards a lower leaf area per secondary shoot where irrigation was applied at 90% depletion. Secondary shoot leaf area showed a similar trend where Cabernet Sauvignon grapevines were subjected to increasing water constraints (Mehmel, 2010). Since leaf area is a function of leaf number per shoot and leaf size, the number of leaves per secondary shoot tended to decrease where grapevines where irrigated at 90% PAW. Consequently, leaf area per secondary shoot will tend to decrease. In the case of irrigation at 30% PAW depletion, suckered VSP grapevines (T1) had a higher leaf area per secondary shoot compared to non-suckered VSP (T2) and sprawling canopy (T3) grapevines.

Table 4.6 The effect of plant available water (PAW) depletion and different canopy management practices on the number of leaves per shoot and the leaf area per shoot of Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

PAW depletion and canopy management practice	Leaves per shoot			Leaf area per shoot (m^2)		
	Primary shoots	Secondary shoots	Total	Primary shoots	Secondary shoots	Total
T1 - 30% - Suckered VSP	14.3 a(1)	38.4 a	52.7 a	0.177 a	0.228 a	0.405 a
T2 - 30% - Non-suckered VSP	18.9 a	29.8 ab	48.7 a	0.184 a	0.156 b	0.340 ab
T3 - 30% - Sprawling canopy	19.6 a	26.1 abc	45.7 a	0.187 a	0.132 b	0.319 ab
T4 - 60% - Suckered VSP	17.9 a	31.5 ab	49.5 a	0.163 ab	0.162 ab	0.324 ab
T5 - 60% - Non-suckered VSP	23.1 a	20.8 bcd	43.9 a	0.156 ab	0.097 bcd	0.253 bcd
T6 - 60% - Sprawling canopy	21.1 a	31.0 ab	52.1 a	0.175 a	0.119 bc	0.295 bc
T7 - 90% - Suckered VSP	19.5 a	22.3 bc	41.9 ab	0.170 ab	0.101 bcd	0.270 bc
T8 - 90% - Non-suckered VSP	18.1 a	8.4 d	26.5 b	0.129 b	0.034 d	0.163 d
T9 - 90% - Sprawling canopy	21.3 a	15.5 cd	36.9 ab	0.148 ab	0.058 cd	0.207 cd

(1)Values within a column followed by the same letter do not differ significantly ($p \le 0.05$).

Visual observation revealed that this trend was probably due to topping which resulted in more secondary shoots on the suckered VSP grapevines, whereas the non-suckered VSP and sprawling canopy grapevines had more primary shoots in which the vigour could be distributed (Tables 4.6 & 4.7). Where grapevines were irrigated at 60% and 90% PAW depletion, canopy management practice had no effect on the leaf area per secondary shoot. This was probably due to the drier soil conditions already limiting vegetative growth and the effect of the canopy management practice being reduced as a result. Level of PAW depletion did not affect the total leaf area per shoot, except for a tendency towards a lower total leaf area with an increase in level of depletion. Canopy management practice had no effect on the total leaf area per shoot (*i.e.* primary plus secondary), except where grapevines were irrigated at 90% PAW depletion. Non-suckered VSP grapevines (T8) had a lower total leaf area per shoot than suckered VSP grapevines (T7). The sprawling canopy grapevines (T9) also tended to have a lower total leaf area per shoot compared to the T7 grapevines. The lower total leaf area per shoot was probably due to T8 grapevines bearing less leaves per secondary shoot. It is important to note that the total leaf area per shoot followed a similar trend as the number of leaves per secondary shoot.

In the case of suckered VSP grapevines, level of PAW depletion did not affect the total number of shoots per grapevine in the 2011/12 season (Table 4.7). In the case of non-suckered VSP grapevines, irrigation at 90% PAW depletion (T8) resulted in slightly less shoots per grapevine compared to 60% PAW depletion (T5). In the case of sprawling canopy grapevines, irrigation at 60% PAW depletion (T6) resulted in slightly less shoots per grapevine compared to 30% PAW depletion (T3). At this stage there is no explanation for these differences. Suckered VSP grapevines (T1, T4 & T7) reduced the number of shoots per grapevine compared to non-suckered VSP (T2, T5 & T8) and sprawling canopy (T3, T6, & T9) grapevines, irrespective of PAW depletion level (Table 4.7). The lower shoot numbers on suckered VSP grapevines was probably due to the removal of additional shoots at *ca.* 30 cm shoot length, *i.e.* shoots that were not allocated to spurs at pruning. Where grapevines were irrigated at 60% PAW depletion, grapevines with sprawling canopies (T6) also had less shoots per grapevine compared to non-suckered VSP grapevines (T5). However, at this stage there is no clear explanation for this trend. In the case of suckered VSP grapevines, irrigation at 90% PAW depletion (T7) reduced total leaf area per grapevine compared to 30% depletion (T1), but only tended to reduce the leaf area per grapevine compared to 60% PAW depletion (T4) (Table 4.7). Total leaf area per grapevine showed a similar trend where Cabernet Sauvignon grapevines were subjected to increasing water constraints (Mehmel, 2010). The leaf area per grapevine of the non-suckered VSP and sprawling canopy grapevines was reduced where irrigation was applied at 90% PAW depletion (T8 & T9) compared to 30% (T2 & T3) and 60% PAW depletion (T5 & T6). This indicated that a decrease in total leaf area per grapevine is evident with increases water constraints. Within a given PAW depletion level, canopy management practice did not affect total leaf area per grapevine (Table 4.7). These results showed that the differences in leaf area per shoot reflected in leaf area per grapevine. Furthermore, on a per grapevine basis, it also suggested that if one management practice alters the vegetative growth it will be compensated for in another way. For example, removing shoots not allocated on spurs will result in more secondary shoots following topping.

Table 4.7 The effect of plant available water (PAW) depletion and different canopy management practices on the total number of shoots and leaf area per grapevine of Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

Treatment	PAW depletion	Canopy management practice	Number of shoots per grapevine	Leaf area per grapevine (m^2)
T1	30%	Suckered VSP	24 c(1)	9.75 abc
T2	30%	Non-suckered VSP	38 ab	11.67 a
T3	30%	Sprawling canopy	39 a	12.38 a
T4	60%	Suckered VSP	25 c	8.20 bcd
T5	60%	Non-suckered VSP	39 a	9.99 abc
T6	60%	Sprawling canopy	36 b	10.56 ab
T7	90%	Suckered VSP	25 c	6.86 d
T8	90%	Non-suckered VSP	36 b	5.91 d
T9	90%	Sprawling canopy	37 ab	7.59 cd

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

2012/13 season: During this particular season, there were less leaves per primary shoot compared to the 2011/12 season. The number of nodes per primary shoot followed the same trend (data not shown). If the latter is considered, the differences in the number of leaves per primary shoot might be due to seasonal differences, but since topping and shoot lengths were comparable, there is no clear explanation for the difference between the seasons. Differences in the number of leaves per primary shoot between two seasons have been reported for Cabernet Sauvignon grapevines, also with no plausible explanation (Mehmel, 2010). In the case of suckered and non-suckered VSP grapevines, level of PAW depletion did not affect the number of leaves per primary shoot (Table 4.8).

Grapevines with sprawling canopies (T3 & T9) tended to have less leaves per primary shoot compared to suckered (T1 & T7) and non-suckered VSP grapevines (T2 & T8), except where grapevines were irrigated at 60% PAW depletion. Since this effect could not be related to level of PAW depletion or canopy management practice, it was probably caused by some external factor that was not quantified. The number of leaves per secondary shoot tended to decrease with an increase in PAW depletion level (Table 4.8). Where grapevines were irrigated at 30% PAW depletion, the number of leaves per secondary shoot was higher for suckered VSP grapevines (T1) compared to non-suckered VSP and sprawling canopy grapevines (T2 & T3). Grapevines of T2 also had a higher number of leaves per secondary shoot compared to grapevines of T3. A similar trend occurred where grapevine canopy management treatments were more or less comparable to canopy treatments applied in this study (Cloete *et al.*, 2006). In the case of irrigation at 60% PAW depletion, suckered VSP grapevines (T4) had more leaves per secondary shoot compared to non-suckered VSP grapevines (T5), but only tended to have more leaves per secondary shoot than sprawling canopy grapevines (T6). In the case of irrigation at 90% PAW depletion, the number of leaves per secondary shoot was higher for suckered VSP grapevines (T7) compared to non-suckered VSP (T8) and sprawling canopy (T9) grapevines. Total number of leaves per shoot followed similar trends as the number of leaves per secondary shoot within the different PAW depletion levels and canopy management practices (Table 4.8). Since total number of leaves per primary shoot did not differ substantially, the difference in total number of leaves was caused by the more pronounced differences in number of leaves per secondary shoot.

In the 2012/13 season, leaf area per primary shoot, leaf area per secondary shoot, as well as total leaf area was lower compared to the 2011/12 season. Level of PAW depletion had no effect on the leaf area per primary shoot in the case of suckered VSP grapevines (Table 4.8). Irrigation at 90% PAW depletion (T8 & T9) reduced leaf area per primary shoot compared to irrigation at 30% and 60% PAW depletion, in the case of both non-suckered VSP (T2 & T5) and sprawling canopy (T3 & T6) grapevines. Where grapevines where irrigated at 30% PAW depletion, grapevines with sprawling canopies (T3) had a lower leaf area per primary shoot compared to suckered VSP grapevines (T1) (Table 4.8).

Table 4.8 The effect of plant available water (PAW) depletion and different canopy management practices on the number of leaves per shoot and the leaf area per shoot of Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

PAW depletion and canopy management practice	Leaves per shoot			Leaf area per shoot (m^2)		
	Primary shoots	Secondary shoots	Total	Primary shoots	Secondary shoots	Total
T1 - 30% - Suckered VSP	10.0 ab(1)	32.4 a	42.4 a	0.152 a	0.179 a	0.331 a
T2 - 30% - Non-suckered VSP	10.6 a	24.3 b	34.9 b	0.139 abc	0.131 ab	0.270 b
T3 - 30% - Sprawling canopy	7.9 b	15.5 cde	25.6 d	0.117 c	0.089 bcd	0.206 d
T4 - 60% - Suckered VSP	9.8 ab	22.7 bc	32.5 bc	0.147 ab	0.123 bc	0.269 bc
T5 - 60% - Non-suckered VSP	11.1 a	11.3 def	22.4 de	0.125 bc	0.047 def	0.172 de
T6 - 60% - Sprawling canopy	11.3 a	16.7 cd	28.1 cd	0.140 abc	0.066 def	0.206 d
T7 - 90% - Suckered VSP	10.5 a	16.8 bcd	27.3 cd	0.132 abc	0.078 cde	0.209 cd
T8 - 90% - Non-suckered VSP	9.0 ab	5.3 f	14.3 f	0.088 d	0.023 f	0.111 f
T9 - 90% - Sprawling canopy	7.6 b	9.0 ef	16.6 ef	0.084 d	0.035 ef	0.119 ef

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$)

This was probably due to the fact that sprawling canopy grapevines had less leaves per primary shoot. However, where grapevines were irrigated at 60% PAW depletion, canopy management practice had no effect on the leaf area per primary shoot. In the case of irrigation at 90% PAW depletion, suckered VSP (T7) grapevines had a higher leaf area per primary shoot compared to non-suckered VSP (T8) and sprawling canopy grapevines (T9). This indicated that the higher shoot numbers, *i.e.* more sinks per grapevine, of T8 and T9 grapevines probably limited leaf area development per primary shoot under dry soil conditions (Tables 4.8 & 4.9). Leaf area per secondary shoot had a tendency to be lower where grapevines were irrigated at 60% and 90% PAW depletion compared to 30% PAW depletion (Table 4.8). Leaf area per secondary shoot tended to be higher for suckered and non-suckered VSP grapevines (T1 & T2) than sprawling canopy grapevines (T3) where irrigation was applied at 30% and 90% PAW depletion level. Where grapevines were irrigated at 60% PAW depletion, non-suckered VSP and sprawling canopy grapevines (T5 & T6) had a lower leaf area per secondary shoot compared to suckered VSP grapevines (T4). As expected, total number of leaves per shoot reflected in total leaf area per shoot, as was the case in the 2011/12 season. Since variation in total leaf number per shoot was caused by variation in the number of leaves per secondary shoot, differences in total leaf area was primarily a function of number of leaves per secondary shoot. A similar trend was also reported for Cabernet Sauvignon grapevines (Mehmel, 2010).

For a given canopy management practice, level of PAW depletion did not affect the total number of shoots per grapevine in the 2012/13 season (Table 4.9). This agrees with previous findings which showed that level of PAW depletion did not affect number of shoots per metre cordon length of two grapevine cultivars (Myburgh, 2011c). Suckered VSP grapevines reduced the number of shoots per grapevine compared to non-suckered VSP and sprawling canopy grapevines, irrespective of PAW depletion level (Table 4.9). These results were consistent with findings in the 2011/12 season. In the case of suckered VSP grapevines, total leaf area per grapevine decreased as the soil dried out (Table 4.9). This agreed with earlier findings reported for Cabernet Sauvignon grapevines (Mehmel, 2010). The leaf area per grapevine of the non-suckered VSP and sprawling canopy grapevines (T8 & T9) were reduced by irrigation at 90% PAW depletion compared to 30% (T2 & T3) and 60% (T5 & T8) PAW depletion. Where grapevines were irrigated at 30% PAW depletion, suckered VSP grapevines (T1) tended to have a higher leaf area per grapevine than non-suckered VSP grapevines

(T2) (Table 4.9). Although T1 had less shoots per grapevine (Table 4.9) compared to T2 and T3, this trend was probably due to a higher leaf area per secondary shoot (Table 4.8). In the case of irrigation at 60% and 90% PAW depletion, canopy management practice did not affect the leaf area per grapevine (Table 4.9). The differences in leaf area were clearly visible in the vineyard (Fig. 4.10).

Table 4.9 The effect of plant available water (PAW) depletion and different canopy management practices on the total number of shoots and leaf area per grapevine of Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

Treatment	PAW depletion	Canopy management practice	Number of shoots per grapevine	Leaf area per grapevine (m^2)
T1	30%	Suckered VSP	25 b(1)	8.19 a
T2	30%	Non-suckered VSP	35 a	6.74 bc
T3	30%	Sprawling canopy	35 a	7.21 ab
T4	60%	Suckered VSP	23 b	6.24 bc
T5	60%	Non-suckered VSP	33 a	5.69 cd
T6	60%	Sprawling canopy	33 a	6.81 abc
T7	90%	Suckered VSP	22 b	4.58 de
T8	90%	Non-suckered VSP	35 a	3.83 e
T9	90%	Sprawling canopy	35 a	4.15 e

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

4.3.4.3 Cane dimensions at pruning

2011/2012 season: Primary cane length, diameter and mass were not affected by level of PAW depletion or canopy management practice (Table 4.10). This was probably due to grapevines of all the treatments being topped about 30 cm above the top trellis wire, which resulted in comparable cane dimensions of the primary canes. In the case of suckered VSP grapevines, level of PAW depletion did not affect secondary cane length (Table 4.10). Furthermore, drier soil conditions tended to reduce secondary cane diameter and reduced cane mass where grapevines were irrigated at 90% PAW depletion compared to 30% PAW depletion.

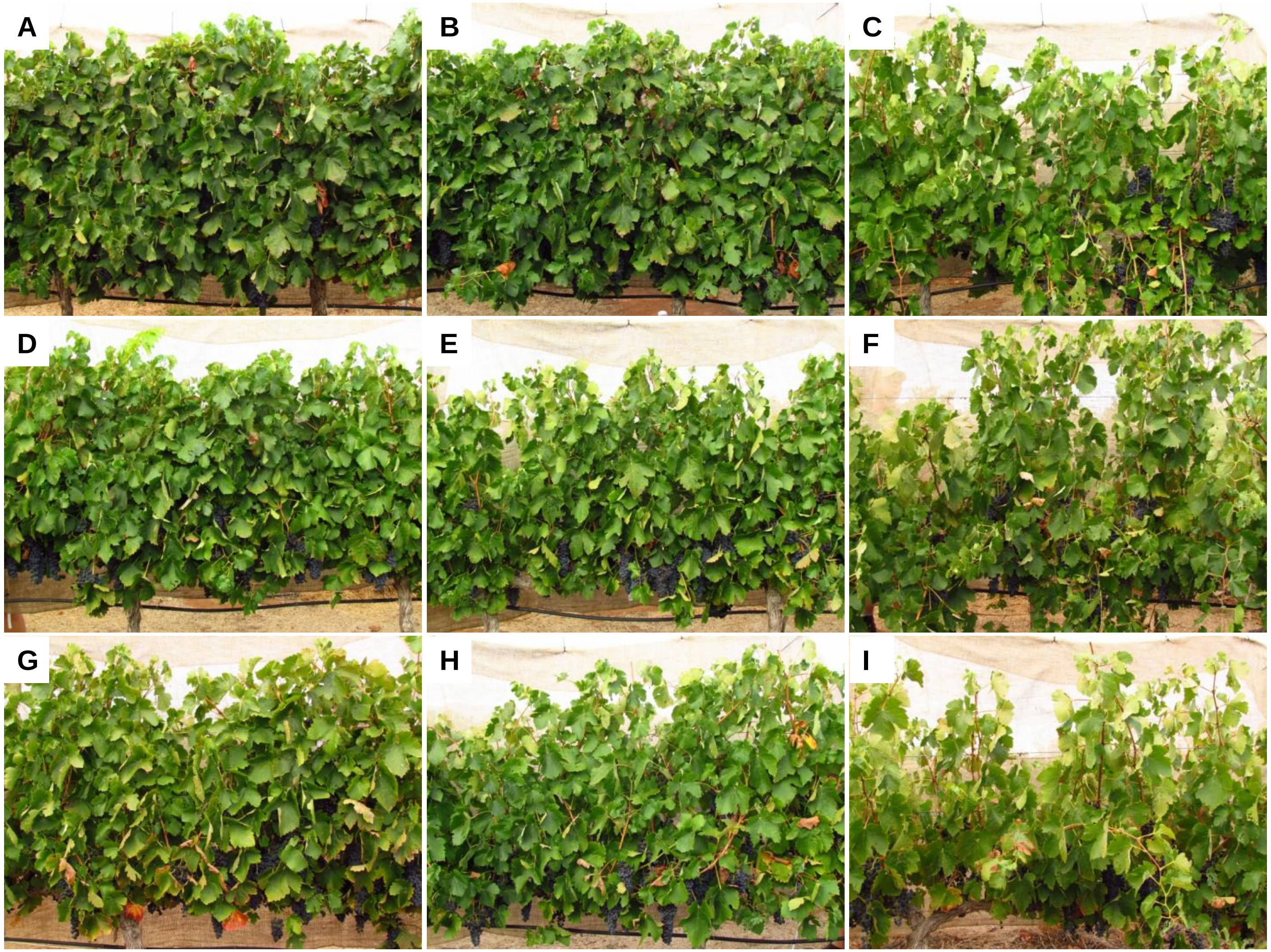

Figure 4.10 Examples illustrating the effect of plant available water (PAW) depletion and canopy management practice on Shiraz/110R grapevines, where (A) is suckered VSP, (B) is non-suckered VSP and (C) is sprawling canopy grapevines irrigated at 30% PAW depletion; (D) is suckered VSP, (E) is non-suckered VSP and (F) is sprawling canopy grapevines irrigated at 60% PAW depletion and (G) is suckered VSP, (H) is non-suckered VSP and (I) is sprawling canopy grapevines irrigated at 90% PAW depletion near Robertson. Photographs were taken before harvest in the 2012/13 season.

In the case of non-suckered VSP grapevines, irrigation at 90% PAW depletion (T8), reduced secondary cane length, diameter and mass compared to 30% PAW depletion (T2). Where grapevines were irrigated at 30% and 90% PAW depletion, secondary cane length, diameter and mass were not affected by canopy management practice (Table 4.10). However, sprawling canopy grapevines (T6) irrigated at 60% PAW depletion, had lower secondary cane length, diameter and mass compared to suckered (T4) and non-suckered VSP grapevines (T5) (Table 4.10). At this stage, there is no clear explanation for this trend.

The number of secondary canes per primary cane, as well as the number of secondary canes per grapevine was not affected by level of PAW depletion or canopy management practice (Table 4.11). Level of PAW depletion also had no effect on total cane length per grapevine in the case of suckered VSP grapevines (T1, T4 & T7). However, total cane length per grapevine of non-suckered VSP was higher when irrigation was applied at 30% PAW depletion (T2) compared to 60% (T5) and 90% PAW depletion (T8) (Table 4.11). A similar trend occurred in the case of sprawling canopy grapevines. In the case of suckered VSP grapevines, irrigation at 90% PAW depletion (T7) reduced cane mass (t/ha) compared to 30% PAW depletion (T1) (Table 4.11). A similar trend occurred in the case of non-suckered VSP grapevines and grapevines with sprawling canopies. In the case of irrigation at 30% PAW depletion, cane mass of sprawling grapevines (T3) were higher compared to non-suckered VSP grapevines (T2), but only tended to be higher compared to suckered VSP grapevines (T1) (Table 4.11). However, in the case of 60% and 90% PAW depletion, canopy management did not affect cane mass. Cane mass was primarily affected by water deficit and to a lesser extent by canopy management practice. It is well documented that increased water constraints leads to a decrease in cane mass, irrespective of cultivar (McCarthy *et al.*, 1983; Van Zyl & Van Huyssteen, 1988; Williams *et al.*, 1994; Myburgh, 1996; Lategan, 2011; Myburgh, 2011a, Fernandes de Oliveira *et al.,* 2013). However, canopy manipulation treatments have been reported to reduce cane mass compared to a control (Reynolds & Wardle, 1989).

Table 4.10 The effect of plant available water (PAW) depletion and different canopy management practices on cane length and mass, as well as mean cane diameter of primary and secondary shoots of Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

PAW depletion and canopy management practice	Cane length (cm)		Cane diameter (mm)		Cane mass (g)	
	Primary	Secondary	Primary	Secondary	Primary	Secondary
T1 - 30% - Suckered VSP	88.4 a(1)	28.5 ab	7.27 a	4.22 a	44.32 a	5.77 a
T2 - 30% - Non-suckered VSP	94.8 a	33.1 a	7.05 a	4.17 ab	43.75 a	7.25 a
T3 - 30% - Sprawling canopy	83.3 a	27.6 ab	6.93 a	4.09 abc	48.27 a	5.68 a
T4 - 60% - Suckered VSP	78.7 a	27.9 ab	6.89 a	4.19 ab	34.61 a	5.26 a
T5 - 60% - Non-suckered VSP	80.0 a	26.9 ab	5.81 a	4.16 ab	26.77 a	4.85 ab
T6 - 60% - Sprawling canopy	91.9 a	10.6 c	6.33 a	3.31 cd	36.98 a	1.32 c
T7 - 90% - Suckered VSP	84.2 a	17.6 bc	6.46 a	3.41 bcd	32.09 a	1.99 c
T8 - 90% - Non-suckered VSP	78.5 a	20.9 bc	5.63 a	3.16 d	23.50 a	2.26 bc
T9 - 90% - Sprawling canopy	77.5 a	11.8 c	6.04 a	3.31 cd	31.16 a	1.84 c

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

Table 4.11 The effect of plant available water (PAW) depletion and different canopy management practices on number of secondary canes per primary cane, number of secondary canes per grapevine, total cane length per grapevine and cane mass of Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

PAW depletion and canopy management practice	Number of secondary canes per primary cane	Number of secondary canes per grapevine	Total cane length per grapevine (cm)	Cane mass (t/ha)
T1 - 30% - Suckered VSP	1.9 a(1)	45 a	339.9 cd	3.5 ab
T2 - 30% - Non-suckered VSP	1.7 a	63 a	559.9 a	3.3 bc
T3 - 30% - Sprawling canopy	1.3 a	50 a	453.8 b	4.2 a
T4 - 60% - Suckered VSP	1.5 a	39 a	310.1 d	2.9 bcd
T5 - 60% - Non-suckered VSP	1.1 a	45 a	421.4 bc	2.4 de
T6 - 60% - Sprawling canopy	1.7 a	64 a	393.1 bcd	2.9 bcd
T7 - 90% - Suckered VSP	2.1 a	53 a	309.1 d	2.2 de
T8 - 90% - Non-suckered VSP	0.5 a	17 a	320.5 cd	2.2 e
T9 - 90% - Sprawling canopy	1.1 a	42 a	338.0 cd	2.7 cde

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

2012/13 season: Primary cane length was not affected by level of PAW depletion or canopy management practice (Table 4.12). In the case of suckered VSP and non-suckered VSP grapevines, 90% PAW depletion (T7 & T8) reduced primary cane diameter compared to irrigation at 30% PAW depletion (T1 & T2). However, in the case of sprawling canopy grapevines, level of depletion did not affect primary cane diameter. This suggested that cane diameter of sprawling grapevines were less sensitive to level of PAW depletion compared to suckered and non-suckered VSP grapevines. Where irrigation was applied at 30% PAW depletion, primary canes of sprawling canopy grapevines (T3) were thinner compared to those of suckered VSP grapevines (T1). The thinner canes were probably due to the growth vigour being distributed amongst more shoots per grapevine. However, in the case of 60% PAW depletion, canes of non-suckered VSP grapevines (T5) were thinner compared to those of suckered VSP grapevines (T4). A similar trend occurred where irrigation was applied at 90% PAW depletion. In the case of suckered VSP grapevines, irrigation applied at 90% PAW depletion (T7) reduced primary cane mass compared to irrigation at 30% PAW depletion (T3) (Table 4.12). In contrast, level of PAW depletion did not affect primary cane mass of non-suckered VSP and sprawling canopy grapevines. Where grapevines were irrigated at 30% PAW depletion, cane mass of suckered VSP grapevines (T1) was higher compared to non-suckered VSP grapevines (T2). In the case of irrigation applied at 60% and 90% PAW depletion, respectively, canopy management practice did not affect primary cane mass.

In the case of suckered VSP grapevines, secondary cane length was lower where grapevines were irrigated at 60% and 90% PAW depletion (T4 & T7) compared to irrigation at 30% PAW depletion (T1) (Table 4.12). In the case of non-suckered VSP grapevines, secondary cane length was also lower where irrigation was applied at 90% PAW depletion (T8) compared to 30% and 60% PAW depletion (T2 & T5). However, secondary cane length of sprawling canopy grapevines was not affected by level of PAW depletion. These results indicated secondary cane length of suckered and non-suckered VSP grapevines were more sensitive to water deficits compared to sprawling canopy grapevines. Within a given PAW depletion level, irrigation applied at 30% and 60% PAW depletion reduced secondary cane length of sprawling canopy grapevines (T3 & T6) compared to suckered (T1 & T4) and non-suckered VSP grapevines (T2 & T5) (Table 4.12).

Table 4.12 The effect of plant available water (PAW) depletion and different canopy management practices on cane length and mass, as well as mean cane diameter of primary and secondary canes of Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

PAW depletion and canopy management practice	Cane length (cm)		Cane diameter (mm)		Cane mass (g)	
	Primary	Secondary	Primary	Secondary	Primary	Secondary
T1 - 30% - Suckered VSP	88.3 a(1)	37.8 a	8.01 a	4.38 a	53.74 a	9.18 a
T2 - 30% - Non-suckered VSP	81.3 a	26.6 ab	6.91 abc	3.99 a	31.87 bc	3.17 b
T3 - 30% - Sprawling canopy	83.5 a	10.9 d	6.57 bcd	2.36 a	35.55 abc	1.79 bcd
T4 - 60% - Suckered VSP	84.3 a	16.6 bc	7.41 ab	3.44 a	46.37 ab	2.75 bc
T5 - 60% - Non-suckered VSP	78.7 a	15.4 bc	5.91 cd	3.03 a	27.14 bc	1.79 bcd
T6 - 60% - Sprawling canopy	88.2 a	6.2 d	6.71 abcd	2.21 a	34.92 abc	0.34 d
T7 - 90% - Suckered VSP	66.1 a	14.3 bc	6.37 bcd	2.79 a	26.89 c	1.80 bcd
T8 - 90% - Non-suckered VSP	60.2 a	10.1 d	5.51 d	2.27 a	18.97 c	1.44 bcd
T9 - 90% - Sprawling canopy	71.9 a	6.7 d	6.15 bcd	2.91 a	27.74 bc	0.71 cd

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

However, in the case of irrigation at 90% PAW depletion, non-suckered VSP grapevines (T8), as well as sprawling canopy grapevines (T9) reduced the secondary cane length compared to suckered VSP grapevines (T7). Secondary cane mass of suckered VSP grapevines irrigated at 30% PAW depletion (T1) was higher compared to 60% and 90% PAW depletion (T4 & T7). In the case of non-suckered VSP and sprawling canopy grapevines, level of PAW depletion did not affect secondary cane mass. Within a given PAW depletion level, irrigation at 30% PAW depletion increased secondary cane mass of suckered VSP grapevines (T1) compared to non-suckered VSP (T2) and sprawling canopy grapevines (T3). Where grapevines were irrigated at 60% PAW depletion, secondary cane mass of suckered VSP grapevines (T4) higher compared to that of sprawling canopy grapevines (T6). However, in the case of irrigation at 90% PAW depletion, canopy management practice had no effect on secondary cane mass.

The number of secondary canes per primary cane tended to decrease with an increase in level of PAW depletion for suckered VSP grapevines (Table 4.13). In the case of non-suckered VSP and sprawling canopy grapevines, level of PAW depletion had no effect on the number of secondary canes per primary cane. Where grapevines were irrigated at 30% PAW depletion, suckered VSP grapevines (T1) had a higher number of secondary canes per primary cane compared to non-suckered VSP (T2) and sprawling canopy grapevines (T3). In the case of irrigation at 60% PAW depletion, non-suckered VSP grapevines (T5) had less canes per primary cane compared to suckered VSP grapevines (T4). However, canopy management practice did not affect the number of secondary canes per primary cane where irrigation was applied at 90% PAW depletion.

Level of PAW depletion and canopy management practice did not affect the number of secondary canes per grapevines (Table 4.13). Total cane length per grapevine was higher for suckered VSP grapevines irrigated at 30% PAW depletion (T1) compared to 60% and 90% PAW depletion (T4 & T7) (Table 4.13). However, non-suckered VSP (T2, T5 & T8) and sprawling canopy grapevines' (T3, T6 & T9) total cane length were not affected by level of PAW depletion. Within a given PAW depletion level, total cane length of non-suckered VSP (T2) and sprawling canopy grapevines (T3) was lower compared to suckered VSP grapevines (T1). However, in the case of irrigation at 60% and 90% PAW depletion, canopy management practice did not affect the total cane length per grapevine.

Table 4.13 The effect of plant available water (PAW) depletion and different canopy management practices on number of secondary shoots per primary shoot, number of secondary shoots per grapevine, total shoot length per grapevine and cane mass of Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

PAW depletion and canopy management practice	Number of secondary canes per primary cane	Number of secondary canes per grapevine	Total cane length per grapevine (cm)	Cane mass (t/ha)
T1 - 30% - Suckered VSP	3.5 a(1)	84 a	527.9 a	4.1 a
T2 - 30% - Non-suckered VSP	1.1 c	37 a	328.0 bc	3.7 b
T3 - 30% - Sprawling canopy	1.2 c	43 a	365.6 b	4.1 ab
T4 - 60% - Suckered VSP	2.9 ab	68 a	322.5 bc	2.7 c
T5 - 60% - Non-suckered VSP	1.2 c	42 a	339.2 bc	2.5 cd
T6 - 60% - Sprawling canopy	1.4 bc	48 a	321.0 bc	2.7 c
T7 - 90% - Suckered VSP	1.7 bc	36 a	192.9 c	2.0 e
T8 - 90% - Non-suckered VSP	0.5 c	17 a	240.2 bc	2.0 e
T9 - 90% - Sprawling canopy	0.9 c	31 a	273.2 bc	2.2 de

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

Primary cane length per grapevine would be expected to be more or less the same, given that grapevines of all treatments were topped about 30cm above the top trellis wire. Therefore, little variation in primary cane length between treatments occurred. The foregoing indicated that differences in total shoot length per grapevine were primarily a function of the secondary shoot length per grapevine. Cane mass (t/ha) of suckered VSP grapevines decreased with an increase in level of PAW depletion (Table 4.13). Cane mass of the non-suckered VSP and sprawling canopy grapevines responded in a similar way to level of PAW depletion. These results indicated that the effect of level of PAW depletion on cane mass decreased with an increase in PAW depletion. Furthermore, the effect of level of PAW depletion on cane mass highlights the strong dependency of cane mass on water deficit. These results indicated that the effect of level of PAW depletion on cane mass decreased with an increase in level of PAW depletion, and the strong dependency of cane mass on water deficit. Within a given PAW depletion level, cane mass of non-suckered VSP (T2) was lower compared to suckered VSP grapevines (T1) where irrigation was applied at 30% PAW depletion. However, where grapevines were irrigated at 60% and 90% PAW depletion, canopy management practice had no effect on cane mass. These results indicated that the effect of canopy management practice on cane mass decreased with an increase in level of PAW depletion.

4.3.4.4 Relationships between cane mass, length and diameter.

In both seasons, linear multiple regression showed that primary cane mass was a highly significant function of primary cane length and cane diameter (Table 4.14). Furthermore, it must be noted that the constant and coefficients of the equations were almost identical for the two seasons. In the case of secondary canes, multiple linear regression showed that cane mass was a highly significant function of secondary cane length and cane diameter in both seasons (Table 4.14). In contrast to the primary shoots, the constant and coefficients of the equations differed slightly between the two seasons. This suggested that the formation of secondary canes was probably more variable between seasons than primary canes. According to the visual similarity of the 95% confidence intervals for the predicted versus observed plots for primary cane mass, there were no differences between seasons (Fig. 4.11). In the case of the secondary shoots, there was also no difference between seasons (Fig. 4.12).

Therefore, this allows the data for the two seasons to be combined into single models for the primary and secondary canes, respectively (data not shown).

Table 4.14 Multiple linear regression models describing the relationship between dependency of cane mass (M) on cane length (L) and cane diameter (Ø) of Shiraz/110R measured at pruning.

Shoot order	Season	Equation	n	R^2	s.e.	P-value
Primary	2011/12	M = -40.026 + 0.278*L + 7.845*Ø	27	0.8044	4.05	0.0001
	2012/13	M = -39.303 + 0.254*L + 7.863*Ø	27	0.8643	4.32	0.0001
Secondary	2011/12	M = -6.557 + 0.170*L + 1.775*Ø	27	0.9262	0.70	0.0001
	2012/13	M = -2.998 + 0.231*L + 0.527*Ø	27	0.9295	0.77	0.0001

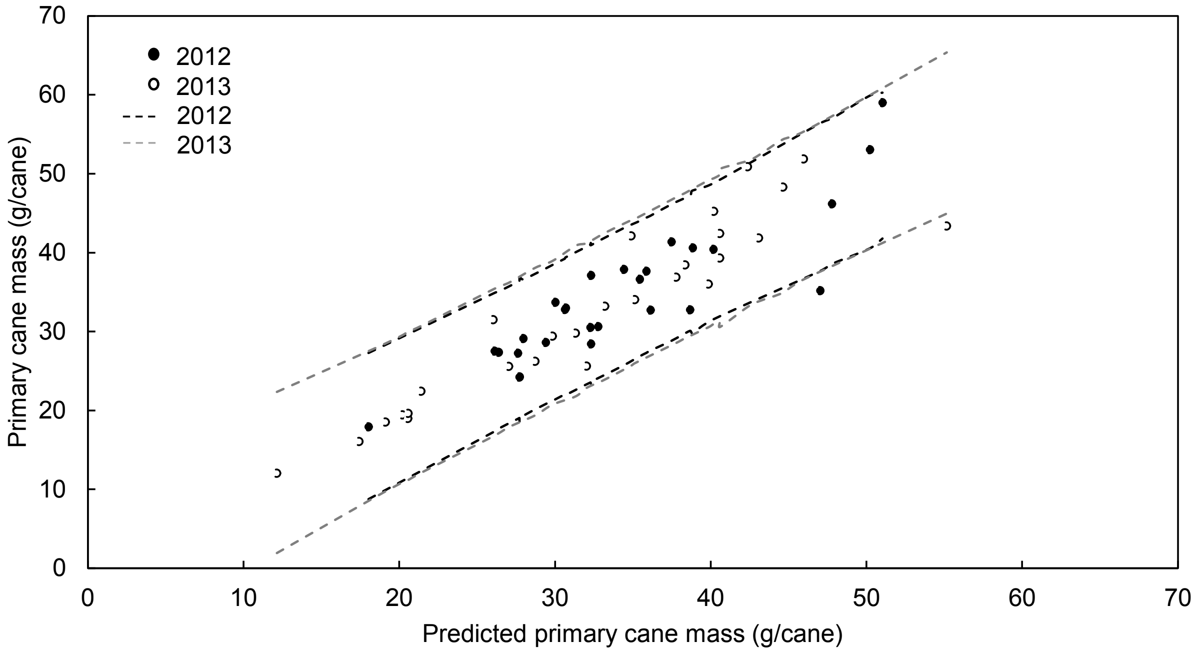

Figure 4.11 Relationship between actual primary cane mass and predicted primary cane mass of Shiraz/110R grapevines determined at pruning in 2012 and 2013 near Robertson. Dashed lines indicate 95% confidence intervals.

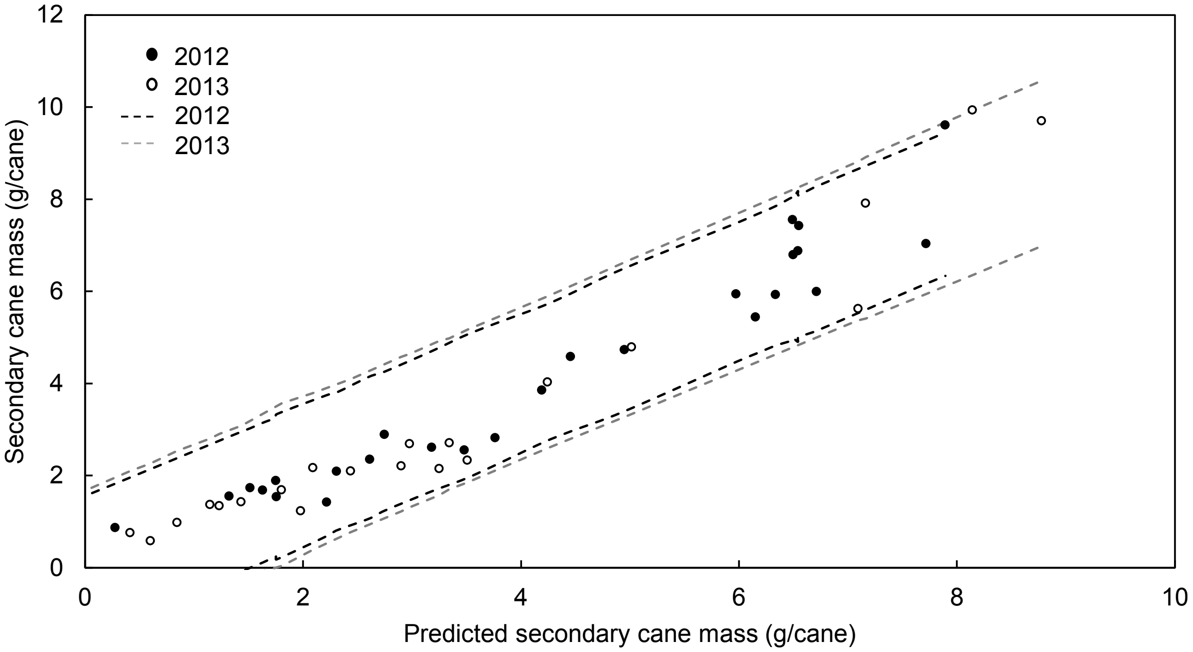

Figure 4.12 Relationship between actual secondary cane mass and predicted secondary cane mass of Shiraz/110R grapevines determined at pruning in 2012 and 2013 near Robertson. Dashed lines indicate 95% confidence intervals.

4.3.5 Grapevine water status

4.3.5.1 Midday plant water potential

2011/12 season: During ripening, midday Ψ_S was measured four times before irrigation during ripening (Table 4.15). On 30 January, grapevines irrigated at 30% PAW depletion on the sprawling canopy (T3) tended to experience more water constraints than the suckered (T1) and non-suckered (T2) VSP canopies. On 7 February, there was no difference in water constraints between canopy management strategies where irrigation was applied at 30% PAW depletion. This was due to irrigation of the 30% PAW depletion level being applied before the measurements were carried out. On 13 February, T3 experienced more water constraints compared to T1 and T2 where irrigation was applied at 30% PAW depletion. On 20 February, grapevines on the sprawling canopy (T3) also tended to experience more water constraints than the VSP grapevines (T1 & T2). Mean Ψ_S during ripening showed a similar trend. The foregoing suggests that more leaves on the sprawling canopy being exposed to sunlight induced more water constraints compared to the VSP canopies. In the case of the 60% PAW depletion, the sprawling canopy (T6) consistently experienced more water constraints during ripening compared to the suckered (T4) and non-suckered (T5) VSP canopies (Table 4.15). In contrast, canopy management practise had no effect on grapevine water constraints where irrigation was applied at 90% PAW depletion (Table 4.15). This suggested that the canopy effect on grapevine water status diminished where drier soil conditions prevailed.

Table 4.15 The effect of plant available water (PAW) depletion and different canopy management practices on stem water potential (Ψ_S) of Shiraz/110R grapevines during ripening in the 2011/12 growing season near Robertson.

PAW depletion and canopy management practice	Ψ_S (MPa)				
	30 Jan	7 Feb	13 Feb	20 Feb	Mean
T1 - 30% - Suckered VSP	-0.68 a(1)	-0.42 a	-0.59 a	-0.68 a	-0.59 a
T2 - 30% - Non-suckered VSP	-0.72 ab	-0.41 a	-0.63 a	-0.77 a	-0.63 ab
T3 - 30% - Sprawling canopy	-0.92 bc	-0.54 a	-0.94 b	-0.84 a	-0.81 b
T4 - 60% - Suckered VSP	-1.09 cd	-1.08 b	-0.98 b	-1.12 b	-1.06 c
T5 - 60% - Non-suckered VSP	-1.03 cd	-0.98 b	-1.05 b	-1.17 b	-1.06 c
T6 - 60% - Sprawling canopy	-1.43 e	-1.35 c	-1.37 c	-1.50 c	-1.41 d
T7 - 90% - Suckered VSP	-1.21 de	-1.37 c	-1.57 cd	-1.66 cd	-1.46 d
T8 - 90% - Non-suckered VSP	-1.37 e	-1.54 c	-1.57 cd	-1.73 cd	-1.55 d
T9 - 90% - Sprawling canopy	-1.37 e	-1.51 c	-1.62 d	-1.81 cd	-1.58 d

(1) Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

2012/13 season: During ripening, midday Ψ_S was also measured four times before irrigation during ripening. On 22 January, grapevines irrigated at 30% PAW depletion on the sprawling canopy (T3) experienced more water constraints than the suckered (T1) and non-suckered (T2) VSP canopies (Table 4.16). However, T2 grapevines also experienced more water constraints compared to T1 grapevines. On 7 February and 25 February, T3 grapevines experienced more water constraints compared to T1 and T2 grapevines where irrigation was applied at 30% PAW depletion. On 4 March, only the suckered VSP grapevines (T1) experienced less water constraints compared to grapevines on the sprawling canopies (T3). The effects of canopy management practice on grapevine water status were comparable to results obtained where irrigation was applied at 30% PAW depletion in the 2011/12 season. With the exception of 22 January, sprawling grapevines (T6) consistently experienced more water constraints compared to the suckered (T4) and non-suckered (T5) VSP canopies where irrigation was applied at 60% PAW depletion (Table 4.16). Similar results were obtained in the first season. In contrast to the 2011/12 season, the effect of canopy management practise on grapevine water status appeared to be more pronounced where irrigation was applied at 90% PAW depletion (Table 4.16). This indicated that canopy management practises could affect grapevine water status where drier soil conditions prevailed.

Table 4.16 The effect of plant available water (PAW) depletion and different canopy management practices on stem water potential (Ψ_S) of Shiraz/110R grapevines during ripening in the 2012/13 growing season near Robertson.

PAW depletion and canopy management practice	**Ψ_S (MPa)**				
	22 Jan	**7 Feb**	**25 Feb**	**4 Mar**	**Mean**
T1 - 30% - Suckered VSP	-0.64 a(1)	-1.12 a	-1.09 a	-1.23 a	-1.02 a
T2 - 30% - Non-suckered VSP	-0.77 b	-1.17 a	-1.26 a	-1.31 ab	-1.13 a
T3 - 30% - Sprawling canopy	-0.91 c	-1.48 b	-1.49 b	-1.53 bc	-1.35 b
T4 - 60% - Suckered VSP	-0.83 bc	-1.45 b	-1.58 bc	-1.61 cd	-1.37 b
T5 - 60% - Non-suckered VSP	-0.84 bc	-1.42 b	-1.47 b	-1.60 cd	-1.33 b
T6 - 60% - Sprawling canopy	-0.83 bc	-1.67 c	-1.72 cd	-1.81 de	-1.51 c
T7 - 90% - Suckered VSP	-1.30 d	-1.71 cd	-1.72 cd	-1.88 e	-1.65 d
T8 - 90% - Non-suckered VSP	-1.24 d	-1.86 d	-1.85 d	-2.05 ef	-1.75 d
T9 - 90% - Sprawling canopy	-1.45 e	-1.87 d	-1.89 d	-2.24 f	-1.86 e

(1) Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

4.3.5.2 Diurnal plant water potential

When diurnal Ψ_L was determined on 25 February 2013, no abnormalities occurred in the atmospheric conditions, except for windy conditions from 15:00 until 02:00 (Figs. 4.13 & 4.14). Grapevines irrigated at 30% PAW depletion experienced weak water constraints during the pre-dawn period according to the classification proposed for Shiraz by Ojeda *et al.* (2002) (Fig. 4.15A). Following this, Ψ_L decreased until the grapevines experienced medium to strong water constraints over the warmest part of the day according to a midday classification for Shiraz as adapted from Lategan (2011). The grapevines experienced no water constraints from 20:00 onwards. Canopy management practice had no effect on grapevine water status where irrigation was applied at 30% PAW depletion (Fig. 4.15A). However, from 20:00 onwards, the sprawling grapevines tended to experience slightly more water constraints than the VSP grapevines. In the case of 60% PAW depletion, T4 grapevines experienced moderate water constraints during the pre-dawn period (Ojeda *et al.*, 2002), whereas T5 and T6 grapevines experienced strong water constraints (Fig. 4.15B).

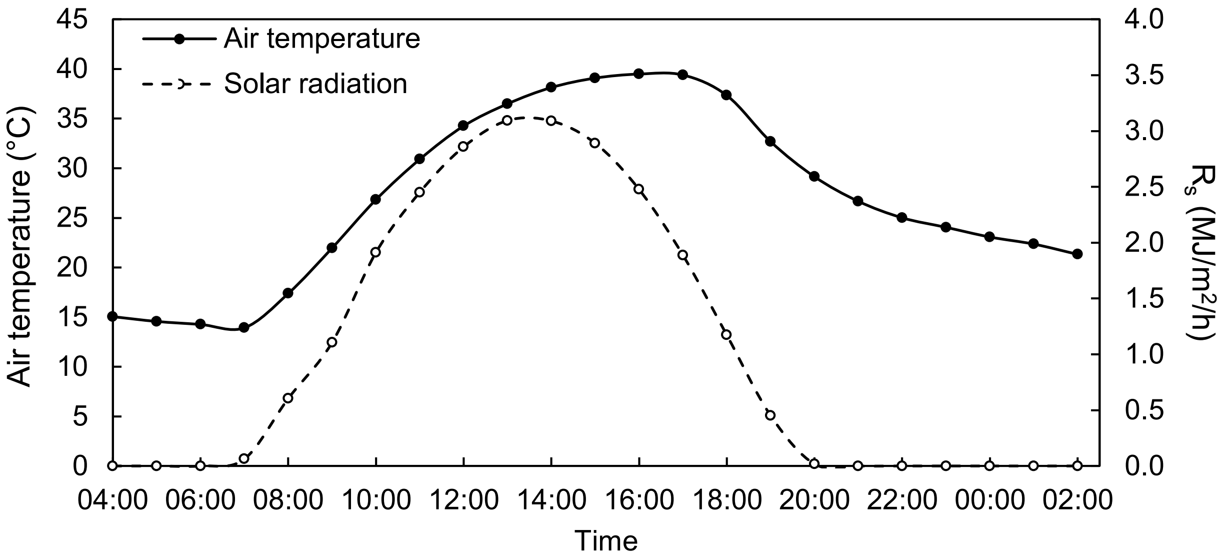

Figure 4.13 Diurnal variation in air temperature and net solar radiation (R_S) on 25 February 2013 near Robertson.

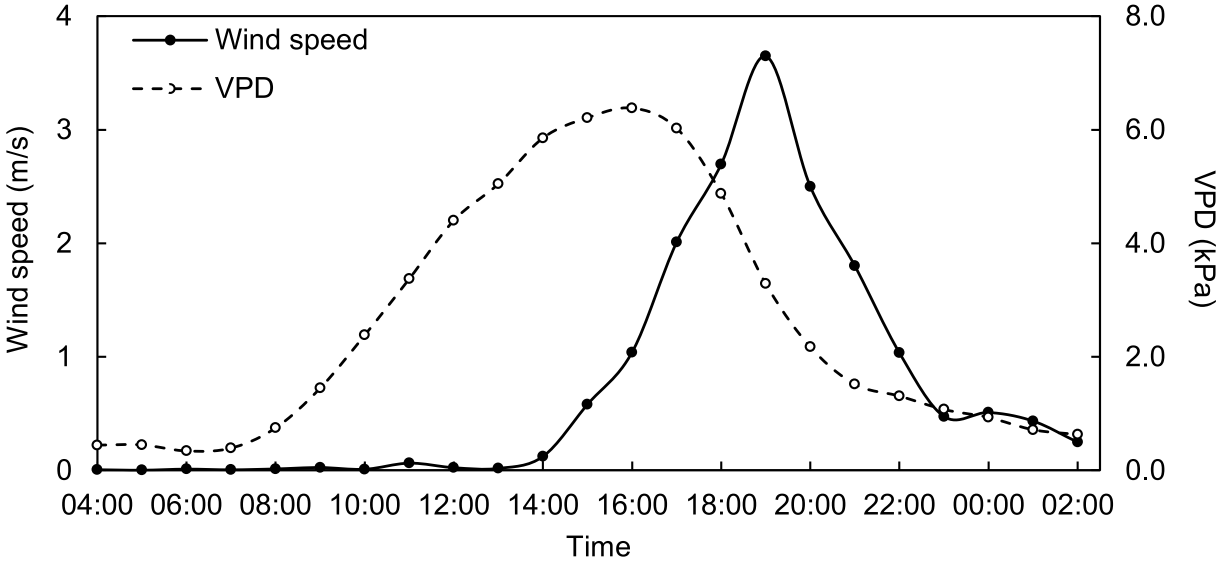

Figure 4.14 Diurnal variation in wind speed and vapour pressure deficit (VPD) on 25 February 2013 near Robertson.

Following this, Ψ_L decreased until the grapevines experienced strong to severe water constraints over the warmest part of the day (Lategan, 2011). However, Ψ_L in T6 grapevines tended to be lower during the morning compared to T4 and T5 grapevines. From 14:00 until 02:00, T6 grapevines experienced more water constraints than T4 and T5, particularly after 20:00 (Fig 4.15B). This indicated that the water status in the sprawling grapevines could not recover during the night to the same extent as VSP grapevines. In the case of irrigation at 90% PAW depletion, grapevines experienced strong water constraints during the pre-dawn period (Ojeda *et al.*, 2002), irrespective of canopy management practise (Fig. 4.15C). Following this, Ψ_L decreased until the grapevines experienced strong to severe water constraints over the warmest part of the day (Lategan, 2011). Where irrigation was applied at 90% PAW depletion, grapevines with sprawling canopies (T9) also experienced more water constraints during the night than the suckered VSP grapevines (T7). It is well documented that lower Ψ_L during the night is an indication that the grapevines could not recover from water constraints induced by soil water deficits (Choné *et al*., 2001; Rogiers *et al*., 2009; Lategan, 2011). Since canopy management practice *per se* did not affect soil water content (Fig. 4.9), the water constraints during the night were probably induced by some other factor(s).

In this regard, it was previously shown that low pre-dawn Ψ_L in Semillon grapevines indicated that water status could not recover during the night, and that high transpiration in the night (E_n) contributed to a reduced pre-dawn Ψ_L (Rogiers *et al*., 2009). This is supported by negative correlations between pre-dawn Ψ_L in grapevines and ambient VPD, since high night-time VPD will increase water losses via transpiration. If grapevines experience water constraints, low VPD during the night can restore cavitation embolisms which formed during the day by the rehydration of tissues (Rogiers *et al*., 2009 and references there in). However, substantial transpiration during the night might result in incomplete tissue rehydration, and subsequently lower Ψ_L. Therefore, bigger, more vigorous canopies may induce more rapid plant dehydration compared to smaller, less vigorous canopies, since larger leaf areas will increase transpiration losses (Rogiers *et al*., 2009).

In the case of 30% PAW depletion, grapevines with sprawling canopies (T3) tended to increase the Ψ_T compared to suckered and non-suckered VSP grapevines (T1 & T2) (Table 4.17). In the case of 60% PAW depletion, sprawling canopy grapevines (T6) experienced more water constraints compared to suckered and non-suckered VSP grapevines (T4 & T5), which resulted in more Ψ_T. Where grapevines were irrigated at 90% PAW depletion, the sprawling canopies (T9) induced a similar Ψ_T trend to 30% and 60% PAW depletion. Furthermore, these trends occurred in the morning, during the day and during the night (Table 4.17). These results indicated that sprawling canopy grapevines tended to have higher Ψ_T compared to suckered and non-suckered VSP grapevines, irrespective of the PAW depletion level.

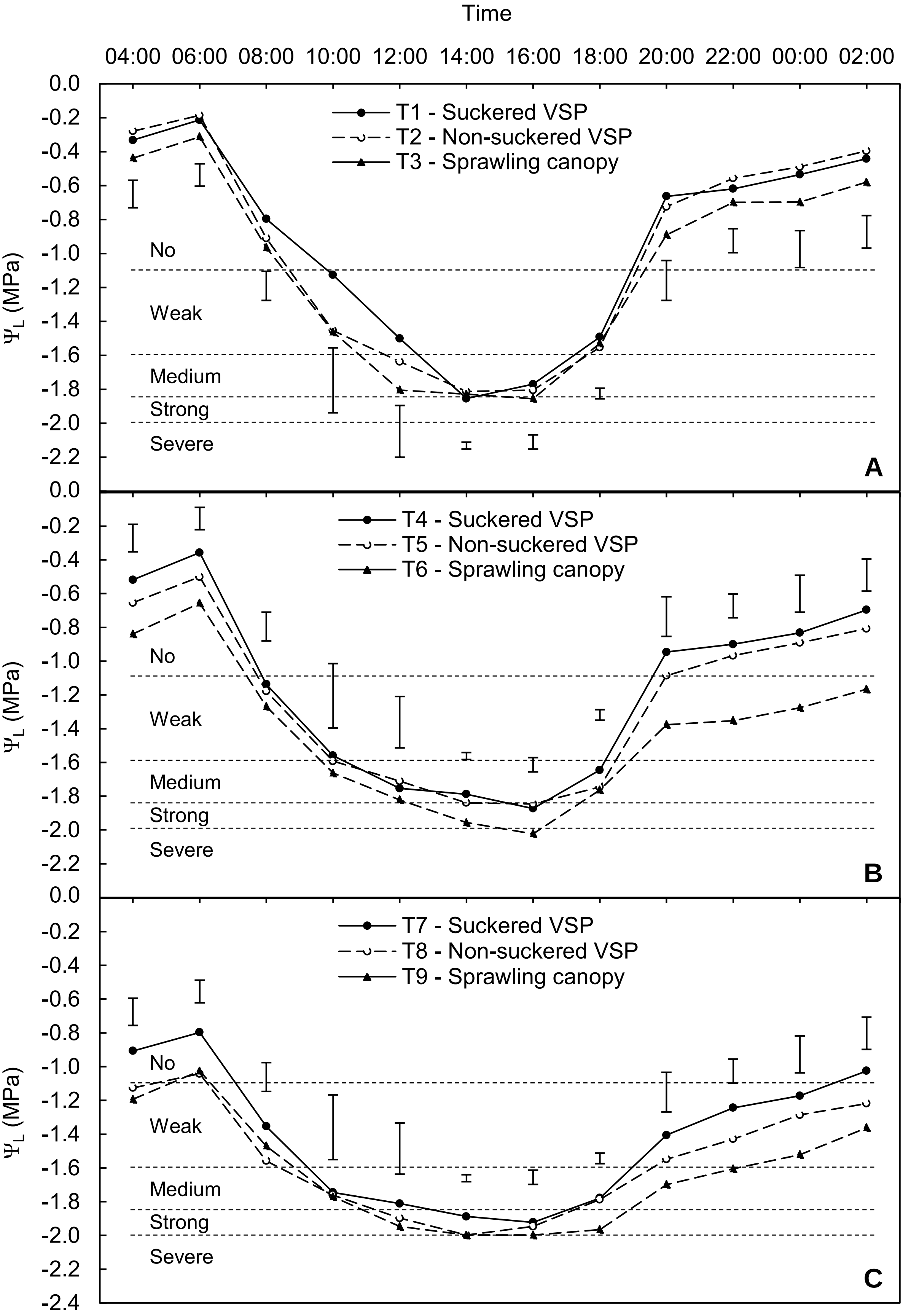

Figure 4.15 Effect of plant available water (PAW) depletion, namely (A) 30%, (B) 60% and (C) 90%, and different canopy management practises on diurnal leaf water potential (Ψ_L) of Shiraz/110R grapevines measured on 25 February 2013 near Robertson. Vertical bars indicate least significant difference ($p \leq 0.05$).

Table 4.17 The effect of plant available water (PAW) depletion and different canopy management practices on accumulated leaf water potential (Ψ_T) of Shiraz/110R grapevines on 25 February near Robertson.

PAW depletion and canopy management	Ψ_T (MPa^2)			
	04:00 until 08:00	08:00 until 18:00	18:00 until 02:00	Total
T1 - 30% - Suckered VSP	1.56 a(1)	14.80 a	5.57 a	21.93 a
T2 - 30% - Non-suckered VSP	1.56 a	15.89 b	5.50 a	22.95 ab
T3 - 30% - Sprawling canopy	2.03 ab	16.40 b	6.69 ab	25.12 bc
T4 - 60% - Suckered VSP	2.37 bc	16.73 b	7.70 bc	26.80 cd
T5 - 60% - Non-suckered VSP	2.83 cd	16.90 bc	8.44 c	28.18 d
T6 - 60% - Sprawling canopy	3.42 de	17.96 cd	10.94 d	32.32 e
T7 - 90% - Suckered VSP	3.86 e	17.87 cd	10.45 d	32.17 e
T8 - 90% - Non-suckered VSP	4.77 f	18.55 d	11.53 de	34.86 ef
T9 - 90% - Sprawling canopy	4.72 f	18.86 d	12.98 e	36.56 f

(1) Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

4.4 CONCLUSIONS

Irrigation applied at low PAW depletion levels, *i.e.* high frequency irrigation, more than doubled pre-harvest irrigation volumes compared to grapevines irrigated at high PAW depletion levels, *i.e.* low frequency irrigation. Post-harvest irrigation volumes of low frequency irrigation treatments were also lower compared to high frequency irrigation treatments. Due to accelerated sugar accumulation which resulted in different harvest dates, canopy management practice indirectly reduced pre-harvest irrigation volumes.

Except for differences in sugar accumulation, level of PAW depletion and canopy management did not have a pronounced effect on the phenological development of the grapevines of the different treatments under the given conditions. Furthermore, differences in atmospheric conditions had no pronounced effects on grapevine phenology. However, cooler conditions prior to flowering in the 2012/13 season seemed to have delayed flowering and fruit set by four and five days, respectively.

Low frequency irrigation seemed to accelerate berry ripening compared to high irrigation frequencies, probably due to smaller berries and lower yields. It was visually observed that sprawling canopy grapevines had a larger exposed leaf area throughout the day compared to VSP grapevines. Sunlight interception could be linked to exposed leaf area. Sprawling canopies consistently enhanced berry ripening due to more sunlight interception by the leaves. Berry ripening of the VSP grapevines was slower, and inconsistent between seasons.

Level of PAW depletion and canopy management practice did not affect the number of leaves per primary shoot. However, differences in the number of leaves per secondary shoot caused differences in the total number of leaves per shoot, *i.e.* primary plus secondary. Low frequency irrigation tended to reduce the number of leaves per secondary shoot, and consequently the total number of leaves per shoot. Leaf area seemed to be a function of leaf number and size, but results indicated that leaf number per shoot made a more important contribution to the leaf area than leaf size *per se*. Therefore, total leaf area per shoot reflected in the leaf area per secondary shoot, which followed similar trends as the number of leaves per secondary shoot.

Under the given conditions, level of PAW depletion did not affect the number of shoots per grapevine. However, suckered VSP grapevines reduced the number of shoots per grapevine compared to non-suckered VSP and sprawling canopy grapevines. Low frequency irrigation reduced the total leaf area per grapevine compared to high frequency irrigation. The effects of canopy management practice were more pronounced in the case of high frequency irrigations compared to low frequency irrigation. Excessive vigour induced by high frequency irrigation, was probably more evenly distributed among the higher number of shoots on the non-suckered VSP and sprawling canopy grapevines compared to less shoots on the suckered VSP grapevines. This suggests that altering the canopy by topping, *i.e.* reducing the growth of primary shoots, the grapevine will compensate by initiating more secondary shoots. However, in the case of non-manipulated canopies, *i.e.* by not removing shoots not allocated on the spurs, less secondary shoots will be initiated.

At pruning, primary cane length was not affected by level of PAW depletion or canopy management practice as all the grapevines were topped about 30 cm above the top trellis wire. However, low frequency irrigation tended to produce thinner and lighter primary canes compared to high frequency irrigation. Suckered VSP grapevines tended to have thicker and heavier primary canes compared to non-suckered VSP and sprawling canopy grapevines. Low frequency irrigation tended to produce shorter, thinner and lighter secondary canes compared to high frequency irrigation. Furthermore, sprawling canopy grapevines tended to have shorter secondary canes compared to suckered and non-suckered VSP grapevines. Secondary cane mass and diameter were not affected by canopy management practice. Multiple linear regression analysis showed that primary cane mass was a highly significant function of primary cane length and diameter. Visual similarity of the 95% confidence intervals for the predicted versus observed primary cane mass showed no differences between seasons. Therefore, the data could be combined into a single model. Similar results were obtained for secondary cane mass which depended on secondary cane length and diameter. The above mentioned differences in cane length, diameter and mass reflected in the pruning mass (t/ha). Furthermore, these results indicated that differences in pruning mass were primarily determined by treatment effects on secondary cane mass.

Low frequency irrigation, *i.e.* 90% PAW depletion, increased grapevine water constraints compared to high frequency irrigation, *i.e.* 30% PAW depletion. Sprawling canopy grapevines also experienced more water constraints compared to suckered and non-suckered VSP grapevines. Diurnal plant water potential revealed that grapevines experienced medium water constraints where grapevines were irrigated at 30% PAW depletion and medium to strong water constraints where grapevines were irrigated at

60% PAW depletion. However, where grapevines were irrigated at 90% PAW depletion, grapevines experienced strong water constraints. Furthermore, sprawling canopy grapevines tended to have higher Ψ_T throughout the day compared to suckered and non-suckered VSP grapevines, irrespective of the PAW depletion level.

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Chapter 5

Research results

The effect of irrigation and canopy management practice on berry development and yield components

5. THE EFFECT OF IRRIGATION AND CANOPY MANAGEMENT PRACTICE ON BERRY DEVELOPMENT AND YIELD COMPONENTS

5.1 INTRODUCTION

Grapevines are mainly cultivated in regions with a Mediterranean climate where summer rainfall is usually low and the evaporative demand high (Williams *et al.*, 1994). In these regions, irrigation is usually necessary to compensate for the inadequate water supply from the winter rainfall stored in the soil (Van Zyl & Weber, 1981; Schultz, 1997). With this in mind, water allocations for agricultural purposes are already restricted and with the rapid increase in water scarcity (Sepaskhah & Akbari, 2005), future allocations will be restricted even more (Petrie *et al.*, 2004). It is evident that irrigation water should be used more effectively, either by producing the same yields with less irrigation water or by producing higher yields with the same volume of water.

It is well documented that soil water availability influences berry size, *i.e*. a reduction in size as the soil dries out, irrespective of grapevine cultivar (Hardie & Considine, 1976; Van Zyl, 1984; Williams *et al.*, 1994; McCarthy, 1997; Schultz, 1997; Ojeda *et al.*, 2002; Petrie *et al.*, 2004; Van Leeuwen *et al.*, 2009; Lategan, 2011; Myburgh, 2011b; Frenandes de Oliveira *et al.,* 2013). Although grapevines that experience water deficit during the post-véraison period reduced berry mass compared to irrigated grapevines (Hardie & Considine, 1976; Petrie *et al.*, 2004), the most sensitive period for water deficit is between post-flowering and véraison (Hardie & Considine, 1976; Williams *et al.*, 1994; McCarthy, 1997). The latter period corresponds with the first and second stage of berry development (Coombe, 1992). However, the first stage, *i.e.* cell division, is where berry size is determined subsequently the effect of water deficit in this particular stage is irreversible (Ojeda *et al.*, 2001). Furthermore, the double-sigmoid growth curve of berry development will not be affected by water constrains (Williams *et al.*, 1994).

Canopy management practices is applied to alter the number of leaves and the amount of shoots and fruit in a certain amount of space to achieve a desired canopy microclimate (Smart *et al.*, 1990). These practices include pruning, suckering, shoot positioning, leaf removal and using improved training systems (Smart *et al.*, 1990). Practices such as different training systems did not seem to affect berry mass (Swanepoel *et al.*, 1990; Wolf *et al.*, 2003). However, canopy management practices such as mechanical pruning, minimal pruning and no pruning reduced berry mass compared to spur pruning (Archer & Van Schalkwyk, 2007). It seems that the number of shoots bearing bunches, *i.e.* bunches per grapevine, is the component responsible for a reduction in the latter case. This could be attributed to smaller bunches with less berries resulting in lighter berries.

Since yield is a function of berry mass, berry numbers per bunch, bunch mass and bunch numbers, it is evident that a reduction in yield will primarily be a result of a reduction in berry size (Petrie *et al.*, 2004). Ways on improving yield with a reduction in water applied and compensation thereof through canopy management should be investigated.

The objective of this study was therefore to determine the combined effects of irrigation and canopy management practices on berry mass and volume, bunch mass and numbers, yield, grape damage, as well as juice characteristics of grapevines.

5.2 MATERIALS AND METHODS

5.2.1 Berry development

5.2.1.1 Berry mass and volume

Berry mass and volume were determined from véraison to harvest in the 2011/12 and 2012/13 seasons. Fifty-berry samples per plot were collected fortnightly until the total soluble solids (TSS) in the juice reached *ca*. 20°B. Following this, berry samples were collected weekly until harvest, *i.e.* when the TSS reached *ca.* 24°B. Berry mass was determined by weighing the samples of both seasons using an electronic balance. Berry volume was determined by water displacement, only in the 2011/12 season. At harvest, ten randomly selected bunches were picked from each experiment plot. These bunches were used to determine bunch mass, number of berries per bunch, berry mass and volume, sunburn damage and the incidence of *Botrytis cinerea* (sour) rot. All berries from each bunch were picked and counted to determine the above-mentioned parameters.

5.2.1.2 Juice characteristics

The TSS, total titratable acidity (TTA) and pH were determined in the juice of the berries that were collected as explained above. Juice TSS, TTA and pH were determined according to standard procedures of the Infruitec-Nietvoorbji Institute of the Agricultural Research Council (ARC) near Stellenbosch. Sugar content per berry (mg/berry) was determined according to the method described by Deloire (2011).

5.2.2 Yield and its components

5.2.2.1 Bunch numbers

At harvest, all bunches of the experiment grapevines on each plot were picked and counted. The number of bunches per grapevine was calculated by dividing total bunch number, *i.e*. including the ten sampled bunches, per plot by number of experiment grapevines per plot.

5.2.2.2 Bunch mass

Bunch mass was determined by weighing the ten-bunch samples (section 5.2.1.1) to calculate average bunch mass per experiment plot.

5.2.2.3 Total grapevine yield

At harvest, all the grapes were picked and weighed to obtain the total mass per experiment plot. Yield per grapevine was calculated and converted to ton per hectare.

5.2.3 Grape damage

To determine the incidence of sour rot, the number of infected bunches per ten bunch-sample were counted. Following this, all the berries were picked from each of the ten bunches. The sunburnt, sour rot infected and unscathed berries were separated. For each group, the number of berries was counted and weighed to obtain mean berry mass of sunburnt, sour rot infected and unscathed berries, respectively. The number of sunburnt and grey rot berries, respectively, was expressed as a percentage of the total number of berries per sample. The difference between damaged and unscathed berries was calculated and used to obtain percentage weight loss caused by sunburn or sour rot. Percentage yield loss was calculated by dividing the weight loss of damaged berries by the total mass of unscathed berries based on the total number of berries per sample.

Total estimated yield loss percentage was calculated by adding the estimated yield loss percentage as a result of sunburn, as well as sour rot.

5.2.4 Statistical analysis

The data were subjected to an analysis of variance. Least significant difference (LSD) values were calculated to facilitate comparison between the treatment means. Means that differed at $p \leq 0.05$ were considered to be significantly different. STATGRAPHICS® was used for the analyses of variance, and to calculate linear regression.

5.3 RESULTS AND DISCUSSION

5.3.1 Berry development

5.3.1.1 Berry mass and volume

2011/12 season: Berry mass decreased after reaching a maximum, irrespective of level of PAW depletion and canopy management practice (Fig. 5.1). According to previous research, berry mass of Shiraz grapevines also decreased irrespective of level of PAW depletion (McCarthy, 2000; Lategan, 2011). However, the extent of the decrease was more pronounced in the case of the later harvest dates. This was consistent with previous results where berry mass decreased more in the case of fully irrigated grapevines compared to non-irrigated grapevines (McCarthy, 1997). This trend was apparently not influenced by the canopy management practise. Under the given conditions, level of PAW depletion seemed to have limited the decrease indirectly by advancing the harvest date. Irrigation at 90% PAW depletion reduced berry mass compared to irrigation at 30% PAW depletion, irrespective of canopy management practice (Fig. 5.1). Similar results have been reported by Hardie & Considine (1976), Van Zyl (1984), McCarthy (1997), Lategan (2011) and Myburgh (2011b). Irrigation at 60% PAW depletion only tended to reduce berry mass compared to irrigation at 30% PAW depletion, only in the case of the sprawling canopy grapevines (T9). Within a canopy management practice, grapevines irrigated at 90% PAW depletion, had smaller berries at harvest compared to 30% PAW depletion (Fig 5.1). In the case of the suckered VSP grapevines, irrigation at 30% and 60% PAW depletion resulted in the same berry mass at harvest (Fig. 5.1A). No difference in berry mass was found Colombar grapevine irrigated at 10%, 30% and 50% PAW depletion levels (Van Zyl, 1984).

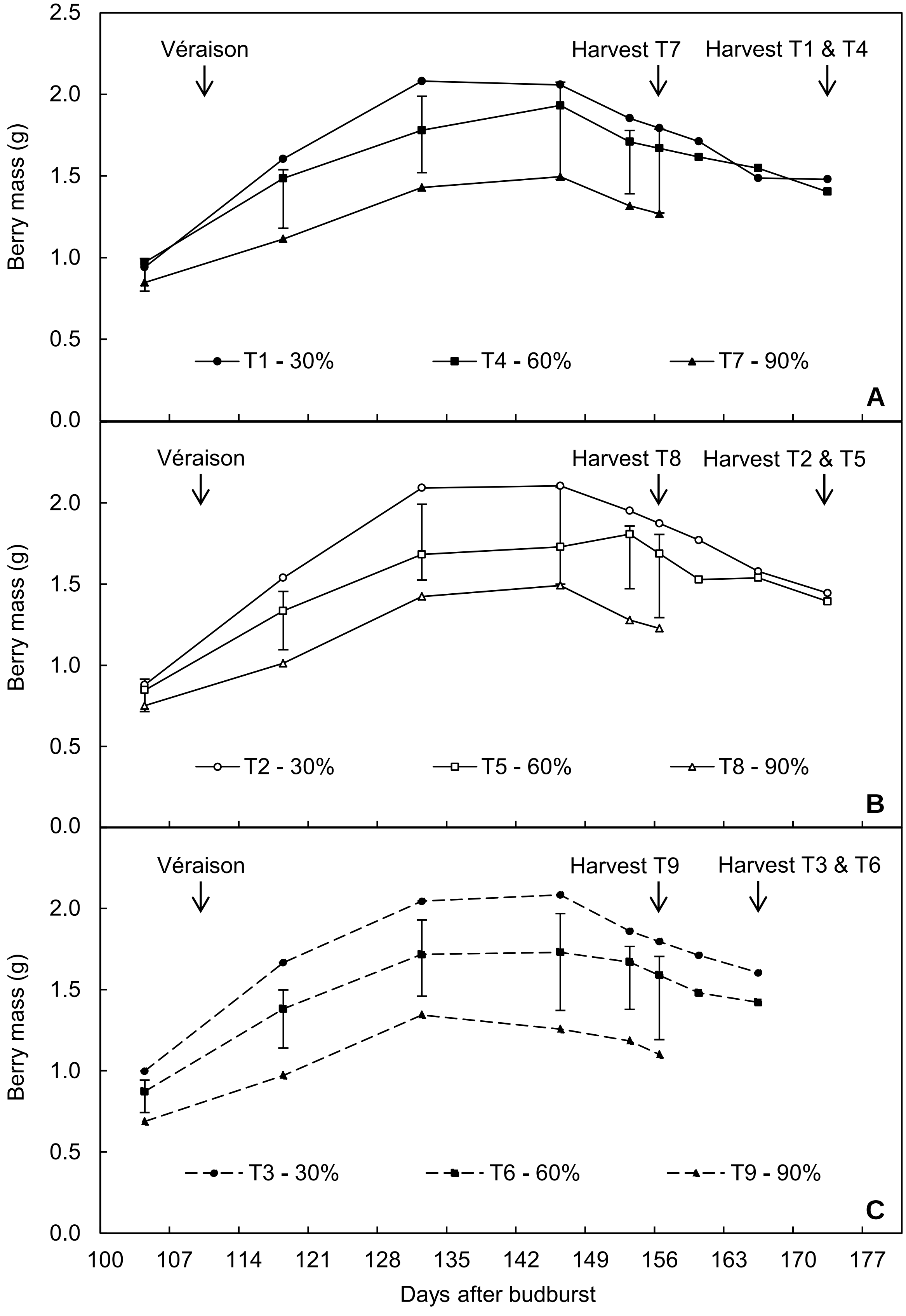

Figure 5.1 The effect of plant available water (PAW) depletion and different canopy management practices on berry mass of (A) suckered VSP, (B) non-suckered VSP and (C) sprawling canopy Shiraz/110R grapevines during the 2011/12 growing season near Robertson. Vertical bars indicate LSD ($p \leq 0.05$).

However, where grapevines were irrigated at 75% PAW depletion, berry mass was reduced compared to the latter depletion levels. This was probably because berries of the 30% PAW depletion level lost more water during the final stages of ripening, under the given conditions. Berry mass of the non-suckered VSP grapevines showed a similar trend (Fig. 5.1B).

As expected, berry volume showed the same temporal variation as berry mass (data not shown). Linear regression showed that the ratio between berry mass and volume was 1:0.932 (Fig. 5.2). This ratio was comparable to a mean of 1:0.940 reported for nine different cultivars in the Stellenbosch and Robertson grape growing regions (Archer & Van Schalkwyk, 2007). However, if only the Robertson data is considered, the ratio was 1:0.928 for six different cultivars. Therefore, the ratio obtained in this study was almost identical to the ratio reported for this region. Furthermore, it is important to note that this ratio remained constant irrespective of the sampling date. However, this does not rule out the possibility that the ratio could have been different in the earlier stages of berry development. Gray and Coombe (2009) reported a highly significant ratio between berry mass and volume throughout all developmental stages by fitting logarithmic curve which had a better fit compared to simple linear regression. Determining the ratio in the earlier stages of berry development was beyond the scope of this study.

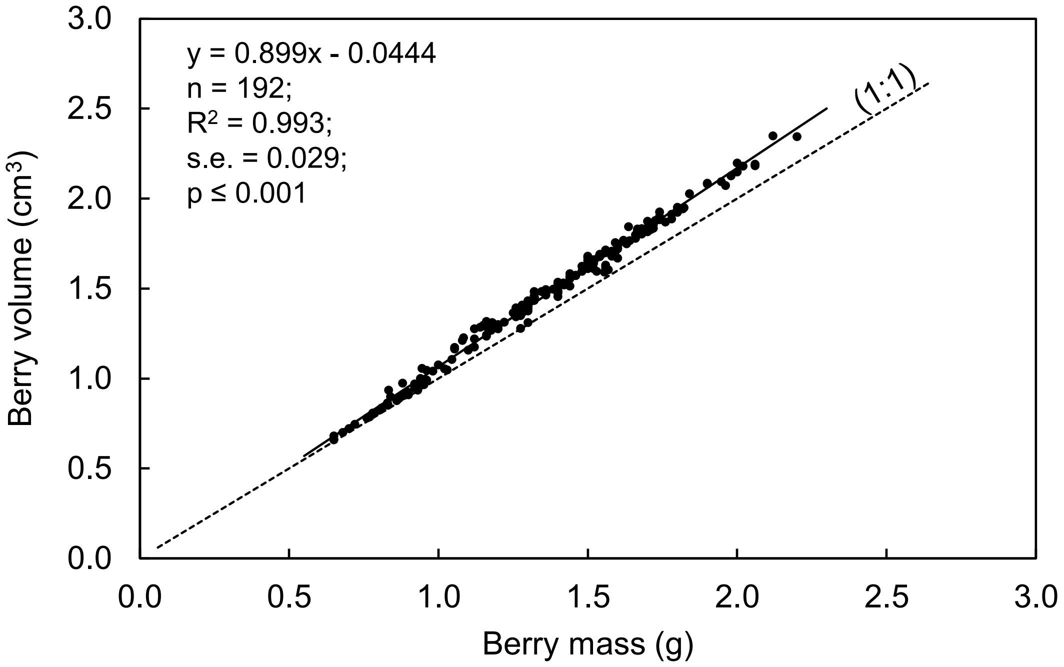

Figure 5.2 The relationship between berry mass and volume of Shiraz/110R grapevines determined during the 2011/12 growing season near Robertson. Dashed line indicates 1:1 relationship.

2012/13 season: Similar to the 2011/12 season, berry mass decreased after reaching a maximum, particularly in the case of suckered and non-suckered VSP grapevines irrigated at 30% and 60% PAW depletion (Fig. 5.3). Irrigation at 90% PAW depletion reduced berry mass during berry ripening compared to irrigation at 30% and 90% PAW depletion, irrespective of canopy management practice (Fig. 5.3). Within a specific canopy management practice, grapevines irrigated at 90% PAW depletion had smaller berries at harvest compared to 30% and 60% PAW depletion (Fig. 5.3). In the case of grapevines with sprawling canopies, irrigation at 60% and 90% PAW depletion advanced the harvest date by approximately 20 days compared to irrigation at 30% PAW depletion (Fig. 5.3). In the case of the suckered and non-suckered VSP grapevines, irrigation at 30% and 60% PAW depletion again resulted in the same berry mass at harvest (Figs. 5.3A & 5.3B). This confirmed that berry mass was insensitive to low levels of PAW depletion under the given conditions, as discussed above.

5.3.1.2 Juice characteristics

2011/12 season: Irrigation at 90% PAW depletion, tended to increase the TSS accumulation compared to irrigation at 30% and 60% PAW depletion (Fig. 5.4). Due to this, grapevines irrigated at 90% PAW depletion reached the target TSS of 24°B earlier compared to grapevines irrigated at 30% and 60% PAW depletion, irrespective of canopy management practice (Fig. 5.4). This was in agreement with an earlier study at the same locality which showed that 90% PAW depletion also enhanced sugar accumulation compared to high frequency irrigation (Lategan, 2011). In addition to this, Colombar grapevines irrigated at low frequencies also enhanced sugar accumulation compared to high frequency irrigation in the same region (Van Zyl, 1984). In contrast, Myburgh (2011a) reported no difference in juice TSS of Shiraz grapevines irrigated at high and low irrigation frequencies in the Lower Olifants River region. Furthermore, it was reported that sugar accumulation in Merlot berries was not slower for non-irrigated grapevines compared to grapevines irrigated at low frequencies near Wellington (Myburgh 2011b). It must be noted that sprawling canopy grapevines reached the target TSS seven days earlier compared to suckered and non-suckered VSP grapevines (Fig. 5.4). This agrees with previous findings where grapevines were subjected to different canopy management practices that were comparable to treatments applied in this study (Volschenk & Hunter, 2001).

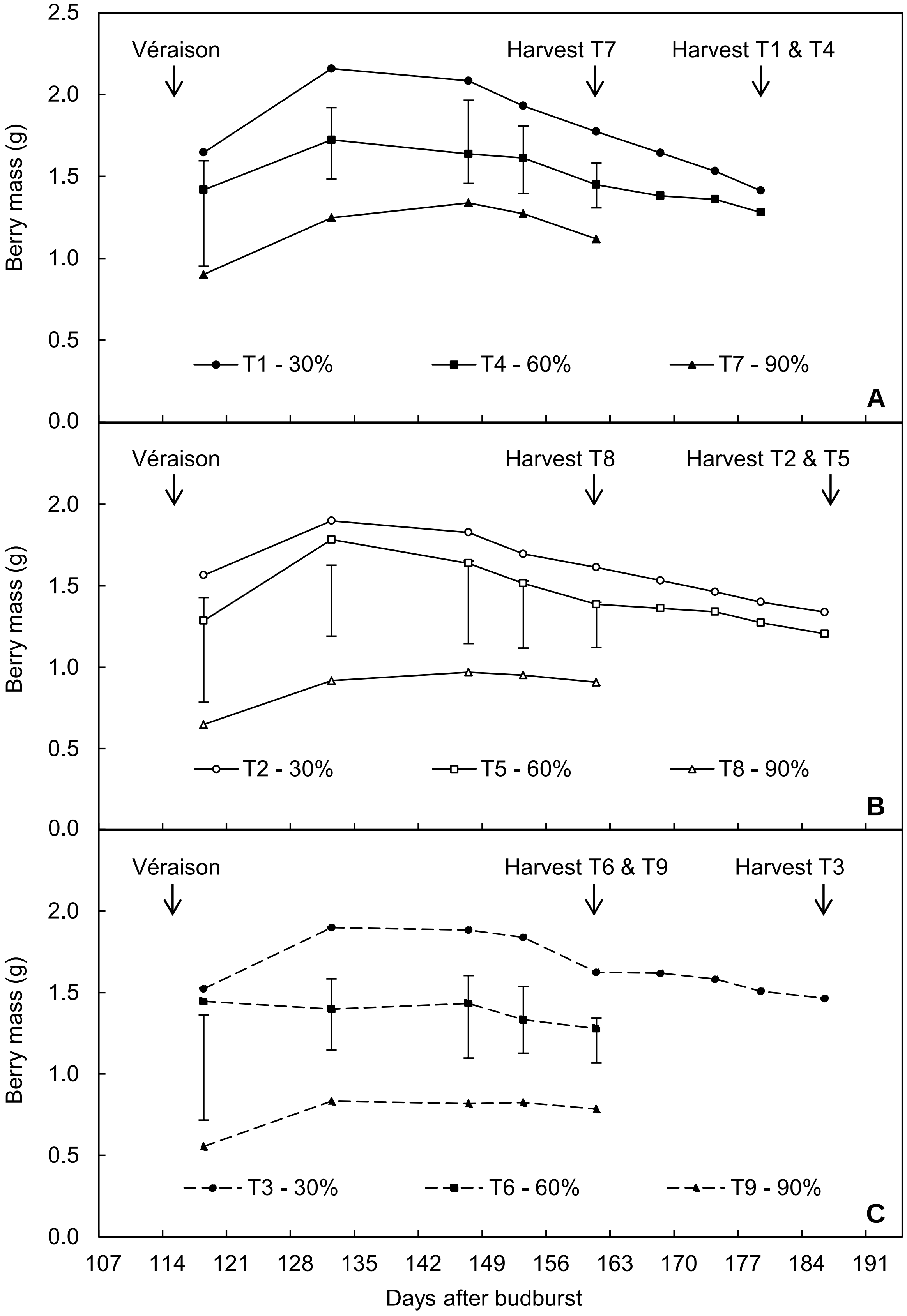

Figure 5.3 The effect of plant available water (PAW) depletion and different canopy management practices on berry mass of (A) suckered VSP, (B) non-suckered VSP and (C) sprawling canopy, Shiraz/110R grapevines during the 2012/13 growing season near Robertson. Vertical bars indicate LSD ($p \leq 0.05$).

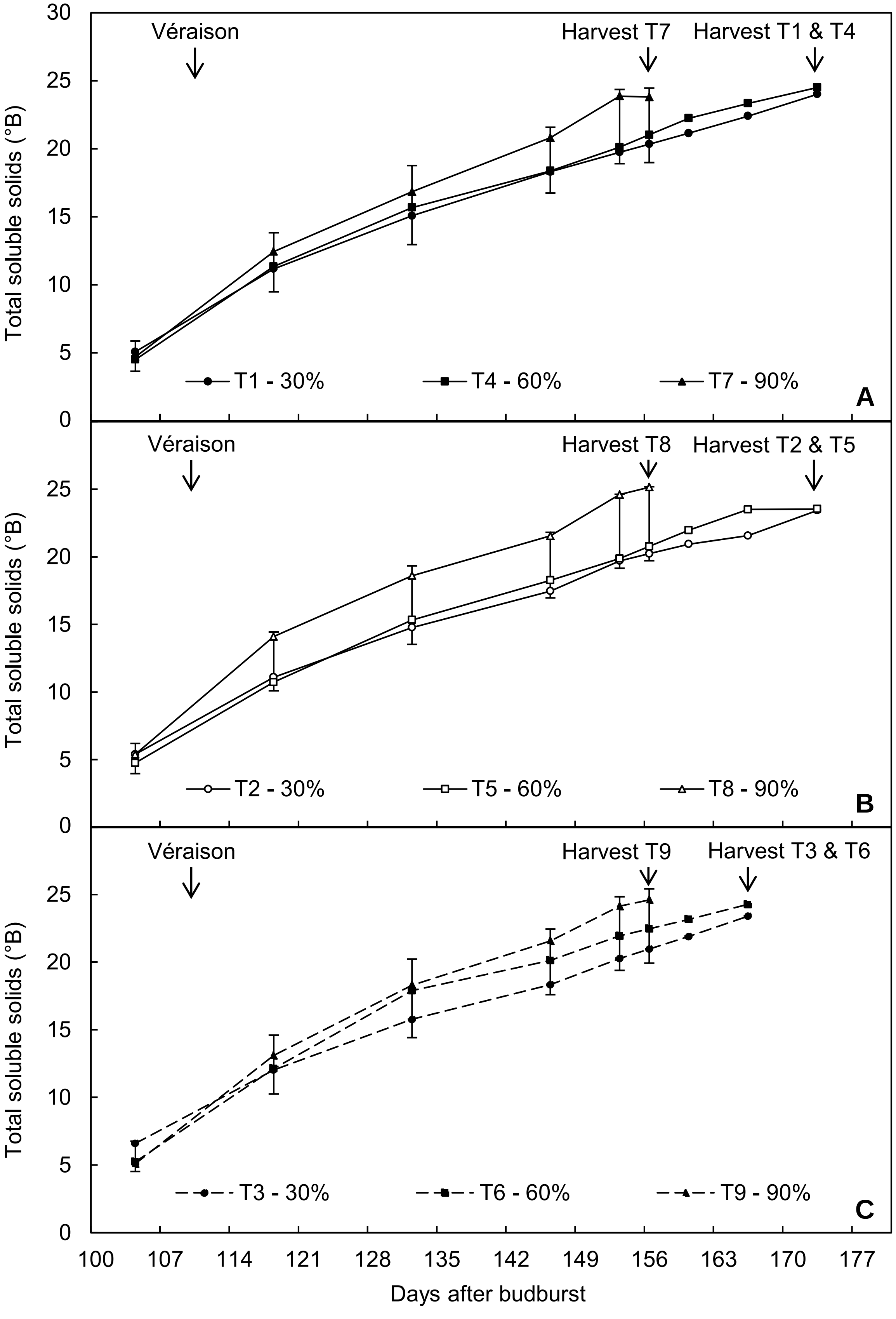

Figure 5.4 The effect of plant available water (PAW) depletion and different canopy management practices on total soluble solids of (A) suckered VSP, (B) non-suckered VSP and (C) sprawling canopy Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

However, grapes were harvested on the same day, irrespective of sugar content. This confirmed that juice TSS concentration in grapes on sprawling canopy grapevines will accumulate more rapidly compared to suckered and non-suckered VSP grapevines. Sugar content per berry tended to incline until it reached a plateau (Fig. 5.5), irrespective of canopy management practice. Previous research has also shown such plateaus in sugar content per berry of irrigated and non-irrigated Shiraz grapes (Hunter & Deloire, 2001, Mehmel, 2010). Since, the target TSS was reached later in the case of the suckered and non-suckered grapevines, the plateau appeared to be more prominent. Furthermore, it seemed that the plateau was reached earlier in the case of sprawling canopy grapevines compared to the VSP grapevines, particularly where grapevines were irrigated at 60% and 90% PAW depletion (Figs. 5.5B & 5.5C).

Since sugar content per berry is a quantity and not a concentration, the sugar content per berry will be higher in berries with larger volumes, and lower in berries with smaller volumes. Given the fact that berry volume is closely correlated to berry mass, berries with larger volumes will have higher masses compared to berries with smaller volumes. Therefore, at any given level of PAW depletion and/or canopy management practice sugar content per berry will closely follow any trends in berry mass development (Figs. 5.1 & 5.5).

At harvest in the 2011/12 season, level of PAW depletion and canopy management practice had no effect on the TSS of the juice (Table 5.1). This was due to the fact that grapevines of a specific treatment were harvested when the target TSS of 24°B was reached. Juice TTA was higher where grapevines was irrigated at 90% PAW depletion compared to irrigation at 30% and 60% PAW depletion, irrespective of canopy management practice (Table 5.1). This was probably due to the fact that grapevines irrigated at 90% PAW depletion were harvested earlier compared to irrigation at 30% and 60% PAW depletion. These results were consistent with the findings of the first season in a previous study carried out in the same vineyard (Lategan, 2011). However, in the following two seasons, different levels of PAW depletion did not affect juice TTA in the latter study. Within a specific level of PAW depletion, canopy management practice had no effect on the juice TTA (Table 5.1). Neither level of PAW depletion, nor canopy management practice affected juice pH. This was consistent with results obtained only in one of three seasons in a previous study carried out in the same vineyard (Lategan, 2011).

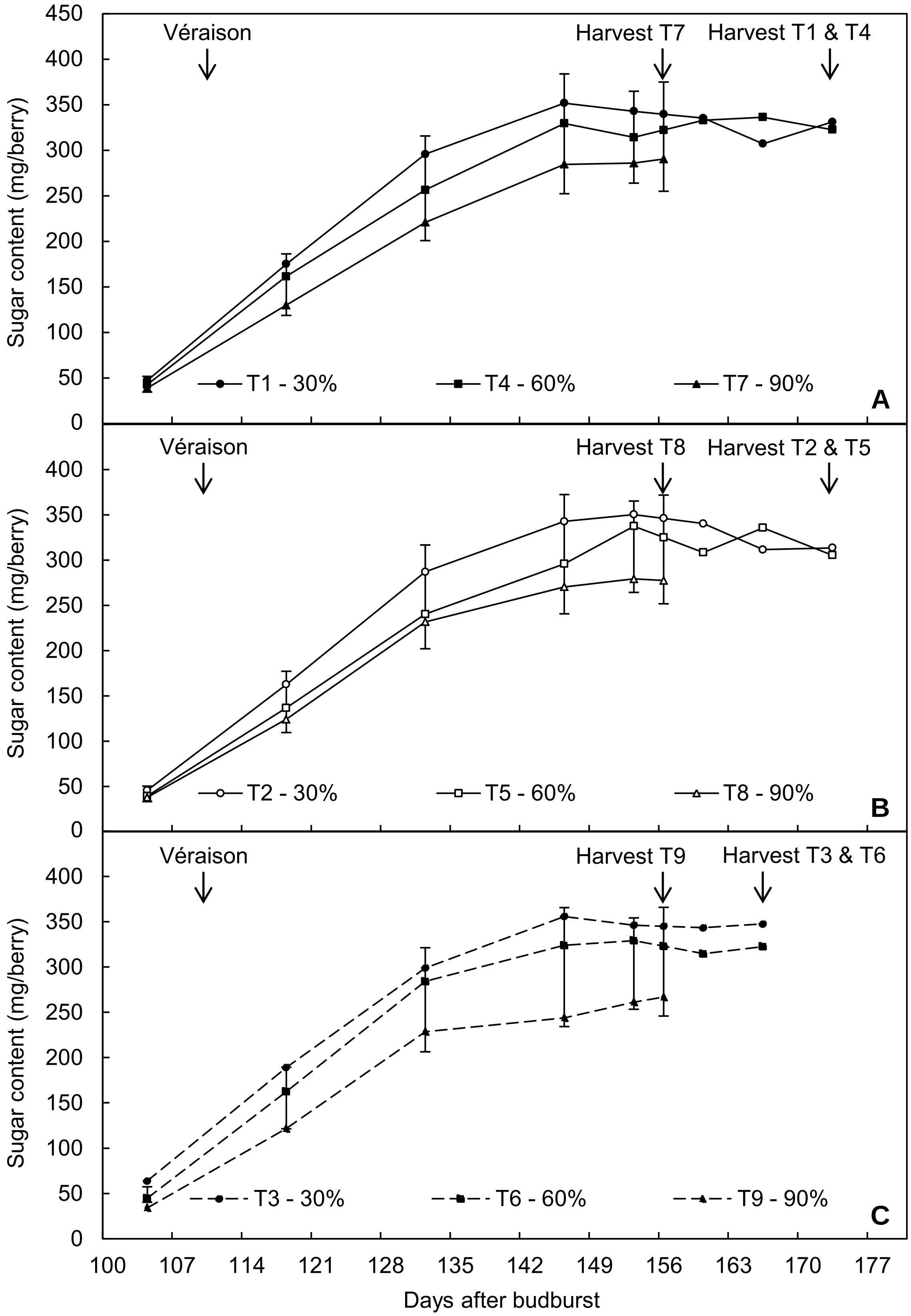

Figure 5.5 The effect of plant available water (PAW) depletion and different canopy management practices on sugar content per berry of (A) suckered VSP, (B) non-suckered VSP and (C) sprawling canopy Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

Furthermore, juice pH was not affected where Shiraz grapevines were irrigated at low and high frequencies in the Lower Olifants River region (Myburgh, 2011a). The foregoing suggested that juice pH appears to be rather insensitive to level of PAW depletion.

Table 5.1 The effect of plant available water (PAW) depletion and different canopy management practices on total soluble solids (TSS), total titratable acidity (TTA) and pH of Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

PAW depletion and canopy management practice	TSS (°B)	TTA (g/L)	pH
T1 - 30% - Suckered VSP	24.3 a(1)	5.25 b	3.95 a
T2 - 30% - Non-suckered VSP	23.0 a	5.10 b	3.82 a
T3 - 30% - Sprawling canopy	23.4 a	5.03 b	3.89 a
T4 - 60% - Suckered VSP	24.0 a	4.90 b	3.99 a
T5 - 60% - Non-suckered VSP	23.8 a	4.80 b	3.97 a
T6 - 60% - Sprawling canopy	23.4 a	4.83 b	3.98 a
T7 - 90% - Suckered VSP	24.0 a	6.62 a	3.83 a
T8 - 90% - Non-suckered VSP	24.3 a	6.45 a	3.90 a
T9 - 90% - Sprawling canopy	24.8 a	6.27 a	3.85 a

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$)

2012/13 season: Irrigation at 90% PAW depletion, tended to increase the TSS accumulation compared to irrigation at 30% and 60% PAW depletion (Fig. 5.6). Due to this, grapevines irrigated at 90% PAW depletion reached the target TSS of 24°B earlier compared to grapevines irrigated at 30% and 60% PAW depletion, irrespective of canopy management practice (Fig. 5.6). Furthermore, in the case of sprawling canopy grapevines, irrigation at 60% PAW depletion tended to increase TSS accumulation compared to 30% PAW depletion (Fig. 5.6C). In this particular season, sugar accumulation of suckered VSP grapevines irrigated at 30% and 60 % PAW depletion, reached the target TSS of 24°B earlier compared to non-suckered VSP grapevines (Figs. 5.6A & 5.6B). This trend was probably due to a higher leaf area per grapevine in relation to crop load enhancing berry ripening (Kliewer & Dokoozlian, 2005). In the latter study, a leaf area to crop weight ratio of 3.99:1 enhanced the harvest date by ten days, 17 days and 25 days compared to ratios of 1.55:1, 1.05:1 and 0.82:1, respectively. In the case of non-suckered VSP grapevines, sugar accumulation was exactly the same throughout berry ripening where grapevines were irrigated at 30% and 90% PAW

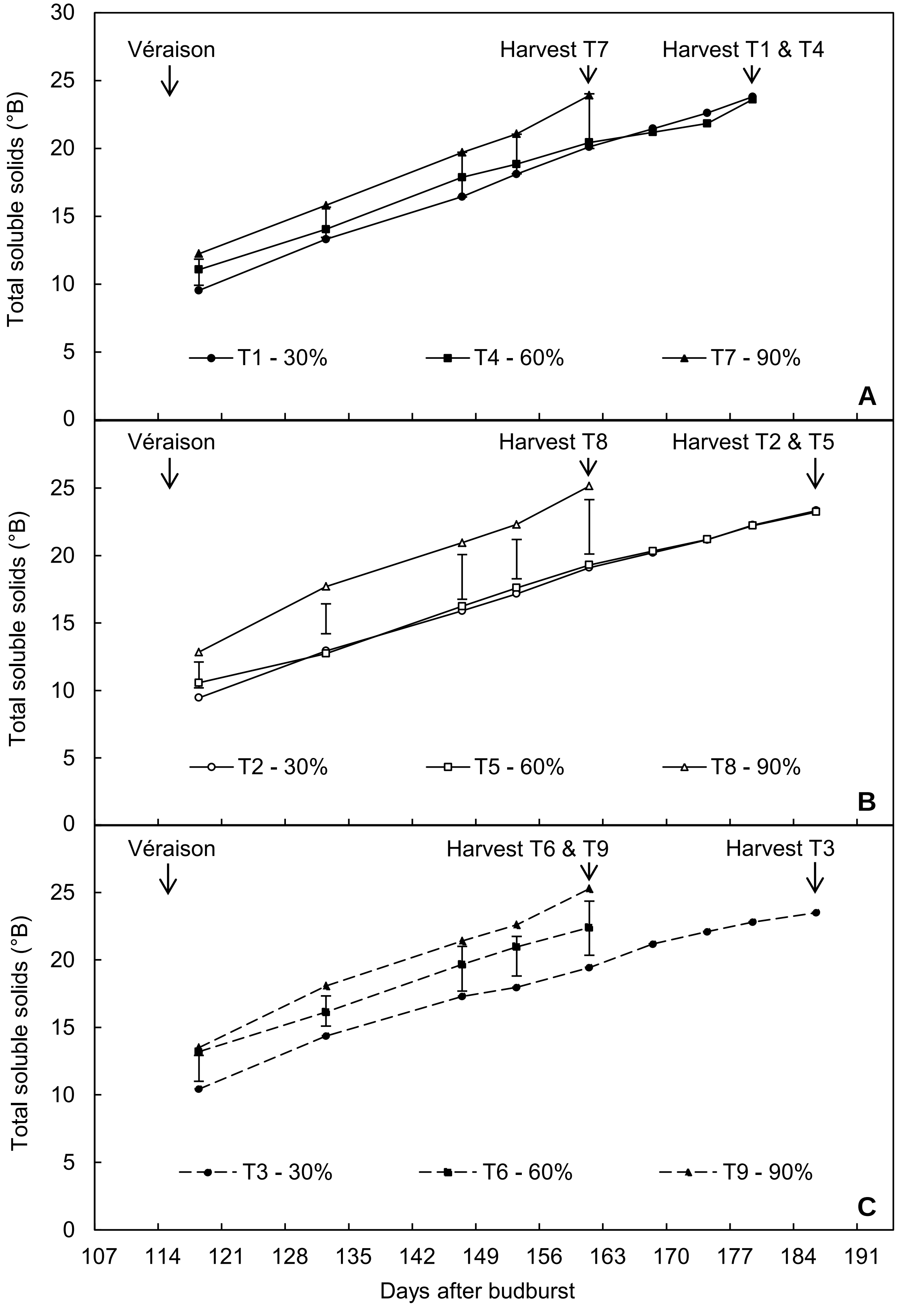

Figure 5.6 The effect of plant available water (PAW) depletion and different canopy management practices on total soluble solids of (A) suckered VSP, (B) non-suckered VSP and (C) sprawling canopy, Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

depletion (Fig 5.6B). In contrast to the 2011/12 season, sprawling canopy grapevines irrigated at 30% PAW depletion did not enhance berry ripening compared to non-suckered VSP grapevines (Figs 5.6B & 5.6C).

Similar to the 2011/12 season, sugar content per berry tended to incline until it reached a plateau (Fig. 5.7), irrespective of canopy management practice. Since the target TSS was reached later in the case of the suckered and non-suckered VSP grapevines, as well as sprawling canopy grapevines irrigated at 30% PAW depletion, the plateau appeared to be more prominent. Furthermore, it seemed that the plateau was reached earlier in the case of sprawling canopy grapevines irrigated at 90% PAW depletion compared to 30% and 60% PAW depletion, as well as all VSP grapevines (Fig. 5.7).

Juice TSS at harvest was higher where irrigation was applied at 90% PAW depletion compared to 30% and 60% PAW depletion, irrespective of the canopy management practice (Table 5.2). Furthermore, canopy management practice had no effect on the TSS within the different levels of PAW depletion. However, it must be noted that the higher sugar concentration where irrigation was applied at 90% PAW depletion was probably caused by logistical constraints where an increase of 3°B occurred over a weekend and the treatments could only be harvested on that Monday.

In the case of suckered grapevines, TTA was higher where irrigation was applied at 90% PAW depletion (T7) compared to 60% PAW depletion (T4), but only tended to be higher compared to irrigation at 30% PAW depletion (T1) (Table 5.2). In the case of sprawling canopy grapevines, TTA was higher where grapevines were irrigated at 90% PAW depletion (T9) compared to irrigation at 30% (T3) and 60% PAW depletion (T6). However, in the case of non-suckered VSP grapevines, where irrigation was applied at 90% PAW depletion (T8) the highest TTA occurred compared to 30% (T2) and 60% PAW depletion (T5). Furthermore, TTA was also higher where grapevines were irrigated at 30% PAW depletion (T2) compared to irrigation at 60% PAW depletion (T5). Where grapevines were irrigated at 30% PAW depletion, TTA was higher for T1 grapevines compared to T3 grapevines, but only tended to be higher compared T2 grapevines (Table 5.2).

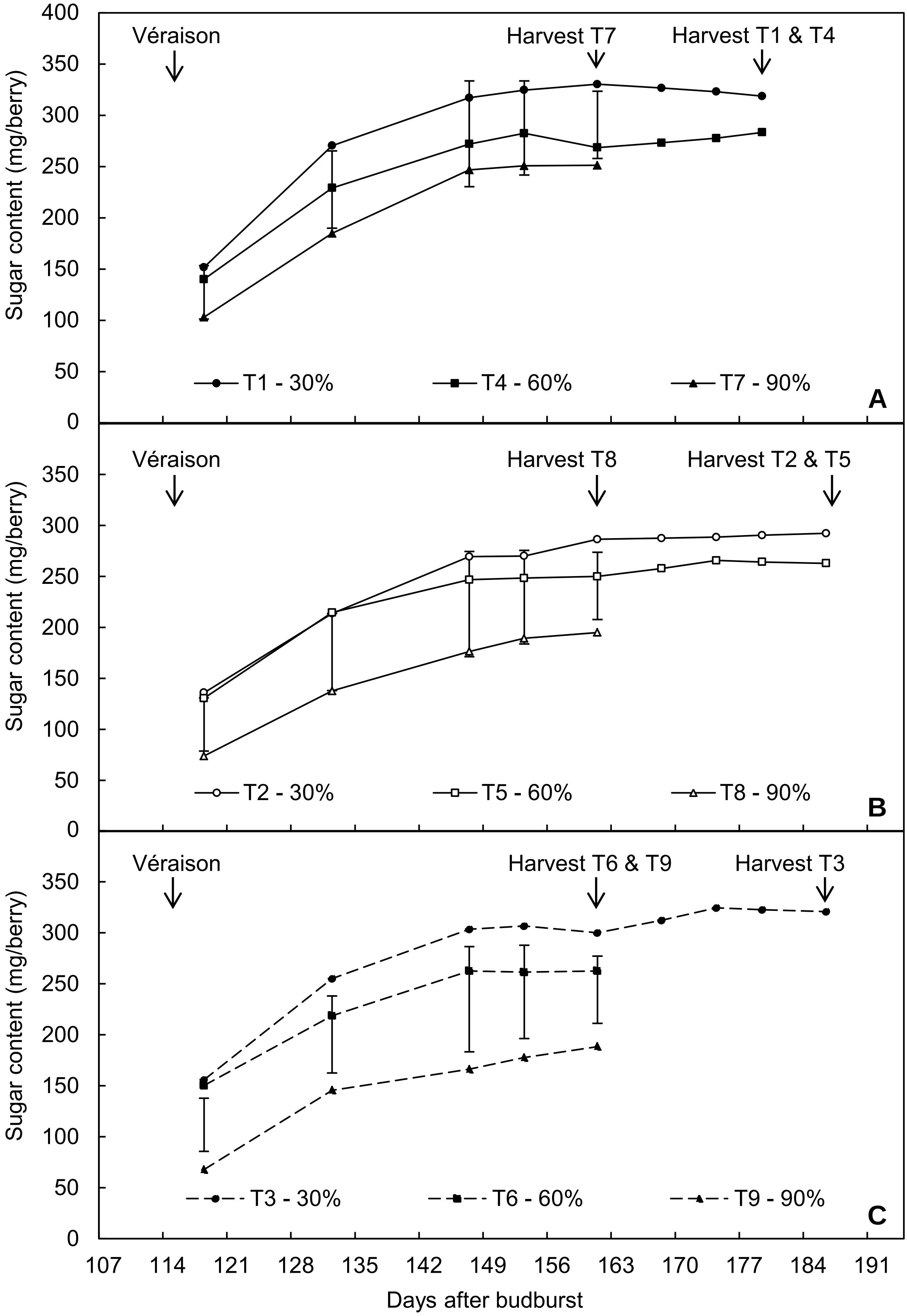

Figure 5.7 The effect of plant available water (PAW) depletion and different canopy management practices on sugar content per berry of (A) suckered VSP, (B) non-suckered VSP and (C) sprawling canopy Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

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Table 5.2 The effect of plant available water (PAW) depletion and different canopy management practices on total soluble solids (TSS), total titratable acidity (TTA) and pH of Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

PAW depletion and canopy management practice	TSS (°B)	TTA (g/L)	pH
T1 - 30% - Suckered VSP	23.8 c(1)	4.80 bc	3.93 a
T2 - 30% - Non-suckered VSP	23.3 c	4.77 cd	4.00 a
T3 - 30% - Sprawling canopy	23.5 c	4.40 de	4.08 a
T4 - 60% - Suckered VSP	23.6 c	4.30 e	3.95 a
T5 - 60% - Non-suckered VSP	23.2 c	4.27 e	3.97 a
T6 - 60% - Sprawling canopy	24.2 bc	4.20 e	4.00 a
T7 - 90% - Suckered VSP	25.4 ab	5.15 ab	3.93 a
T8 - 90% - Non-suckered VSP	25.6 ab	5.27 a	4.00 a
T9 - 90% - Sprawling canopy	26.1 a	5.37 a	4.11 a

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$)

These responses were similar to results reported for a field trial where comparable canopy management practices were applied to Chenin blanc grapevines (Volschenk & Hunter, 2001). Unfortunately, no information on the irrigation scheduling and soil water status was reported. In the current study, where grapevines were irrigated at 60% and 90% PAW depletion, canopy management had no effect on TTA. Level of PAW depletion and canopy management practice had no effect on the juice pH at harvest. The insensitivity of juice pH to level of PAW depletion agrees with the results obtained in the 2011/12 season.

5.3.2 Yield

5.3.2.1 Number of berries per bunch

2011/12 season: Within a specific canopy management practice, irrigation at 90% PAW depletion substantially reduced the number of berries per bunch compared to 30% PAW depletion (Table 5.3). Irrigation at 60% PAW depletion only tended to reduce the number of berries per bunch compared to 30% PAW depletion. Previous research showed that the number of berries per bunch of non-irrigated Cabernet Sauvignon grapevines was lower compared to irrigated grapevines near Wellington (Mehmel, 2010).

Table 5.3 The effect of plant available water (PAW) depletion and different canopy management practices on berries per bunch, bunches per grapevine, bunch mass and yield of Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

PAW depletion and canopy management practice	Berries per bunch	Bunches per grapevine	Bunch mass (g)	Yield per grapevine (kg/grapevine)	Yield (t/ha)
T1 - 30% - Suckered VSP	158 a(1)	33 de	200.6 a	6.6 bc	21.6 bc
T2 - 30% - Non-suckered VSP	136 ab	51 a	162.1 ab	8.3 a	27.1 a
T3 - 30% - Sprawling canopy	109 bc	49 a	157.7 ab	7.8 ab	23.9 ab
T4 - 60% - Suckered VSP	114 bc	31 de	170.5 ab	5.2 cd	17.1 cd
T5 - 60% - Non-suckered VSP	102 bcd	47 ab	144.1 bc	6.7 bc	22.0 bc
T6 - 60% - Sprawling canopy	86 cd	36 cd	121.9 bcd	4.3 d	14.1 d
T7 - 90% - Suckered VSP	82 cd	30 e	101.6 cd	4.2 d	13.7 d
T8 - 90% - Non-suckered VSP	69 d	42 bc	89.1 d	4.4 d	14.5 d
T9 - 90% - Sprawling canopy	66 d	45 ab	69.6 d	4.2 d	13.6 d

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$)

Within a given level of PAW depletion, where grapevines were irrigated at 30% PAW depletion there were fewer berries per bunch in the case of sprawling canopy grapevines compared to suckered VSP grapevines. In the case of 60% and 90% PAW depletion, canopy management practice had no effect on the number of berries per bunch.

2012/13 season: Within a specific canopy management practice, irrigation at 90% PAW depletion reduced the number of berries per bunch in the case of suckered and non-suckered VSP grapevines compared to irrigation at 30% PAW depletion (Table 5.4). However, irrigation at 60% PAW depletion only tended to reduce the number of berries per bunch of suckered and non-suckered VSP grapevines compared to irrigation at 30% PAW depletion. In the case of sprawling canopy grapevines (T3, T6 & T9), irrigation at 90% PAW depletion reduced the number of berries per bunch compared to irrigation at 30% and 60% PAW depletion. Furthermore, irrigation at 60% PAW depletion reduced the number of berries per bunch of sprawling canopy grapevines compared to 30% PAW depletion. Where grapevines were irrigated at 30% PAW depletion, the number of berries per bunch was lower on non-suckered VSP (T2) and sprawling canopy grapevines (T3) compared to suckered VSP grapevines (T1) (Table 5.4). In the case of irrigation at 60% PAW depletion, the number of berries per bunch was lower only on sprawling canopy grapevines (T6) compared to suckered (T4) and non-suckered VSP grapevines (T5). Where irrigation was applied at 90% PAW depletion, suckering increased the number of berries per bunch compared to non-suckered VSP grapevines (T8), whereas bunches on sprawling canopy grapevines (T9) had fewer berries compared to T8 grapevines. Results showed a trend towards more berries per bunch in the case of suckered VSP grapevines compared to non-suckered VSP and sprawling canopy grapevines.

5.3.2.2 Bunch numbers and mass

2011/12 season: In the case of suckered VSP grapevines (T1, T4 & T7), level of PAW depletion had no effect on the number of bunches per grapevine (Table 5.3). This agrees with previous findings in Cabernet Sauvignon grapevines where the number of bunches were more or less the same, irrespective of soil water status (Mehmel, 2010). However, in the case of the non-suckered VSP grapevines, irrigation at 90% PAW depletion (T8) reduced the number of bunches per grapevine compared to irrigation at 30% PAW depletion (T2).

Table 5.4 The effect of plant available water (PAW) depletion and different canopy management practices on berries per bunch, bunches per grapevine, bunch mass and yield of Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

PAW depletion and canopy management practice	Berries per bunch	Bunches per grapevine	Bunch mass (g)	Yield per grapevine (kg/grapevine)	Yield (t/ha)
T1 - 30% - Suckered VSP	171 a(1)	32 e	189.0 a	6.0 bc	19.6 bc
T2 - 30% - Non-suckered VSP	137 b	53 bc	135.6 bc	7.2 a	23.6 a
T3 - 30% - Sprawling canopy	141 b	50 c	137.2 bc	6.9 ab	22.5 ab
T4 - 60% - Suckered VSP	152 ab	38 de	162.6 ab	5.7 c	18.7 c
T5 - 60% - Non-suckered VSP	151 ab	61 a	114.9 cd	7.0 ab	22.9 ab
T6 - 60% - Sprawling canopy	114 c	57 ab	101.6 d	5.7 c	18.8 c
T7 - 90% - Suckered VSP	147 b	40 d	134.4 bc	5.0 cd	16.5 cd
T8 - 90% - Non-suckered VSP	106 c	56 abc	66.9 e	4.3 de	14.2 de
T9 - 90% - Sprawling canopy	78 d	62 a	52.4 e	3.9 e	12.7 e

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$).

The number of bunches of spur pruned grapevines was higher for grapevines experiencing less water constrains compared to grapevines experiencing more water constraints (Petrie *et al.*, 2004). In the case of sprawling canopy grapevines, irrigation at 60% PAW depletion (T6) reduced the number of bunches per grapevine compared to T3 grapevines, whereas 90% PAW depletion only tended to reduce the number of bunches per grapevine compared to T3 grapevines (Table 5.3). Within a given level of PAW depletion, suckering reduced the number of bunches per grapevine compared to non-suckered VSP and sprawling canopy grapevines, except where sprawling canopy grapevines were irrigated at 60% PAW depletion. At this stage there is no explanation for the latter response. The lower number of bunches per grapevine was the result of shoot removal when the VSP grapevines were suckered (T1, T4 & T7) (Table 4.7).

For a specific canopy management practice, bunches on suckered VSP grapevines irrigated at 90% PAW depletion were smaller compared to grapevines irrigated at 30% PAW depletion, but only tended to be smaller for grapevines irrigated at 60% PAW depletion (Table 5.3). A similar trend occurred in the case of non-suckered VSP grapevines. However, in the case of sprawling canopy grapevines irrigation at 60% and 90% PAW depletion reduced bunch size compared to irrigation at 30% PAW depletion. Furthermore, sprawling canopy grapevines irrigated at 90% PAW depletion reduced bunch size compared to irrigation at 60% PAW depletion. Within a given level of PAW depletion, canopy management practice did not affect the bunch mass except for a trend towards smaller bunches on the non-suckered VSP and sprawling canopy grapevines. In a study on alternative pruning methods, bunch mass was higher for spur pruned grapevines compared to mechanical, minimal and no pruned grapevines (Archer & Van Schalkwyk, 2007). However, the latter trend was due to less shoots per vine on the spur pruned grapevines compared to the other pruning treatments, which reduced bunch mass.

2012/2013 season: In the case of suckered VSP grapevines (T1, T4 & T7), irrigation at 30% PAW depletion reduced the number of bunches per grapevine compared to irrigation at 90% PAW depletion (Table 5.4). In the case of non-suckered VSP grapevines (T2, T5 & T8), irrigation at 30% PAW depletion reduced the number of bunches per grapevine compared to irrigation at 60% PAW depletion which resulted in the highest number of bunches per grapevines. Furthermore, irrigation at 90% PAW depletion only tended to reduce the number of bunches on non-suckered VSP grapevines compared to 60% PAW depletion. In the case of sprawling canopy grapevines, grapevines irrigated at 30% PAW depletion reduced the number of bunches compared to irrigation at 60% and 90%PAW depletion. Suckered VSP grapevines reduced the number of bunches per grapevine throughout the PAW depletion levels compared to non-suckered VSP and sprawling canopy grapevines (Table 5.4). This was probably as a result of shoot removal when the VSP grapevines were suckered (T1, T4 & T7) (Tables 4.9).

Within a canopy management practice, suckered VSP grapevines irrigated at 90% PAW depletion had smaller bunches compared to irrigation at 30% PAW depletion (Table 5.4). In the case of non-suckered VSP grapevines, 90% PAW depletion reduced bunch mass compared to 30% and 60% PAW depletion. However, in the case of sprawling canopy grapevines, bunch mass was reduced as the level of depletion increased. Within a given level of PAW depletion, non-suckered VSP and sprawling canopy grapevines reduced the bunch mass compared to suckered VSP grapevines.

5.3.2.3 Total grapevine yield

2011/12 season: Within a specific canopy management practice, irrigation at 90% PAW depletion reduced yield of suckered VSP grapevines compared to irrigation at 30% PAW depletion (Table 5.3). In the case of non-suckered VSP grapevines, irrigation at 60% PAW depletion reduced yield compared to irrigation at 30% PAW depletion, whereas irrigation at 90% PAW depletion resulted in a further yield reduction. However, in the case of sprawling canopy grapevines, irrigation at 60% and 90% PAW depletion reduced the yield compared to 30% PAW depletion. These results agrees with many previous findings that also showed that a reduction in yield with an increase in water deficit, irrespective of the cultivar (Hardie & Considine, 1976; Williams *et al.*, 1994; Myburgh, 1996; Schultz, 1997; Mehmel, 2010; Lategan, 2011; Myburgh, 2011b). Where grapevines with different canopies were irrigated at the same level of PAW depletion, suckering (T1) reduced the yield compared to non-suckered VSP grapevines irrigated at 30% PAW depletion (T2) (Table 5.3). Similar results were reported for Chenin blanc grapevines where suckering reduced yields compared to non-suckered grapevines (Volschenk & Hunter, 2001). In the case of 60% PAW depletion, sprawling canopy grapevines (T6) had a lower yield compared to non-suckered VSP grapevines (T5). However, canopy management practice did not affect the yield per grapevine where irrigation was applied at 90% PAW depletion. This indicated that irrigation at 90% PAW depletion reduced the sensitivity of yield to canopy management practice under the given conditions.

2012/13 season: Level of PAW depletion did not affect the yield per grapevine in the case of suckered VSP grapevines (Table 5.4). Since bunch mass decrease from 30% PAW depletion to 90% PAW depletion and bunches per grapevine decreased from 90% PAW depletion to 30% PAW depletion, it is possible that the yield could have remained the same given the little difference in berry mass between levels of PAW depletion at harvest (Table 5.4) (Fig. 5.1A). In the case of non-suckered VSP grapevines, grapevines irrigated at 90% PAW depletion reduced the yield compared to irrigation at 30% and 60% PAW depletion. However, in the case of grapevines with sprawling canopies, irrigation at 60% and 90% PAW depletion reduced the yield per grapevine compared to 30% PAW depletion. Furthermore, irrigation at 90% depletion also reduced yield for sprawling canopy grapevines compared to 60% PAW depletion. Where grapevines were irrigated at 30% PAW depletion, suckered VSP grapevines (T1) tended to decrease the yield per grapevine compared to non-suckered VSP (T2) and sprawling canopy grapevines (T3). In the case of irrigation at 60% PAW depletion, suckered VSP (T4) and sprawling canopy grapevines (T6) reduced the yield per grapevine compared to non-suckered VSP grapevines (T5). The reduced yield for T4 grapevines could be explained by shoot removal at suckering, but reduced yield for T6 grapevines was probably due to smaller bunches with less berries (Table 5.4). However, where grapevines were irrigated at 90% PAW depletion, non-suckered VSP (T8) tended to reduce and sprawling canopy grapevines (T9) reduced the yield compared to suckered VSP grapevines (T7). This was probably due to the bunch mass of T7 being more than double that of T8 and T9, but bunches per grapevine for T8 and T9 were not even close to double that of T7 (Table 5.4). The differences in bunch composition, *i.e.* berry size, berries per bunch and bunch size, were clearly visible in the vineyard (Fig. 5.8).

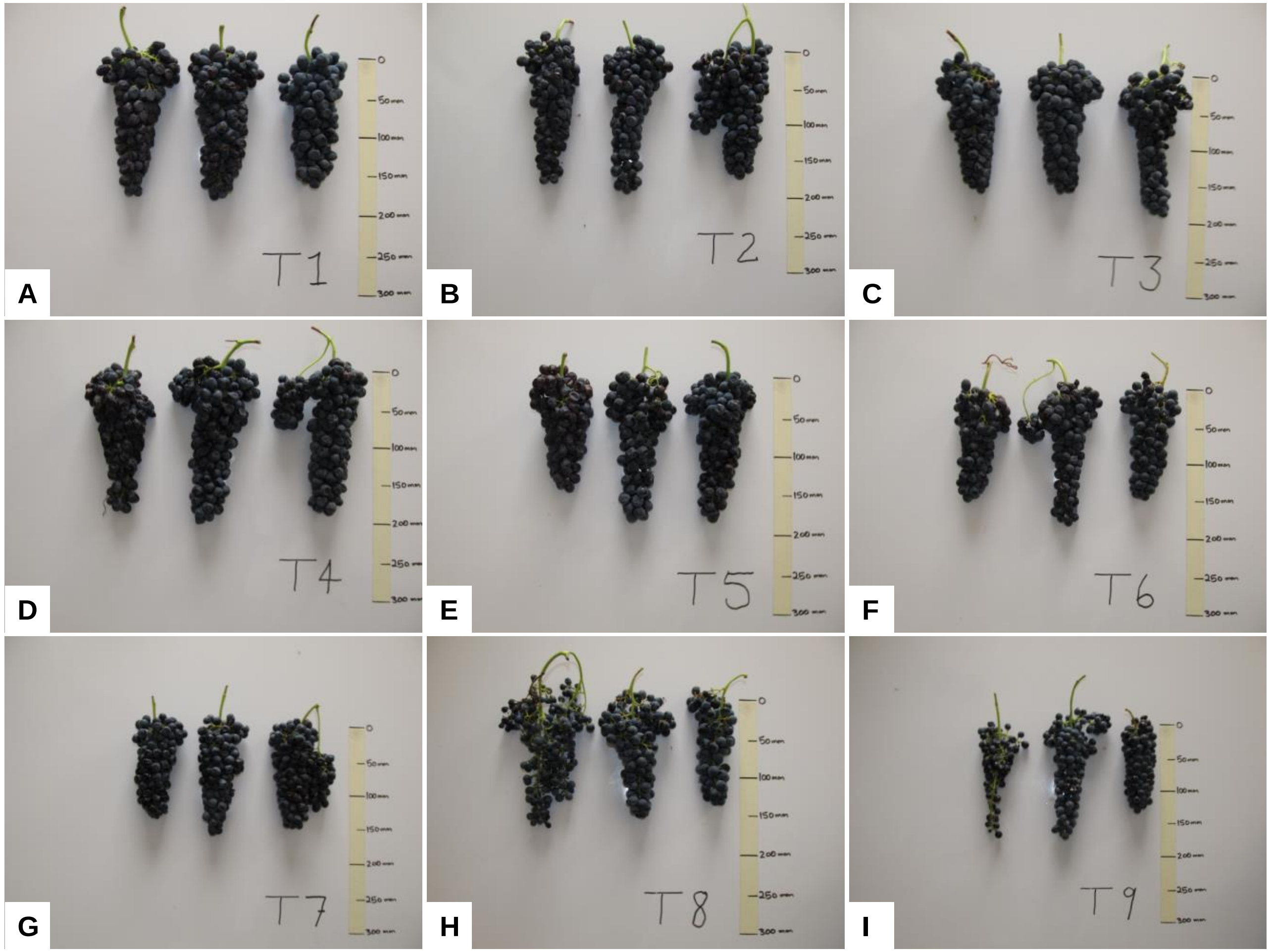

Figure 5.8 Examples illustrating the effect of plant available water (PAW) depletion and canopy management practice on bunches of Shiraz/110R grapevines, where (A) is suckered VSP, (B) is non-suckered VSP and (C) is sprawling canopy grapevines irrigated at 30% PAW depletion; (D) is suckered VSP, (E) is non-suckered VSP and (F) is sprawling canopy grapevines irrigated at 60% PAW depletion and (G) is suckered VSP, (H) is non-suckered VSP and (I) is sprawling canopy grapevines irrigated at 90% PAW depletion near Robertson. Photographs were taken at harvest in the 2012/13 season.

5.3.3 Grape damage

2011/12 season: Within a given canopy management practice, level of PAW depletion did not affect the percentage of sunburnt berries on suckered and non-suckered VSP grapevines (Table 5.5). However, in the case of the sprawling canopy grapevines, irrigation at 60% PAW depletion (T6), resulted in a higher percentage sunburnt berries compared to 30% (T3) and 90% PAW depletion (T9). At this stage there is no explanation for this trend. Where grapevines were irrigated at the same level of PAW depletion, more sunburnt berries occurred on sprawling canopy grapevines (Table 5.5). This trend also occurred where grapevines were irrigated at 60% and 90% PAW depletion, respectively. This indicated that bunches on the sprawling canopy grapevines were more exposed to direct sunlight than bunches on the VSP grapevines during the warmest part of the day. Visual observation revealed that leaves on the sprawling canopy grapevines covered a larger horizontal area, thereby creating gaps in the canopy. It was previously shown that sprawling canopy grapevines tended to intercept more sunlight in the bunch zone at 14:00 hours compared to suckered and non-suckered VSP Chenin blanc grapevines (Volschenk & Hunter, 2001). As expected, estimated yield loss percentage as a result of sunburn followed similar trends as the percentage sunburnt berries (Table 5.5).

The incidence of sour rot was comparable to previously reported levels (Volschenk & Hunter, 2001). However, the severity was considerably lower compared to results reported for Chenin blanc grapevines on a sprawling canopy. Chenin blanc is known to generally have more compact bunches, whereas Shiraz has fairly loose bunches (Goussard, 2008). Therefore, the severity of sour rot in the Chenin blanc bunches could have been attributed to the more compact bunches (Savage & Sall, 1984; Ferreira & Marais, 1987). Within a given level of PAW depletion, canopy management practice did not affect the incidence, severity or estimated yield losses due to sour rot, except where sprawling canopy grapevines were irrigated at 30% PAW depletion (Table 5.5). In vigorous growing vineyards, the disease levels are often high (Savage & Sall, 1984), as wide and dense canopies present problems in disease control due to reduced air movement and increased relative humidity inside these canopies (Creasy & Creasy, 2009). Although differences in growth vigour occurred (Table 4.7), it must be noted that it did not result in substantial differences in total estimated yield losses between treatments, except for slightly more losses in the case of sprawling canopy grapevines (Table 5.5).

Table 5.5 The effect of plant available water (PAW) depletion and different canopy management practices on sunburn, rot and estimated yield loss of Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

PAW depletion and canopy management practice	Sunburn		Rot			Total estimated yield loss
	Affected berries (%)	Estimated yield loss (%)	Incidence (%)	Severity (%)	Estimated yield loss (%)	(%)
T1 - 30% - Suckered VSP	1.64 d[1]	1.27 cd	7 bc	0.13 b	0.07 b	1.34 c
T2 - 30% - Non-suckered VSP	2.22 cd	1.77 bcd	10 bc	0.36 b	0.15 b	1.93 c
T3 - 30% - Sprawling canopy	5.91 b	5.11 b	60 a	3.39 a	2.67 a	7.78 ab
T4 - 60% - Suckered VSP	2.54 bcd	2.04 bcd	3 bc	0.17 b	0.11 b	2.14 c
T5 - 60% - Non-suckered VSP	3.14 bcd	2.65 bcd	13 b	0.49 b	0.23 b	2.88 c
T6 - 60% - Sprawling canopy	11.42 a	10.56 a	3 bc	0.04 b	0.02 b	10.57 a
T7 - 90% - Suckered VSP	0.98 d	0.71 d	0 c	0.00 b	0.00 b	0.71 c
T8 - 90% - Non-suckered VSP	3.50 bcd	2.76 bcd	0 c	0.00 b	0.00 b	2.76 c
T9 - 90% - Sprawling canopy	5.60 bc	4.75 bc	0 c	0.00 b	0.00 b	4.75 bc

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$)

2012/13 season: Level of PAW depletion and canopy management practice had no effect on the percentage of berries affected by sunburn, as well as the estimated yield loss percentage (Table 5.6). Although no statistical difference, a similar trend occurred as in the 2011/12 season where sprawling canopy grapevines were more affected by sunburn and its effect on estimated yield loss percentage throughout the levels of PAW depletion compared to suckered VSP and non-suckered VSP grapevines.

The incidence of sour rot was lower compared to the 2011/12 season. This could be due to atmospheric conditions during ripening, since more rain occurred in January and February of the 2011/12 season (Fig. 4.4). In this particular season, the incidence of rot were only prominent were grapevines were irrigated at 30% PAW depletion. However, in the case of sprawling canopy grapevines, the severity had no pronounced effect as in the case of non-suckered VSP grapevines (T2) (Table 5.6). Estimated yield loss percentage as a result of sour rot followed similar trends as severity. Although no differences in total estimated yield loss percentage occurred, it must be noted that the latter was primarily caused by sunburn and not sour rot. These results indicated that the total estimated yield loss was primarily a function of sunburn damage rather than sour rot infection, and a similar trend occurred in the 2011/12 season.

Table 5.6 The effect of plant available water (PAW) depletion and different canopy management practices on sunburn, rot and estimated yield loss of Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

PAW depletion and canopy management practice	Sunburn		Rot			Total estimated yield loss
	Affected berries (%)	Estimated yield loss (%)	Incidence (%)	Severity (%)	Estimated yield loss (%)	(%)
T1 - 30% - Suckered VSP	1.59 a(1)	1.14 a	0 b	0.00 b	0.00 b	1.14 a
T2 - 30% - Non-suckered VSP	2.74 a	2.04 a	33 a	3.11 a	1.69 a	3.73 a
T3 - 30% - Sprawling canopy	4.68 a	3.19 a	27 a	0.62 b	0.28 b	3.47 a
T4 - 60% - Suckered VSP	3.16 a	2.18 a	3 b	0.02 b	0.02 b	2.20 a
T5 - 60% - Non-suckered VSP	2.26 a	1.52 a	7 b	0.46 b	0.48 b	2.00 a
T6 - 60% - Sprawling canopy	5.30 a	4.04 a	0 b	0.00 b	0.00 b	4.04 a
T7 - 90% - Suckered VSP	3.00 a	2.02 a	0 b	0.00 b	0.00 b	2.02 a
T8 - 90% - Non-suckered VSP	3.09 a	2.13 a	0 b	0.00 b	0.00 b	2.13 a
T9 - 90% - Sprawling canopy	8.60 a	6.37 a	0 b	0.00 b	0.00 b	6.37 a

(1)Values within a column followed by the same letter do not differ significantly ($p \leq 0.05$)

5.4 CONCLUSIONS

Berry mass decreased after reaching a maximum berry mass during ripening, irrespective of level of PAW depletion and canopy management practice. The extent to which the berry loses mass seemed to be related to level of PAW depletion. Low frequency irrigation, *i.e.* high level of PAW depletion, reduced the berry mass losses compared to high frequency irrigation. However, this could be related to harvest dates, which was earlier for low frequency irrigation compared to high frequency irrigation, therefore reducing berry mass losses. Final berry mass at harvest was reduced by irrigation at 90% PAW depletion compared to irrigation at 30% and 60% PAW depletion. However, almost no differences were found in berry mass at harvest between 30% and 60% PAW depletion levels. Within a specific canopy management practice, berry mass was reduced for grapevines irrigated at low frequencies compared to grapevines irrigated at high frequencies. The relationship between berry mass and volume was a ratio of 1:0.932, which was comparable to the ratio of six different cultivars in the same region. Furthermore, the ratio was consistent during ripening, irrespective of sampling date.

Low irrigation frequencies, *i.e.* irrigation at high PAW depletion, tended to accelerate TSS accumulation compared to high irrigation frequencies, which lead to earlier harvest dates. Furthermore, sprawling canopy grapevines also enhanced berry ripening, particularly at lower irrigation frequencies, compared to suckered and non-suckered VSP grapevines. However, suckered VSP grapevines can also enhance berry ripening, as was the case in the 2012/13 season. This was a result of a lighter crop load in relationship to leaf area. Sugar content per berry tended to incline until it reached a plateau which was more prominent at high irrigation frequencies compared to low irrigation frequencies. Furthermore, the plateau was reached earlier for sprawling canopy grapevines compared to suckered and non-suckered VSP grapevines.

Since grapes of all treatment were harvested as close as possible to the target TSS of 24°B, there were no differences in TSS at harvest within a given level of PAW depletion and canopy management practice, except where grapevines could not be harvested due to logistical constraints. Total titratable acidity at harvest seemed to be a function of the duration of berry ripening with higher TTA where grapevines were harvested earlier. However, the duration of ripening was determined by level of PAW depletion, primarily, and canopy management practice. Therefore, low frequency irrigation resulted in higher

TTA at harvest compared to high frequency irrigation. Furthermore, a lighter crop load in relationship to a higher leaf area resulted in higher TTA at harvest, compared to a heavier crop load. Level of PAW depletion and canopy management practice did not affect pH at harvest of the different treatments.

Berries per bunch tended to be higher at high frequency irrigation, *i.e.* low levels of PAW depletion, compared to low frequency irrigation. Furthermore, berries per bunch tended to be higher for suckered VSP grapevines compared to non-suckered VSP and sprawling canopy grapevines. Bunch numbers per grapevine showed no clear trends that could be related to water constraints experienced by grapevines. With regards to canopy management, suckered VSP grapevines reduced bunches per grapevine compared to non-suckered VSP and sprawling canopy grapevines. Bunch mass followed similar trends to berries per bunch. Yield was substantially reduced by low irrigation frequencies compared to high irrigation frequencies. Suckered VSP grapevines tended to reduce yields compared to non-suckered VSP and sprawling canopy grapevines, however, the effect was diminished where grapevines were irrigated at 90% PAW depletion.

Grape damage as a result of sunburn showed no clear trends that could be related to level of PAW depletion. However, sunburn seemed to affect sprawling canopy grapevines more, compared to suckered and non-suckered VSP grapevines. Estimated yield loss percentage followed similar trends as the percentage of sunburnt berries. Grape damage due to sour rot seemed to be more prominent at high frequency irrigation compared to low frequency irrigation, although severity of the incidence was low. Furthermore, non-suckered VSP and sprawling canopy grapevines seemed to have a higher incidence of sour rot at low PAW depletion levels. Estimated yield loss percentage followed similar trends as the severity of sour rot. However, results showed that total estimated yield loss percentage was primarily a function of sunburn rather than sour rot infection.

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Chapter 6

General conclusions and recommendations

6. GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL CONCLUSIONS

Aerial imagery showed that abnormal growth occurred in one of the proposed experiment plots. However, the cause of the problem could be rectified before the field trial commenced. It was concluded that the homogeneity of vegetative growth would not have any effect on canopy management treatments of the proposed field trial. Results indicated that RVI could be related to grapevine cane mass if the latter showed relatively large variability. The RVI could not be related to grapevine trunk circumference, probably due to a lack of variation between plots.

Irrigation applied at low PAW depletion levels, *i.e.* high frequency irrigation, required substantially higher pre-harvest irrigation volumes compared to low frequency irrigation. Due to accelerated ripening, which resulted in different harvest dates, canopy management practice indirectly reduced pre-harvest irrigation volumes. Except for differences in sugar accumulation, level of PAW depletion and canopy management did not have a pronounced effect on the phenological development of grapevines under the given conditions. Low frequency irrigation seemed to accelerate berry ripening compared to high irrigation frequencies, probably due to smaller berries and lower yields. It was visually observed that sprawling canopy grapevines had a larger exposed leaf area throughout the day compared to VSP grapevines. Sunlight interception could be linked to exposed leaf area. Sprawling canopies consistently enhanced berry ripening due to more sunlight interception by the leaves. Berry ripening of the VSP grapevines was slower, and inconsistent between seasons.

Level of PAW depletion and canopy management practice did not affect the number of leaves per primary shoot. However, differences in the number of leaves per secondary shoot caused differences in the total number of leaves per shoot. Low frequency irrigation tended to reduce the number of leaves per secondary shoot. Leaf area seemed to be a function of leaf number and size, but results indicated that leaf number per shoot made a more important contribution to total leaf area than leaf size.

Under the given conditions, level of PAW depletion did not affect the number of shoots per grapevine. However, suckered VSP grapevines reduced the number of shoots per grapevine compared to non-suckered VSP and sprawling canopy grapevines. Low frequency irrigation reduced the total leaf area per grapevine compared to high frequency irrigation. The effects of canopy management practice were more pronounced in the case of high frequency irrigations compared to low frequency irrigation. Excessive vigour induced by high frequency irrigation, was probably more evenly distributed among the higher number of shoots on the non-suckered VSP and sprawling canopy grapevines compared to less shoots on the suckered VSP grapevines. This suggests that altering the canopy by topping, the grapevine will compensate by initiating more secondary shoots. However, in the case of non-manipulated canopies less secondary shoots will be initiated.

At pruning, primary cane length was not affected by level of PAW depletion or canopy management practice. Low frequency irrigation tended to produce thinner and lighter primary canes compared to high frequency irrigation. Suckered VSP grapevines tended to have thicker and heavier primary canes compared to non-suckered VSP and sprawling canopy grapevines. Low frequency irrigation tended to produce shorter, thinner and lighter secondary canes compared to high frequency irrigation. Sprawling canopy grapevines tended to have shorter secondary canes compared to suckered and non-suckered VSP grapevines. Secondary cane mass and diameter were not affected by canopy management practice. Multiple linear regression analysis showed that cane mass was a highly significant function of cane length and diameter.

Low frequency irrigation increased grapevine water constraints compared to high frequency irrigation. Sprawling canopy grapevines also experienced more water constraints compared to VSP grapevines. Diurnal plant water potential revealed that grapevines experienced medium water constraints where grapevines were irrigated at 30% PAW depletion and medium to strong water constraints where grapevines were irrigated at 60% PAW depletion. However, grapevines irrigated at 90% PAW depletion experienced strong water constraints. Furthermore, sprawling canopy grapevines tended to have higher Ψ_T throughout the day compared to suckered and non-suckered VSP grapevines, irrespective of the PAW depletion level.

Berry mass decreased after reaching a maximum berry mass during ripening, irrespective of level of PAW depletion and canopy management practice. The extent, to which berry weight losses occurred, seemed to be related to level of PAW depletion. Low frequency irrigation reduced the berry mass losses compared to high frequency irrigation. However, this could be related to harvest dates, which was earlier for low frequency irrigation compared to high frequency irrigation. Final berry mass at harvest was reduced by irrigation at 90% PAW depletion compared to irrigation at 30% and 60% PAW depletion. However, almost no differences were found in berry mass at harvest between 30% and 60% PAW depletion levels. Within a specific canopy management practice, berry mass was reduced for grapevines irrigated at low frequencies compared to grapevines irrigated at high frequencies.

Low irrigation frequencies tended to accelerate TSS accumulation compared to high irrigation frequencies. Sprawling canopy grapevines also enhanced berry ripening, particularly at lower irrigation frequencies, compared to VSP grapevines. However, suckered VSP grapevines can also enhance berry ripening, as was the case in the 2012/13 season, probably due to a lighter crop load in relationship to leaf area. Sugar content per berry tended to incline until it reached a plateau which was more prominent at high irrigation frequencies compared to low irrigation frequencies. The plateau was reached earlier for sprawling canopy grapevines compared to VSP grapevines.

Since grapes of all treatment were harvested as close as possible to the target TSS of 24°B, there were no differences in TSS at harvest. Total titratable acidity at harvest seemed to be a function of the duration of berry ripening with higher TTA where grapevines were harvested earlier. Low frequency irrigation resulted in higher TTA at harvest compared to high frequency irrigation. Lighter crop load in relationship to higher leaf area resulted in higher TTA at harvest, compared to a heavier crop load. Level of PAW depletion and canopy management practice did not affect pH at harvest.

Berries per bunch tended to be higher at high frequency irrigation compared to low frequency irrigation. Berries per bunch tended to be higher for suckered VSP grapevines compared to non-suckered VSP and sprawling canopy grapevines. Bunch numbers per grapevine showed no clear trends that could be related to water constraints experienced by grapevines. With regards to canopy management, suckered VSP grapevines reduced bunches per grapevine compared to non-suckered VSP and sprawling canopy grapevines. Bunch mass followed similar trends to berries per bunch. Yield was substantially reduced by low irrigation frequencies compared to high irrigation frequencies. Suckered VSP grapevines tended to reduce yields compared to non-suckered VSP and sprawling canopy grapevines, however, the effect was diminished where grapevines were irrigated at 90% PAW depletion.

Grape damage as a result of sunburn showed no clear trends that could be related to level of PAW depletion. However, sunburn seemed to affect sprawling canopy grapevines more, compared to VSP grapevines. Yield loss percentage followed similar trends as the percentage of sunburnt berries. Grape damage due to sour rot seemed to be more prominent at high frequency irrigation compared to low frequency irrigation, although severity of the incidence was low. Non-suckered VSP and sprawling canopy grapevines seemed to have a higher incidence of sour rot at low PAW depletion levels. Yield loss percentage followed similar trends as the severity of sour rot. However, results showed that total yield loss percentage was primarily a function of sunburn rather than sour rot infection.

In general, level of PAW depletion controlled grapevine water status which reflected in vegetative growth, yield and rate of berry ripening. At a given level of PAW depletion, canopy management practice affected foliage characteristics and the rate of berry ripening. Therefore, combinations of level of PAW depletion and canopy management practice can be applied to manipulate grapevine vegetative growth, yield and juice characteristics. The choice of combination will depend on the production objectives for a particular vineyard, *e.g.* higher yield with moderate wine quality or lower yield with high wine quality.

6.2 RECOMMENDATIONS

6.2.1 Recommendations for practical application

- Since irrigation at low frequencies reduce yield, it cannot be recommended under comparable conditions if high grape yields are the objective.
- Low frequency irrigation can be applied to enhance berry ripening, thereby obtaining higher juice TTA.
- Sprawling canopy and non-suckered VSP systems might not be suitable for cultivars that are susceptible to sour rot, particularly if irrigation is applied at a high frequency.
- In summer rainfall regions, sprawling canopy and non-suckered VSP systems might increase the incidence of sour rot.

6.2.2 Recommendations for future research

Although effects of irrigation and canopy management practices on vegetative growth, yield and juice characteristics provide some answers, there are still aspects regarding the effects of combined irrigation and canopy management practices that need to be investigated such as:

- The response of different cultivars.
- Responses under different climatic conditions and different soil types.
- Grapevine physiology, *i.e.* photosynthesis and transpiration responses.
- Canopy micro-climate conditions.
- Evaporation from the soil surface.
- Wine characteristics and quality.
- Economic viability of labour inputs.
- Evaluating plant water potentials, particularly leaf water potential, on different shoots, *i.e.* horizontal and vertical, and incorporating micro-climate conditions and prevailing atmospheric conditions.
- Effects of level of PAW depletion on mechanical pruning with regard to grapevine physiology, as well as vegetative growth, yield and wine quality.