DEFICIT IRRIGATION AND CANOPY MANAGEMENT PRACTICES TO IMPROVE WATER USE EFFICIENCY AND PROFITABILITY OF WINE GRAPES

Report to the

WATER RESEARCH COMMISSION and WINETECH

Compiled by

EL LATEGAN & CL HOWELL

SOIL AND WATER SCIENCE PROGRAMME

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Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a project entitled *Deficit irrigation and canopy management practices to improve water use efficiency and profitability of wine grapes* (WRC Project No. K5/2080)

EXECUTIVE SUMMARY

Background

In 2012, *ca.* 69% of vineyards for the production of wine in South Africa were irrigated and/or established under drip irrigation compared to less than 23% in 1996. Water savings obtained by using drip irrigation are in line with the optimal use of water resources as prescribed by the South African National Water Act no. 36 of 1998. The positive and negative effects of water constraints on grapevines have been reported on numerous occasions. However, most of the irrigation research in South Africa on wine grapes was carried out in flood or micro-sprinkler irrigated vineyards. Although the positive effects of canopy manipulation on the quality aspect of wine have been reported, all grapevines regardless of the canopy manipulations applied, received the same irrigation volumes and irrigation applications were indicated very vaguely or not at all. Therefore, there is no knowledge regarding the water requirement or usage of different canopy manipulated grapevines. Canopy management also requires a lot of labour inputs. In 2010, labour costs accounted for 41% of the total production costs of wine grapes. The effect that different irrigation strategy and canopy management combinations will have on the water requirement, vegetative growth, yield components, wine quality, labour inputs, and the economic implications thereof, has not previously been investigated. In 2010, representatives of the South African wine industry's Breede River region approached two researchers (Soil and Water Science Programme) of ARC Infruitec-Nietvoorbij to investigate implementing deficit irrigation as a means to manage grapevine foliage growth. This would enable farmers and growers to plan and apply specific irrigation and canopy management practices for their individual vineyard needs, and in so doing, managing limited and expensive resources, *i.e.* water, electricity and labour, to produce the economically viable grapes. Knowledge could also aid viticulturists and irrigation consultants with their recommendations for scheduling individual vineyard blocks.

The aim of this field trial was to determine the effect of different drip irrigation strategies and canopy manipulation combinations on the vegetative growth, plant water potential, water usage, yield, overall wine quality and profitability of Shiraz grapevines in a semi-arid region.

Project objectives

- To determine the effect that deficit irrigation has on canopy density and vegetative growth of non-manipulated grapevines compared to manipulated grapevines.
- To determine the effect of different combinations of deficit irrigation strategies and canopy manipulations on the yield and wine quality.

- To determine the effect of different irrigation strategies and canopy manipulations on the water use efficiency.
- To determine the optimal balance between irrigation water application, yield, overall wine quality and canopy management costs.
- To determine if reduced canopy management inputs are economically viable.

Experimental layout

The experiment was carried out in a commercial vineyard (S 33°54′04″, E 19°40′33″) *ca.* 23 km southwest of Robertson on the farm Wansbek in the Agterkliphoogte ward of the Breede River Valley region. The vineyard was situated on the flood plain of the Poesjenels River on a southeast facing slope at an altitude of 201 m above sea level. The region has a cool semi-arid climate and based on the growing degree days from 1 September until 31 March, the specific locality is in a class V climatic region. Shiraz grapevines, grafted onto 110 Richter rootstock, were planted in August 2000 in a northwest/southeast row direction after the soil was double delved (cross-ripped) to a depth of 0.8 m during soil preparation. Grapevines were planted 2.5 m × 1.22 m and trained onto a five strand lengthened Perold trellis system.

Three different irrigation strategies were applied to grapevines, namely irrigation at *ca.* 30%, *ca.* 60% or *ca.* 90% plant available water (PAW) depletion. For each level of PAW depletion, the grapevine canopies were left to grow naturally and hang open, or shoots were tucked into trellis wires without the suckering (removal) of water shoots (vertical shoot positioning or VSP), or shoots tucked into trellis wires with the suckering of water shoots. Therefore, there were nine different irrigation/canopy manipulation treatments. These nine treatments were hand pruned. In addition to the nine different irrigation/canopy manipulation treatments, there was a further treatment which was irrigated at 90% PAW depletion and mechanically pruned. Therefore, in total there were ten treatments in the field trial.

All treatments were replicated three times in a randomised block design. The first replication of treatments was allocated furthest away and third replication closest to the river to account for possible soil differences that may have occurred towards the Poesjenels River. Each experimental plot comprised two rows of six experimental grapevines with two buffer grapevines at either end and a buffer row on each side. Each experimental plot covered 122 m^2. The field trial ran for four seasons, *i.e*. from 2011/12 to 2014/15.

Atmospheric conditions

Atmospheric conditions prevalent in the 2011/12 season were generally within the long term values, with the exception of the summer rainfall which was very low. The 2012/13 season was characterized by many cloudy days. The summer rainfall in the 2013/14 season was substantially higher than the long term values. Furthermore, 73% of this rain fell in November and January. In particular, the rainfall in January could have negative consequences for wine colour and quality. It appeared as if the 2014/15 season was similar to the 2011/12 season with respect to the prevailing atmospheric conditions.

Soil water content (SWC) and irrigation volumes applied

Irrigation applied at low PAW depletion levels more than doubled irrigation volumes compared to grapevines irrigated at high PAW depletion levels. Due to accelerated sugar accumulation which resulted in different harvest dates, canopy management practice indirectly reduced pre-harvest irrigation volumes. In the area in which the field experiment was done, grapevines will need irrigation applications until *ca*. May that follows the growing season. Even though grapevines received the irrigation at the same depletion level during the post-harvest period, grapevines irrigated at low frequencies during the season had lower irrigation requirement compared to high frequency irrigated vines.

Grapevine vegetative growth

Under the given conditions, the different canopy manipulations did not affect total leaf area per grapevine within an irrigation strategy. Non-suckered grapevines produced more shoots compared to suckered ones. More frequent irrigation of grapevines caused more vigorous shoot growth. Within the same irrigation strategy, non-suckered VSP grapevines tended to produce lower cane mass compared to suckered VSP and sprawling canopy grapevines. The leaf area per grapevine within the fraction of soil surface area covered by the particular canopy during the solar zenith (LA_{CPS}) gave a better indication of canopy orientation, volume and density than the leaf area index alone. By measuring the plant spacing, canopy width and photosynthetically active radiation (PAR) interception, the LA_{CPS} can be estimated. Winter pruned cane mass can be estimated by non-destructive measurements of primary and secondary shoots. This would enable a viticulturist, producer or irrigation consultant to use the VINET model during ripening to predict grapevine water requirements.

Grapevine water status

Mid-day leaf- (Ψ_L) and stem water potential (Ψ_S) in grapevines within the same irrigation strategy did not differ, irrespective of the canopy manipulations applied. However, sprawling canopy grapevines tended to have lower mid-day Ψ_L and Ψ_S than the VSP grapevines. Grapes from grapevines subjected to severe water constraints ripened more rapidly than those experiencing no or medium water constraints. Low frequency irrigation, *i.e.* 90% PAW depletion, increased grapevine water constraints compared to high frequency irrigation, *i.e.* 30% PAW depletion. Results from the diurnal Ψ_L cycles showed that grapevines with sprawling canopies tended to have lower Ψ_L than the VSP grapevines after 18:00 and throughout the night. This indicated that the water status in the sprawling canopy grapevines could not recover during the night to the same extent as VSP grapevines.

Evapotranspiration

Higher irrigation frequencies resulted in higher evapotranspiration losses from the grapevine root volume of soil (ET_{GR}), while losses from under sprawling canopies, particularly those irrigated at *ca*. 30% PAW depletion, tended to be higher in February than those with VSP canopies. The evapotranspiration losses from the grapevine work row volume of soil increased in periods that followed rainfall incidences and was much lower than the ET_{GR}. As a result, the monthly full surface evapotranspiration (ET_{FS}) was much lower than the monthly ET_{GR}. The seasonal ET_{FS} was more sensitive to irrigation frequency than to different canopy manipulations. The diurnal and cumulative soil surface evaporation (E_s) losses under grapevines with sprawling canopies was lower than under VSP grapevines, irrespective of the level of PAW depletion. Higher mean leaf area per grapevine caused by more frequent irrigations caused denser canopies. The 0 to 300 mm soil water content of treatments irrigated at *ca*. 30% PAW depletion were always in stage 1 of evaporation, while that of grapevines irrigated at *ca*. 60% PAW depletion occasionally went into stage 2, particularly that of the sprawling canopy. The water content of soil under grapevines irrigated at *ca*. 90% PAW depletion spend most of the season in stage 2. The effect of the evaporation canopy factor (C_f) on the E_s losses of the sprawling canopies was lower than that of the VSP grapevines, irrespective of PAW depletion. Less frequent irrigation and a decrease in LA_{CPS} of experimental grapevines increased the evaporation C_f.

During the three seasons, the mean crop coefficient (K_c) for grapevines that were irrigated at *ca*. 30% PAW depletion were higher compared to those of other strategies, with those irrigated at *ca*. 90% PAW depletion being the lowest. Grapevines irrigated particularly at *ca*. 30% and 60% PAW depletion, grapevines with sprawling canopies tended to result in higher K_c values during ripening than those with VSP canopies. The mean peak K_c was generally obtained in February of the experimental seasons for grapevines that were irrigated at *ca*. 30% PAW depletion, while the lowest K_c was found during the same period at *ca*. 90% PAW depletion irrigations. Because drip irrigation system only wet the soil volume partially during irrigation applications, the crop coefficient for the wetted percentage of the soil volume would be a more realistic coefficient for producers and consultants in the scheduling of irrigation requirement. The transpiration losses determined during ripening show that as irrigation frequency increased so did transpiration losses, with sprawling canopies tending to have higher losses than VSP grapevines. Higher frequency irrigation increased the fraction of K_c contributable to evaporation, whereas lower frequency irrigation increased the fractional contribution of the basal crop coefficient. Compared to measured values, the VINET model generally underestimated ET when higher irrigation frequencies were applied, whereas it overestimated ET when very low frequency to no irrigation was applied. Transpiration of grapevines could be split into vertical canopy and sprawling canopy groups when related to the LA_{CPS}.

Yield

Grapevines subjected to severe water constraints ripened their grapes more rapidly than those experiencing no or medium water constraints. Furthermore, grapes of sprawling canopy grapevines ripened more rapidly compared to VSP grapevines within the same level of PAW depletion. With the exception of mechanically pruned grapevines, irrigation frequency had a more pronounced impact on yield than canopy manipulation. Higher rainfall in 2013/14 increased vegetative growth and yield compared to previous seasons. Low frequency irrigations resulted in higher production water use efficiency compared to medium and high frequency irrigation. Within a given canopy management practice, level of PAW depletion did not affect the percentage of sunburnt berries. In addition to this, there were also more sunburnt berries on the sprawling canopy grapevines within a given level of PAW depletion. Results showed that the incidence of grey rot was substantially higher during the wetter season of 2013/14, compared to that of the other three seasons.

Grape juice and wine characteristics

Grapes were harvested as close to the target total soluble solids level of 24ºB as possible. Where severe water constraints enhanced berry maturation, juice total titratable acidity (TTA) was higher and pH lower compared to grapes that were harvested later. Within a given PAW depletion level, canopy manipulations did not affect juice TTA contents. Irrigation applied at a higher PAW depletion level, *i.e. ca.* 90%, improved overall wine quality compared to more frequent irrigation. Within the lower levels of PAW depletion levels, *i.e.* 30% and 60%, non-suckered VSP grapevines produced wines of the poorest overall quality. Highest overall wine quality was obtained where non-suckered VSP, sprawling canopy and mechanically pruned grapevines were irrigated at 90% PAW depletion. Wine alcohol content, pH, potassium, malic and tartaric acids and polyphenol concentrations were not affected by level of PAW depletion or canopy management practice.

Economic viability

Less frequent irrigations reduced summer canopy management requirements. However, grapevines bearing more shoots required higher labour inputs at harvest. Pruning labour input requirements seem to be affected by the number of shoots produced per grapevine and the individual mass per shoot. Within the same irrigation strategy, sprawling canopy grapevines tended to require more labour inputs during winter pruning, compared to other summer canopy management strategies. The total seasonal canopy management labour inputs decreased as the volume of irrigation water applied decreased. Sprawling canopy grapevines generally required less labour. Pump costs were affected by the frequency of irrigation applications, while transport costs of grape differed minimally between treatments. During seasons with low to normal rainfall, grapevines with sprawling canopies that were irrigated at *ca*. 60% PAW depletion produced the highest gross margins, followed by box pruned grapevines irrigated at *ca*. 90% PAW depletion. In seasons characterised by high summer rainfall, box pruned grapevines irrigated at *ca*. 90% PAW depletion, as well as non-suckered VSP canopies irrigated at *ca*. 30% PAW depletion would have highest gross margins. This was due to the gross margin being strongly determined by the gross income. In general, grapevines with sprawling canopies, particularly those irrigated *ca*. 60% PAW depletion, produced the best balance between yield and quality, thereby ensuring the best gross margin. The gross margin water use efficiency (WUE_{GM}) increased with an increase in PAW depletion level, *i.e.* a decrease in irrigation water applied, with box pruned grapevine consistently having the highest WUE_{GM}.

Recommendations

Based on the project results, the following criteria should be considered when deciding on what irrigation and canopy management strategies to apply to vineyards:

(i) Since irrigation at high frequencies increased yield substantially, it can be recommended under comparable conditions if high grape yields are the objective, *i.e*. if producers are not compensated for higher quality, irrigation should be applied at *ca*. 30% to *ca*. 60% PAW depletion;

(ii) Since irrigation at lower frequencies increased wine colour and quality substantially, it can be recommended under comparable conditions where the objective is to produce good wine quality or to minimize viticultural labour inputs, irrigation should be applied at *ca*. 80% to *ca*. 90% PAW depletion;

(iii) Low frequency irrigation can be applied to enhance berry ripening, thereby also obtaining higher juice TTA;

(iv) Sprawling canopy grapevines might not be suitable for cultivars that are susceptible to sunburn, particularly if irrigation is applied at a low frequency. Under such conditions it would be preferable to tuck shoots into trellis wires;

(v) Sprawling canopy grapevines might not be suitable for cultivars, *i.e*. Chenin blanc, that are very susceptible to rot, particularly if grapevines have low cordon heights (lower than 1.2 m) and irrigation is applied at a high frequency;

(vi) In summer rainfall regions, higher trained cordons should be established if grapevines are not suckered and shoots left to sprawl to decrease the incidence of rot; and

(vii) Considering the gross margin analyses, the most consistent economically viable production of red wine grapes in the Robertson area would be when grapevines are not suckered, shoots left to sprawl open and where irrigation is applied at *ca*. 60% PAW depletion or alternatively, grapevines box pruned and irrigated at *ca*. 90% PAW depletion.

ACKNOWLEDGEMENTS

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Dr C.L. Howell	ARC Infruitec-Nietvoorbij
Dr P.A. Myburgh	ARC Infruitec-Nietvoorbij
Mr R.A. Stolk	Student (MSc Agric – Viticulture, Stellenbosch University)
Mr V.D.W. Louw	Student (MSc Agric – Agricultural Economics, Stellenbosch University)
Mr T. Harris	ARC Infruitec-Nietvoorbij

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PROJECT REFERENCE GROUP

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Mr J.H. Booysen	Winetech
Mr B. Stipp	Robertson Winery
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Ms T. Nell	Secretary, ARC Infruitec-Nietvoorbij

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MEANING	ABBREVIATION/UNIT
abscisic acid	ABA
Agricultural Research Council	ARC
analysis of variance	ANOVA
area allocated to each dripper	DS
area of arable land	A_{Arable}
area of experimental plot	A_{plot}
area soil surface area covered by canopy during solar zenith	A_{CD}
area planted with wine grapes	$A_{Wine\ grapes}$
area within plant spacing, *i.e.* 2.5 m × 1.22 m (m^2)	A_{PS}
average hourly actual water vapour pressure	e_a
bulk density	ρ_b
cane mass per grapevine	$CM_{grapevine}$
cent	c
cent per kilowatt hour	$c.kWh^{-1}$
change in soil water content in the 300 mm soil layer below 750 mm soil depth	ΔSWC_{750+}
change in soil water content in the grapevine root volume of vineyard	ΔSWC_{GR}
change in soil water content in the work row portion of vineyard	ΔSWC_{WR}
crop coefficient	K_c
crop coefficient of the irrigated volume of soil	$K_{c,GR}$
cubic metre	m^3
cubic metre per hectare per day	$m^3.ha^{-1}.d^{-1}$
cubic metre per hectare	$m^3.ha^{-1}$
cultivar	cv.
Cytokinin	CK
degrees	º
degrees Balling	ºB
degrees Celsius	ºC
diameter	Ø
distance from farm to winery	d_{winery}

energy requirement for irrigation per hectare	E_{ha}
electricity usage cost	C_{eu}
equation	Eq.
evaporation	E_s
evaporation canopy factor	C_f
evaporation characteristic soil parameter	β
evapotranspiration	ET
evapotranspiration out of whole vineyard (full surface)	ET_{FS}
evapotranspiration out of grapevine root zone portion of vineyard	ET_{GR}
evapotranspiration out of work row portion of vineyard	ET_{WR}
field water capacity	FC
fractional canopy area with regard to the plant spacing soil surface area	fCPS
fractional PAR interception	fPAR
fraction of K_c contributable to basal crop coefficient	fK_{cb}
fraction of K_c contributable to evaporation	fK_e
fraction of soil volume occupied by grapevine roots	F_{RZ}
fresh weight	FW
gram per berry	$g.berry^{-1}$
gross margin water use efficiency	WUE_{GM}
growing degree days	GDD
height of canopy above the cordon	H_C
incident flux of PAR	PAR_I
incoming solar radiation	R_s
irrigation applied	I
kilogram per hectare	$kg.ha^{-1}$
kilogram per cubic metre	$kg.m^{-3}$
kilovolt ampere	kVA
kilowatt	kW
kilowatt hour	kWh
leaf area index	LAI

leaf area per grapevine within the fraction of soil surface area covered by the particular canopy during the solar zenith LA_{CPS}

leaf area per grapevine $LA_{grapevine}$

leaf area per grapevine shoot LA_{shoot}

leaf water potential Ψ_L

least significant difference LSD

long term mean LTM

mass per primary shoot M_{PS}

mass per secondary shoot M_{SS}

mean diameter per primary shoot $Ø_{PS}$

mean diameter per secondary shoot $Ø_{SS}$

mean hourly air temperature T_{hr}

mean hourly wind speed at 2 m height u_2

mean length per primary shoot L_{PS}

mean length per secondary shoot L_{SS}

mega joules per square metre $MJ.m^{-2}$

mega joules per square metre per hour $MJ.m^{-2}.h^{-1}$

megapascal MPa

metre per second $m.s^{-1}$

number of labourers applying the labour input $n_{labourers}$

number of grapevine shoots (primary) n_{PS}

number of secondary shoots per primary shoot $n_{SS/PS}$

PAR intercepted by the canopy PAR_{canopy}

permanent wilting point PWP

photosynthetically active radiation PAR

plant available water PAW

pre-dawn leaf water potential Ψ_P

producers' price point per ton of grapes delivered P_{grapes}

production water use efficiency WUE_P

psychrometric constant γ

rain (precipitation)	P
readily available water	RAW
reference evapotranspiration	ET_o
relative humidity	RH
saturation water vapour pressure at air hourly temperature (T_{hr})	$e^o(T_{hr})$
selling price of specific wine category	P_{wine}
slope water vapour pressure curve (T_{hr})	Δ
soil water content ($mm.mm^{-1}$)	SWC
soil heat flux density	G
South African Rand	R
standard error	s.e.
stem water potential	Ψ_S
temperature	T
time	t
tonne per hectare	$t.ha^{-1}$
tonne per megalitre	$t.ML^{-1}$
total fresh mass of leaves	LM_{Total}
total titratable acidity	TTA
total soluble solids	TSS
transition point from stage 1 to stage 2 of evaporation	β^2
transmitted flux of PAR	PAR_T
transpiration per grapevine	$T_{grapevine}$
vertical shoot positioning	VSP
Vineyard evapotranspiration	VINET
volatile acidity	VA
volumetric soil water content	θ_v
water vapour pressure deficit	VPD
winery processing cost per ton of grapes	C_p

CHAPTER 1: THE EFFECT OF DIFFERENT IRRIGATION STRATEGIES AND CANOPY MANIPULATIONS ON GRAPEVINE RESPONSE: BACKGROUND, PROJECT OBJECTIVES AND KNOWLEDGE REVIEW

1.1. BACKGROUND OF STUDY

South Africa is a relatively dry country with a mean annual rainfall of 450 mm and a high evaporation rate (NWRS, 2004). Only 7% of the country's area receives more than the mean annual world rainfall of 860 mm (NWRS, 2004). The mean annual rainfall is the lowest in the north-western part of South Africa and gradually increases to the east south-eastern part of the country (Fig. 1.1). The Western Cape, where 95% of the 101 325 hectares of total wine grape vineyards in the South African wine industry are planted, has a mean annual rainfall of 348 mm which is quite erratically distributed due to the high mountain ranges in the province (Cupido & Isaacs, 2009; NWRS, 2004). Agriculture, particularly fruit and grape production, has to compete with urban and industrial needs for water. Consequently, irrigation water is a scarce resource. Considering possible climate changes, lower rainfall will reduce natural water resources, and higher air temperatures increase the water requirements of vineyards.

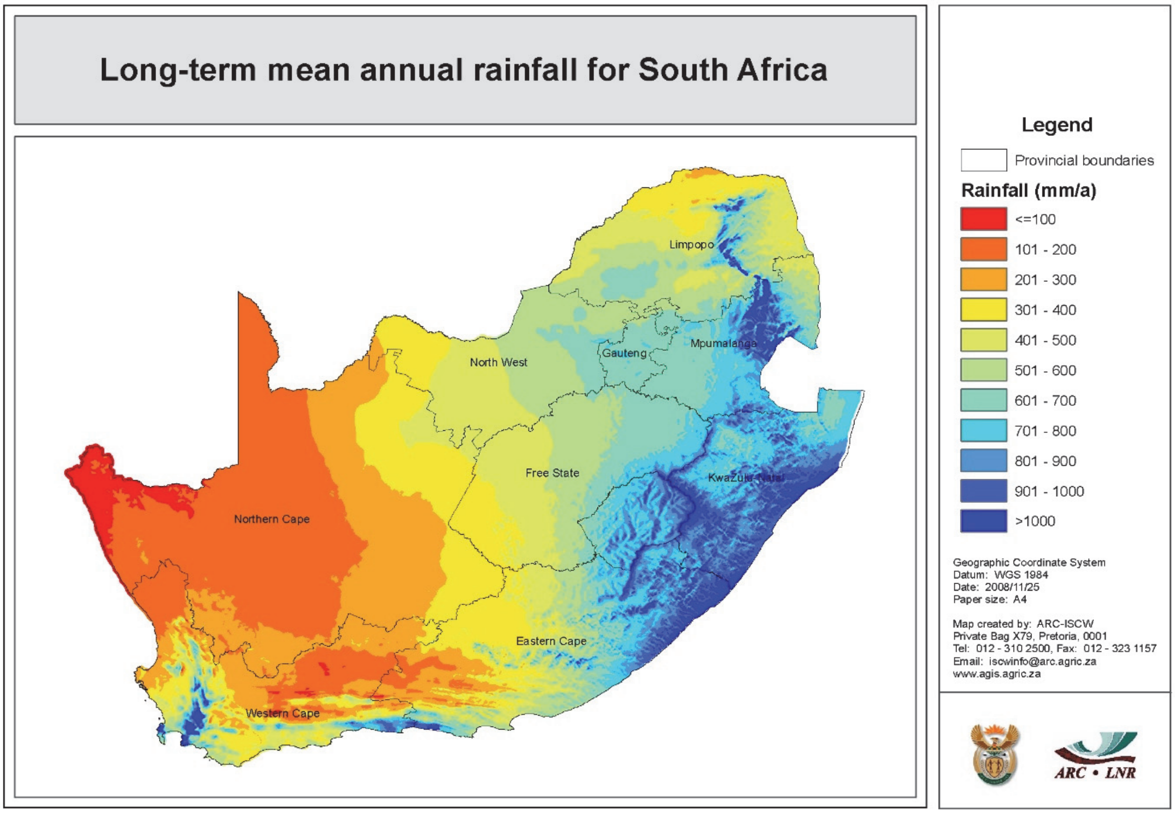

Figure 1.1 Long term mean annual rainfall distribution in South Africa (Agricultural Research Council's Institute for Soil, Climate and Water).

In 2008, approximately 53% of the vineyards were being irrigated and/or established under drip irrigation compared to less than 23% in 1996 (Cupido & Isaacs, 2009). Water savings obtained by using drip irrigation (Van Zyl & Van Huyssteen, 1988) are in line with the optimal use of water resources as prescribed by the South African National Water Act no. 36 of 1998.

The positive and negative effects of water constraints on grapevines have been reported on numerous occasions. However, most of the irrigation research in South Africa on wine grapes was carried out in flood or micro-sprinkler irrigated vineyards (Van Zyl, 1984; Myburgh, 2005; Myburgh, 2006b; Myburgh, 2007; Myburgh, 2011a). Although the positive effects of canopy manipulation on the quality aspect of wine have been reported, all grapevines of the canopy treatments received the same irrigation volumes (strategies) and irrigation applications were indicated very vaguely or not at all (Hunter, 2000; Hunter & Volschenk, 2001; Volschenk & Hunter, 2001; Archer & Van Schalkwyk, 2007). Thus, no knowledge regarding the water requirement or usage of different canopy manipulated grapevines under South African conditions exist. Canopy management also requires a lot of labour inputs (Volschenk & Hunter, 2001; Archer & Van Schalkwyk, 2007). In 2010, labour costs accounted for 41% of the total production of wine grapes (Van Wyk & Le Roux, 2011). Consequently, knowledge regarding the effect that different irrigation strategy and canopy management combinations will have on the water requirement, vegetative growth, yield components, labour inputs and wine quality of grapevines, and the economic implications thereof, have thus not previously been investigated.

In 2010, representatives of the South African wine industry's Breede River region (Messrs Briaan Stipp, Jaco Lategan, Hennie Visser and Willem Botha) approached Mr Vink Lategan and Dr Philip Myburgh (Soil and Water Science Programme) of the ARC Infruitec-Nietvoorbij with a request to investigate the possibility of implementing deficit irrigation as a means to manage grapevine foliage. Knowledge of how different canopy management practices at different deficit irrigation strategies will influence the combination of vegetative growth, production, production water use efficiency and wine quality is limited.

This knowledge would enable farmers and growers to plan and apply a different irrigation and canopy management for their individual vineyard needs, and in doing so managing limited and expensive resources, *i.e.* water and electricity, to produce the economically viable grapes. Knowledge could also aid viticulturists and irrigation consultants in their recommendations for scheduling individual vineyard blocks.

1.2. PROJECT OBJECTIVES

- To determine the effect that deficit irrigation has on canopy density and vegetative growth of non-manipulated grapevines compared to manipulated grapevines.
- To determine the effect of different combinations of deficit irrigation strategies and canopy manipulations on the yield and wine quality.
- To determine the effect of different irrigation strategies and canopy manipulations on the water use efficiency.
- To determine the optimal balance between irrigation water application, yield, overall wine quality and canopy management costs.
- To determine if reduced canopy management inputs are economically viable.

1.3. KNOWLEDGE REVIEW

1.3.1. Introduction

Grapevine *(Vitis vinifera)* is a temperate climate species adapted to hot summers and mild to cold winters (Williams *et al.*, 1994). Grapevines are cultivated in some of the hottest areas on earth, between the 30º and 50ºN and 30º and 40ºS latitudes (Williams *et al.*, 1994). In such areas, with low annual rainfall and high evaporation demands, irrigation is usually necessary to produce economically viable crops (Van Zyl, 1981; Williams *et al.*, 1994). The oldest recordings of irrigated viticulture date back to *ca.* 2 900 BC in Babylonia and *ca.* 1 500 BC in Egypt (Younger, 1966). Grape and wine quality is either affected directly or indirectly by the terroir, relative humidity, wind exposure, micro climate (through canopy structure) and soil related factors (Hunter *et al*., 1995; Deloire *et al.,* 2005; Bruwer, 2010; Mehmel, 2010). Since international wine markets are increasingly becoming more competitive, it is important to find a balance between optimum yield and wine quality (Mehmel, 2010). Much research on the effect of different irrigation strategies and canopy manipulation techniques on grapevine response to obtain optimum yields and wine quality has been done in the past. However, these two disciplines have not been investigated simultaneously under the same set of viticultural conditions.

The aim of this knowledge review is to discuss the effect of water constraints and canopy manipulation on the grapevine water potential, vegetative growth, water use, yield and its components, juice and wine quality, as well as canopy management labour inputs.

1.3.2. Grapevine water status

Diurnal water constraint patterns in grapevines appear when transpiration losses exceed water uptake, even if grapevines are exposed to adequate available water in the soil (Hardie & Considine, 1976). Leaf water potential (Ψ_L) in grapevines can be quantified by means of the pressure chamber technique (Scholander *et al.*, 1965). Grapevine Ψ_L decreases and fluctuates during the day, irrespective of the quantity of water available to the grapevines, with the most negative potential occurring between 12:00 and 14:00 (Van Zyl, 1984; Van Zyl, 1987). Leaf water potential increases at night and more so if adequate soil water is available to the plant (Williams *et al.*, 1994). Grapevine water status can be influenced by incoming solar radiation, relative humidity, temperature, atmospheric pollutants, wind, soil environment and plant factors (Smart & Coombe, 1983). Choné *et al.* (2001), Lebon *et al.* (2003) and Loveys *et al.* (2004) documented that pre-dawn leaf water potential (Ψ_P) is the preferred reference indicator of soil water potential in many species including grapevines. It was shown that at pre-dawn, each leaf on a grapevine has the same water potential and that this water potential is in equilibrium with the wettest soil layer explored by the root system (Van Leeuwen *et al.*, 2009). Pellegrino *et al.* (2004) also found a narrow correlation between the Ψ_P measurements of Shiraz and Gewürztraminer and the fraction of transpirable soil water or percentage plant available water (PAW) depletion (Fig. 1.2). Furthermore, a reduction in grapevine Ψ_L, stomatal conductance and CO_2 assimilation rate can be expected when soil water becomes less available (Williams *et al.*, 1994; Schultz, 1996; Naor & Bravdo, 2000; Williams & Araujo, 2002; Patakas *et al.*, 2005; Pellegrino *et al.*, 2005; Soar *et al.*, 2006; Van Leeuwen *et al.,* 2009).

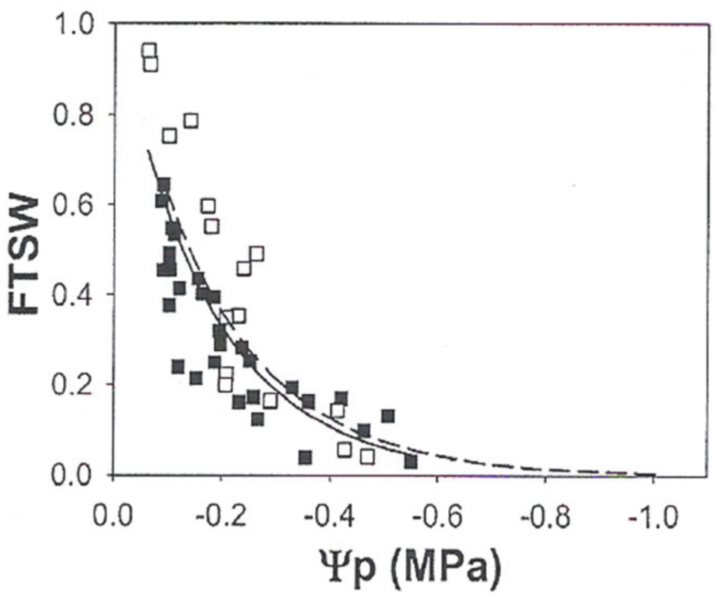

Figure 1.2 Fraction of transpirable soil water (FTSW) plotted against pre-dawn leaf water potential (Ψp) in Shiraz (□) and Gewürztraminer (■) (Pellegrino *et al.*, 2004).

Correlations between Ψ_L and grapevine physiology, vegetative growth and yield have been reported (Williams *et al.*, 1994 and references therein). Stem water potential (Ψ_S) can also be used to quantify grapevine water status. The Ψ_S is measured by covering a leaf using a double lined plastic and aluminium foil bag at least an hour before the measurements (Choné *et al*., 2001). This potential is considered to be a better indicator of differences in plant water status than Ψ_L (Choné *et al*., 2001; Williams & Araujo, 2002; Patakas *et al*., 2005; Van Leeuwen *et al*., 2009). It was observed that Ψ_L regulation depended on soil water availability and other external factors, such as water vapour pressure deficit, leaf intercepted radiation, plant hydraulic conductivity and stomatal regulation (Choné *et al*., 2001). Due to this, Ψ_S seemed to be the best indicator of soil water availability, followed by Ψ_P. The difference between Ψ_S and Ψ_L ($\Delta\Psi$) was found to be significantly correlated to transpiration, and can thus be a useful method of estimating transpiration of field grown grapevines (Choné *et al*., 2001). Furthermore, Ψ_S could also serve as an indicator of hydraulic conductivity in the trunk and shoot sap pathway (Choné *et al*., 2001).

Threshold values for grapevine water constraint classes based on Ψ_P in Shiraz were proposed (Ojeda *et al*., 2002). These classes are no constraints (> -0.2 MPa), weak constraints (-0.2 to -0.4 MPa), medium constraints (-0.4 to -0.6 MPa) and strong constraints (< -0.6 MPa). Greenspan (2005) suggested that irrigation applications in California should begin when mid-day Ψ_L of white grapevine cultivars reach -0.8 MPa and red cultivars -1.0 MPa. As a general guideline, mid-day Ψ_L measurements could be classified as no constraints (> -1.0 MPa), mild constraints (-1.0 to -1.2 MPa), moderate constraints (-1.2 to -1.4 MPa), high constraints (-1.4 to -1.6 MPa) and severe constraints (< -1.6 MPa) (Greenspan, 2005).

Hunter (2000) reported that east-west planted grapevines that were suckered and had their shoots tucked into trellis wires experienced less water constraints than grapevines that were left unsuckered and shoots not tucked in even though both treatments received the same irrigation applications. This can be attributed to the fact that the untreated grapevines had a higher leaf area that was exposed to the sun throughout the day, resulting in higher transpiration water loss (Myburgh, 1998).

1.3.3. Vegetative growth

Increased grapevine vegetative growth almost invariably occurs when high soil water availability is maintained by applying more frequent irrigation and/or greater volumes of water, compared to ones exposed to water constraints, irrespective of the cultivar (Van Zyl, 1981; Smart, 1982; McCarthy *et al.,* 1983; Myburgh, 1996; Myburgh, 2003; Dokoozlian, 2009; Myburgh, 2011b). Water constraints caused by inadequate plant available soil water have an inhibitory effect on vegetative growth and can even alter grapevine phenology (Coombe & Dry, 1988). Furthermore, active shoot growth may continue throughout the whole season when adequate water is present (Van Zyl, 1981). In dry soil, the inhibition of vegetative growth can be attributed to the rise in abscisic acid (ABA) and decrease in cytokinin (CK) concentrations in the shoots due to the CK/ABA antagonism (Thimann, 1992; Lovisolo *et al.*, 2010). In some cases, mild soil water deficits may not have any effect on the vegetative growth of grapevines when compared to ones that are exposed to adequate soil water availability. This effect was found in Muscat d'Alexandrie and Castelão (Santos *et al.*, 2003), Mourvédre (De La Hera *et al.*, 2007) as well as Merlot (Lategan & Howell, 2010a).

Adequate water supply during the post-véraison stage may stimulate re-growth of shoots (Lategan, unpublished data). These actively growing shoot tips during ripening compete directly with berries for carbohydrates produced by active green leaves (Saayman, 1992) since the distribution of photosynthetic products is regulated by the source to sink relationship (Johnson *et al*., 1982). Severe water constraints may not only terminate shoot growth, but could cause yellowing of basal leaves and even leaf abscission (Van Zyl & Weber, 1977). Mild grapevine water constraints may terminate shoot growth, which can improve bunch exposure to sunlight. The termination of shoot growth could have positive implications, particularly in the case of red grape cultivars (Williams *et al*., 1994), where over-shading due to excessive vegetative growth can have a detrimental effect on wine colour (Smart, 1982). For both Colombar (Van Zyl, 1984) and Shiraz (McCarthy, 2000), vegetative growth was most sensitive to soil water constraints during the period following flowering. Colombar grapevines irrigated every seven days throughout the growing season produced a higher pruning mass in comparison to ones that were irrigated every 14 days, 21 days and 28 days (Myburgh, 2007). No further reduction in the pruning mass between the longer irrigation intervals indicated the sensitivity of the vegetative growth of grapevines to moderate or severe soil water constraints compared to no or low constraints. Pinotage and Sauvignon blanc irrigated at ≤ 50% readily available water (RAW) depletion throughout the growing season produced higher cane mass in comparison to grapevines that were irrigated at a higher RAW depletion levels for some period of the season (Myburgh, 2011c). The desired rapid growth during spring followed by a cessation of shoot growth between véraison and ripening can be achieved by means of irrigation manipulations in dry climate (Bravdo & Hepner, 1987). The judicious use of irrigation water can therefore be a useful tool for controlling grapevine vigour in warm, arid climates.

Different pruning methods can also have an effect on the grapevine canopy vigour. Although mechanically pruned grapevines will produce more shoots than spur pruned grapevines, the shoots of mechanically pruned grapevines will tend to be shorter (Archer & Van Schalkwyk, 2007). Ashley (2004) reported that mechanically pruned Shiraz grapevines had lower cane mass during winter pruning, compared to grapevines that were spur pruned and received the same irrigation volumes. However, this response was not found where Chardonnay, Chenin blanc Colombar, Sauvignon blanc, Ruby Cabernet and Shiraz grapevines were subjected to spur or mechanical pruning in the Breede River Valley (Archer & Van Schalkwyk, 2007).

1.3.4. Grapevine water use

Irrigated grapevines trained onto vertical trellis systems will use only a fraction of the prevailing reference evapotranspiration (ET_o) (McCarthy, 2000 and references therein). This is due to the fact that the crop evapotranspiration (ET_c) of row crops differs distinctly from ET_o, as ground cover, canopy properties and aerodynamic resistance of the crop are different from a well-watered grass used to determine the ET_o (Allen *et al*., 1998). The effects of canopy characteristics that distinguish row crops from grass covers are integrated into the crop coefficient (K_c). In the crop coefficient approach, ET_c is calculated by multiplying ET_o by K_c (Allen *et al*., 1998).

The type of training system used to cultivate grapevines will have an effect on the water use of the vineyard (Van Zyl & Van Huyssteen, 1980). When overhead sprinkler irrigated Chenin blanc/101-14 Mgt grapevines were trained as bush vines, onto a 1.7 m slanting trellis, a 5-wire lengthened Perold and a 3-wire Perold system, K_c values were 0.31, 0.26, 0.24 and 0.21, respectively (Van Zyl & Van Huyssteen, 1980). The higher water use can be explained by the fact that in the case of the bush vines and 1.7 m slanting trellis system, a larger leaf area was exposed to prevailing atmospheric conditions (solar radiation, temperature and wind) for longer periods, than in the case of the two Perold trellises (Myburgh, 1998).

The type of irrigation system used will also affect the water consumption of vineyards. Grapevines irrigated at 10% PAW depletion by means of under-vine sprinklers and micro-sprinklers increased water consumption by 25% to 30% compared to those irrigated by means of drip irrigation at the same depletion level (Van Zyl & Van Huyssteen, 1988). However, the drip irrigated grapevines required more frequent and smaller irrigation volumes to maintain the foregoing soil water depletion level compared to the less frequent and larger volumes applied in the case of the full surface irrigation systems (Van Zyl & Van

Huyssteen, 1988). Grapevines irrigated by microsprinklers in the Robertson area at 50% and 80% RAW depletion level consumed 2.5 mm/day and 2.8 mm/day more, respectively, than grapevines growing under similar conditions and that were irrigated at similar depletion levels by means of drip irrigation (Myburgh, 2011a; Lategan, 2011). This suggested that more water evaporated from the larger wetted soil surface than the partially wetted surface due to the high evaporation rate during the first two stages of evaporation (Hillel, 1980; Myburgh, 1998).

1.3.5. Yield components

Grape berry growth can be divided into four stages. Stage I is the herbaceous growth phase that last until 40 to 50 days after flowering (Deloire, 2010). Stage II is called the herbaceous plateau and during this stage berry growth slows down or ceases (Deloire, 2010). Stage III is characterised as the part of the season when berries expand rapidly, start to change colour and soften and this stage corresponds with the start of maturation (Deloire, 2010). During Stage IV, known as maturation, the berry growth rate slows down or stops.

Small berries can contribute to high wine quality for red grape cultivars (Bravdo *et al*., 1985; McCarthy, 2000; Kennedy *et al*., 2002). Final berry size is most sensitive to water constraints during Stage I of berry development (Van Zyl, 1984; Matthews *et al.*, 1986; Williams *et al*., 1994 and references therein). Berry size of Shiraz (McCarthy, 2000) and Pinot noir (Girona *et al*., 2006) was most sensitive to water constraints during the *ca.* four-week period after flowering (between flowering and pea size). Where Shiraz grapevines were subjected to water constraints during different phenological stages (Fig. 1.3), smallest berries were produced where strong water constraints occurred between anthesis and véraison (Ojeda *et al.*, 2002). Furthermore, a reduction in berry size caused by soil water deficits during Stage I cannot be reversed by more irrigations during Stage II and/or Stage III (Smart *et al*., 1974; Van Rooyen *et al*., 1980; Ojeda *et al.*, 2002).

The duration and timing of water constraints can also influence final berry size. Irrigation at *ca*. 80% RAW depletion throughout the season reduced Pinotage berry size compared to 50% depletion, but irrigation at 80% depletion either before véraison or after véraison had no effect on berry mass (Myburgh, 2011d). Sauvignon blanc berry size responded similarly, except that irrigation at *ca*. 50% RAW depletion before véraison followed by 80% depletion during berry ripening also reduced berry mass (Myburgh, 2011e). In the case of the latter irrigation strategy, berries shrunk when the grapevines were suddenly exposed to high soil water deficits (Myburgh, 2011e). Grapevine manipulation by means of management practices, *e.g.* the use of vigour reducing rootstocks, canopy manipulations by means of different trellis systems and management practices are not necessarily sufficient to ensure smaller berries (Ellis, 2008). Based on this, it was concluded that irrigation strategy plays an important role in the manipulation of berry size (Ellis, 2008). Mechanically pruned grapevines tend to produce smaller berries compared to grapevines that were spur pruned (Archer & Van Schalkwyk, 2007; Holt *et al.*, 2008).

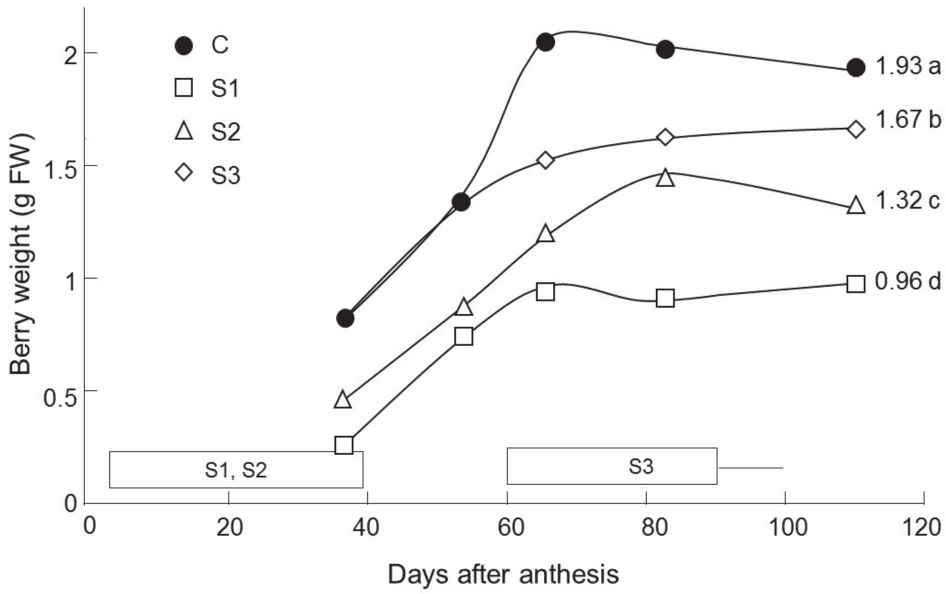

Figure 1.3 Changes in fresh weight (FW) (g) of Shiraz berries subjected to water deficit treatments as a function of number of days after anthesis (flowering). C = control; S1 = strong; S2 = medium levels of early water deficit between anthesis and véraison; S3 = strong late water deficit between véraison and harvest maturity. Arrow indicates onset of véraison. Vertical bars indicate standard deviation (n = 6). Values followed by the same letter are not significantly different (p < 0.05) (Ojeda *et al.*, 2002).

Irrigation improved fruit set and increased berry size of Chenin blanc grapevines which reflected in bigger bunches compared to rain fed grapevines (Van Zyl & Weber, 1977). Previous research also showed that lower bunch masses were obtained where Pinotage and Sauvignon blanc grapevines were irrigated at *ca.* 50% RAW depletion before and *ca.* 80% RAW depletion after véraison, compared to those irrigated at *ca.* 50% RAW depletion throughout the season (Myburgh, 2011d; Myburgh, 2011e). The smaller berries seemed to be a function of berry shrinkage due to the sudden water constraints experienced by the grapevines. Bunch mass of Merlot in the Coastal region of South Africa also seemed to be related to the volume of irrigation water applied *via* its effect on berry mass (Myburgh, 2011f). During the growing season, different irrigation strategies should have no effect on the number of bunches produced per grapevine. The number of bunches per grapevine can be controlled by the winter pruning method, *i.e.* spur *vs.* mechanical pruning, and a negative linear relationship can be expected between the number of bunches per grapevine and mean bunch mass (Ashley, 2004, Archer & Van Schalkwyk, 2007). Severe water constraints during winter, in combination with very low relative humidity of the atmosphere, could also affect the number of bunches produced in the following growing season (Myburgh, 2008).

In the Stellenbosch area, a single irrigation application increased Chenin blanc yields compared to non-irrigated grapevines (Van Zyl & Weber, 1977). However, additional irrigations held no further advantage on yield. Irrigating Colombar in the Lower Orange River region every week to field water capacity (FC) increased yield compared to irrigation to FC every 14 days, 21 days or 28 days, respectively (Myburgh, 2007). Where Pinotage was irrigated at *ca.* 50% RAW depletion throughout the season or irrigated at *ca.* 80% RAW depletion before véraison followed by *ca.* 50% RAW depletion during ripening tended to produce higher yields in the Breede River Valley region (Myburgh, 2011d). Pinotage grapevines that were irrigated at *ca.* 80% RAW depletion during ripening tended to produce lower yields (Myburgh, 2011d). Merlot yields in the Breede River Valley (Lategan & Howell, 2010b) as well as Coastal regions (Myburgh, 2011f) of South Africa increased with increasing precipitation in the growing season, *i.e.* rain plus irrigation, until it reached a plateau. Following this point, no further yield increases were obtained with increased precipitation. It is evident from previous research that yield seems to be a stronger function of berry mass than bunch mass, *i.e.* higher yields could be expected if berry masses are higher (Ashley, 2004). Grapevine canopy manipulations by means of the suckering of water shoots will result in a decrease in yield compared to grapevines that were unsuckered (Volschenk & Hunter, 2001). Yield increases of between 22% and 54% have been reported when mechanically pruned Shiraz grapevines were compared to spur pruned grapevines (Ashley, 2004; Archer & Van Schalkwyk, 2007).

1.3.6. Juice characteristics

A freely available water supply to grapevines during ripening has been reported to stimulate vegetative re-growth (Lategan, 2011). These actively growing shoots compete with berries for carbohydrates synthesised in green leaves and reduces availability to accumulate sugar in the berries (Saayman, 1992). According to Van Zyl (1981), a higher sugar concentration can be expected in the juice of grapevines that receive no, or low frequency irrigation compared to grapevines that receive more irrigation in the same climatic region. The beneficial effect of mild water constraints during ripening can enhance grape and wine quality (Van Zyl & Weber, 1977), and is probably caused by the reducing effect of water constraints on vegetative growth (Smart & Coombe, 1983). In contrast, severe water constraints can retard sugar accumulation (Smart & Coombe, 1983). No significant differences were present in the final sugar concentration between more frequently and less frequently irrigated Shiraz grapevines (Ojeda *et al.*, 2002). The total soluble solids per berry were proportional to berry size as quantified in terms of berry mass. Similarly, different levels of water constraints during berry ripening (Myburgh, 2005) had no effect on the sugar concentration in Sauvignon and Chenin blanc grapes at harvest in the Stellenbosch region (Myburgh, 2006a).

High wine pH has a negative effect on the colour intensity of red wines and the aging potential of the wine (Ribéreau-Gayon *et al.,* 1998). A luxurious water supply to grapevines not only slows berry ripening, but elevates juice pH and reduces acidity (Smart & Coombe, 1983). Grape juice containing a high potassium (K) concentration tends to have high pH and high malate concentrations (Jackson & Lombard, 1993). The latter may decrease during the vinification process causing a further pH increase. Dense grapevine canopies caused by high irrigation frequencies, *i.e.* low levels of PAW depletion, will induce excessive shading in the bunch zone (Jackson & Lombard, 1993). Under such conditions, K would be more readily absorbed and transported through the plant to the fruit, causing higher juice pH. Where Cabernet Sauvignon grapevines received 100% of their seasonal water requirement, pH, tartaric acid, malic acid and K concentration in the juice was higher compared to grapevines that only received 70% or 50% of their seasonal water requirement (Prichard & Verdegaal, 1998).

The organic acid content of grape berries consists primarily of tartaric, malic and citric acids (Ribéreau-Gayon *et al.*, 1998). Total titratable acidity (TTA) is an important quality factor since wine containing too high acidity is tart in taste, whereas wine containing low acidity may produce a bland taste. Microbial activity is more likely in high pH wines (Ribéreau-Gayon *et al.,* 1998). The malic and tartaric acid concentrations in grape berries are highest between pea size and véraison (Van Zyl, 1984; Hunter *et al.*, 1991; Hunter & Ruffner, 2001). During berry ripening, malic acid levels decrease (Van Zyl, 1984; Iland & Coombe, 1988; Hunter *et al.*, 1991; Coombe, 1992) due to malic acid metabolism (Iland & Coombe, 1988), whereas the tartaric acid concentration tends to remain constant (Van Zyl, 1984). In California, Cabernet Sauvignon grapevines that received the "minimal irrigation", *i.e.* only 32 L per grapevine once Ψ_L reached -1.6 MPa, produced the highest TTA and lowest pH, respectively, compared to grapevines that received 32 L and 64 L per grapevine per week, irrespective of Ψ_L (Chapman *et al.*, 2005). Grapevines that were suckered and had their shoots tucked into trellis wires produced juice with a higher TTA concentration than grapevines that received the same irrigation volumes, but were unsuckered and/or tucked in (Volschenk & Hunter, 2001).

1.3.7. Wine quality characteristics

Soil water status may induce substantial differences in leaf and canopy development that can cause conditions varying from excessively shaded to highly exposed bunches (Ellis, 2008). A reduction of berry size will result in less compact bunches, and in conjunction with a more open canopy, a greater berry surface area that would be exposed to sunlight (Ellis, 2008). The higher sunlight exposure within and around bunches may improve the colour of grape berries and, subsequently, the wine (Smart, 1982). Phenolic compounds which produce the unique cultivar taste characteristics occur primarily in the skin and seeds of the grape berry (Ojeda *et al*., 2002). Flavonoid compounds in grape berries, particularly anthocyanins and flavanols, are major contributors to wine colour (intensity and stability), astringency and wine flavour (Ristic *et al*., 2010). The final berry size indirectly affects the phenolic concentrations of the juice since the concentration depends on the skin surface to berry volume ratio (Singleton, 1972; Ojeda *et al*., 2002). Higher anthocyanins and skin tannin concentrations in berries, coupled with a lower seed tannin concentration, were associated with higher wine quality (Ristic *et al*., 2010).

The anthocyanin concentration in Shiraz berries is most sensitive to a very high availability of water during ripening (Ojeda *et al*., 2002). The highest phenolic concentrations in Shiraz grapes juice are obtained by no, to little irrigation during ripening (Petrie *et al.*, 2004). Similarly, anthocyanin concentrations in Pinotage wines tended to be higher in wines made from grapes irrigated *ca.* 80% RAW depletion grapevines compared to ones irrigated at *ca.* 50% RAW depletion (Myburgh, 2006b). It was found that highest concentrations of phenolics and anthocyanins in Shiraz wines were obtained with non-irrigated grapevines compared to ones receiving drip irrigation with crop coefficients of 0.2 or 0.4, respectively (McCarthy *et al.*, 1983). Pinot noir grapevines that experienced soil water deficits during ripening also produced the highest concentrations of anthocyanins and polyphenols (Girona *et al*., 2006). Similarly, Cabernet Sauvignon grapevines exposed to high soil water deficits produced higher juice phenolic concentrations, extracted phenols and anthocyanins in berry skins compared to frequently irrigated grapevines (Matthews *et al*., 1987). Where Shiraz canopies were managed to allow high bunch exposure to sunlight, grapevines that received excessive water during the growing season produced wines containing only 70% of the total anthocyanins and tannins compared to wines where grapevines were subjected to water deficits (Ristic *et al*., 2010).

Müller-Thurgau grapevines, grown in pots and subjected to high soil water deficits during ripening produced wine which was rated as "fruity, fragrant and elegant", compared to the "full-bodied and less elegant" wine obtained where water availability was "adequate" (Becker & Zimmerman, 1983). Wines least preferred were those produced from grapevines that were subjected to dry soil conditions until véraison followed by wet soil conditions during ripening. Semillon grapevines exposed to excessive available soil water produced wines with a grassy taste, whereas a fruitier taste was present in wine made from grapes produced by grapevines that were subjected to soil water deficits (Ureta & Yavar, 1982). In a study on the effect of irrigation in a warm climate on grape juice flavour and aroma as perceived by tasting panels, non-irrigated grapevines produced juice containing higher levels of potential volatile terpenes (McCarthy & Coombe, 1984). Non-irrigated grapevines also produced wines of higher sensorial quality (McCarthy *et al.*, 1986). Cabernet Sauvignon growing in sandy soils in a hot climate produced wines with the highest berry character and overall quality when adequate irrigation water was applied during the growing season (Bruwer, 2010). In cooler climates or in loamy soils with higher soil water holding capacities, better cultivar character and overall quality can be expected when medium to high water constraints occur in Cabernet Sauvignon grapevines (Bruwer, 2010). During dry growing seasons, Merlot grapevines produced better wine colour, cultivar character and overall wine quality when three irrigations were applied to restore the soil to FC in the Coastal region of South Africa (Myburgh, 2011f). In these dry growing seasons, particularly ones following low rainfall winters, non-irrigated grapevines were exposed to excessive water constraints and produced inferior wines. Wine colour and overall quality was negatively affected when more than three irrigations were applied per season. Pinotage and Sauvignon blanc grapevines growing in the semi-arid Breede River Valley region of South Africa irrigated at *ca.* 80% RAW depletion during ripening, produced the best overall quality wines (Myburgh, 2011d; Myburgh, 2011e). Pinotage grapevines irrigated at *ca.* 80% RAW depletion before véraison and at *ca.* 50% RAW depletion after véraison, produced wines with the lowest anthocyanin concentration, cultivar character and overall quality (Myburgh, 2011d). Sauvignon blanc grapevines irrigated at *ca.* 50% RAW depletion during ripening tended to produce higher sensorial vegetative or grassy wine characters (Myburgh, 2011e). Where canopy management resulted in bunches fully shaded, moderately exposed or fully exposed to sunlight, high frequency irrigated Shiraz grapevines produced wines characterised by herbaceous and straw aromas (Ristic *et al.*, 2010). On the other hand, wines had a dominant liquorice (spicy) character aroma where grapevines were subjected to soil water deficits, and bunches were fully exposed. Neither irrigation nor canopy management had an effect on berry aroma (raspberry and cherry) in the experimental wines (Ristic *et al.*, 2010).

1.3.8. Economic impact due to different canopy management labour inputs

Variations in the amount of labour necessary to apply different grapevine canopy manipulations can be expected (Volschenk & Hunter, 2001) (Table 1.1). Grapevines that were manipulated intensively and irrigated frequently during the season were harvested more quickly and pruned more easily during winter, compared to those not as intensively manipulated. This can be explained not only by the fact that canopies were more open due to fewer shoots per grapevine and the bunches being more readily harvestable, but also because less grapes were produced by these intensively manipulated grapevines (Volschenk & Hunter, 2001). The application of the more intensive grapevine canopy manipulations resulted in *ca.* 32 % higher labour costs per hectare (Table 1.1.).

Table 1.1 Labour inputs for pruning, canopy management and harvesting (man hours per hectare) (Volschenk & Hunter, 2001).

Treatment	Pruning	Suckering	Shoot positioning	Harvesting	Total
Control	93.7 a	0	0	133.7 a	227 b
Shoot positioning	84.8 b	0	81.3 a	132.9 a	299 a
Suckering and shoot positioning	65.6 c	71.1	71.9 b	92.5 b	301 a

The cost to apply mechanical pruning can vary between R669 and R972 per hectare, depending on the row spacing and the type of pruning machine, a double sided or single sided pruning, being used (Le Roux, 2009). A double sided pruning machine can prune grapevines at *ca.* 2.2 hours/ha while it will take double the time to prune a hectare of grapevines using a single sided pruning machine (Le Roux, 2009). Thus, by applying mechanical pruning and no other canopy management practices, the cost of canopy manipulation can be drastically reduced, without influencing the wine quality.

1.3.9. Summary

Plant water status is a good indicator of grapevine responses to soil water availability and other environmental and cultivar specific factors. Grapevine water status will respond more negatively as soil water becomes less available for plant uptake and use. Leaf water potential has been used as an indicator of plant water status for many years, but during the new millennium Ψ_P has been preferred as an indicator of plant water constraints. However, it has been found that Ψ_S is a much more reliable indicator of constraints since Ψ_P and Ψ_L measurements are more readily affected by reigning climate conditions.

Grapevine canopies that are not manipulated and left to hang open may result in higher water constraints as a larger leaf area will be exposed to climatic factors.

Mild to strong water constraints are necessary before véraison to inhibit vegetative growth during berry ripening. This would stop actively growing shoot tips from competing with ripening grapes for photosynthetic products. Severe water constraints in grapevines should be avoided between flowering and véraison. Higher grapevine water consumption can be expected in more vigorous growing canopy systems due to higher leaf areas exposed to prevailing weather conditions. By making use of partially soil surface wetting irrigation systems, *e.g.* drip irrigation, water can be saved without compromising on yield and quality, provided the irrigation scheduling is managed properly.

Severe constraints from flowering and véraison will have a negative effect on berry size, yield and acid content of berries. Moderate water constraints during the first stage of berry development would result in small berries and looser bunches, with no detrimental effect on final yield. Compared to intensively manipulated hand pruned grapevines, mechanically pruned grapevines will produce more, but smaller grape bunches, higher yields and not necessarily more inferior quality wine. Mechanically pruned vineyards may be more profitable than low input hand pruned vineyards. Luxurious water availability during ripening will result in higher pH, lower titratable acidity as well as lower anthocyanins and phenols in grape juice. As a result, atypical cultivar characteristics or low quality wines could be expected if grapevines are exposed to high water availability, particularly during berry ripening. Canopy manipulations, particularly suckering, will have a negative effect on grapevine yields, but not necessarily a positive effect on the quality of the produced wine.

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CHAPTER 2: EXPERIMENTAL VINEYARD AND TRIAL LAYOUT

2.1. INTRODUCTION

From 2005 to 2009, the Irrigation team of the Soil and Water Science Division, ARC Infruitec-Nietvoorbij, investigated the effect of irrigations at different soil water depletion levels on the water usage, production, growth, plant water potentials and overall wine quality of Shiraz grapevines growing in a commercial vineyard near Robertson (Lategan, 2011). However, in this study, the same canopy management practices were applied to all of the grapevines of all of the different irrigation treatments. Suckering, *i.e.* the removal of excess shoots not growing on spurs left during winter pruning, was performed before flowering. Shoots were tucked into the trellis wires before the end of October and topping of active growing shoot tips was carried out in the beginning of December. Since the same canopy management practices were applied, the extent to which the measured parameters would have been affected if the canopies of grapevines within the same irrigation strategy were managed differently, was unknown.

As a complex irrigation system was already installed for the application of the irrigation treatments during the previous field trial, it was decided to use the same vineyard for the new study to save costs.

2.2. VINEYARD CHARACTERISTICS

The experiment was carried out in a commercial vineyard (S 33°54′04″, E 19°40′33″) *ca.* 23 km southwest from Robertson on the farm Wansbek in the Agterkliphoogte ward of the Breede River Valley region (Fig. 2.1). The vineyard was situated on the flood plain of the Poesjenels River on a southeast facing slope (< 1°) at an altitude of 201 m above sea level. The region has a cool semi-arid climate (Peel *et al*., 2007) and based on the growing degree days (GDD), from 1 September until 31 March (Amerine & Winkler, 1944), the specific locality is in a class V climatic region (Le Roux, 1974).

Shiraz (*syn*. Syrah) (clone SH1A) grapevines (*Vitis vinifera*), grafted onto 110 Richter (*Vitis berlandieri* x *Vitis rupestris*), were planted in August 2000 in a northwest/southeast row direction after the soil was double delved (cross-ripped) to a depth of 0.8 m during soil preparation (Van Huyssteen, 1983). Grapevines were planted 2.5 m × 1.22 m and trained onto a five strand lengthened Perold trellis system (Booysen *et al.*, 1992). Before the field trial started, irrigations were applied on a weekly basis during the growing season by means of 1 m spaced 3.5 L/h RAM drippers (Netafim, Kraaifontein). Grapevines were pruned to two bud spurs at *ca.* 12 cm intervals to allow five spurs for each of the two cordon arms. In September,

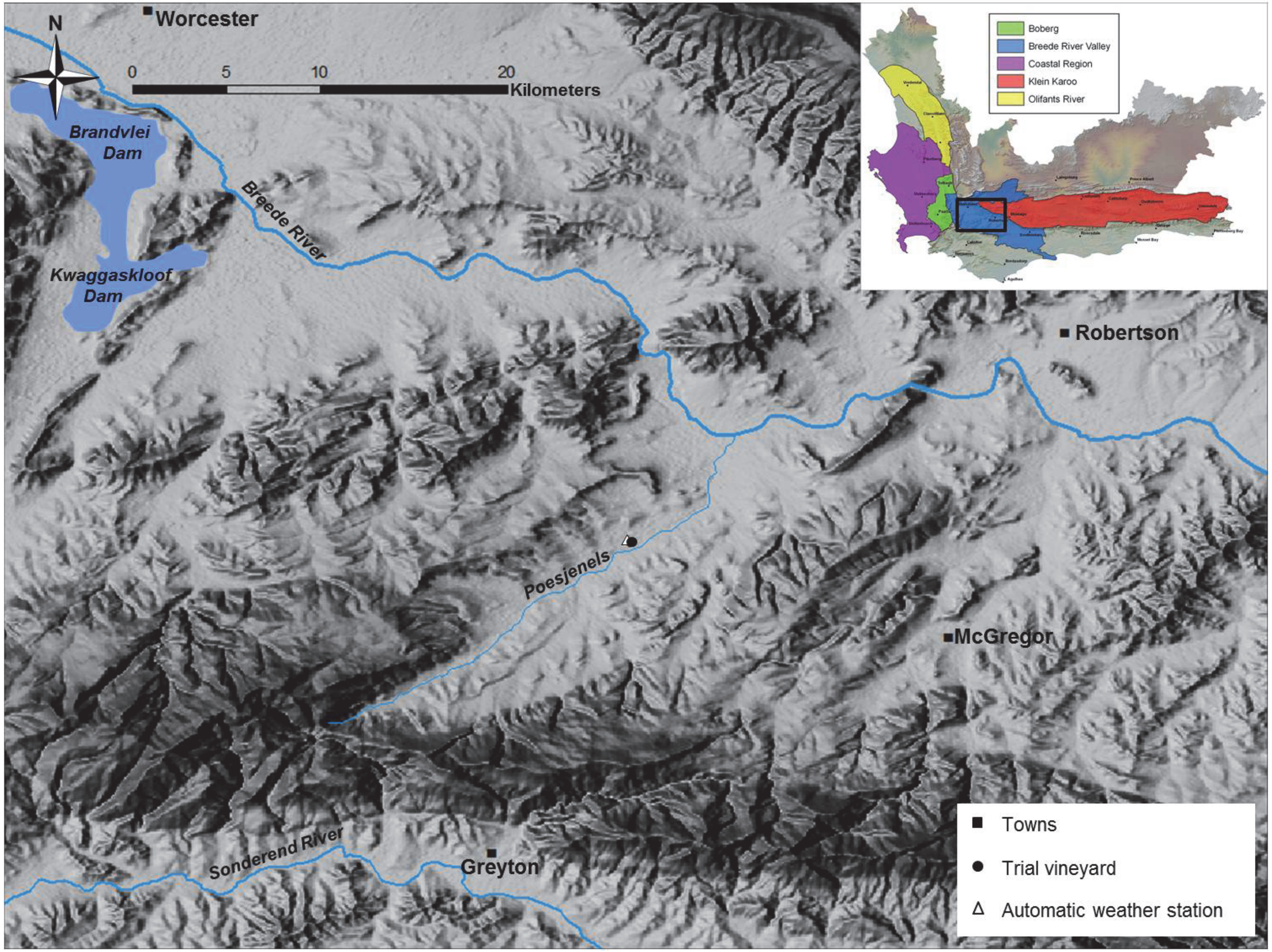

Figure 2.1 Map indicating the locality of the Shiraz/110R vineyard near Robertson where the field experiment was carried out.

i.e. before bud break, the experimental grapevines received the same annual fertilizer application as the rest of the commercial block. Fertilization amounted to 150 kg.ha^{-1} KNO_3 applied by hand under the drippers and leached into the soil profile by means of a 12 hour irrigation.

After the conclusion (October 2009) of the previous field experiment profile pits were dug in this commercial vineyard for soil classification (Lategan, 2011). The soil was classified as a Valsrivier soil form (Soil Classification Working Group, 1991), *i.e.* with an orthic A horizon and pedocutanic B horizon overlying a horizon consisting of unconsolidated material without signs of wetness, or Cutanic Luvisol (IUSS Working Group WRB, 2001; Fey, 2010). The soil has medium to high yield potential and represent 12.3% of the surveyed soils in the Breede River Valley (Oberholzer & Schloms, 2011).

According to the soil particle distribution, the 0 to 300 mm and 300 to 750 mm depth soil layers had a fine sandy loam texture (Table 2.1). Soil texture was reasonably homogenous across the experiment vineyard. The mean ρ_b was 1 517 kg.m^{-3} and 1 526 kg.m^{-3} for the 0 to 300 mm and 300 to 700 mm soil layers, respectively, which indicated that no excessive soil compaction occurred in the root zones (Van Huyssteen, 1981; Van Huyssteen, 1983).

Table 2.1 The mean particle size distribution, sand grade, soil textural class and bulk density in the soil where the field experiment was done near Robertson.

Soil depth (mm)	Clay (%)	Silt (%)	Fine sand (%)	Medium sand (%)	Coarse sand (%)	Sand grade	Soil texture class	Soil bulk density (kg.m^{-3})
0-300	13.5	6.0	65.3	12.2	3.0	Fine	Sandy loam	1517
	±3.3	±1.5	±6.7	±6.2	±1.8			±85
300-750	18.8	5.3	59.4	11.4	5.1	Fine	Sandy loam	1526
	±7.6	±1.8	±7.8	±5.5	±6.0			±51

The soil water characteristic curves were determined *in situ* during the previous field trial (Lategan, 2011). The water holding capacity in the 0 to 450 mm soil layer was *ca.* 0.127 mm.mm^{-1}, compared to *ca.* 0.122 mm.mm^{-1} in the 450 to 750 mm layer. The total soil water holding capacity in the root zone was 94 mm per 0.75 m. Field capacity (FC) and permanent wilting point (PWP) amounted to 165 mm per 0.75 m and 71 mm per 0.75 m, respectively.

During the soil classification (October 2009), root distribution throughout the soil profile was quantified by means of the root profile wall method (Böhm, 1979). A trench, 3 m long and 1 m deep, was excavated across the grapevine row between four experimental grapevines, with the long sides 100 mm from the grapevines. Roots were painted white and photographs were taken for presentation purposes and it was clearly evident that the majority of the grapevine roots were distributed in only *ca*. 33% of the soil volume to a depth of *ca*. 0.75 m (Figs. 2.2. & 2.3.). As these grapevines were established in 2000 with drip irrigation and considering that the summer rainfall is very erratic and that the area has relatively dry winters (long term mean rainfall between April and August of *ca*. 117 mm), it was assumed that the root development primarily occurred in the soil volume which was wetted during irrigations. Thus, it was accepted that the volume of soil under each dripper wetted during and after irrigations was a third of the soil volume allocated to each dripper spacing. Although some roots were present outside this volume (Figs. 2.2. & 2.3.), transpiration water losses were expected to have occurred mainly from the aforementioned third of the soil volume after irrigations.

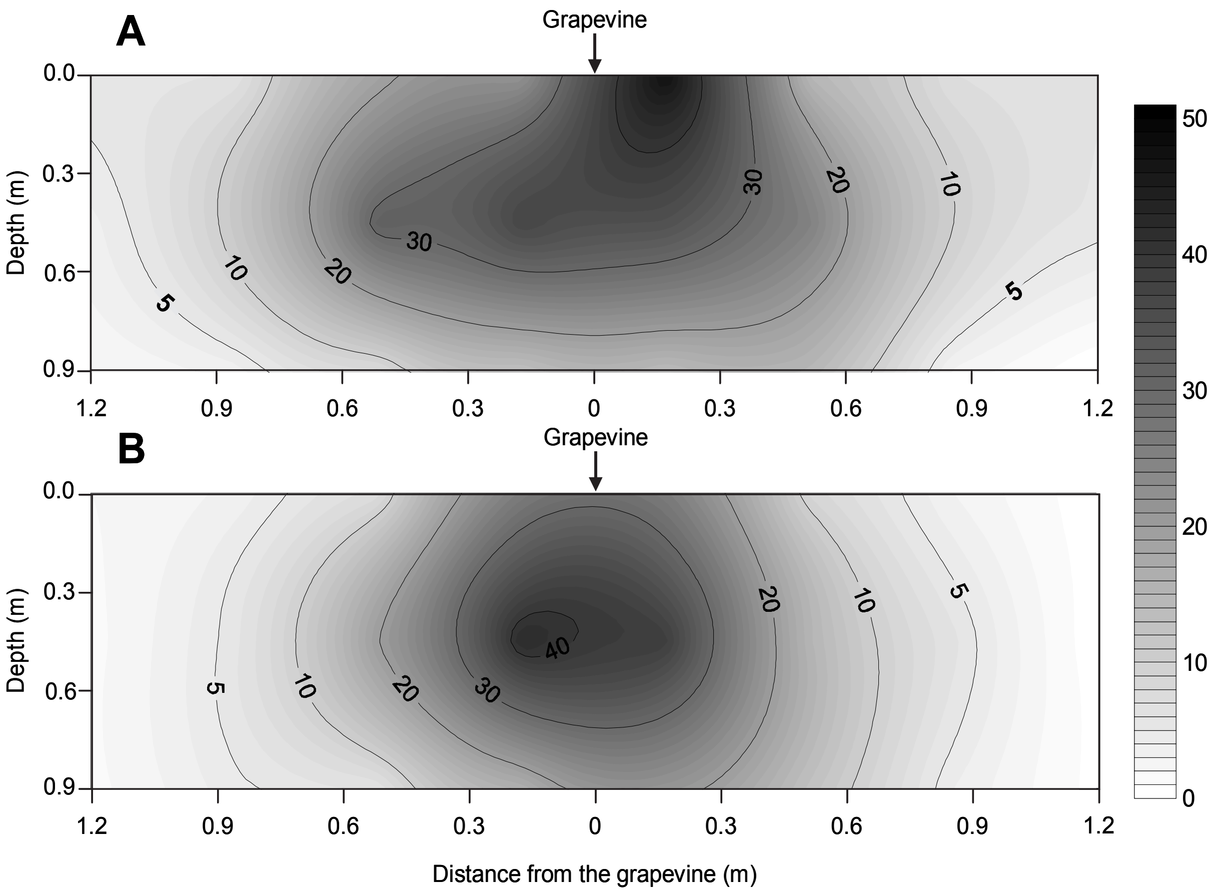

Figure 2.2 Root distribution profile across the grapevine row of Shiraz/110R grapevines spaced at 2.5 m × 1.22 m in a fine sandy loam soil after grapevines were (A) irrigated at 30% to 40% PAW depletion level and (B) irrigated at *ca*. 90% PAW depletion level near Robertson from the 2006/07 to the 2008/09 season. The scale on the right hand side of the figure indicates actual number of roots per 10 cm × 10 cm soil profile wall.

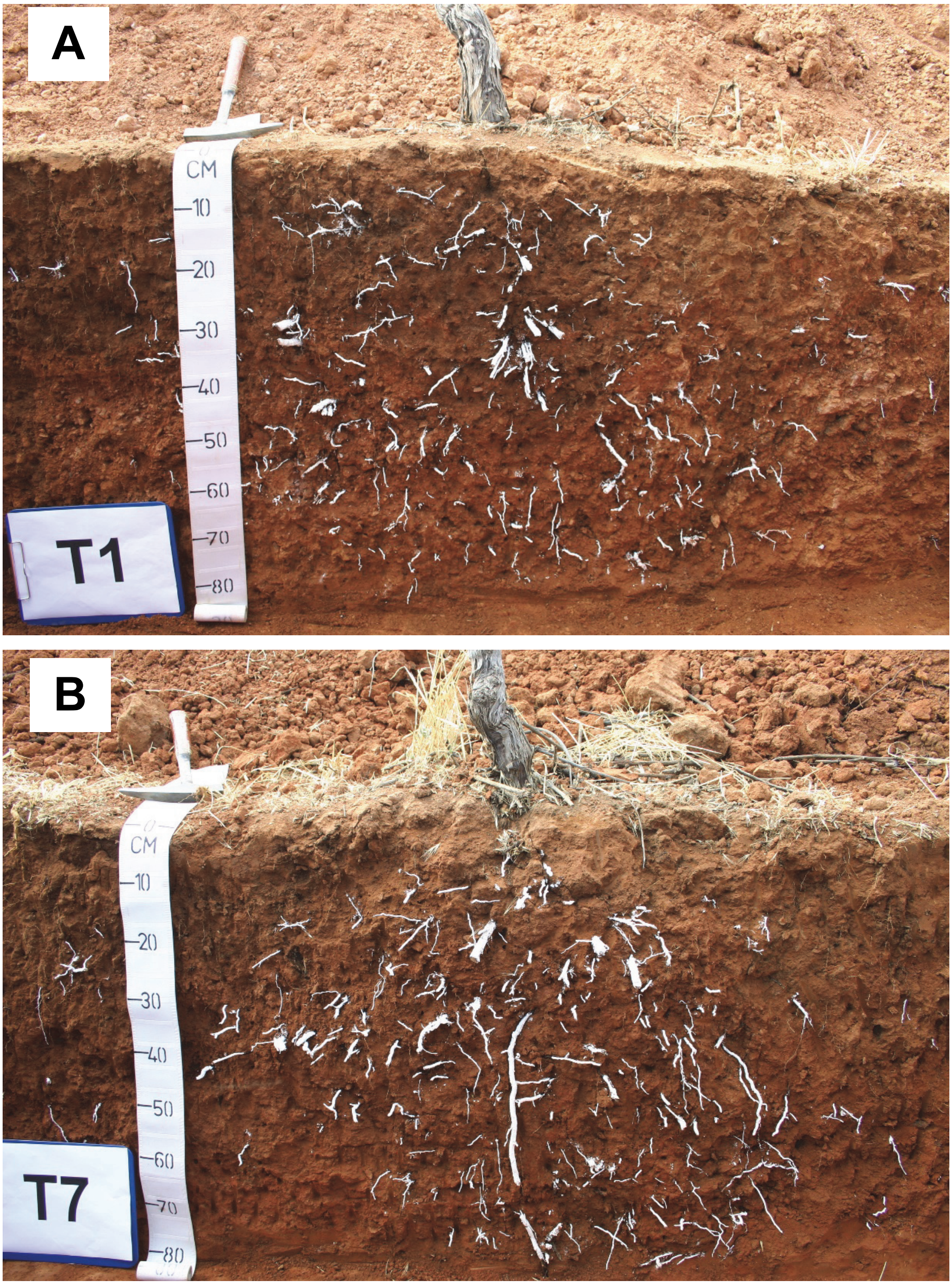

Figure 2.3 Example of the root distribution across the grapevine row of Shiraz/110R grapevines spaced at 2.5 m × 1.22 m in a fine sandy loam soil that were (A) irrigated at 30% to 40% PAW depletion level and (B) irrigated at *ca*. 90% PAW depletion level near Robertson from the 2006/07 to the 2008/09 season.

2.3. LONG TERM MEAN CLIMATE DATA

The climate of the region was described using long-term air temperature, relative humidity (RH) and rainfall data of 25 years, as well as the reference evapotranspiration (ET_o), incoming solar radiation and wind speed data of 10 years for a weather station at Rabiesdal (S 33°55′12″, E 19°38′17″), *ca*. 3.8 km from the experimental vineyard. The weather data was obtained from the ARC Institute for Soil, Climate and Water in Pretoria and is presented in Table 2.2.

Table 2.2 The long term mean daily maximum (T_x) and minimum temperature (T_n), maximum (RH_x) and minimum (RH_n) relative humidity, daily incoming solar radiation (R_s), wind (u_2), mean reference evapotranspiration (ET_o) and mean amount of rain for each month of the grape growing season near Robertson.

Month	T_x (1) (°C)	T_n (1) (°C)	RH_x (1) (%)	RH_n (1) (%)	R_s (2) ($MJ.m^{-2}.d^{-1}$)	u_2 (2) ($m.s^{-1}$)	ET_o (1)(3) ($mm.d^{-1}$)	Rain (1) (mm)
September	22.0	8.1	90.3	36.5	16.6	1.8	3.6	17
October	24.8	11.0	87.9	35.6	19.6	1.6	4.7	22
November	27.1	12.9	85.8	34.2	22.9	1.6	5.7	21
December	29.4	15.5	85.3	34.6	24.6	1.7	6.3	18
January	31.0	16.6	85.2	34.5	25.2	1.5	6.5	9
February	31.0	16.7	86.4	35.1	23.1	1.5	6.1	8
March	29.4	15.2	87.9	35.3	19.3	1.3	4.9	11

(1) Long term mean values was seen as the mean of 25 years' data from the Rabiesdal weather station (S 33°55′12″, E 19°38′17″) of the ARC Institute for Soil, Climate and Water.
(2) Long term mean values was seen as the mean of 10 years' data from the Rabiesdal weather station (S 33°55′12″, E 19°38′17″) of the ARC Institute for Soil, Climate and Water.
(3) ET_o determined using a modified daily Penman-Monteith equation.

2.4. EXPERIMENTAL LAYOUT AND TREATMENTS

Grapevines of nine of the treatments were hand pruned, whereas those of the tenth treatment (T10) were mechanically pruned. Three different irrigation strategies were applied to grapevines, namely, irrigation at *ca.* 30% plant available water (PAW) depletion, irrigation at *ca.* 60% PAW depletion and irrigation at *ca.* 90% PAW depletion. The canopies of the different treatment grapevines were either left to grow naturally and hang open (sprawing canopies), shoots tucked into trellis wires and vertical shoot positioning (VSP) applied without suckering of water (unwanted) shoots, or shoots tucked into trellis wires with suckering of water shoots. The different combinations of irrigation applications and canopy manipulations that were applied in the field trial are given in Table 2.3 and Figure 2.4.

Table 2.3 Ten different irrigation and canopy manipulation combination treatments applied to Shiraz/110R grapevines growing in a sandy loam soil near Robertson.

Treatment	Irrigation Strategy	Canopy manipulation applied		
		Pruning method	Suckered	Shoots tucked in
T1	*ca.* 30% PAW[(1)] depletion level	Hand	Yes	Yes
T2		Hand	No	Yes
T3		Hand	No	No
T4	*ca.* 60% PAW depletion level	Hand	Yes	Yes
T5		Hand	No	Yes
T6		Hand	No	No
T7	*ca.* 90% PAW depletion level	Hand	Yes	Yes
T8		Hand	No	Yes
T9		Hand	No	No
T10		Mechanical/box	No	No

(1) Plant available water.

All treatments were replicated three times in a randomised block design (Fig. 2.5). The first replication of treatments was allocated furthest away and third replication closest to the river to account for possible soil differences that may have occur towards the Poesjenels River (Fig. 2.6). Each experimental plot comprised of two rows of six experimental grapevines with two buffer grapevines at each end and a buffer row on each side (Fig. 2.7). Each plot covered 122 m^2.

A manifold was tapped into the farm's main irrigation line to obtain water to irrigate the experimental grapevines of the previous field trial (Fig. 2.8). This manifold consisted of five solenoid valves (Bermad, Macsteel, Bellville) which each controlled a designated irrigation strategy. A network of 25 mm polyethylene pipe and manual ball valves enabled these solenoid valves to control up to five different irrigation strategies throughout the season. Treatments irrigated at the same level of PAW depletion were controlled *via* a single valve. Consequently, irrigation of T1, T2 and T3, irrigation at *ca*. 30% PAW depletion, were controlled by valve No. 1 (Fig. 2.8). Similarly, valves No. 2 and No. 3 controlled T4, T5 and T6 (irrigation at *ca*. 60% PAW depletion) and T7, T8 and T9 (irrigation at *ca*. 90% PAW depletion), respectively. The only exception was that the irrigation of T10 grapevines, which were also irrigated at *ca*. 90% PAW depletion, was controlled by a separate valve. Subsurface blind 20 mm Ø polyethylene pipe connected the manifold outlets to the 17 mm Ø drip lines (3.5 L/h RAM, Netafim, Kraaifontein). The drippers were spaced 1.0 m apart in the laterals on the grapevine rows. The irrigation scheduling was done based on the mean SWC of the three canopy manipulation treatments within the same irrigation strategy.

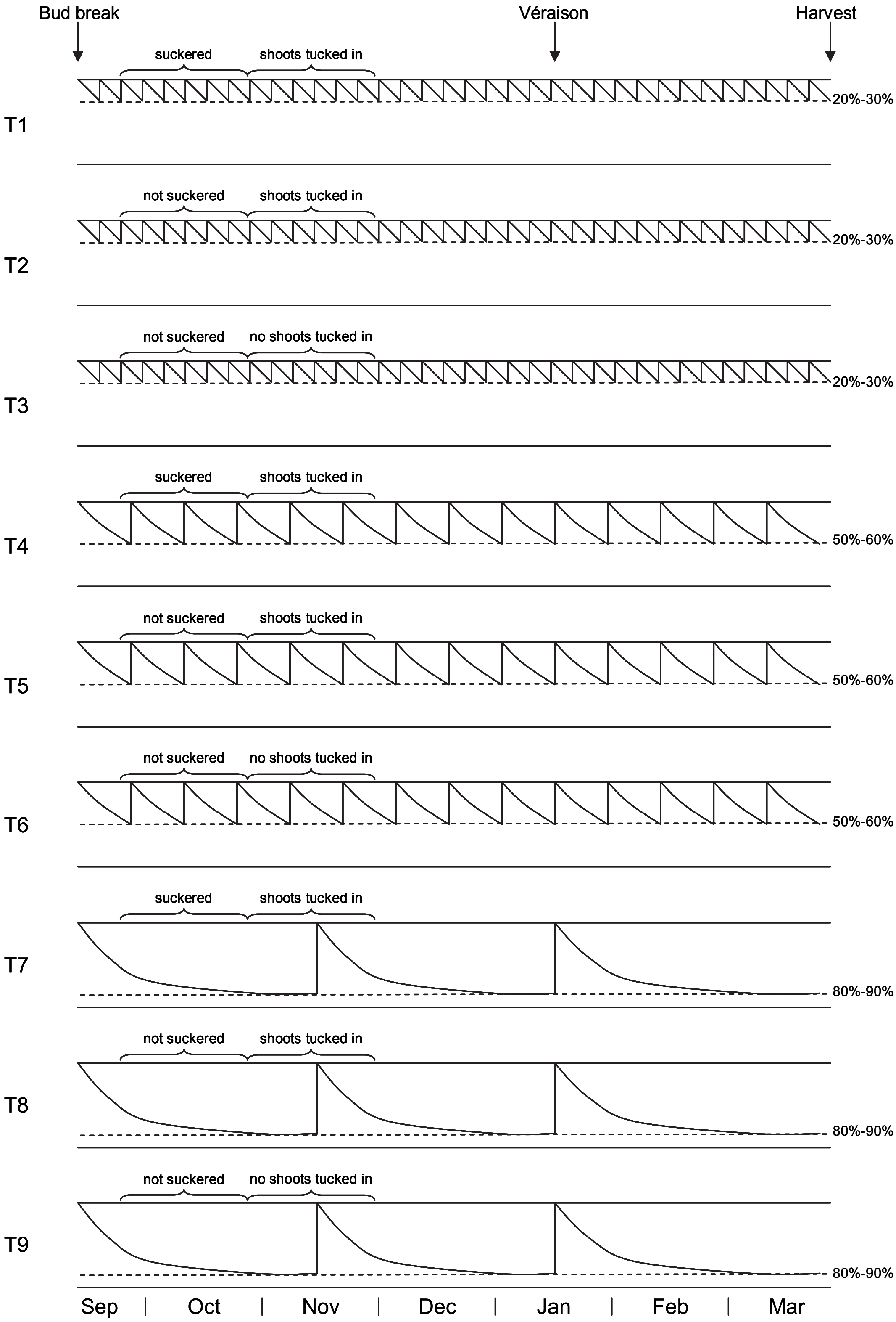

Figure 2.4 Schematic illustration of the soil water depletion patterns in combination with the canopy management inputs. Grapevines of T10 were mechanically simulated or box pruned, while grapevines of all the other treatments were pruned by hand.

N ↙

R3T5(30)	R3T7(24)	R3T8(18)	R3T6(12)	R3T9(6)	Replication 3
R3T2(29)	R3T3(23)	R3T1(17)	R3T10(11)	R3T4(5)	
R2T8(28)	R2T4(22)	R2T7(16)	R2T5(10)	R2T1(4)	Replication 2
R2T6(27)	R2T10(21)	R2T2(15)	R2T9(9)	R2T3(3)	
R1T9(26)	R1T5(20)	R1T6(14)	R1T7(8)	R1T10(2)	Replication 1
R1T4(25)	R1T1(19)	R1T3(13)	R1T8(7)	R1T2(1)	

Figure 2.5 Randomised block layout of field experimental plots within a Shiraz/110R vineyard near Robertson that were subjected to different irrigation/canopy management strategies between September 2011 and March 2015. Value in brackets indicate the experimental plot number.

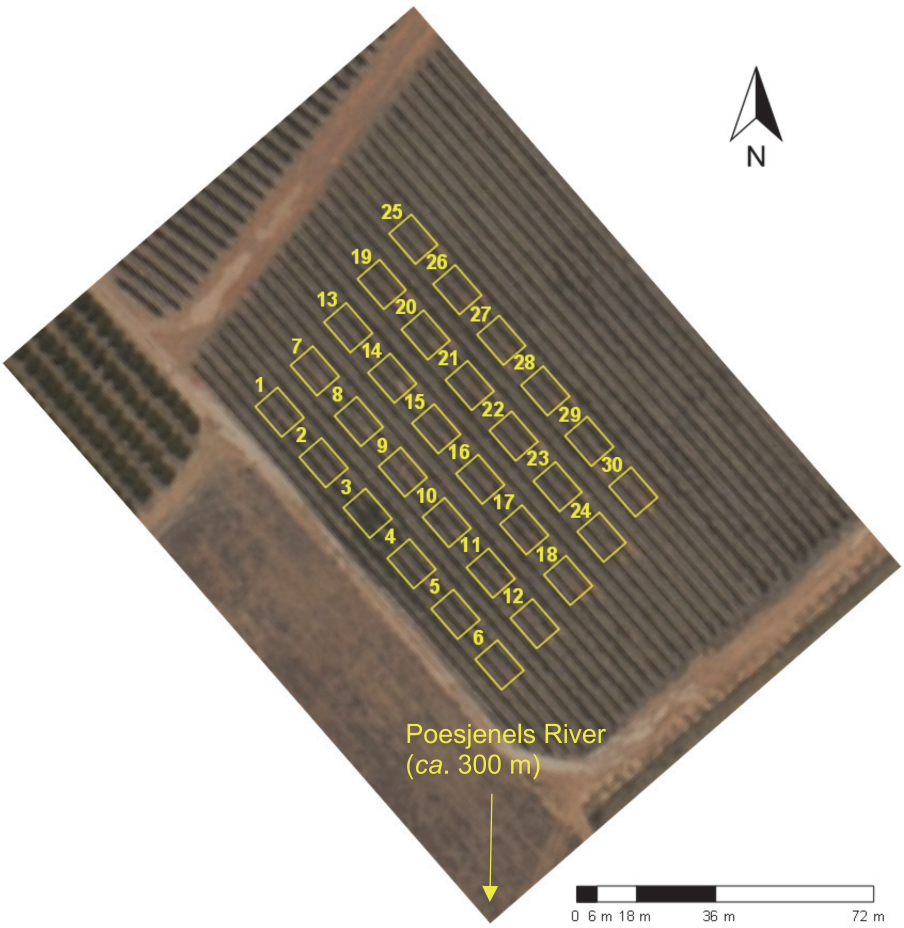

Figure 2.6 Layout of 30 proposed experiment plots for the field experiment near Roberson. Plot numbers refer to the value in brackets in Figure 2.5.

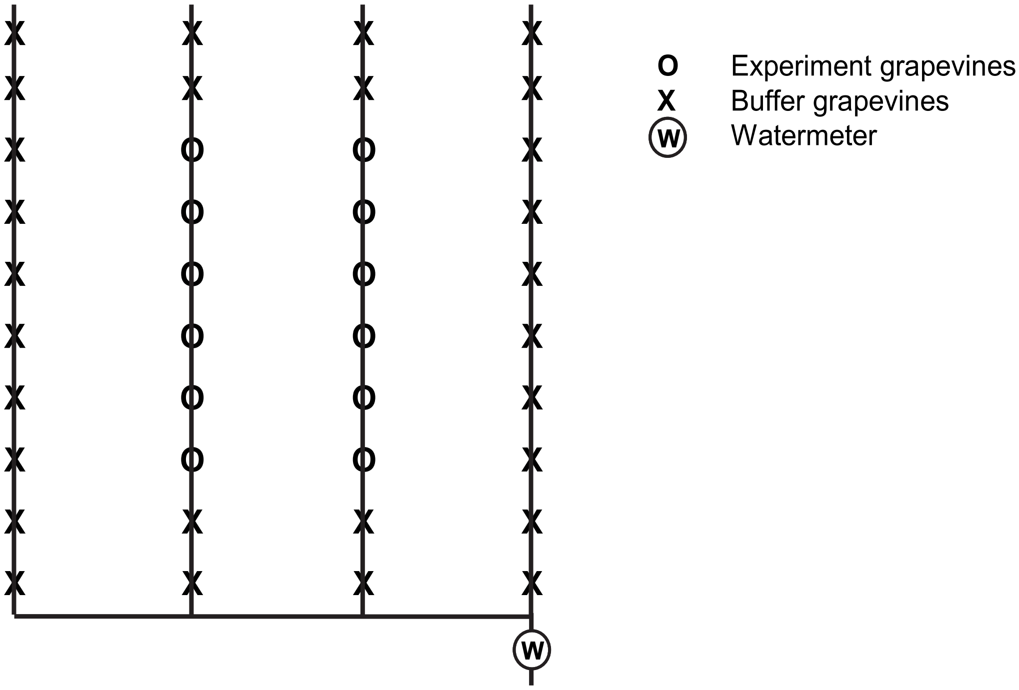

Figure 2.7 Schematic illustration of an experimental plot.

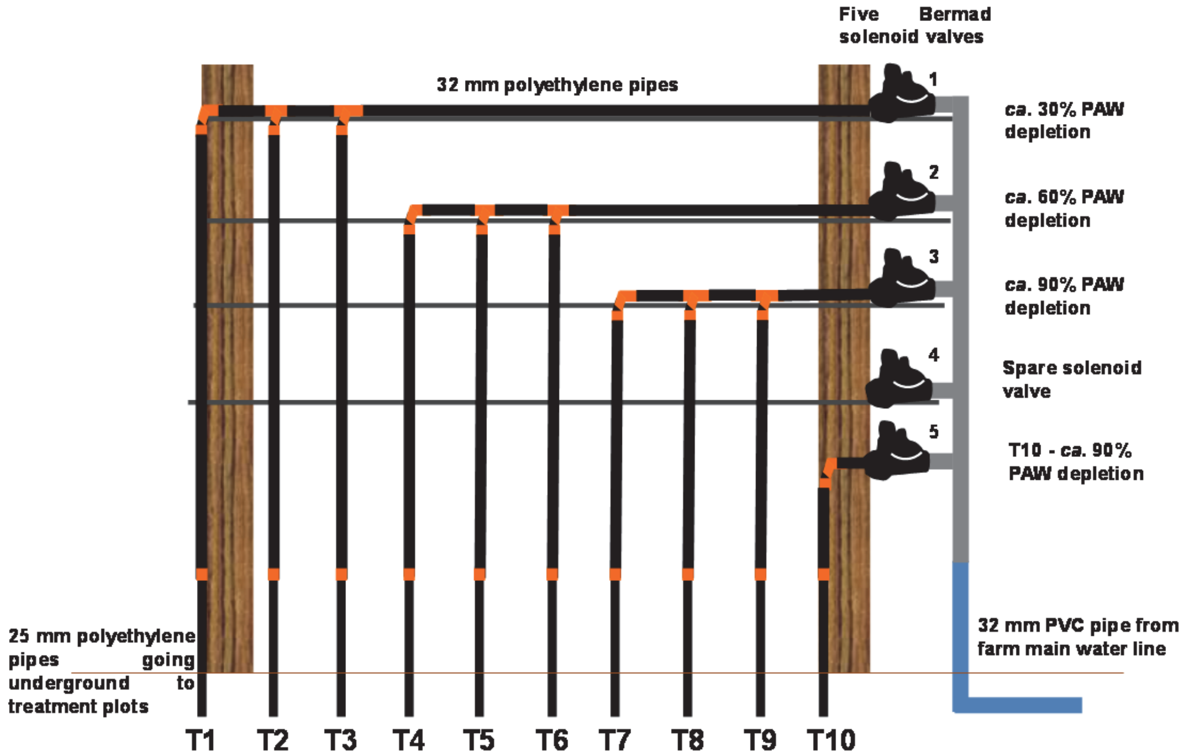

Figure 2.8 Manifold used in the field experiment to apply three different irrigation strategies to Shiraz/110R in a fine sandy loam soil near Robertson. Solenoid valve 1 controlled treatments that were irrigated at *ca*. 30% plant available water (PAW) depletion, valve 2 treatments irrigated at *ca*. 60% PAW depletion, valve 3 treatments irrigated at *ca*. 90% PAW depletion and valve 5 the grapevines of T10, *i.e*. also irrigated at *ca*. 90% PAW depletion. Valve 4 was not used during the trial and was only there to act as a backup valve should one of the other valves malfunction.

2.5. INITIAL MEASUREMENTS

On 2 June 2011, trunk circumferences of the 12 experimental grapevines per plot were measured 30 cm above the soil surface. Vegetative growth was quantified by measuring cane mass of the experimental grapevines in each plot during winter pruning on 13 July 2011 using a hanging balance. Cane mass was calculated by converting the kilogram cane mass per experimental plot to tonne per hectare. This was done to determine if there were growth differences between the grapevines of the different treatment plots before application of the treatments, and to use as a possible covariant in future statistical analyses.

After all the grapevines in the experimental part of the vineyard were irrigated the same for two seasons after the previous field trial, neither the mean trunk circumferences nor the cane mass of the experimental grapevines differed at winter pruning (Table 2.4). It was therefore assumed that there was no carry over effects in the grapevines due to the different irrigation treatments applied during the previous field trial.

Table 2.4 The mean trunk circumference and cane mass measured in July 2011 before the commencement of the field trial investigating the effect of different irrigation and canopy manipulation combination treatments applied to Shiraz/110R grapevines near Robertson.

Treatment	Mean trunk circumference (mm)	Cane mass ($t.ha^{-1}$)
T1[(1)]	176 a[(2)]	3.4 a
T2	172 a	3.3 a
T3	173 a	3.4 a
T4	164 a	3.0 a
T5	175 a	3.4 a
T6	169 a	3.2 a
T7	174 a	3.4 a
T8	166 a	3.0 a
T9	168 a	3.2 a
T10	174 a	3.1 a

(1) For treatment descriptions please refer to Table 2.3.
(2) Values designated by the same letter within each column do not differ significantly ($p \leq 0.05$).

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CHAPTER 3: ATMOSPHERIC CONDITIONS AND SOIL WATER STATUS

3.1. INTRODUCTION

In 2010, representatives of the South African wine industry's Breede River region (Messrs Briaan Stipp, Jaco Lategan, Hennie Visser and Willem Botha) approached Mr Vink Lategan and Dr Philip Myburgh of ARC Infruitec-Nietvoorbij with a request to investigate the implementation of deficit irrigation as a means to manage grapevine foliage. At that stage, there was no knowledge of how different irrigation strategies in combination with different canopy management practices would influence grapevine vegetative growth, yield, production water use efficiency and wine quality. Such information would enable growers to plan and apply different irrigation and canopy management strategies for their individual vineyard needs, and in doing so manage limited and expensive resources, *i.e.* water and electricity, for economically viable wine grape production. Knowledge could also help viticulturists and irrigation consultants in their recommendations for scheduling individual vineyard blocks.

The objective of the chapter is to report the prevailing atmospheric conditions, as well as the soil water status and the irrigation volumes applied, for the duration of the trial at the experimental vineyard.

3.2. MATERIALS AND METHODS

3.2.1. Atmospheric conditions

Hourly air temperature, relative humidity, incoming solar radiation and wind speed and wind direction was recorded from April 2011 until March 2015 by means of an automatic weather station (CS Africa, Stellenbosch) installed *ca*. 110 m from the experimental vineyard. Hourly data were used to calculate the mean daily minimum, maximum and mean air temperatures, daily minimum and maximum relative humidity of the atmosphere, daily incoming solar radiation and mean daily wind speed per month over the afore mentioned period. The daily ET_o was calculated from hourly ET_o determined by the mean air temperature, solar irradiance, relative humidity and wind speed values recorded by the automatic weather station near the experimental vineyard. The following modified Penman-Monteith equation was used to calculate the hourly ET_o (Allen *et al.*, 1998):

$$ET_o = \frac{0.408\,\Delta\,(R_s - G) + \gamma \dfrac{37}{T_{hr} + 273} u_2 (e^o(T_{hr}) - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)} \qquad \text{(Eq. 3.1)}$$

where: ET_o = reference evapotranspiration ($mm.h^{-1}$)

R_s	= incoming solar radiation at crop surface ($MJ.m^{-2}.h^{-1}$)
G	= soil heat flux density ($MJ.m^{-2}.h^{-1}$)
T_{hr}	= mean hourly air temperature (ºC)
u_2	= mean hourly wind speed at 2 m height ($m.s^{-1}$)
$e^o(T_{hr})$	= saturation water vapour pressure at air temperature T_{hr} (kPa)
e_a	= average hourly actual water vapour pressure (kPa)
Δ	= slope water vapour pressure curve at T_{hr} ($kPa.ºC^{-1}$)
γ	= psychrometric constant ($kPa.ºC^{-1}$)

3.2.2. Soil water content and irrigation volumes applied

Soil water content (SWC) was measured by means of the neutron scattering technique using a neutron probe (HYDROPROBE 503DR, CPN®, California). A 50 mm Ø class 4 Polyvinyl chloride [IUPAC: Poly(chloroethanediyl)] neutron probe access tube was installed in the grapevine row of each experimental plots. In September 2012, neutron probe access tubes were also installed in the middle of the work row of two experimental plots per irrigation treatment to monitor the SWC of the non-irrigated volume of soil. A 50 mm Ø custom built tube auger was used to minimize the disturbance of the soil around the access tubes. Soil water content was measured by lowering the probe to 200, 300, 600 and 900 mm soil depths. Neutron counts were calibrated against gravimetric SWC and converted to volumetric SWC for the 50 to 250 mm, 250 to 450 mm, 450 to 750 mm and 750 to 1 050 mm soil depth increments in a field calibration carried out in the same vineyard by Lategan (2011). A previous study, carried out in the same vineyard (Lategan, 2011), showed that the majority of the roots occurred to a depth of *ca.* 750 mm. 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 over irrigation occurred. Soil water content was measured once a week during September and October. From November until harvest in March, SWC was measured at least twice a week, as well as before and after irrigation. Following harvest, SWC was measured weekly until the first winter rainfall. Subsequently, SWC was measured monthly until the end of August. Total plant available water (PAW), *i.e.* water retained between FC (matric potential of -0.008 MPa) and PWP (matric potential of -1.500 MPa), was determined in a previous study (Lategan, 2011).

Water meters were used to measure irrigation volumes of the different treatments, and divided by the area of a plot to calculate the amount of water applied to the soil in mm.

3.3. RESULTS AND DISCUSSION

3.3.1. Atmospheric conditions

In the 2011/12 season, mean monthly air temperatures were comparable with the LTM, except for higher temperatures in September and January and lower temperatures in November (Table 3.1). Relative humidity, wind speed and solar radiation tended to be lower compared to the LTM (Tables 3.2 & 3.3). The ET_o was generally higher than the LTM (Table 3.4). Typical of the erratic rainfall in South Africa, the 49 mm seasonal rainfall was not comparable to the 106 mm LTM summer rainfall (Table 3.4).

In the 2012/13 season, the mean monthly air temperatures were comparable with the LTM, except for higher temperatures in November and December and lower temperatures in October (Table 3.1). Relative humidity, wind speed and solar radiation tended to be lower compared to the LTM (Tables 3.2 & 3.3). With the exception of September, November, January and March, the ET_o was lower compared to long term values (Table 3.4). This can be attributed to the visually observed of cloud covered days and the mean incoming solar radiation for the season. Although the summer rainfall of 79 mm was not too far off from with the LTM of 106 mm for summer rainfall in this region, 90% of this rain fell in September and October (Table 3.4).

In 2013/14, the mean monthly daily maximum temperatures were comparable to the LTM, with the exception of a warmer September and February which was substantially cooler than the LTM (Table 3.1). The mean monthly daily minimum temperatures were also comparable to the LTM with the exception of September, which was substantially lower than the LTM (Table 3.1). Relative humidity, wind speed and solar radiation tended to be lower compared to the LTM (Tables 3.2 & 3.3). The ET_o of September, October and January was comparable to the LTM, whereas the other months were higher (Table 3.4). This can be attributed to the lower minimum relative humidity and higher minimum temperatures even though lower wind speeds and mean daily incoming solar radiation were recorded. The rainfall of 208 mm measured in the 2013/14 season was almost double that of the LTM of 106 mm (Table 3.4). Furthermore, 73% of this rain precipitated in two incidences in November and January. Total amount of rain per season from the 1900/01 season to the 2014/15 season (September to March), as well as the rain during ripening and the month of January for this 115-year span, are presented in Figures A.1 to A.3 in Appendix A.

Table 3.1 The monthly mean daily maximum (T_x) and minimum air temperature (T_n) during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

Month	T_x (ºC)					T_n (ºC)				
	LTM[(1)]	2011/12	2012/13	2013/14	2014/15	*LTM*	2011/12	2012/13	2013/14	2014/15
September	*22.0*	22.8	21.4	22.0	23.1	*8.1*	7.2	7.2	6.5	8.0
October	*24.8*	24.2	22.2	24.9	26.6	*11.0*	10.3	10.7	10.3	11.4
November	*27.1*	25.5	28.7	27.1	27.3	*12.9*	11.3	12.2	13.4	13.0
December	*29.4*	28.6	30.9	29.5	28.8	*15.5*	14.2	17.1	15.7	15.5
January	*31.0*	32.7	30.5	30.6	32.2	*16.6*	17.4	16.2	17.1	16.7
February	*31.0*	30.6	30.8	30.9	29.4	*16.7*	15.9	15.8	17.4	14.5
March	*29.4*	30.0	29.8	29.2	30.0	*15.2*	15.5	14.2	14.5	15.2

(1) Long term mean values was seen as the mean of mean of 25 years' data from the Rabiesdal weather station (S 33°55′12″, E 19°38′17″) of the ARC Institute for Soil, Climate and Water.

Table 3.2 The long monthly mean daily maximum (RH_x) and minimum (RH_n) relative humidity during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

Month	RH_x (%)					RH_n (%)				
	LTM[(1)]	2011/12	2012/13	2013/14	2014/15	*LTM*	2011/12	2012/13	2013/14	2014/15
September	*90.3*	89.9	91.5	88.4	90.9	*36.5*	30.1	33.6	32.5	32.2
October	*87.9*	84.2	89.7	90.0	88.5	*35.6*	27.3	38.9	32.0	30.0
November	*85.8*	83.4	87.1	88.2	87.0	*34.2*	28.1	24.7	32.3	30.6
December	*85.3*	82.6	84.0	85.4	82.5	*34.6*	25.5	31.8	30.2	33.1
January	*85.2*	85.4	83.0	89.3	83.5	*34.5*	26.9	27.9	32.2	25.2
February	*86.4*	83.8	84.6	87.4	84.8	*35.1*	26.8	27.2	28.9	27.8
March	*87.9*	86.7	87.4	85.6	87.8	*35.3*	29.0	27.8	28.7	31.0

(1) Long term mean values was seen as the mean of 25 years' data from the Rabiesdal weather station (S 33°55′12″, E 19°38′17″) of the ARC Institute for Soil, Climate and Water.

Table 3.3 The monthly mean daily incoming solar radiation (R_s) and wind (u_2) during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

Month	R_s ($MJ.m^{-2}.d^{-1}$)					u_2 ($m.s^{-1}$)				
	LTM[1]	2011/12	2012/13	2013/14	2014/15	*LTM*	2011/12	2012/13	2013/14	2014/15
September	*16.6*	17.4	16.5	16.8	14.6	*1.8*	1.8	1.6	1.6	1.1
October	*19.6*	19.6	17.1	18.2	19.5	*1.6*	1.6	1.7	1.5	1.6
November	*22.9*	23.8	24.5	22.2	22.7	*1.6*	1.6	1.4	1.6	1.4
December	*24.6*	27.3	23.5	24.0	23.0	*1.7*	1.8	1.1	1.7	1.7
January	*25.2*	25.7	24.9	23.8	25.8	*1.5*	1.4	1.5	1.3	1.5
February	*23.1*	22.6	21.9	21.8	22.8	*1.5*	1.3	1.3	1.4	1.4
March	*19.3*	18.7	19.2	19.0	18.3	*1.3*	1.3	1.2	1.5	1.2

(1) Long term mean values was seen as the mean of 10 years' data from the Rabiesdal weather station (S 33°55′12″, E 19°38′17″) of the ARC Institute for Soil, Climate and Water.

Table 3.4 The monthly mean daily reference evapotranspiration (ET_o) and rain during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

Month	ET_o[1] ($mm.d^{-1}$)					Rain (mm)				
	LTM[2]	2011/12	2012/13	2013/14	2014/15	*LTM*	2011/12	2012/13	2013/14	2014/15
September	*3.6*	4.8	4.1	4.2	3.5	*17*	0	17	0	12
October	*4.7*	5.6	4.3	4.9	5.5	*22*	3	54	37	4
November	*5.7*	6.4	6.6	6.0	6.0	*21*	12	0	80	22
December	*6.3*	7.7	6.0	6.9	6.6	*18*	1	3	1	0
January	*6.5*	7.5	6.9	6.4	7.6	*9*	19	0	72	2
February	*6.1*	6.1	6.1	6.3	6.4	*8*	9	1	2	8
March	*4.9*	5.3	5.2	5.5	3.5	*11*	5	4	16	0
Seasonal Total (mm)	1144	1316	1186	1217	1183	106	49	79	208	48

(1) ET_o determined using a modified daily Penman-Monteith equation.
(2) Long term mean values was seen as the mean of 10 years' data for ET_o and 25 years' data for rain from the Rabiesdal weather station (S 33°55′12″, E 19°38′17″) of the ARC Institute for Soil, Climate and Water.

During the 2014/15 season, the mean monthly air temperatures for September, October and January were warmer while December and February were cooler than the LTM temperatures (Table 3.1). Relative humidity, wind speed and solar radiation tended to be lower compared to the LTM (Tables 3.2 & 3.3). With the exception of September and March, ET_o was higher compared to long term values, as well as previous seasons (Table 3.4). This can be attributed to the lower minimum relative humidity and higher minimum temperatures even though lower wind speeds and mean daily incoming solar radiation were recorded. The 48 mm rainfall during the season was substantially lower than the LTM of 106 mm rainfall during summer. The rainfall recorded in the summer of the 2014/15 season was, in fact, the lowest summer rainfall recorded at the weather station in the last ten years (data not shown).

3.3.2. Soil water content

The variation in SWC of the three different irrigation strategies for the 2011/12 season is presented in Figure 3.1. Furthermore, the mean SWC in the 75 to 105 cm soil layer indicated that very little over irrigation occurred (data not shown). The variation in SWC of the different irrigation strategies for the 2012/13 season is presented in Figure 3.2. It should be noted that there were labour protests in the Boland region during November 2011, and it was impossible to gain access to the vineyard during this time to take the neutron probe measurements. The variation in SWC of the different irrigation strategies for the 2013/14 season is presented in Figure 3.3. The SWC of grapevines with sprawling canopies tended to dry out gradually toward the end of the season, particularly during February (Appendix B), while those with VSP canopies that were suckered tended to increase (Appendix B). This trend was more prominent where irrigations were applied at lower depletion levels (Appendix B). Due to a lower budget and human capacity, the SWC of plots were measured only once per week in the 2014/15 season. Irrigation requirements the previous three seasons showed that grapevines irrigated at *ca*. 30% PAW depletion needed to be irrigated twice per week while those irrigated at *ca*. 60% PAW depletion needed to be irrigated once per week in order for SWC not to exceed the target PAW depletion levels. Since fewer trips were made to the trial in this particular season, an irrigation controller was set to irrigate the soil back to field capacity. The variation in SWC of the different irrigation strategies for the 2013/14 season is presented in Figure 3.4.

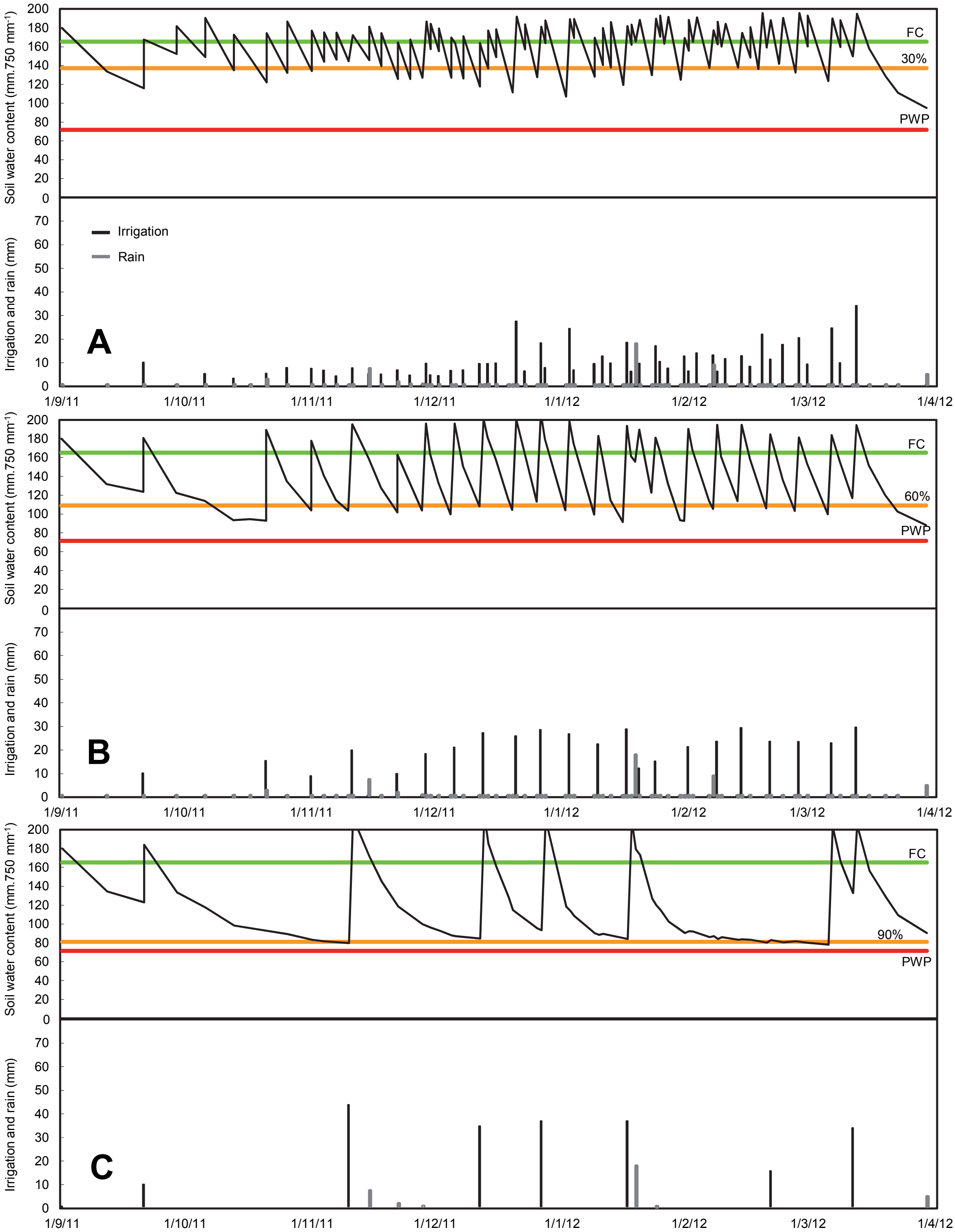

Figure 3.1 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at (A) *ca*. 30% plant available water (PAW) depletion, (B) *ca*. 60% PAW depletion and (C) *ca*. 90% PAW depletion during 2011/12 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation (black) volumes and rain (grey), respectively. For variation within each irrigation strategy please refer to Appendix B.

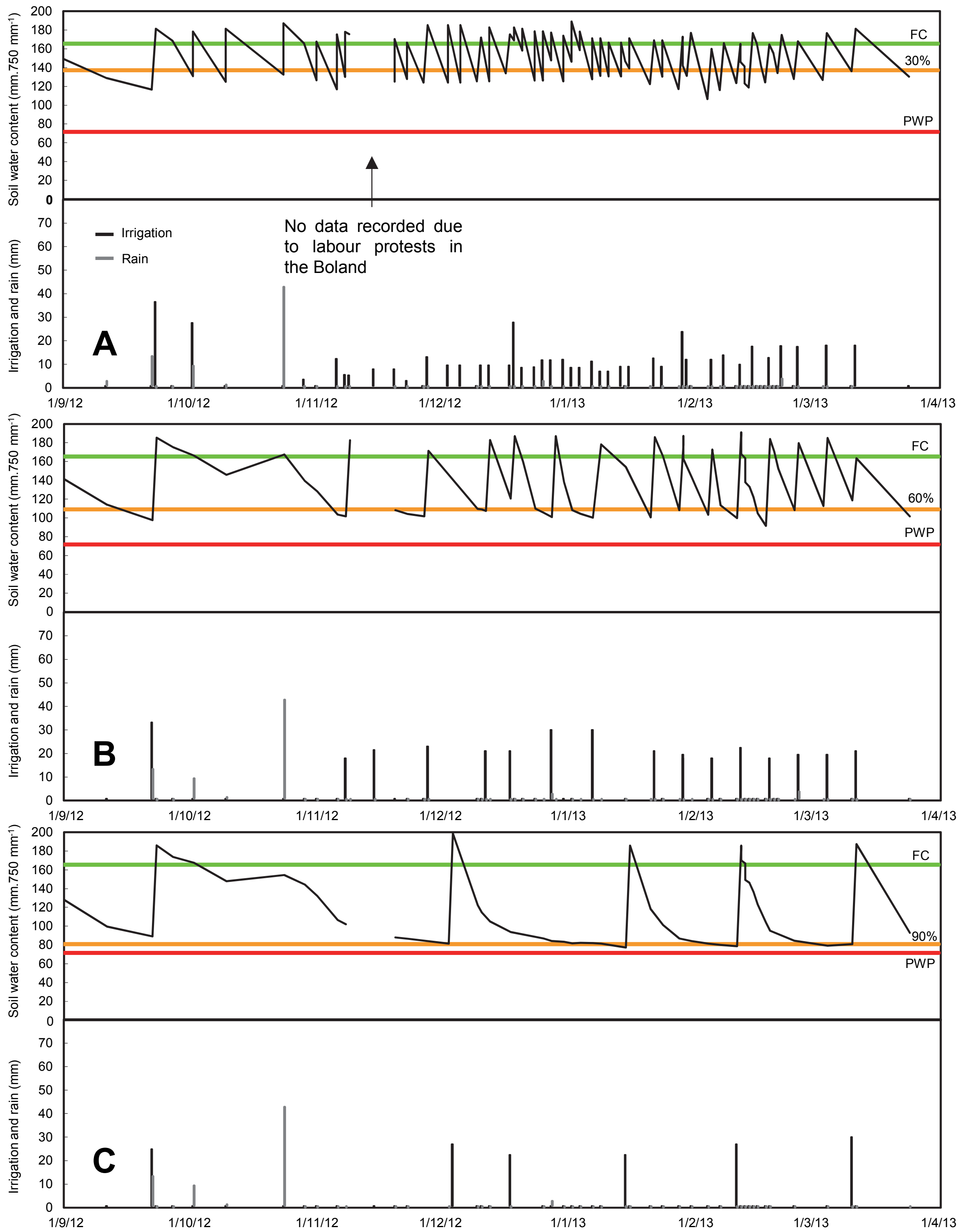

Figure 3.2 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at (A) *ca*. 30% plant available water (PAW) depletion, (B) *ca*. 60% PAW depletion and (C) *ca*. 90% PAW depletion during 2012/13 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation (black) volumes and rain (grey), respectively. For variation within each irrigation strategy please refer to Appendix B.

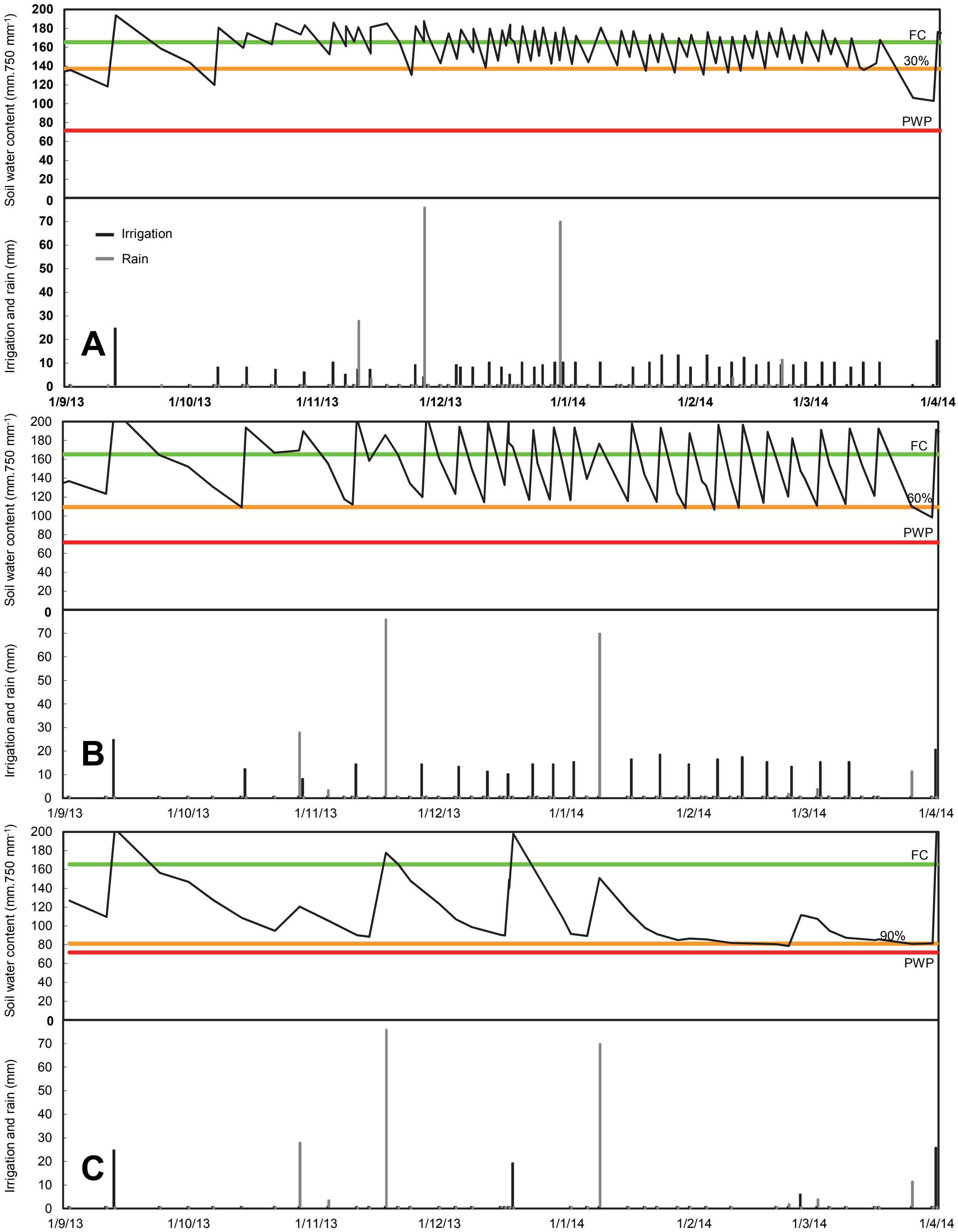

Figure 3.3 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at (A) *ca*. 30% plant available water (PAW) depletion, (B) *ca*. 60% PAW depletion and (C) *ca*. 90% PAW depletion during 2013/14 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation (black) volumes and rain (grey), respectively. For variation within each irrigation strategy please refer to Appendix B.

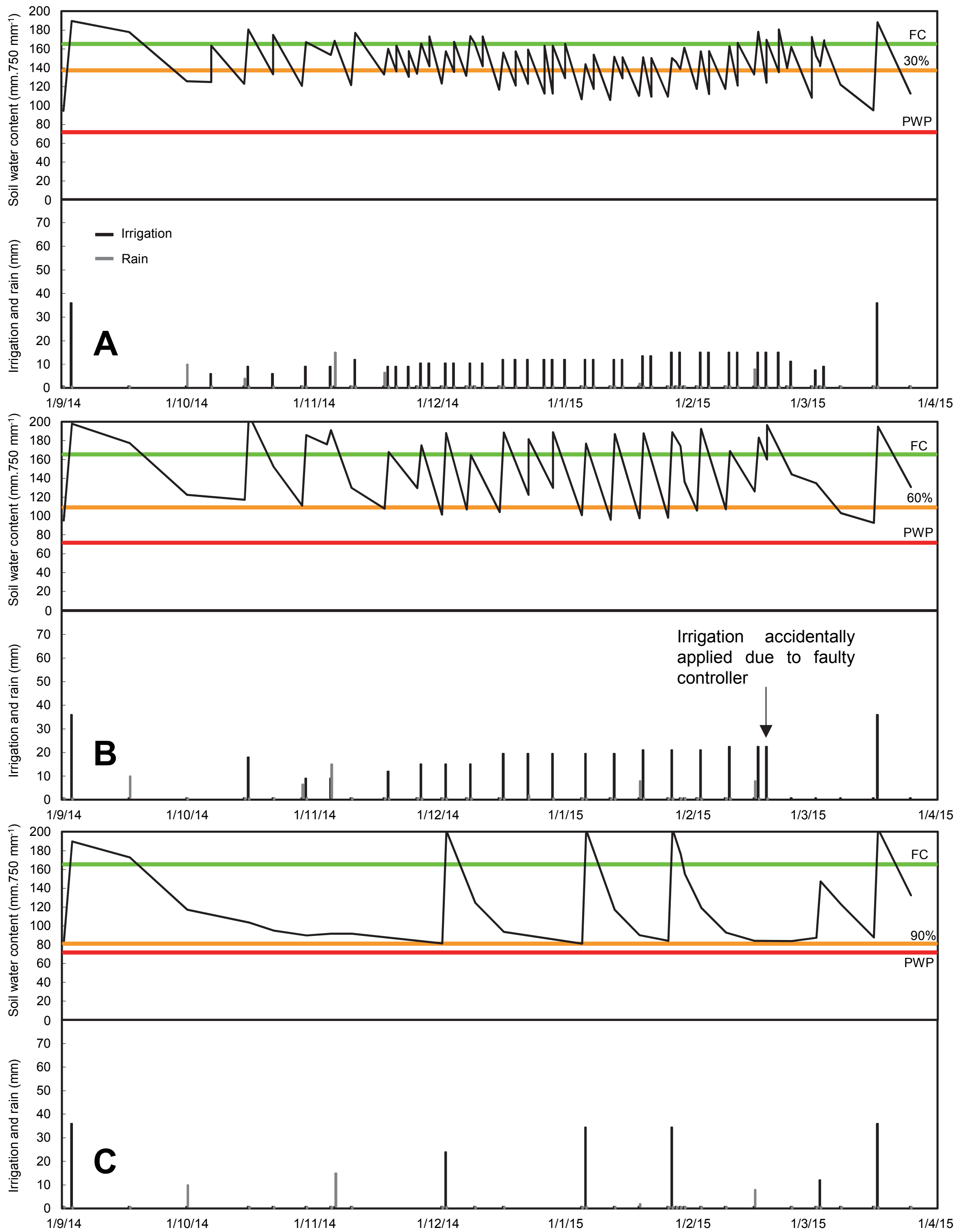

Figure 3.4 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at (A) *ca*. 30% plant available water (PAW) depletion, (B) *ca*. 60% PAW depletion and (C) *ca*. 90% PAW depletion during 2014/15 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation (black) volumes and rain (grey), respectively. For variation within each irrigation strategy please refer to Appendix B.

The mean SWC variation measured in the 2012/13 season in the work row is presented in Figure 3.5A. The SWC in the work row gradually decreased throughout the season, and by the end of March 2013, the SWC in the work row had dried out to such an extent that the SWC was almost at permanent wilting point (PWP). For the 2013/14 seasons, the mean SWC variation is presented in Figure 3.5B. It was clear that the mean SWC in the work row in this season was substantially higher than the previous season. This was due to abnormally high rainfall in November 2013 (80 mm) and January 2014 (72 mm). Due to the low rainfall during the 2014/15 season, the inter-row soil volume was generally dry and below *ca*. 90% PAW depletion from the beginning to the end of the season (Fig. 3.5C).

3.3.3. Irrigation volumes applied

The irrigation amounts applied in the 2011/12, 2012/13, 2013/14 and 2014/15 seasons are given in Table 3.5. As expected, irrigations at lower PAW depletion levels resulted in higher irrigation amounts needed to maintain the SWC at the specific target levels. Irrigation applied at low PAW depletion levels, *i.e. ca.* 30% PAW depletion, more than doubled irrigation volumes compared to grapevines irrigated at high PAW depletion levels, *i.e. ca.* 90% PAW depletion. The different canopy manipulations did not seem to have affected the water requirement of the grapevines within a given irrigation strategy (Table 3.5). However, due to accelerated sugar accumulation of sprawling canopies resulting in earlier harvest dates, canopy management practice indirectly reduced pre-harvest irrigation volumes. Due to the unseasonal rainfall in November 2013 and January 2014, substantially less water was applied to grapevines in this season, particularly where grapevines were irrigated at *ca.* 90% PAW depletion.

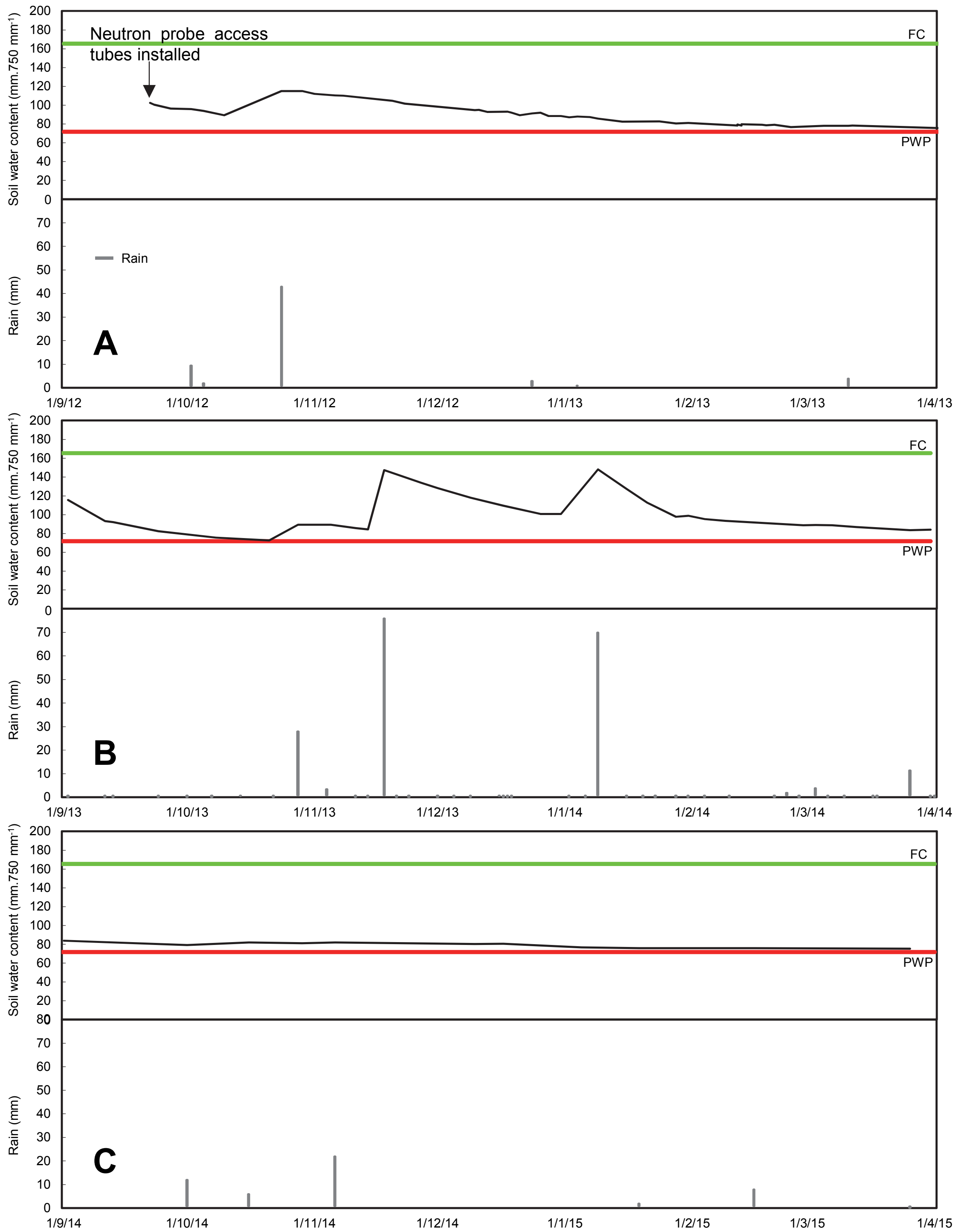

Figure 3.5 Variation in mean soil water content in the middle of the work row of a Shiraz/110R vineyard during the (A) 2012/13. (B) 2013/14 and (C) 2014/15 seasons near Robertson. Two measurement points were installed on 23 September 2012 per irrigation strategy, *i.e.* six tubes in total. Field capacity and permanent wilting point are presented by FC and PWP, respectively. Vertical bars indicate rain.

Table 3.5 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on irrigation amounts applied to Shiraz/110R grapevines during the 2011/12, 2012/13, 2013/14 and 2014/15 growing seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca*. 30% PAW depletion**			***ca*. 60% PAW depletion**			***ca*. 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Irrigation amounts applied from pre-bud break to harvest (mm)**									
2011/12	536	536	501	426	426	403	151	151	151	168[(1)]
2012/13	557	593	593	357	377	317	124	124	124	124
2013/14	413	413	403	297	311	282	38	38	38	42[(1)]
2014/15	454	454	454	322	322	322	77	77	77	77
Season	**Irrigation amounts applied post-harvest (mm)**									
2011/12	34	34	69	30	30	53	52	52	52	34
2012/13	37	37	37	37	37	58	69	69	69	69
2013/14	20	20	20	21	21	21	26	26	26	26
2014/15	67	67	67	67	67	67	78	78	78	78
Season	**Total irrigation amounts applied within season (mm)**									
2011/12	570	570	570	456	456	456	203	203	203	202
2012/13	594	630	630	394	414	375	193	193	193	193
2013/14	433	433	423	318	332	303	64	64	64	68
2014/15	521	521	521	389	389	389	155	155	155	155

(1) Grapevines received an extra irrigation in February compared to the other 90% PAW depletion treatments during ripening.

3.4. CONCLUSIONS

Atmospheric conditions prevalent in the 2011/12 season were generally within the long term values, with the exception of the summer rainfall which was very low. The 2012/13 season was characterized by many cloudy days. The summer rainfall in the 2013/14 season was substantially higher than the long term values. Furthermore, 73% of this rain fell in November and January. In particular, the rainfall in January could have had negative consequences for wine colour and quality. It appeared as if the 2014/15 season was similar to the 2011/12 season with respect to the prevailing atmospheric conditions.

Irrigation applied at low PAW depletion levels more than doubled irrigation volumes compared to grapevines irrigated at high PAW depletion levels. Due to accelerated sugar accumulation which resulted in different harvest dates, canopy management practice indirectly reduced pre-harvest irrigation volumes. In the area in which the field experiment was done, grapevines will need irrigation applications until *ca*. May that follows the growing season. Even though grapevines received the irrigation at the same depletion level during the post-harvest period, grapevines irrigated at low frequencies during the season had lower irrigation requirement compared to high frequency irrigated vines.

3.5. REFERENCES

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Lategan, E.L., 2011. Determining of optimum irrigation schedules for drip irrigated Shiraz vineyards in the Breede River Valley. M.Sc. Agric Thesis. Stellenbosch University, Private Bag X1, 7602 Matieland (Stellenbosch), South Africa.

CHAPTER 4: EFFECT OF DIFFERENT IRRIGATION AND CANOPY MANAGEMENT STRATEGIES ON VEGETATIVE GROWTH

4.1. INTRODUCTION

Vegetative growth of grapevines can 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). 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, 2011; 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, 2001; 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 tonne per hectare ($t.ha^{-1}$) 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 $t.ha^{-1}$ compared to non-irrigated grapevines and 1.4 $t.ha^{-1}$ compared to the single drip line. In the other locality, similar trends occurred. An average cane mass increase of 1.0 $t.ha^{-1}$ 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 $t.ha^{-1}$ over four seasons where grapevine were irrigated five times during the season in the grapevine row compared to non-irrigated grapevines (Myburgh, 2011). Total leaf area per grapevine of Cannonua grapevines increased from 2.73 m^2 per grapevine to 4.02 m^2 per 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 per 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, 2001). Mechanical pruning reduced cane mass of Cabernet Sauvignon grapevines compared to spur pruned grapevines at Nietvoorbij near Stellenbosch (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.

The objective of the study was to investigate the effect of irrigation strategy and canopy manipulation on vegetative growth responses of Shiraz grapevines growing in the Breede River Valley.

4.2. MATERIALS AND METHODS

4.2.1. Mean leaf area per shoot

To determine mean leaf area per shoot, ten shoots were randomly selected during grape ripening (prior to harvest). For unbiased sampling of shoots, an elastic band marked at five intervals was stretched along the bunch zone of the experimental 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 2013/14 and 2014/15 seasons. 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).

4.2.2. Mean number of shoots per grapevine

During pruning in winter, the number of shoots of all 12 the experimental grapevines per plot were counted and the total number of shoots were divided by the number of experimental grapevines to calculate the number of shoots per grapevine.

4.2.3. Mean leaf area per grapevine

During pruning the number of shoots per grapevine were counted and multiplied by the mean leaf area per shoot to determine the mean leaf area per grapevine ($LA_{grapevine}$):

$$LA_{grapevine} = \text{mean leaf area per shoot} \times \text{number of shoots per grapevine} \quad \text{(Eq. 4.1)}$$

The number of shoots per grapevine was also split into vertically growing shoot, *i.e.* shoots growing within the trellis wires, and horizontally growing shoots, *i.e.* those sprawling or hanging open.

4.2.4. Canopy dimensions and volume per grapevine

The number of shoots per grapevine was also split into vertically growing shoot, *i.e.* shoots growing within the trellis wires, and horizontally growing shoots, *i.e.* those hanging open. Before harvest in the 2013/14 and 2014/15 seasons, the grapevine canopy dimensions of the different treatments were measured. The grapevine canopy volume was calculated by multiplying the canopy height with the area of the canopy with regard to the covered soil surface:

$$\text{Canopy volume } (m^3) = A_{CD} \times H_C \qquad \text{(Eq. 4.2)}$$

where: A_{CD} = soil surface area covered by canopy during solar zenith (m^2)
H_C = height of canopy above the cordon (m)

4.2.5. Leaf area index

The mean leaf area index (LAI) per grapevine of the different treatments was determined by dividing the leaf area per grapevine by the plant spacing:

$$LAI = \frac{LA_{grapevine}}{A_{PS}} \qquad \text{(Eq. 4.3)}$$

where: LAI = leaf area index
$LA_{grapevine}$ = leaf area per grapevine (m^2)
A_{PS} = spacing between grapevines (m^2)

The mean $LA_{grapevine}$ of each treatment was also expressed as the leaf area per grapevine within the fraction of soil surface area covered by the particular canopy during the solar zenith (LA_{CPS}), *i.e.* canopy width x plant spacing within the row, with regard to the plant spacing:

$$ƒCPS = \frac{A_{CD}}{A_{PS}} \qquad \text{(Eq. 4.4)}$$

where: ƒCPS = fraction of soil surface area covered by canopy during solar zenith with regard to the plant spacing
A_{CD} = soil surface area covered by canopy during solar zenith (m^2)
A_{PS} = spacing between grapevines (m^2)

Thus:

$$LA_{CPS} = LA_{grapevine} \times ƒCPS \qquad \text{(Eq. 4.5)}$$

4.2.6. Canopy photosynthetically active radiation (PAR) interception

The photosynthetically active radiation (PAR) interception by grapevine canopies was measured by means of a ceptometer (AccuPAR LP-80, Decagon Devices, Washington, U.S.A) during ripening of the 2012/13, 2013/14 and 2014/15 seasons. The incident flux of PAR (PAR_I) was measured *ca*. 1.5 m above the soil surface between two experimental grapevine rows within each experimental plot (Fig. 4.1). This was done by holding the sensor probe of the ceptometer parallel to the two grapevine rows and ensuring that the bubble level stayed within the level ring and the PAR_I reading was logged. Hereafter, the ceptometer's sensor probe was placed diagonally within the grapevine canopy just above the grapevine cordon and the probe was kept level and stable before a transmitted flux of PAR (PAR_T) reading was logged (Fig. 4.1). This action was repeated three times in the left hand experimental grapevine row of each of the plots, between grapevines 1 and 2, 3 and 4, 5 and 6, to give an average PAR_T value of the three replications and ensure unbiased measurements.

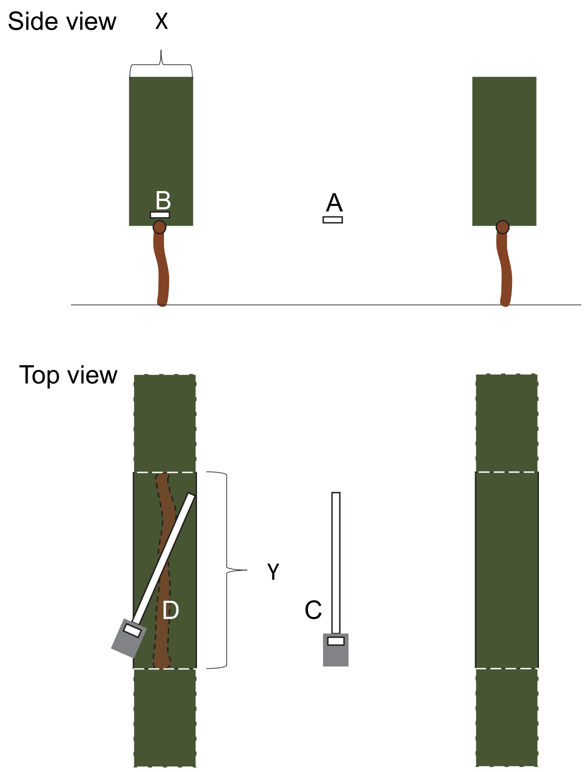

Figure 4.1 Schematic illustration of the method in which the photosynthetically active radiation (PAR) measurements were taken. The positions where incident flux of PAR was measured, as viewed from the side and the top, are indicated by A and C, respectively. Position B indicates where the ceptometer probe sensor was placed within the grapevine canopy, while position D indicates the diagonally placement as viewed from above while measuring the transmitted flux of PAR. The lengths of X and Y represent the soil surface area covered by canopy during solar zenith and the plant spacing within the grapevine row, respectively, that was used to calculate the total PAR intercepted by the grapevine canopy at the solar zenith.

The fractional PAR interception (fPAR) was calculated using equation 4.6 (McClymont *et al.*, 2009):

$$fPAR = \left(1 - \frac{PAR_T}{PAR_I}\right) \qquad \text{(Eq. 4.6)}$$

To calculate the amount of PAR intercepted by the canopy (PAR_{canopy}) of each treatment at the solar zenith, the PAR_I was multiplied by the fractional canopy PAR interception measured and the area of canopy:

$$PAR_{grapevine} = PAR_I \times fPAR \times A_{CD} \qquad \text{(Eq. 4.7)}$$

4.2.7. Cane measurements and mass

To quantify growth vigour, cane mass at pruning (July) was weighed per experimental plot using a hanging balance. Cane mass per plot (kg) was converted to tonnes per hectare.

Cane length and diameter of primary and secondary shoots was determined at pruning in July 2012 and July 2013. For unbiased sampling, shoots were collected using the same procedure described for the collection of the shoots to determine their leaf areas (Refer to Section 4.2.1). The number of nodes per primary shoot was counted to calculate the internode length. Shoot length was measured with a flexible measuring 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, individual primary and secondary shoots were weighed separately.

4.2.8. Statistical analyses

The data were subjected to an analysis of variance (ANOVA) by using Statgraphics®. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means, which differed at $p \leq 0.05$, were considered significantly different.

4.3. RESULTS AND DISCUSSION

4.3.1. Mean leaf area per shoot

In the 2011/12 season, canopy manipulations did not seem to have an effect of the total number of leaves per shoot, except in the case were grapevines were subjected to severe water constraints (T8 & T9) (Table 4.1). Suckered grapevines (T1, T4 & T7) tended to produce a higher number of secondary leaves compared to non-suckered grapevines within the same irrigation strategy (Table 4.1). The suckered grapevines within an irrigation strategy also tended to produce larger leaves, compared to their non-suckered counterparts.

The mean leaf area per shoot (Table 4.2) decreased as the number of shoots per grapevine, or metre cordon, increased (Table 4.3). Similar to 2011/12, suckered grapevines (T1, T4 & T7) tended to produce a higher number of secondary leaves compared to non-suckered grapevines within the same irrigation strategy in the 2012/13 season (Table 4.1). Non-suckered grapevines exposed to high water constraints produced the lowest number of leaves per shoot. The suckered grapevines also tended to produce larger leaves, compared to their non-suckered counterparts within the same irrigation strategy. The mean leaf area per shoot (Table 4.2) decreased as the number of shoots per grapevine, or metre cordon, increased (Table 4.3).

In the 2013/14 season, suckered VSP and sprawling canopy grapevines tended to produce a higher number of secondary leaves compared to non-suckered VSP grapevines within a specific level of PAW depletion (Table 4.1). Non-suckered grapevines exposed to high water constraints produced the lowest number of leaves per shoot. The suckered grapevines also tended to produce larger leaves, compared to their non-suckered counterparts within a specific level of PAW depletion. The mean leaf area per shoot (Table 4.2) was directly related to the number of secondary leaves per shoot (Table 4.1). As in the preceding three seasons, in the 2014/15 season the suckered VSP grapevines produced a higher number of secondary leaves and subsequently higher total number of leaves per shoot compared to non-suckered VSP grapevines within a specific level of PAW depletion (Table 4.1). The mean leaf area per shoot (Table 4.2) was directly related to the number of secondary leaves per shoot (Table 4.1). Non-suckered grapevines exposed to high water constraints (T8, T9 & T10) produced the lowest number of leaves per shoot (Table 4.1). The suckered grapevines also tended to produce larger leaves, compared to their non-suckered counterparts within a specific PAW depletion level.

Table 4.1 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean number of leaves per primary and secondary shoots, as well as the total number of leaves per shoot of Shiraz/110R grapevines during the 2011/12, 2012/13, 2013/14 and 2014/15 growing seasons near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca*. 60% PAW depletion			*ca*. 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Season	Number of leaves on primary shoots									
2011/12	14 b[1]	19 ab	20 ab	18 ab	23 a	21 ab	20 ab	18 ab	21 ab	17 ab
2012/13	10 abc	11 ab	8 cd	10 abcd	11 ab	12 a	11 ab	9 bcd	8 d	9 bcd
2013/14	10 cd	11 cd	10 cd	9 d	10 cd	11 cd	12 bc	14 ab	15 a	14 ab
2014/15	12 bc	13 bc	12 bcd	12 cd	14 b	10 d	19 a	11 cd	14 b	11 cd
Season	Number of leaves on secondary shoots									
2011/12	38 a	30 ab	26 abc	32 ab	21 bcd	31 ab	22 bc	8 d	16 cd	9 d
2012/13	32 a	24 b	12 cd	23 b	11 cde	17 bc	17 bc	5 de	9.0 cde	4 e
2013/14	83 a	62 b	70 ab	58 bc	44 c	54 bc	20 d	20 d	22 d	11 d
2014/15	41 a	20 bcd	20 bcd	25 b	12 cde	20 bc	12 cde	8 de	9 cde	2 e
Season	Total number of leaves per shoot									
2011/12	53 a	49 ab	46 ab	49 ab	44 ab	52 ab	42 ab	26 c	37 bc	26 c
2012/13	42 a	35 b	20 efg	33 bc	22 def	29 bcd	28 cde	14 g	17 fg	13 g
2013/14	92 a	72 b	82 ab	67 bc	54 cd	65 bc	32 e	34 e	37 de	25 e
2014/15	53 a	33 bc	32 bc	37 b	26 bcd	30 bcd	31 bcd	19 de	23 cde	13 e

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 4.2 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean leaf area per primary and secondary shoots, as well as the total leaf area per shoot of Shiraz/110R grapevines during the 2011/12, 2012/13, 2013/14 and 2014/15 growing seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca*. 60% PAW depletion			*ca*. 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Mean leaf area per primary shoot (m^2)**									
2011/12	0.177 a[(1)]	0.184 a	0.187 a	0.163 ab	0.156 ab	0.175 a	0.170 ab	0.129 b	0.148 ab	0.133 b
2012/13	0.152 a	0.139 abc	0.117 c	0.147 ab	0.125 bc	0.140 abc	0.132 abc	0.088 d	0.084 d	0.083 d
2013/14	0.153 a	0.150 a	0.157 a	0.155 a	0.140 a	0.156 a	0.132 a	0.138 a	0.140 a	0.098 b
2014/15	0.157 a	0.160 a	0.159 a	0.139 a	0.153 a	0.154 a	0.158 a	0.075 b	0.096 b	0.069 b
Season	**Mean leaf area per secondary shoot (m^2)**									
2011/12	0.228 a	0.156 b	0.132 b	0.162 ab	0.097 bcd	0.119 bc	0.101 bcd	0.034 d	0.058 cd	0.036 d
2012/13	0.179 a	0.131 b	0.089 bcd	0.123 bc	0.047 defg	0.066 def	0.078 cde	0.023 fg	0.035 efg	0.013 g
2013/14	0.511 a	0.322 cd	0.448 ab	0.368 bc	0.241 d	0.296 cd	0.087 e	0.084 e	0.087 e	0.032 e
2014/15	0.182 a	0.090 bcd	0.105 bc	0.129 ab	0.045 cde	0.098 bcd	0.041 de	0.020 e	0.018 e	0.005 e
Season	**Mean total leaf area per shoot (m^2)**									
2011/12	0.405 a	0.340 ab	0.319 abc	0.324 abc	0.253 cde	0.295 bc	0.270 bcd	0.163 f	0.207 def	0.168 ef
2012/13	0.331 a	0.270 b	0.206 c	0.269 b	0.172 cd	0.206 c	0.209 c	0.111 e	0.119 de	0.096 e
2013/14	0.663 a	0.472 cd	0.605 ab	0.523 bc	0.381 d	0.452 cd	0.219 e	0.223 e	0.226 e	0.130 e
2014/15	0.339 a	0.249 b	0.264 b	0.268 ab	0.197 b	0.253 b	0.200 b	0.096 c	0.114 c	0.073 c

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

Table 4.3 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean number of shoots per metre cordon, mean leaf area and mean leaf area index (LAI) of Shiraz/110R grapevines during the 2011/12, 2012/13, 2013/14 and 2014/15 growing seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Mean number of shoots per metre cordon**									
2011/12	19.7 d[(1)]	31.1 bc	32.0 b	20.5 d	32.0 b	29.5 c	20.5 d	29.5 bc	30.3 bc	45.1 a
2012/13	20.2 c	26.1 b	28.6 b	19.0 c	26.9 b	27.2 b	18.0 c	28.7 b	28.8 b	48.4 a
2013/14	18.0 d	27.3 bc	23.7 bcd	18.3 cd	27.4 b	19.4 bcd	19.7 bcd	22.7 bcd	28.0 b	46.3 a
2014/15	19.8 f	31.7 bc	25.0 de	19.1 f	30.8 bcd	26.0 d	20.0 ef	34.5 b	26.5 cd	56.5 a
Season	**Mean leaf area per grapevine (m^2)**									
2011/12	9.8 abcd	11.7 ab	12.3 a	8.2 cdef	10.0 abcd	10.1 abc	6.9 ef	5.9 f	7.6 def	9.3 bcde
2012/13	8.2 a	6.7 abc	7.2 ab	6.2 bc	5.7 cd	6.8 abc	4.6 de	3.8 e	4.2 e	5.7 cd
2013/14	14.6 a	14.9 a	14.8 a	11.9 ab	12.0 ab	9.0 bc	5.3 d	5.7 cd	6.0 cd	6.5 cd
2014/15	7.9 ab	9.4 a	8.1 ab	6.1 bcd	7.3 abc	7.9 ab	4.9 cd	3.9 d	3.7 d	5.0 cd
Season	**LAI**									
2011/12	3.20 bcd	3.83 ab	4.06 a	2.69 cdef	3.28 abcd	3.46 abc	2.25 ef	1.94 f	2.49 def	3.06 bcde
2012/13	2.68 a	2.21 abc	2.36 ab	2.04 bc	1.87 cd	2.23 abc	1.50 de	1.26 e	1.36 e	1.86 cd
2013/14	4.79 a	4.90 a	4.84 a	3.89 ab	3.95 ab	2.95 bc	1.72 d	1.85 cd	1.98 cd	2.14 cd
2014/15	2.58 ab	3.09 a	2.67 ab	2.02 cde	2.38 abc	2.58 ab	1.6 de	1.29 e	1.20 e	1.64 de

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

By removing all the primary and secondary leaf lamina (severed with scissors at the petiole while still attached to shoot) of a known number of randomly selected shoots, the fresh mass of leaves removed could be used to estimate the mean leaf area per shoot by using the following equation derived from the simple regression in Figure 4.2:

$$LA_{shoot} = \frac{5.197 \times LM_{Total} - 0.064}{n_{PS}} \quad \text{(Eq. 4.7)}$$

where: LA_{shoot} = leaf area per grapevine shoot (m^2)

LM_{Total} = total fresh mass of leaves removed (kg)

n_{PS} = number of primary shoots from which leaves were removed

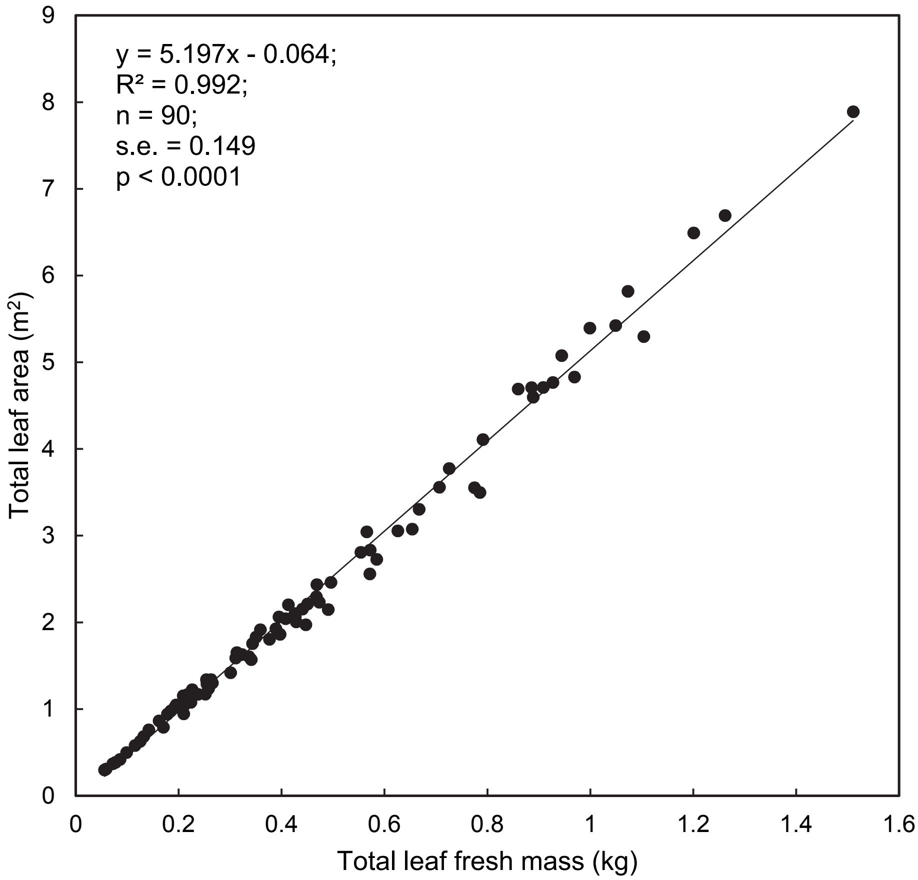

Figure 4.2 Relationship between the total leaf area and the total leaf fresh mass of 10 randomly sampled Shiraz/110R shoots per experimental plot during ripening of the 2012/13, 2013/14 and 2014/15 growing season near Robertson.

4.3.2. Mean number of shoots per grapevine

As expected, suckering resulted in less shoots per grapevine in all four seasons (Table 4.3). In general, non-suckered VSP grapevines produced more shoots than those left sprawling (Table 4.3).

4.3.3. Mean leaf area per grapevine

The canopy manipulations did not affect total leaf area per grapevine within an irrigation strategy in the 2011/12 season (Table 4.3). Total leaf area also tended to decrease with an increase in the level of PAW depletion (Table 4.3). This suggested that the total leaf area per grapevine was a result of the combination of irrigation strategy and canopy manipulation. In 2012/13, the different canopy manipulations also did not affect total leaf area per grapevine within an irrigation strategy, although that of the suckered grapevines irrigated more frequently (T1 & T4) tended to be lower than that of the non-suckered grapevines (Table 4.3). Total leaf area also tended to decrease with an increase in the level of PAW depletion. This suggested that the total leaf area per grapevine was affected not only by canopy management inputs, but also by the frequency at which irrigations were applied. Within the three different irrigation strategies, the, different canopy manipulations did not affect total leaf area per grapevine in 2013/14 (Table 4.3). However, it was clear that the total leaf area per grapevine tended to decrease with an increase in the level of PAW depletion. This confirmed that the total leaf area per grapevine was affected by the frequency at which irrigations were applied. The leaf area per grapevine during the 2013/14 season was appreciably higher than in the previous two seasons (Table 4.3). This trend was probably due to more water being available in the inter-row soil volume following the two high rainfall events as discussed in Chapter 3. Although the majority of the roots were in the third of the soil volume under the grapevine row, there were some roots in the rest of the soil volume that caused an above surface vegetative reaction to the wetter soil conditions (Figs. 2.2, 2.3 & 3.5B). In 2014/15, results obtained were similar to the previous seasons (Table 4.3).

4.3.4. Leaf area index

In general, the LAI of grapevines irrigated at more frequently was higher than for those irrigated at *lower* depletion levels (Table 4.3). Furthermore, the LAI for grapevines within the same irrigation strategy was similar, irrespective of the canopy manipulation applied (Table 4.3).

4.3.5. Canopy dimensions and volume per grapevine

Figures 4.3 and 4.4 illustrate the difference in the canopy dimensions and volume of different irrigation strategy and canopy manipulation treatments. Compared to the VSP grapevines where all the shoots were positioned vertically, a third of the shoots of sprawling canopies grew vertically (data not shown). This implied that grapevines with sprawling canopies had a great leaf area exposed to intercept solar irradiation throughout the day. This was particularly more during the few hours around the solar zenith than that of grapevines with VSP canopies within the same irrigation strategy, due to the majority of their leaves being more horizontally positioned. Within a specific irrigation depletion level, the potential canopy volume of the sprawling grapevines (T3, T6 & T9) was substantially higher than that of the VSP grapevines (Table 4.4). The potential canopy volume of the VSP grapevines was comparable within the same irrigation strategy (Table 4.4) in both the 2013/14 and 2014/15 seasons.

When the soil surface area that the different canopies covered was expressed as a fraction of the plant spacing area (fCPS), the fractions covered by the grapevines with sprawling canopies was substantially higher than for the VSP canopy grapevines (Table 4.5). The fCPS of the grapevines irrigated at *ca*. 90% PAW depletion was tended to be lower than that of those irrigated *ca*. 30% and *ca*. 60% PAW depletion, within the same canopy manipulation treatments.

The LA_{CPS} decreased with an increase in PAW depletion level (Table 4.5). Grapevines with sprawling canopies had higher LA_{CPS} values than grapevines irrigated the same with VSP canopies. During the 2013/14 seasons the LA_{CPS} of particularly the grapevines irrigated at *ca*. 30% and *ca*. 60% PAW depletion was much higher than for the 2012/13 and 2014/15 seasons. This can be attributed to the higher SWC in the inter-row soil volume as discussed in section 4.3.3.

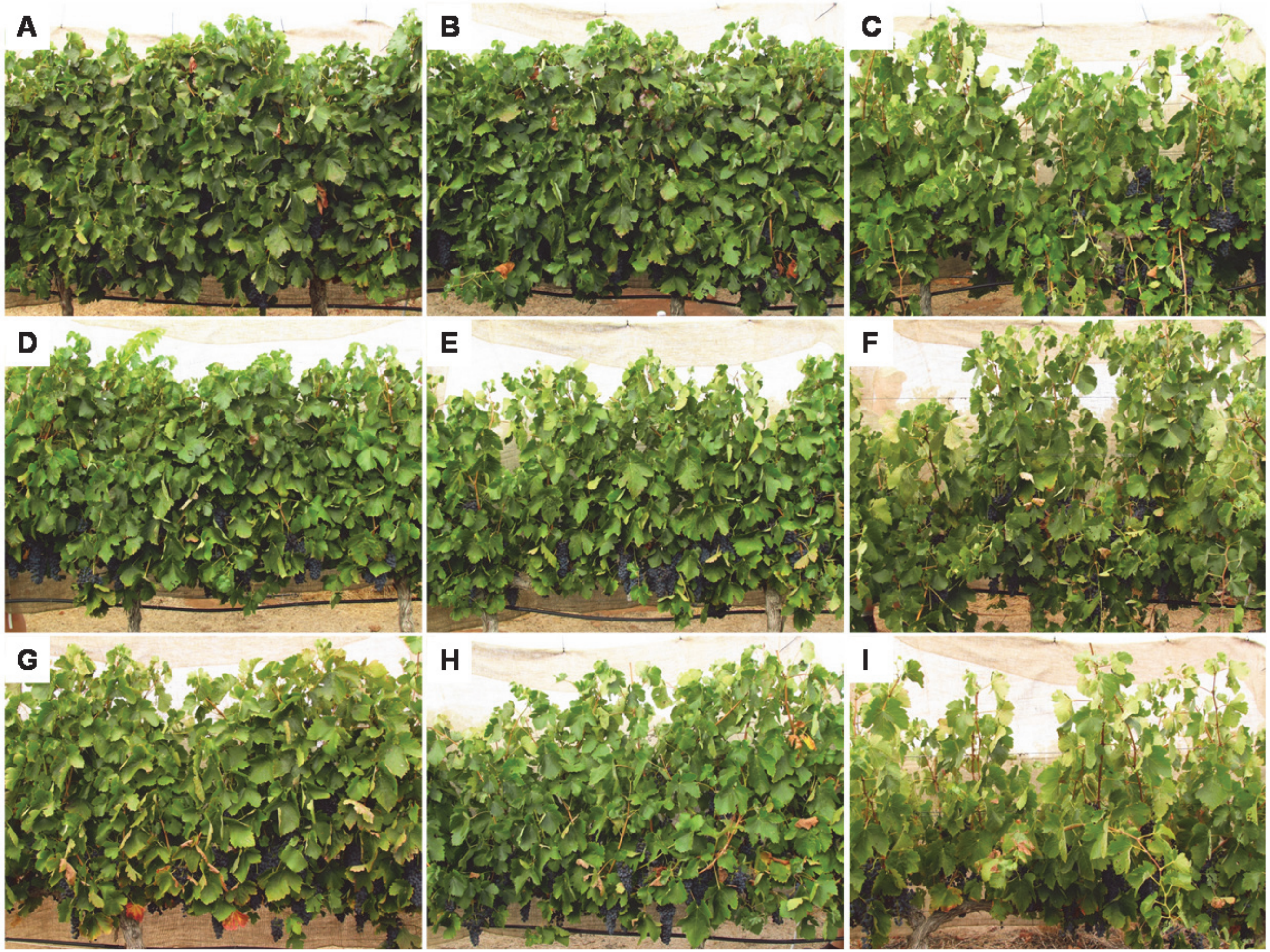

Figure 4.3 Examples illustrating the effect of plant available water (PAW) depletion and canopy management practice on Shiraz/110R grapevines as seen from the inter-row spacing, where (A) is suckered VSP, (B) is non-suckered VSP and (C) is sprawling canopy grapevines irrigated at *ca*. 30% PAW depletion; (D) is suckered VSP, (E) is non-suckered VSP and (F) is sprawling canopy grapevines irrigated at *ca*. 60% PAW depletion and (G) is suckered VSP, (H) is non-suckered VSP and (I) is sprawling canopy grapevines irrigated at *ca*. 90% PAW depletion near Robertson. Photographs were taken before harvest in the 2012/13 season.

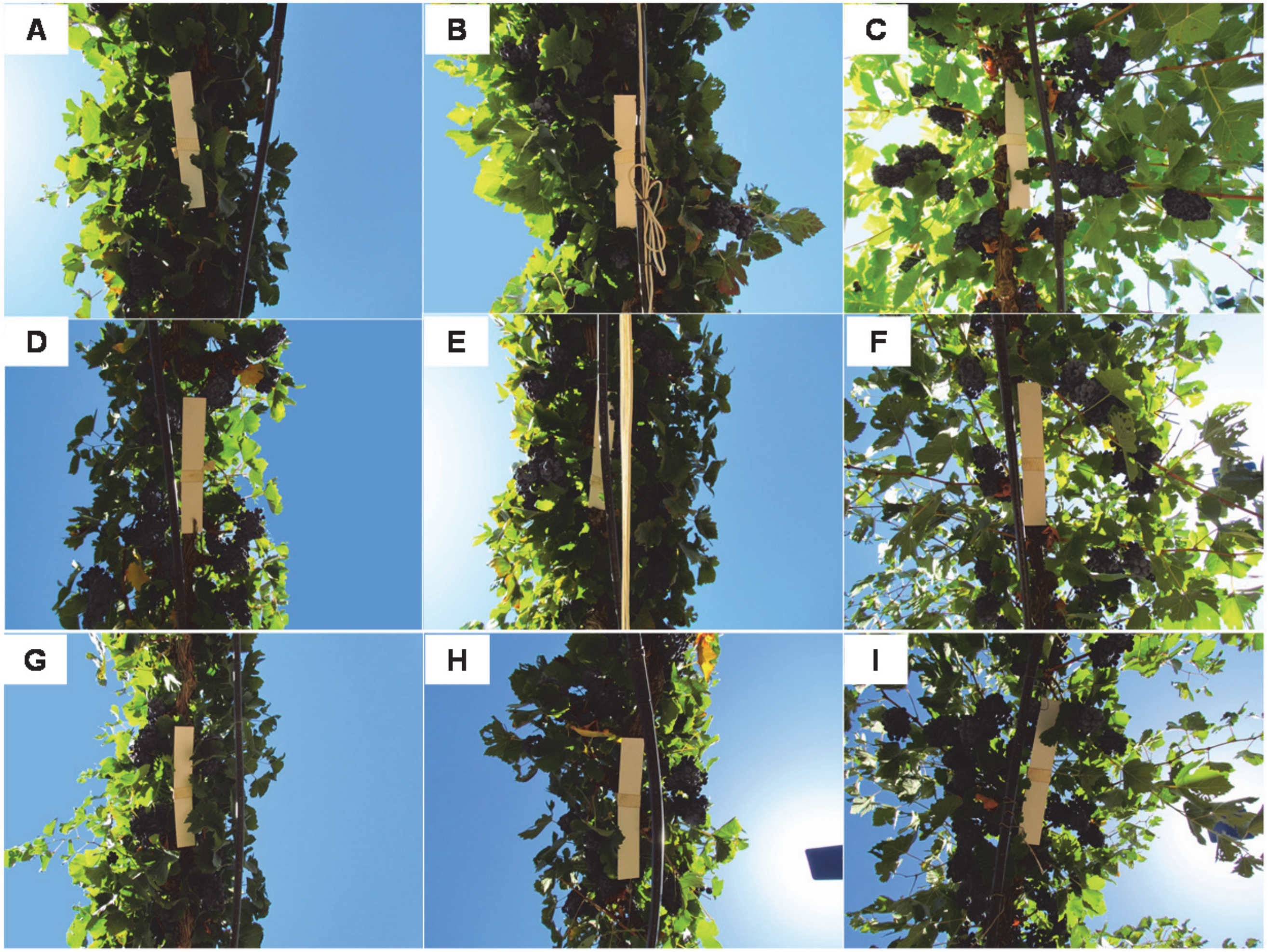

Figure 4.4 **Examples illustrating the effect of plant available water (PAW) depletion and canopy management practice on the worm's-eye view of Shiraz/110R grapevines, where (A) is suckered VSP, (B) is non-suckered VSP and (C) is sprawling canopy grapevines irrigated at *ca*. 30% PAW depletion; (D) is suckered VSP, (E) is non-suckered VSP and (F) is sprawling canopy grapevines irrigated at *ca*. 60% PAW depletion and (G) is suckered VSP, (H) is non-suckered VSP and (I) is sprawling canopy grapevines irrigated at *ca*. 90% PAW depletion near Robertson. Photographs were taken before harvest in the 2012/13 season.**

Table 4.4 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean canopy width and height, as well as the canopy volume of Shiraz/110R grapevines during the 2012/13, 2013/14 and 2014/15 growing seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca*. 60% PAW depletion			*ca*. 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Mean canopy width across plant row (m)**									
2012/13	0.56 d[(1)]	0.57 d	1.50 a	0.45 e	0.44 e	1.42 b	0.32 f	0.31 f	0.89 c	0.92 c
2013/14	0.48 c	0.51 c	1.52 a	0.42 c	0.49 c	1.47 a	0.41 c	0.42 c	1.10 b	1.13 b
2014/15	0.45 c	0.50 c	1.50 a	0.40 c	0.50 c	1.43 a	0.38 c	0.43 c	0.87 b	0.92 b
Season	**Mean canopy height above grapevine cordon (m)**									
2012/13	0.94 a	0.92 a	0.90	0.89 ab	0.88 ab	0.86 b	0.83 b	0.79 b	0.70 c	0.59 c
2013/14	0.95 a	0.93 a	0.92 a	0.93 a	0.93 a	0.90 a	0.79 ab	0.72 b	0.70 b	0.68 b
2014/15	0.93 a	0.90 ab	0.90 ab	0.83 bc	0.80 c	0.77 c	0.78 c	0.67 d	0.63 d	0.52 e
Season	**Mean canopy volume per grapevine (m^3)**									
2012/13	0.526 de	0.524 de	1.350 a	0.401 ef	0.387 ef	1.221 b	0.249 ef	0.237 f	0.623 c	0.543 cd
2013/14	0.547 d	0.569 d	1.398 a	0.469 de	0.547 d	1.323 a	0.389 e	0.363 e	0.770 b	0.768 c
2014/15	0.512 de	0.549 cde	1.350 a	0.407 ef	0.488 ef	1.101 b	0.366 ef	0.350 f	0.435 ef	0.473 d

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 4.5 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean fraction of soil surface area covered by canopy during solar zenith with regard to the plant spacing (*ƒ*CPS) and the leaf area per grapevine within the fraction of soil surface area covered by the particular canopy during the solar zenith (LA_{CPS}) of Shiraz/110R grapevines during the 2012/13, 2013/14 and 2014/15 growing seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca*. 30% PAW depletion**			***ca*. 60% PAW depletion**			***ca*. 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	***ƒ*CPS**									
2012/13	0.22 c[1]	0.23 b	0.60 a	0.18 e	0.18 e	0.57 b	0.13 f	0.12 f	0.36 c	0.37 c
2013/14	0.19 a	0.20 c	0.61 a	0.17 c	0.20 c	0.59 a	0.16 c	0.17 c	0.44 b	0.45 b
2014/15	0.18 c	0.20 c	0.60 a	0.16 c	0.20 c	0.57 a	0.15 c	0.17 a	0.28 b	0.36 b
Season	**LA_{CPS}**									
2012/13	0.54 bc[1]	0.44 cde	1.42 a	0.33 def	0.30 ef	1.25 a	0.18 f	0.15 f	0.49 cd	0.67 bc
2013/14	1.34 bc	1.37 b	2.91 a	0.62 d	0.63 d	1.70 b	0.23 d	0.22 d	0.73 d	0.78 cd
2014/15	0.48 bc	0.62 b	1.60 a	0.32 cd	0.48 bc	1.48 a	0.24 d	0.22 d	0.31 cd	0.59 b

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

4.3.6. Canopy photosynthetically active radiation (PAR) interception

In 2012/13, grapevines with VSP canopies tended to have a higher PAR interception then those with sprawling canopies within the same irrigation strategy (Table 4.6). This trend was only present for grapevines irrigated at *ca*. 60% and *ca*. 90% PAW depletion during the 2013/14 and 2014/15 seasons. Box pruned grapevines had similar PAR interception to that of the sprawling canopy grapevines irrigated at *ca*. 90% PAW depletion (Table 4.6). The PAR_{canopy} decreased with increased in PAW depletion levels (Table 4.6). Grapevines with sprawling canopies had higher PAR_{canopy} than VSP grapevines irrigated the same.

There was a good correlation between PAR_{canopy} and LA_{CPS} (Fig. 4.5). This implies that the LA_{CPS} can be predicted by making use of a ceptometer for grapevines spaced 2.5 × 1.22 m with a maximum PAR_{canopy} of *ca*. 3 500 μmol.grapevine^{-1}.s^{-1}.

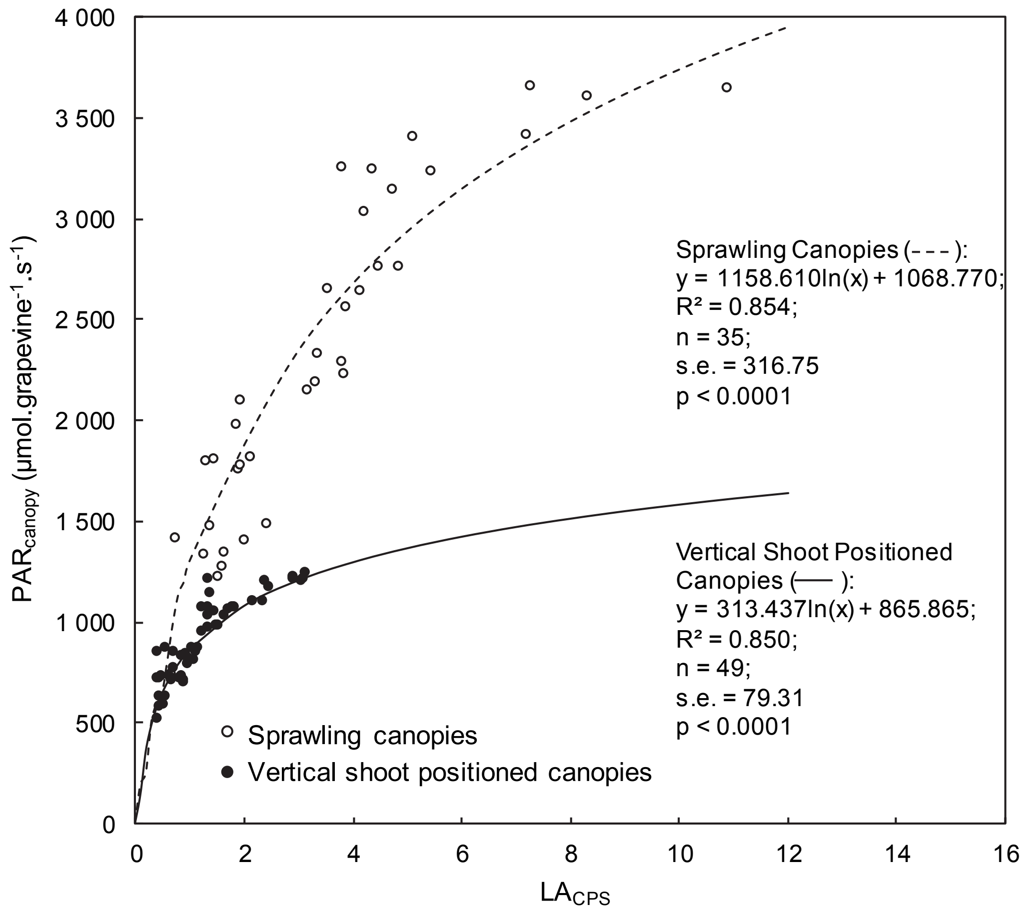

Figure 4.5 Relationship between the photosynthetically active radiation interception (PAR_{canopy}) per Shiraz grapevine canopy and the leaf area per grapevine within the fraction of soil surface area covered by the particular canopy during the solar zenith (LA_{CPS}) per Shiraz/110R grapevine canopy with a 2.5 m × 1.22 m plant spacing during ripening of the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

Table 4.6 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on the photosynthetically active radiation (PAR) interception and the total intercepted photosynthetically active radiation (PAR_{canopy}) per Shiraz/110R canopies during the 2012/13, 2013/14 and 2014/15 growing seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca*. 30% PAW depletion**			***ca*. 60% PAW depletion**			***ca*. 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**PAR interception ($\mu mol.m^{-2}.s^{-1}$)**									
2012/13	1 777 a[(1)]	1 744 ab	1 485 c	1 588 bc	1 606 abc	1 466 cd	1 634 abc	1 557 bc	1 156 e	1 280 de
2013/14	1 985 a	1 973 a	1 985 a	1 958 a	1 971 a	1 832 b	1 958 a	1 940 a	1 836 b	1 794 b
2014/15	1 747 ab	1 756 a	1 749 ab	1 748 ab	1 745 ab	1 617 abc	1 621 abc	1 590 bc	1 500 c	1 630 abc
Season	**PAR_{canopy} ($\mu mol.grapevine^{-1}.s^{-1}$)**									
2012/13	1 084 d	1 064 d	2 717 a	775 e	784 e	2 504 b	598 f	570 f	1 269 c	1 406 c
2013/14	1 695 d	1 685 d	3 632 a	955 e	962 e	3 136 b	797 e	710 e	2 012 c	1 969 cd
2014/15	961 def	1 071 de	3 201 a	853 ef	1 064 de	2 826 b	757 f	834 ef	1 206 d	1 790 c

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

4.3.7. Cane measurements and mass

As expected, cane mass of more frequently irrigated grapevines, regardless of the canopy manipulation applied, tended to be higher than that of less frequently irrigated grapevines.at pruning in July 2012 (Table 4.7). In addition to this, grapevines that weren't suckered and had their shoots tucked into trellis wires tended to produce lower cane mass compared to those that were suckered and had their shoots tucked in, as well as those that was not suckered and their shoots left to hang open (Table 4.7). In July 2013, where irrigation was applied at *ca.* 30% PAW depletion in the 2012/13 season, the cane mass was higher compared to less frequently irrigated grapevines, irrespective of the canopy manipulation applied (Table 4.7). As in the previous season, non-suckered VSP grapevines tended to produce lower cane mass compared to the suckered VSP grapevines, as well as the sprawling canopy grapevines (Table 4.7). In the 2013/14 season, irrigation applied at *ca.* 30% PAW depletion resulted in higher cane mass of grapevines compared to the *ca.* 60% and *ca.* 90% PAW depletion levels, irrespective of the canopy manipulation applied (Table 4.7). Non-suckered VSP grapevines tended to produce lower cane mass compared to the suckered VSP grapevines, as well as the sprawling canopy grapevines (Table 4.7). With the exception of grapevines irrigated at *ca*. 90% PAW depletion, cane mass in the 2013/14 season was higher than that of the 2012/13 season (Table 4.7). This was probably due to 208 mm of rain during the 2013/14 season, which was substantially higher than the long term mean (LTM) of 106 mm. With regard to the 2014/15 season, irrigation applied at *ca.* 30% PAW depletion also resulted in higher cane mass of grapevines compared to less frequently irrigated ones, irrespective of the canopy manipulation applied (Table 4.7). The VSP grapevines tended to produce lower cane mass compared to the sprawling canopy when grapevines were irrigated at *ca*. 30% and *ca*. 60% PAW depletion (Table 4.7). This was, however, not the case where irrigation was applied at *ca*. 90 PAW depletion, as grapevines with suckered VSP canopies tended to produce higher cane mass than those that were left unsuckered (Table 4.7). Although similar irrigation volumes were necessary to maintain depletion levels when compared to that of the previous season, the much lower rainfall during the 2014/15 season and, subsequently, drier inter-row soil volume contributed to the lower mean seasonal leaf area and cane mass per grapevine.

Table 4.7 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on cane mass at pruning of Shiraz/110R grapevines during the 2011/12, 2012/13, 2013/14 and 2014/15 growing seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca*. 30% PAW depletion**			***ca*. 60% PAW depletion**			***ca*. 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Cane mass (t.ha^{-1})**									
2011/12	3.53 ab[(1)]	3.32 bc	4.17 a	2.90 bcd	2.43 de	2.86 bcd	2.25 de	2.16 e	2.52 cde	2.09 e
2012/13	4.11 a	3.68 a	4.06 a	2.72 b	2.51 bc	2.71 b	2.04 de	1.96 de	2.24 cd	1.60 e
2013/14	4.79 b	4.35 bc	5.79 a	3.49 d	3.47 d	3.96 cd	1.64 ef	1.28 ef	1.72 e	1.08 f
2014/15	2.65 b	2.56 b	3.19 a	1.85 c	1.87 c	2.60 b	1.25 d	1.01 d	1.21 d	0.91 d

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

During the cane measurements taken during the 2012 and 2013 pruning, 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 were as follows:

Primary shoot mass (M_{PS}):

$M_{PS} = 0.00024*L_{PS} + 0.00996*Ø_{PS} – 0.05049$ (Eq. 4.8)

($R^2 = 0.870$; $n = 54$; $se = 0.004$; $p < 0.0001$)

where: M_{PS} = mass per primary shoot (kg)

L_{PS} = mean length per primary shoot (mm)

$Ø_{PS}$ = mean diameter per primary shoot (mm)

Secondary shoot mass (M_{SS}):

$M_{SS} = 0.00018*L_{SS} + 0.00166*Ø_{SS} – 0.00612$ (Eq. 4.9)

($R^2 = 0.918$; $n = 54$; $se = 0.001$; $p < 0.0001$)

where: M_{SS} = mass per secondary shoot (kg)

L_{SS} = mean length per secondary shoot (mm)

$Ø_{SS}$ = mean diameter per secondary shoot (mm)

These models could be useful to predict cane mass per grapevine in a non-destructive manner as early as ripening. This information can be calculated using the following equation and can assist in estimation of irrigation requirements done by the VINET model (Myburgh, 1998):

$CM_{grapevine} = [M_{PS} + (M_{SS} \times n_{SS/PS})] \times n_{PS}$ (Eq. 4.10)

where: $CM_{grapevine}$ = cane mass per grapevine (kg)

M_{PS} = mass per primary shoot calculated using Eq. 4.8

M_{SS} = mass per secondary shoot calculated using Eq. 4.9

$n_{SS/PS}$ = number of secondary shoots per primary shoot

n_{PS} = number of primary shoots per grapevine

4.4. CONCLUSIONS

Under the specific conditions of the field trial, the different canopy manipulations did not affect total leaf area per grapevine within an irrigation strategy, but were affected negatively as less water was applied. Non-suckered grapevines produced more shoots compared to suckered ones. More frequent irrigation of grapevines caused more vigorous shoot growth. Within the same irrigation strategy, non-suckered VSP grapevines tended to produce lower cane mass compared to suckered VSP and sprawling canopy grapevines. The LA_{CPS} gives a better indication of canopy orientation, *i.e.* sprawling vs VSP canopies, than the LAI alone. By measuring the plant spacing, canopy width, non-linear regressions of LA_{CPS} and total grapevine PAR interception for different canopy orientations can be estimated. Winter pruned cane mass can be estimated by non-destructive measurements of primary and secondary shoots. This would enable a viticulturist, producer or irrigation consultant to use the VINET model during ripening to predict grapevine water requirements as LA is estimated using cane mass.

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CHAPTER 5: EFFECT OF DIFFERENT IRRIGATION AND CANOPY MANAGEMENT STRATEGIES ON PLANT WATER STATUS

5.1. INTRODUCTION

Grapevine *(Vitis vinifera)* is a temperate climate species adapted to hot summers and mild to cold winters (Williams *et al.*, 1994). Grapevines are cultivated in some of the hottest areas of the earth, between the 30º and 50ºN and 30º and 40ºS latitudes (Williams *et al.*, 1994). In such areas, with low annual rainfall and high evaporation demands, irrigations are usually necessary to produce economically viable crops (Van Zyl, 1981; Williams *et al.*, 1994). Grape and wine quality is either affected directly or indirectly by the terroir, relative humidity, wind exposure, micro climate (through canopy structure) and soil related factors (Hunter *et al.*, 1995; Deloire *et al.,* 2005; Bruwer, 2010; Mehmel, 2010). A great deal of research on the effect of different irrigation strategies and canopy manipulations on the grapevines responses to obtain optimum yields and wine quality has been done in the past. However, these two disciplines have not been investigated in combination under the same set of viticultural conditions.

Diurnal water constraint patterns in grapevines appear when transpiration losses exceed water uptake, even if grapevines are exposed to adequate available water in the soil (Hardie & Considine, 1976). Leaf water potential (Ψ_L) in grapevines can be quantified by means of the pressure chamber technique (Scholander *et al.*, 1965). Grapevine Ψ_L decreases and fluctuates during the day, irrespective of the quantity of water available to the grapevines, with the most negative potential occurring between 12:00 and 14:00 (Van Zyl, 1984; Van Zyl, 1987). The Ψ_L increases at night particularly if adequate soil water is available to the plant (Williams *et al.*, 1994). Grapevine water status can be influenced by incoming solar radiation, relative humidity, air temperature, atmospheric pollutants, wind, soil environment and plant factors (Smart & Coombe, 1983). Choné *et al.* (2001), Lebon *et al.* (2003) and Loveys *et al.* (2004) documented that pre-dawn leaf water potential (Ψ_P) is the preferred reference indicator of soil water potential in many species including grapevines. At pre-dawn, each leaf on a grapevine has the same water potential and that this water potential is in equilibrium with the wettest soil layer explored by the root system (Van Leeuwen *et al.*, 2009). Pellegrino *et al.* (2004) also found a narrow correlation between the Ψ_P measurements of Shiraz and Gewürztraminer and the fraction of transpirable soil water or percentage plant available water (PAW) depletion. Furthermore, a reduction in grapevine Ψ_L, stomatal conductance and CO_2 assimilation rate can be expected when soil water becomes less available (Williams *et al.*, 1994; Schultz, 1996; Naor & Bravdo, 2000; Williams

& Araujo, 2002; Patakas *et al*., 2005; Pellegrino *et al*., 2005; Soar *et al*., 2006; Van Leeuwen *et al.,* 2009).

Correlations between Ψ_L and grapevine physiology, vegetative growth and yield have been reported (Williams *et al*., 1994 and references therein). Stem water potential (Ψ_S) can also be used to quantify grapevine water status and is measured by covering a leaf using a double lined plastic and aluminium foil bag at least an hour before the measurements (Choné *et al*., 2001). This potential is considered to be a better indicator of differences in plant water status than Ψ_L (Choné *et al*., 2001; Williams & Araujo, 2002; Patakas *et al*., 2005; Van Leeuwen *et al*., 2009). It was observed that Ψ_L regulation depended on soil water availability and other external factors, such as vapour pressure deficit, leaf intercepted radiation, plant hydraulic conductivity and stomatal regulation (Choné *et al*., 2001). Due to this, Ψ_S seemed to be the best indicator of soil water availability, followed by Ψ_P. The difference between Ψ_S and Ψ_L ($\Delta\Psi$) was found to be significantly correlated to transpiration, and can thus be a useful method of estimating transpiration of field grown grapevines (Choné *et al*., 2001). Furthermore, Ψ_S could also serve as an indicator of hydraulic conductivity in the trunk and shoot sap pathway (Choné *et al*., 2001). Threshold values for grapevine water constraint classes based on Ψ_P in Shiraz (Ojeda *et al.*, 2002) and Ψ_L for red and white cultivars (Greenspan, 2005) have been proposed.

Hunter (2000) reported that east-west planted grapevines that were suckered and had their shoots tucked into trellis wires experienced less water constraints than grapevines that were left unsuckered and shoots not tucked in even though both treatments received the same irrigation applications. This can be attributed to the fact that the untreated grapevines had a higher leaf area that was exposed to the sun throughout the day, resulting in higher transpiration water losses (Myburgh, 1998).

The aim of this study was to determine the combined effects of irrigation and canopy management practices on plant water status of Shiraz grapevines growing in the Breede River Valley.

5.2. MATERIALS AND METHODS

5.2.1. Plant water potentials

Grapevine water status was quantified by determining plant 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). Measurements were completed within 30 minutes by using two pressure chambers which were custom built, and their pressure gauges calibrated against a precision gauge. Mid-day 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. Mid-day leaf water potential (Ψ_L) was measured in mature leaves fully exposed to the sun between 12:00 and 13:00. Water potentials were determined in all treatments in one grapevine per plot as regularly as possible in all four seasons on full sunshine days.

5.2.2. Diurnal variation in leaf water potential

The diurnal leaf water potentials (Ψ_L) were measured every two hours from 04:00 until 02:00 the next morning in all three replications of all the treatments. The diurnal Ψ_L cycles were measured on 21 February 2012, 25 and 27 February 2013, 16 and 23 January 2014, 6 March 2014 and 3 March 2015 shortly before harvest.

5.2.3. Statistical analyses

The data were subjected to an analysis of variance (ANOVA) by using Statgraphics®. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means, which differed at $p \leq 0.05$, were considered significantly different.

5.3. RESULTS AND DISCUSSION

5.3.1. Pre-dawn leaf water potentials

Pre-dawn leaf and mid-day Ψ_S gave a better reflection of the prevailing soil water status, whereas the mid-day Ψ_L seemed to be influenced by a combination of the soil water status, exposed leaf area and prevailing atmospheric conditions.

5.3.2. Mid-day leaf- and stem water potentials

The 2011/12 season was characterised by frequent overcast days, as indicated by lower incoming solar radiation compared to the long term mean values (Refer to Table 3.3). This limited mid-day Ψ_L measurements since it would have caused misinterpretations of the actual grapevines water constraints. On the days when measurements were possible, it was evident that the level of PAW depletion, rather than canopy manipulation, affected the plant water potentials (Table 5.1). This was probably due to the fact that total exposed leaf area per grapevine was similar within an irrigation strategy (Table 4.3). According to a proposed water constraint classification (Lategan, 2011), grapevines irrigated at *ca.* 30% PAW depletion experienced no water constraints before irrigations were applied (Table 5.1). In contrast, grapevines irrigated at *ca.* 60% PAW and 90% PAW depletion, respectively, experienced medium and strong/severe water constraints before irrigations were applied. Grapevine mid-day Ψ_L increased sufficiently after irrigations were applied (Table 5.1), according to the water constraint classification of Lategan (2011).

The 2012/13 season was characterised by even more frequent overcast days than in the 2011/12 season. The high frequency of cloud cover is evident when the seasonal lower incoming solar radiation is compared with the long term mean values (Refer to Table 3.3). This limited the measurement of mid-day Ψ_L. On the days when measurements were possible, it was evident that within level of PAW depletion, non-suckered grapevines with sprawling canopies tended to have higher water constraints (Table 5.2). Pre-dawn leaf and mid-day Ψ_S gave a better reflection of the prevailing soil water status, whereas the mid-day Ψ_L seemed to be influenced by a combination of the soil water status, exposed leaf area and prevailing atmospheric conditions. According to a proposed water constraint classification (Lategan, 2011), grapevines irrigated at *ca.* 30% PAW depletion experienced no water constraints before irrigations were applied. In contrast, grapevines irrigated at *ca.* 60% and 90% PAW depletion experienced weak/medium and strong/severe water constraints, respectively, before irrigations were applied. Grapevine mid-day Ψ_L increased sufficiently after irrigations were applied and did not differ between irrigation strategies or canopy manipulations (Table 5.2).

On the 16 and 23 January 2014, for a given level of PAW depletion, the mid-day Ψ_L and Ψ_S of non-suckered grapevines with sprawling canopies tended to be lower than the VSP grapevines (Table 5.3). It should be noted that 72 mm rainfall occurred on 9 January 2014. On 6 March 2014, within the *ca.* 30% and *ca.* 60% PAW depletion levels, non-suckered grapevines with sprawling canopies had lower mid-day Ψ_L than the VSP grapevines. However, there were no differences in Ψ_P and mid-day Ψ_S for grapevines irrigated at *ca.* 30% and *ca.* 60% PAW depletion levels, irrespective of canopy management practise (Table 5.3). According to a proposed water constraint classification based on Ψ_L (Lategan, 2011), grapevines irrigated at *ca.* 30% and 60% PAW depletion experienced no water constraints before irrigation was applied on 6 March 2014. In contrast, grapevines irrigated at *ca.* 90% PAW depletion were subjected to medium water constraints before irrigation was applied.

Table 5.1 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on pre-dawn leaf (Ψ_P), mid-day leaf (Ψ_L) and stem water potential (Ψ_S) of Shiraz/110R grapevines during ripening of the 2011/12 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Date	Ψ_P (MPa)									
21/02/2012(1)	-0.242 a(2)	-0.217 a	-0.233 a	-0.200 a	-0.192 a	-0.175 a	-0.900 b	-1.000 b	-1.033 b	-0.975 b
Date	Ψ_L (MPa)									
20/02/2012	-1.425 a	-1.408 a	-1.467 a	-1.692 b	-1.683 b	-1.767 bc	-1.925 cd	-1.883 cd	-1.983 d	-1.900 cd
21/02/2012	-1.242 a	-1.350 a	-1.592 bc	-1.450 ab	-1.442 ab	-1.600 bc	-1.917 d	-1.917 d	-1.950 d	-1.775 cd
Date	Ψ_S (MPa)									
20/02/2012	-0.775 a	-0.867 a	-0.942 a	-1.217 b	-1.275 b	-1.600 c	-1.767 d	-1.833 d	-1.908 d	-1.783 cd
21/02/2012	-0.500 a	-0.608 ab	-0.775 b	-0.650 ab	-0.717 ab	-0.783 b	-1.633 c	-1.758 cd	-1.867 d	-1.625 c

(1) On 21 February 2012, measurements were carried out after the 30% and 60% PAW depletion level treatments were irrigated.
(2) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 5.2 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on pre-dawn leaf (Ψ_P), mid-day leaf (Ψ_L) and stem water potential (Ψ_S) of Shiraz/110R grapevines during ripening of the 2012/13 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Date	Ψ_P (MPa)									
25/02/2013	-0.333 a(1)	-0.279 a	-0.439 ab	-0.518 bc	-0.654 c	-0.839 d	-0.907 de	-1.126 f	-1.194 f	-1.041 ef
27/02/2013(2)	-0.146 a	-0.187 a	-0.162 a	-0.171 a	-0.137 a	-0.221 a	-0.840 b	-0.908 b	-0.898 b	-0.857 b
Date	Ψ_L (MPa)									
25/02/2013	-1.501 a	-1.638 ab	-1.805 bcde	-1.754 bcd	-1.711 bc	-1.821 cde	-1.812 bcde	-1.897 de	-1.947 e	-1.914 de
27/02/2013	-1.399 a	-1.561 ab	-1.621 abc	-1.406 a	-1.592 abc	-1.727 bcd	-1.954 de	-1.878 cde	-2.089 e	-2.055 e
Date	Ψ_S (MPa)									
25/02/2013	-1.095 a	-1.261 ab	-1.486 bc	-1.585 cd	-1.475 bc	-1.721 def	-1.719 def	-1.855 ef	-1.889 f	-1.656 cde
27/02/2013	-0.856 a	-0.932 a	-0.975 a	-0.882 a	-0.924 a	-0.916 a	-1.650 b	-1.879 c	-1.963 c	-1.854 bc

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).
(2) On 27 February 2013, measurements were carried out after the 30% and 60% PAW depletion level treatments were irrigated.

Table 5.3 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on pre-dawn leaf (Ψ_P), mid-day leaf (Ψ_L) and stem water potential (Ψ_S) of Shiraz/110R grapevines during ripening of the 2013/14 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Date	Ψ_P (MPa)									
16/01/2014	-0.168 a[(1)]	-0.173 ab	-0.186 abc	-0.194 abc	-0.212 bcd	-0.251 de	-0.239 d	-0.224 cd	-0.309 f	-0.288 ef
23/01/2014	-0.209 a	-0.210 a	-0.247 ab	-0.240 ab	-0.238 ab	-0.309 bc	-0.336 c	-0.340 c	-0.390 c	-0.381 c
06/03/2014	-0.148 a	-0.157 ab	-0.218 ab	-0.182 ab	-0.186 ab	-0.223 ab	-0.455 bc	-0.689 cd	-0.802 d	-0.695 cd
Date	Ψ_L (MPa)									
16/01/2014	-1.050 a	-1.200 ab	-1.341 bc	-1.266 bc	-1.432 cd	-1.561 d	-1.615 d	-1.461 cd	-1.615 d	-1.598 d
23/01/2014	-1.167 a	-1.142 a	-1.474 b	-1.382 b	-1.457 b	-1.686 cd	-1.632 cd	-1.756 d	-1.615 c	-1.623 cd
06/03/2014	-1.086 a	-1.163 ab	-1.539 c	-1.377 bc	-1.240 ab	-1.573 c	-1.880 d	-2.068 d	-2.111 d	-2.034 d
Date	Ψ_S (MPa)									
16/01/2014	-0.660 a	-0.701 a	-0.768 ab	-0.809 abc	-0.892 bcd	-1.025 de	-1.000 de	-0.942 cd	-1.208 f	-1.150 ef
23/01/2014	-0.577 a	-0.593 a	-0.776 a	-0.776 a	-0.768 a	-1.017 b	-1.125 bc	-1.125 bc	-1.324 c	-1.308 c
06/03/2014	-0.519 a	-0.585 a	-0.901 a	-0.735 a	-0.760 a	-0.917 a	-1.557 b	-1.748 b	-1.848 b	-1.782 b

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

The research team attempted to take plant water potential measurements as regularly as possible during ripening in the 2014/15 season. Due to the less frequent trips made to the experimental vineyard and the incidence of cloudy days, mid-day Ψ_L and Ψ_S measurements were possible on five days (Table 5.4). On 28 January 2015, grapevines irrigated at *ca.* 90 PAW depletion level had less water constraints than those irrigated at *ca.* 30% and *ca.* 60 PAW depletion levels. This can be attributed to a 24-hour irrigation that the *ca.* 90 PAW depletion grapevines received a week before at véraison and their smaller canopies, compared to those of the more frequently irrigated grapevines. As the season progressed, though, these grapevines didn't receive any more irrigation before harvest and their plant water constraints became increasingly higher than those of the *ca.* 30% and *ca.* 60 PAW depletion irrigated grapevines. Suckered VSP grapevines tended to have lower water constraints compared to the non-suckered grapevines, irrespective of the depletion level at which irrigation was applied (Table 5.4). According to a proposed water constraint classification based on Ψ_L and Ψ_S (Lategan, 2011), grapevines irrigated at *ca.* 30% PAW depletion experienced no water constraints before irrigations were applied, whereas grapevines irrigated at *ca.* 60% and *ca.* 90 PAW depletion experienced medium and severe water constraints before irrigation (Table 5.4).

5.3.3. Diurnal variation in leaf water potential

On 25 February 2013, there tended to be no differences in the bi-hourly Ψ_L measurements of different manipulated grapevines within the same irrigation strategy (Fig. 5.1). Irrigations at higher PAW depletion levels caused a decrease in the Ψ_L. Grapevines with sprawling canopies tended to have lower Ψ_L than the VSP grapevines, particularly after 18:00 and throughout the night (Fig. 5.1). This indicated that the water status in the sprawling grapevines could not recover during the night to the same extent as VSP grapevines. Atmospheric conditions for the 25 February 2013 are illustrated in Figures 5.2 and 5.3.

On 3 March 2015, there tended to be no differences in the bi-hourly Ψ_L measurements of different manipulated grapevines within a specific level of PAW depletion measured during the diurnal cycle (Fig. 5.4). Grapevines with sprawling canopies tended to have lower Ψ_L than the VSP grapevines irrigated at *ca.* 30% and *ca.* 60% PAW depletion, particularly after 18:00 and throughout the night (Fig. 5.1). This indicated that the water status in the sprawling grapevines irrigated at *ca.* 30% and *ca.* 60% PAW depletion could not recover during the night to the same extent as VSP grapevines. Atmospheric conditions for the 3 March 2015 are illustrated in Figures 5.5 and 5.6.

Table 5.4 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mid-day leaf (Ψ_L) and stem water potential (Ψ_S) of Shiraz/110R grapevines during ripening of the 2014/15 growing season near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca*. 60% PAW depletion			*ca*. 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Date	Ψ_L (MPa)									
28/01/2015	-1.210 b[1]	-1.440 c	-1.430 c	-1.100 ab	-1.190 ab	-1.250 bc	-1.140 ab	-1.090 ab	-1.010 a	-1.080 ab
30/01/2015	-1.200 a	-1.300 abc	-1.510 def	-1.460 cde	-1.570 ef	-1.670 f	-1.330 abc	-1.270 ab	-1.420 bcde	-1.370 bcd
09/02/2015	-1.470 a	-1.480 ab	-1.620 ab	-1.580 ab	-1.640 ab	-1.670 ab	-1.680 b	-1.640 ab	-1.650 ab	-1.680 b
25/02/2015	-0.760 a	-0.760 a	-0.810 a	-0.810 a	-0.880 a	-0.880 a	-1.760 bc	-1.820 c	-1.870 c	-1.670 b
03/03/2015	-1.390 a	-1.420 a	-1.380 a	-1.370 a	-1.470 ab	-1.600 b	-1.900 c	-2.100 d	-1.920 c	-1.880 c
Date	Ψ_S (MPa)									
28/01/2015	-0.640 abc	-0.720 bcd	-0.880 d	-0.490 a	-0.790 cd	-0.520 ab	-0.630 abc	-0.600 abc	-0.530 ab	-0.650 abc
30/01/2015	-0.680 a	-0.860 abc	-0.870 abc	-1.040 cd	-1.160 de	-1.290 e	-0.840 ab	-0.820 ab	-0.830 ab	-0.950 bc
09/02/2015	-0.930 ab	-0.870 a	-1.140 abc	-1.220 bc	-1.290 c	-1.420 c	-1.270 c	-1.360 c	-1.450 c	-1.410 c
25/02/2015	-0.540 a	-0.570 a	-0.670 a	-0.59 a	-0.680 a	-0.680 a	-1.460 b	-1.660 c	-1.670 c	-1.510 bc
03/03/2015	-0.740 a	-0.840 a	-0.880 ab	-0.780 a	-1.050 bc	-1.140 c	-1.590 d	-1.950 e	-1.850 e	-1.800 e

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

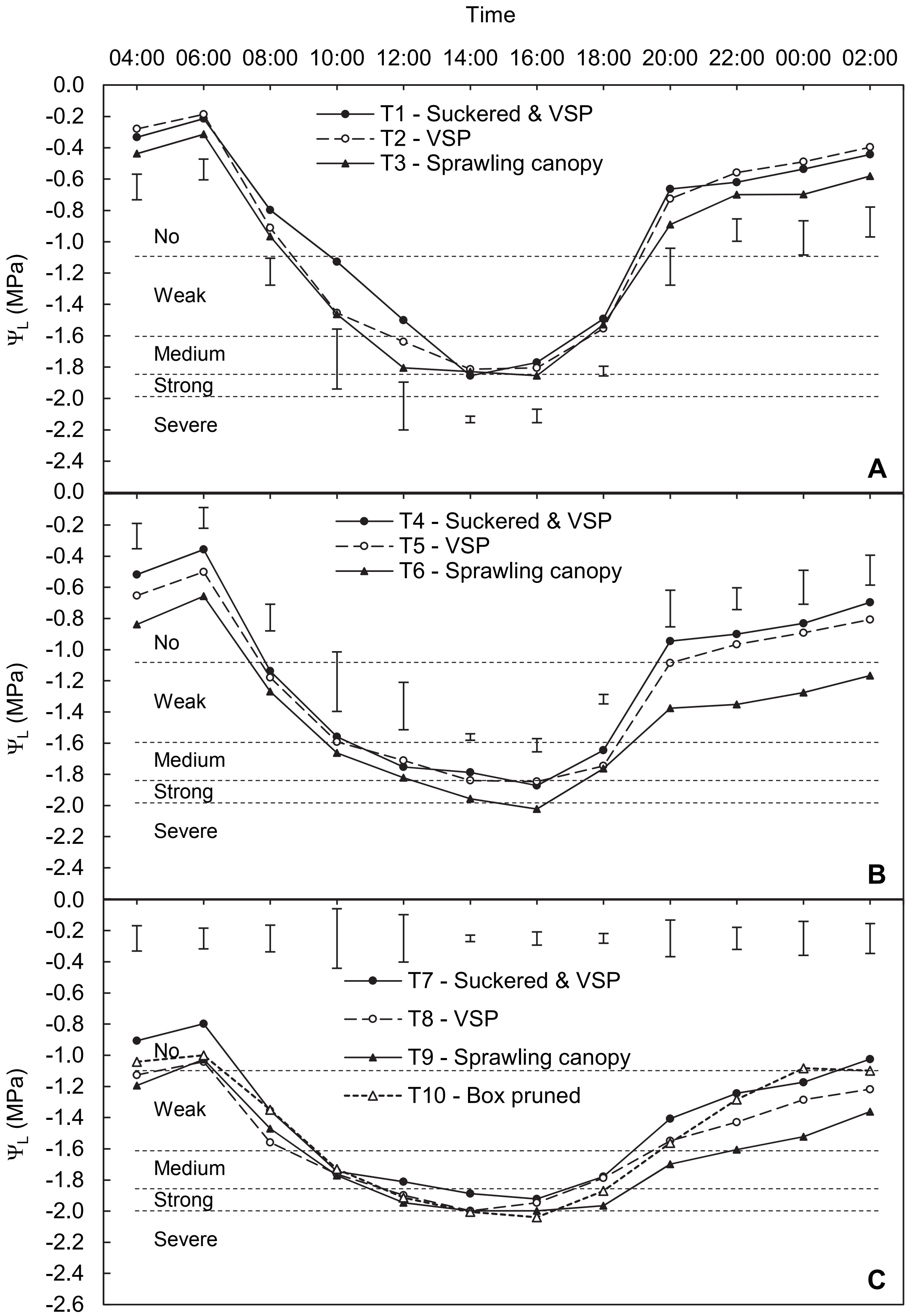

Figure 5.1 The effect of (A) *ca*. 30%, (B) *ca*. 60% and (C) *ca*. 90% plant available water depletion in combination with three canopy manipulations on the diurnal leaf water potential of Shiraz/110R grapevines in a fine sandy loam soil near Robertson on 25 February 2013. Vertical bars indicate least significant difference ($p < 0.05$). Dashed horizontal lines indicate different water constraint classes for Shiraz grapevines as adapted by Lategan (2011).

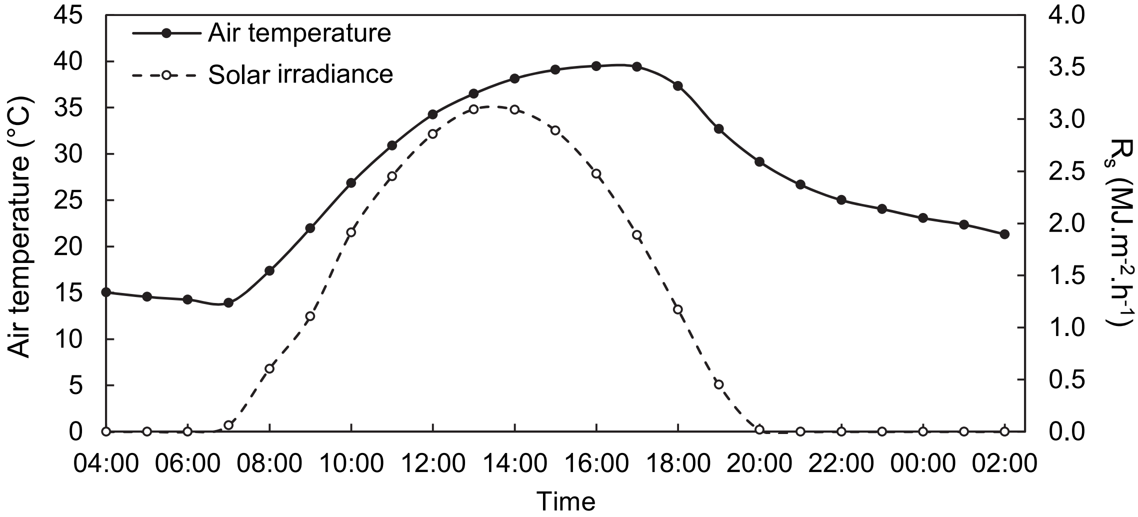

Figure 5.2 Diurnal variation in air temperature and solar irradiance (R_s) on 25 February 2013 near Robertson.

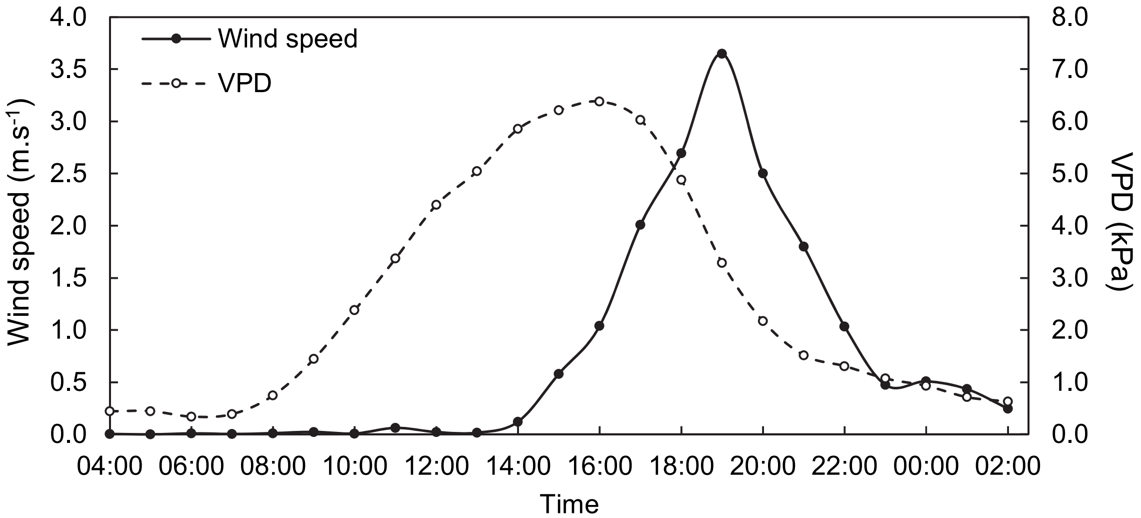

Figure 5.3 Diurnal variation in wind speed and water vapour pressure deficit (VPD) on 25 February 2013 near Robertson.

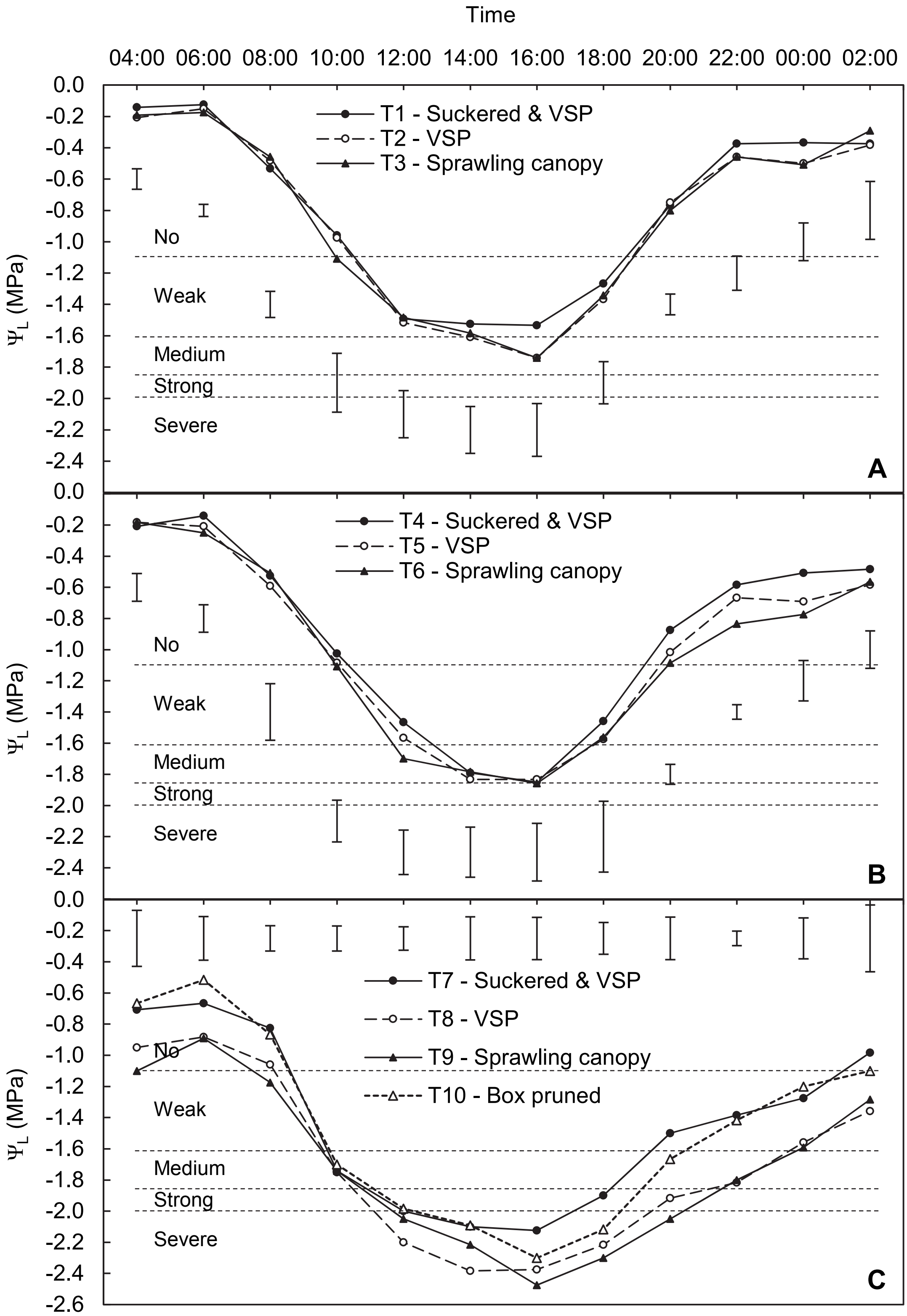

Figure 5.4 The effect of (A) *ca*. 30%, (B) *ca*. 60% and (C) *ca*. 90% plant available water depletion in combination with three canopy manipulations on the diurnal leaf water potential of Shiraz/110R grapevines in a fine sandy loam soil near Robertson on 3 March 2015. Vertical bars indicate least significant difference ($p < 0.05$). Dashed horizontal lines indicate different water constraint classes for Shiraz grapevines as adapted by Lategan (2011).

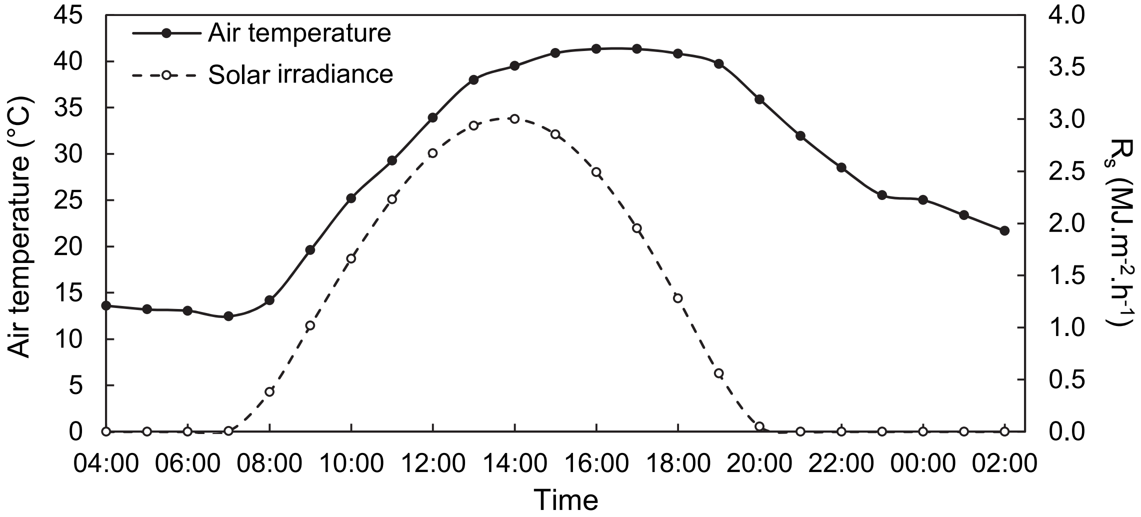

Figure 5.5 Diurnal variation in air temperature and solar irradiance (R_s) on 3 March 2015 near Robertson.

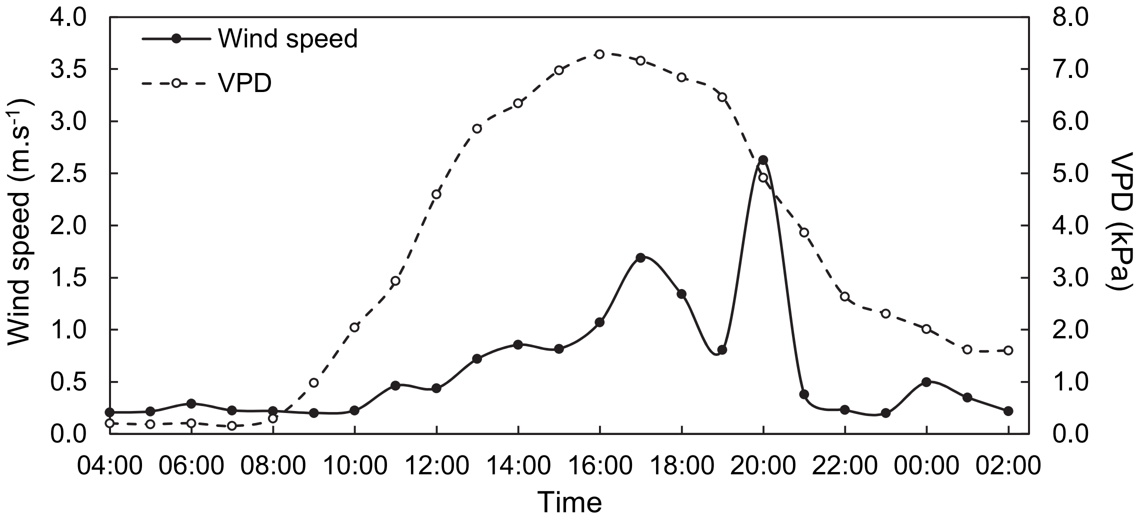

Figure 5.6 Diurnal variation in wind speed and water vapour pressure deficit (VPD) on 3 March 2015 near Robertson.

5.4. CONCLUSIONS

Mid-day Ψ_L and Ψ_S in grapevines within the same irrigation strategy did not differ, irrespective of the canopy manipulations applied. However, sprawling canopy grapevines tended to have lower mid-day Ψ_L and Ψ_S than the VSP grapevines. Grapes on grapevines subjected to severe water constraints ripened more rapidly than those experiencing no or medium water constraints. Low frequency irrigation, *i.e.* 90% PAW depletion, increased grapevine water constraints compared to high frequency irrigation, *i.e.* 30% PAW depletion. Results from the diurnal Ψ_L cycles showed that grapevines with sprawling canopies tended to have lower Ψ_L than the VSP grapevines after 18:00 and throughout the night. This indicated that the water status in the sprawling canopy grapevines could not recover during the night to the same extent as VSP grapevines.

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CHAPTER 6: EFFECT OF DIFFERENT IRRIGATION AND CANOPY MANAGEMENT STRATEGIES ON EVAPOTRANSPIRATION

6.1. INTRODUCTION

In many previous grapevine irrigation studies, different irrigation levels were obtained by applying irrigations at different fractions of reference evapotranspiration (ET_o) or crop coefficients (K_c) (McCarthy *et al*., 1983; Ojeda *et al*., 2002; Kaiser *et al*., 2004; El-Ansary *et al*., 2005; Patakas *et al*., 2005; Scholasch *et al*., 2005; Tarara *et al*., 2007; Olivo *et al*., 2009). Different treatments were also induced by applying irrigation as a percentage of the water that a control treatment received (Ojeda *et al*., 2002; Kaiser *et al*., 2004; Chapman *et al*., 2005; Chaves *et al*., 2007). Another approach is refilling the soil profile back to field water capacity (FC) at certain physiological stages (Van Zyl, 1975; Hunter & Deloire, 2001; Ojeda *et al*., 2002; Myburgh, 2005; Ellis, 2008) or within a specific time frame (Myburgh, 2006). Since it is not always stated how many water was still available for grapevine uptake when the irrigation was applied, there is some doubt around the applicability of such treatments. For example, irrigation applied in a semi-arid climate region at 0.75 of ET_o can be refilling of the soil water content with 75% of the ET_o on a daily, weekly or three weekly basis or any time in between. The longer the soil is allowed to dry out, the lower the soil water matric potential (Ψ_m) will be and the higher the water stress that could affect grapevine physiology (Williams *et al*., 1994). Nieuwoudt (1962), Van Zyl (1984; 1988), Myburgh (1996; 2006; 2011) and Pellegrino *et al*. (2004) have all used fractions of soil water availability, either readily plant available water (RAW) or total plant available water (PAW), to which the soil was allowed to dry out before a refill irrigation back to FC was applied. This enabled the determination of crop coefficients for different depletion levels in different climatic regions for different irrigation strategies. Following this approach, the research was less scenario-bound since treatments, and in some way results, became applicable in other areas as soil characteristics were the main criteria for irrigation applications. Van Zyl (1984) did however found that Colombar grapevines in the Breede River Valley irrigated at 10% PAW depletion level by means of micro-sprinkler irrigation needed *ca.* 200 mm more water compared to grapevines irrigated at the same depletion level by means of drip irrigation. This indicate that irrigation system type can have a big influence on the water requirement of grapevines.

In South Africa, most of the previous irrigation research on grapevines was carried out on full surface flood, overhead sprinkler or micro-sprinkler irrigation irrigated vineyards, while grapevines canopy manipulations were done similarly (Van Zyl & Weber, 1977; Van Zyl, 1984; Myburgh, 1996; Myburgh, 1998; Myburgh, 2003; Myburgh, 2006; Myburgh, 2011). Although the positive effects of canopy manipulation on the quality aspect of wine have been reported, all grapevines of the canopy treatments received the same irrigation volumes (strategies) and irrigation applications were indicated very vaguely or not at all (Hunter, 2000; Hunter & Volschenk, 2001; Volschenk & Hunter, 2001; Archer & Van Schalkwyk, 2007). Thus, little knowledge regarding the water requirement or usage of different canopy manipulated grapevines under South African conditions exists.

The aim of this chapter is to determine the effect of ten different drip irrigation strategy and canopy manipulation combinations on the water use of Shiraz grapevines in a semi-arid region.

6.2. MATERIALS AND METHODS

6.2.1. Vineyard evapotranspiration (ET)

Root studies in 2009 revealed that grapevine roots occupied only a *ca*. third of the soil volume allocated to each grapevine. Due to the fact that SWC in the inter-grapevine row soil volume was not affected by either the frequency at which irrigation was applied or canopy management practices, crop transpiration losses were expected to occur primarily out of only a third of the soil volume. Thus, the full surface ET of the vineyard can be calculated by the following equation:

$$ET_{FS} = \frac{2}{3}ET_{WR} + \frac{1}{3}ET_{GR} \qquad \text{(Eq. 6.1)}$$

where: ET_{FS} = full surface evapotranspiration of vineyard ($m^3.ha^{-1}$)

ET_{WR} = evapotranspiration out of work row portion of vineyard ($m^3.ha^{-1}$)

ET_{GR} = evapotranspiration out of grapevine root portion of vineyard ($m^3.ha^{-1}$)

The fraction of ET from the work row volume of soil was determined by the following soil water balance equation:

$$ET_{WR} = \Delta SWC_{WR} + P - \Delta SWC_{750+} \qquad \text{(Eq. 6.2)}$$

where: ET_{WR} = evapotranspiration out of work row portion of vineyard (mm)

ΔSWC_{WR} = change in soil water content in the work row portion of vineyard (mm)

P = rain (mm)

ΔSWC_{750+} = change in soil water content in the 300 mm soil layer below 750 mm soil depth (mm)

Evapotranspiration from the volume of soil under the grapevines was determined by equation 6.3:

$$ET_{GR} = \Delta SWC_{GR} + I + P - \Delta SWC_{750+} \quad \text{(Eq. 6.3)}$$

where: ET_{GR} = evapotranspiration out of grapevine root portion of vineyard (mm)
ΔSWC_{GR} = change in soil water content in the grapevine root zone (volume) of vineyard (mm)
I = irrigation applied (mm)
P = rain (mm)
ΔSWC_{750+} = change in soil water content in the 300 mm soil layer below the root zone (mm)

Visual observation revealed that no run off occurred during irrigation applications. Soil water contents were measured as soon as possible after rainfall incidences to determine how effective the rain infiltration was. Subsurface flow was not quantified and assumed to be zero.

Each micro-lysimeter pot was constructed with a 125 mm length of 110 mm Ø polyvinyl chloride (PVC) pipe. A tight fit 3 mm PVC disk was glued into each pipe to create a micro-lysimeter pot. Thirteen 5 mm drainage holes were drilled in each disk and hole edges were rounded. Top soil from the vineyard was collected in 30 litre heavy duty plastic bags and brought back to the Irrigation Laboratory at the ARC Infruitec-Nietvoorbij's Nietvoorbij campus. The water content of the soil in each bag was determined and taken into account during the calculation of the quantity of soil that had to be packed into the pots at a bulk density similar to that of the trial vineyard's top soil (*ca*. 1 520 $kg.m^{-3}$). The packing was done by means of placing the calculated quantity of soil into the pots and then compacted with the help of a bench screw press. In January 2013, in each experimental plot, a 250 mm length of 125 mm Ø PVC was installed under the grapevine row in the adjacent row opposite each of the neutron probe access tubes. These pipes were installed with their top edges level with the soil surface to act as sleeves for the micro-lysimeter pots (Fig. 6.1). Each pipe was filled with gravel and compacted until it was filled half way.

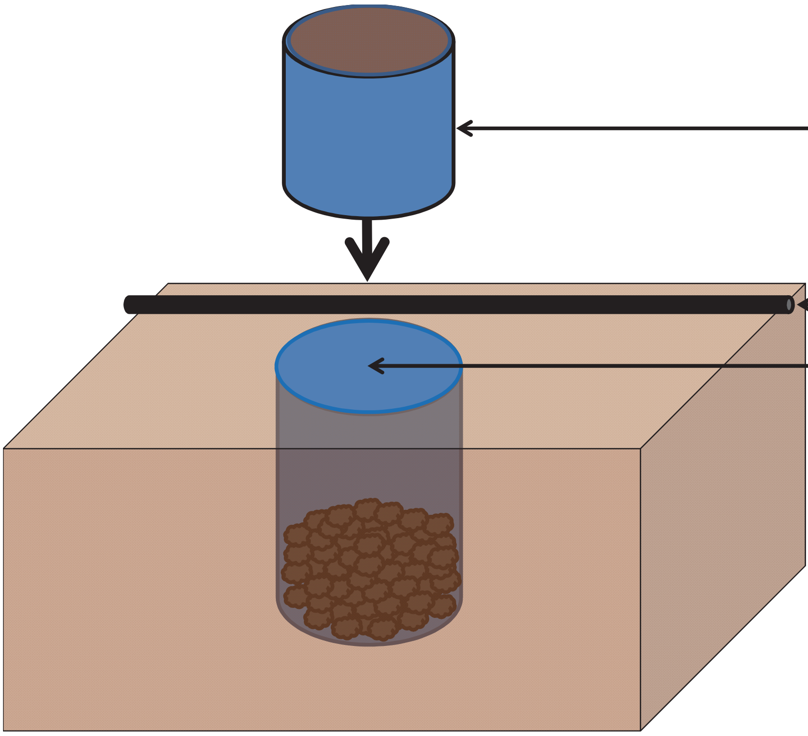

Figure 6.1 Illustration of sleeve inserted into the soil under the grapevine row and the placement of a micro-lysimeter pot therein.

Before evaporation rates (E_s) could be measured, the soil in pots had to be saturated to simulate the saturated soil directly under the drippers. This was done by placing a pot, either early in the morning or early evening, on two grey paver bricks and irrigating two pots by means of a 2 $L.h^{-1}$ button dripper that was inserted into the dripper line for half an hour or until water drained freely out of the drainage holes (Fig. 6.2).

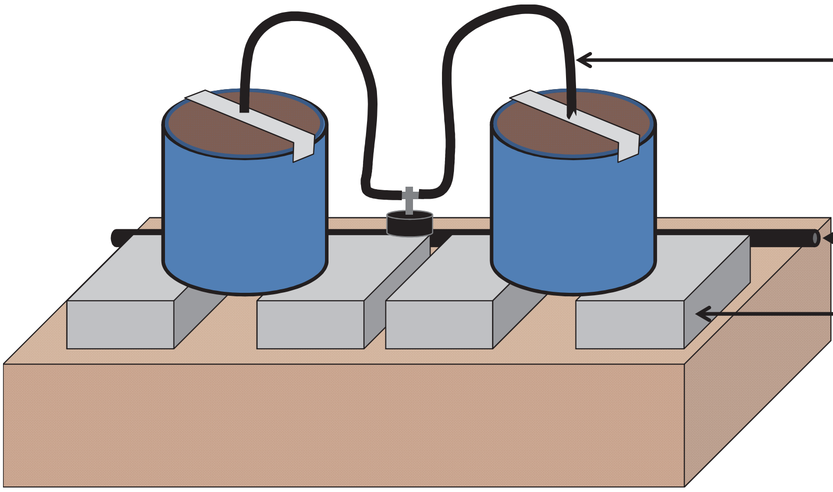

Figure 6.2 Illustration of a micro-lysimeter irrigation station for two micro-lysimeter pots.

The pots were covered with lids to ensure evaporation did not start before pots were weighed and left overnight to ensure excess water drained out of pots. At 07:00 the following morning, pots were carried out of the vineyard to a top pan balance to be weighed before returning them to their experimental plot and placing them in their sleeves. To investigate the effect of different grapevine canopies on diurnal variation in evaporation rates, micro-lysimeter pots were removed hourly from under the grapevine canopies and carried to the top pan balance to be weighed before returning them to their allocated positions. To determine the effect of canopy manipulation and irrigation strategy combinations on the cumulative E_s, micro-lysimeter pots were measured daily between 07:00 and 08:00. Afterwards the following equation was used to calculate the E_s:

$$E_s = \frac{\left(\frac{M_1 - M_2}{A}\right)}{\Delta t} \qquad \text{(Eq. 6.4)}$$

where:

	E_s	=	evaporation rate ($mm.h^{-1}$ or $mm.d^{-1}$)
	M_1	=	mass of micro-lysimeter pot – first measurement (kg)
	M_2	=	mass of micro-lysimeter pot – second measurement (kg)
	A	=	soil surface area in micro-lysimeter pot (m^2)
	Δt	=	time elapsed between measurements (hours or days)

It was suggested by the WRC steering committee that E_s be measured for window periods to determine grapevine transpiration. Transpiration within this window period (ripening) was calculated as follow:

$$T_{grapevine} = \left(\frac{(ET_{GR} - \Sigma E_s)}{DS}\right) \times F_{RZ} \qquad \text{(Eq. 6.5)}$$

where:

	$T_{grapevine}$	=	transpiration per grapevine ($L.d^{-1}$)
	ET_{GR}	=	cumulative evapotranspiration out of grapevine root portion of vineyard (mm)
	ΣE_s	=	cumulative evaporation out of root zone over specific period (mm)
	DS	=	area allocated to each dripper (m^2)
	F_{RZ}	=	fraction of soil volume occupied by grapevine roots and from which water uptake will occur

Soil water losses due to evaporation are equal to that of the cumulative ET_o of the first stage of evaporation as given in Eq. 6.6 (Myburgh, 1998). The second stage is characterised by a decrease in ΣE_s below the ΣET_o as seen in the equations given below.

$\Sigma E_s = \Sigma ET_o$ (for $\Sigma ET_o < \beta^2$, *i.e.* stage 1 of evaporation) (Eq. 6.6)

$\Sigma E_s = \Sigma ET_o$ (for $\Sigma ET_o = \Sigma E1 = \beta^2$) (Eq. 6.7)

$\Sigma E_s = \beta (\Sigma ET_o)^{0.5}$ (for $\Sigma ET_o > \beta^2$, *i.e.* stage 2 of evaporation) (Eq. 6.8)

The β ($mm^{0.5}$) is a soil evaporation parameter defined as the square root of the amount of stage 1 evaporation to take place before stage 2 evaporation commences. It is calculated as the slope of the ΣE_s vs $(\Sigma ET_o)^{0.5}$ curve (Boesten & Stoosnijder, 1986; Myburgh, 1998). The SWC where the transition from stage 1 to stage 2 of evaporation occurs is β^2 (Boesten & Stoosnijder, 1986). In order to calculate this value for the soil in this study, cumulative E_s was measured by weighing the micro-lysimeters daily 07:00 and 08:00 between 2 and 17 September 2014. Gravimetric soil samples were also taken during this period from 0 to 100 mm, 100 mm to 200 mm and 200 mm to 300 mm soil depths.

The factor with which each treatment's canopy affected the evaporation (C_f) was determined by dividing the cumulative E_s out of the micro-lysimeter placed in the ground underneath the grapevine canopy after rain or an irrigation application by the cumulative ET_o during stage 1 of evaporation:

$$C_f = \frac{\Sigma E_{s,micro\text{-}lysimeter}}{\Sigma ET_o} \quad \text{for } \Sigma E_{s,micro\text{-}lysimeter} < \beta^2 \qquad \text{(Eq. 6.9)}$$

6.2.2. Crop coefficients (K_c)

The mean monthly approximated crop coefficient (K_c) for each of the ten different treatments during the experimental seasons was calculated by dividing the ET_c by the ET_o over the same period (Smart & Coombe, 1983; Allen *et al.*, 1998; Myburgh, 2003):

$$K_c = \frac{ET_c}{ET_o} \qquad \text{(Eq. 6.10)}$$

The crop coefficient for the whole vineyard, as well as the volume of soil wetted during irrigation applications (root zone) was determined.

6.2.3. VINET model

The VINET (VINeyard EvapoTranspiration) model is based on the dual crop coefficient concept that distinguishes between evaporation and transpiration (Myburgh, 1998). Soil evaporation (E_s) is estimated by means of a simple parametric model (Boesten & Stroosnijder, 1986; Stroosnijder, 1987). Daily E_s for clean cultivated soil is calculated using

ET_o and a soil specific parameter, the so-called β-value. The β-value could also be dependent on canopy orientation, *i.e.* horizontal *vs* vertical (Myburgh, 1998). Stage 1 E_s is also adjusted according to vineyard canopy changes over the growing season (Myburgh, 2015). Total leaf area per grapevine, canopy orientation and ET_o are used in the calculation of transpiration (Myburgh, 1998). Transpiration is related to total leaf area per grapevine, canopy orientation and ET_o (Myburgh, 2016). Whole grapevine sap flow measurements were carried out to develop the transpiration model. Total leaf area per grapevine is estimated from the cane mass per grapevine at pruning in winter.

6.2.4. Statistical analyses

The data were subjected to an analysis of variance (ANOVA) by using Statgraphics®. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means, which differed at $p \leq 0.05$, were considered significantly different.

6.3. RESULTS AND DISCUSSION

6.3.1. Crop evapotranspiration

Higher irrigation frequencies resulted in higher ET_{GR} losses during all the experimental seasons (Tables 6.1, 6.2, 6.3 & 6.4). Evapotranspiration losses from soils under sprawling canopies, particularly those irrigated at *ca*. 30% PAW depletion, tended to be higher in February than those with VSP canopies. The SWC of the VSP grapevines tended to increase during this period due to the fact that grapevines within the same irrigation strategy were irrigated by the same solenoid valve (Refer to Chapter 2 and Appendix B).

The ET_{WR} increased in periods that followed rainfall incidences (Tables 3.4 & 6.5). This was particularly pronounced for November 2013 and January 2014 (Table 6.5). The mean ET_{WR} during the 2014/15 season was substantially lower than the previous two seasons. This was expected due to the much drier conditions than the preceding seasons.

Due to the fact that neutron probe access tubes were only installed in the work row volumes in September 2012, no ET_{FS} could be calculated for the 2011/12 season. The monthly ET_{FS} (Tables 6.6 to 6.8) was much lower than the monthly ET_{GR} (Tables 6.2 to 6.4) for the 2012/13, 2013/14 and 2014/15 seasons. This was to be expected because the work row soil volume was not wetted during irrigation applications by means of the drip irrigation system (Fig. 3.5).

Irrigation at higher frequencies increased the seasonal ET_{FS} (Table 6.9). Within the same depletion level, canopy manipulation did not have an effect on the seasonal ET_{FS}.

The diurnal E_s losses under grapevines with sprawling canopies was lower than under VSP grapevines, irrespective of the level of PAW depletion (Figs. 6.3 & 6.4). Visual observation revealed that the wetted soil surface under the sprawling canopies remained shaded for longer periods compared to the VSP grapevines. The hourly E_s losses decrease between *ca.* 11:00 and 16:00 and can be attributed to the shading of the grapevine canopies over the wetted soil surface during this period (Fig. 6.5). Thus, longer shading under the sprawling canopies probably reduced the E_s compared to that from under VSP canopies (Fig. 6.5). Within a given canopy manipulation treatment, E_s tended to increase as the level of PAW depletion increased, *i.e.* that the E_s under grapevines irrigated at *ca.* 90% PAW depletion was higher than those irrigated at *ca.* 30% PAW depletion, due to a reduction in total leaf area per grapevine (Figs. 6.3 & 6.4). This trend was probably due to more shading by the denser canopies, *i.e.* higher mean leaf area per grapevine caused by more frequent irrigations, which subsequently reduced solar radiation at the wetted soil surface (Figs. 6.3 & 6.4).

Table 6.1 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean daily evapotranspiration (ET_{GR}) out of the grapevine root zone of Shiraz/110R grapevines during the 2011/12 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca*. 30% PAW depletion**			***ca*. 60% PAW depletion**			***ca*. 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	**ET_{GR} ($mm.d^{-1}$)**									
Sep 2011	2.0 a[(1)]	1.8 ab	2.0 a	2.3 a	1.4 b	1.9 ab	2.4 a	1.9 ab	1.5 b	1.9 ab
Oct 2011	6.3 a	6.2 a	6.0 a	3.9 b	2.5 bc	3.6 b	1.0 c	1.4 c	1.4 c	1.6 c
Nov 2011	11.1 a	10.5 ab	10.1 ab	10.1 ab	5.7 bc	10.4 ab	4.2 c	3.7 c	4.2 c	3.1 c
Dec 2011	13.7 ab	14.2 a	14.8 a	13.1 abc	8.6 abcd	13.7 ab	7.6 bcd	6.1 d	7.0 cd	5.5 d
Jan 2012	13.9 a	13.9 a	14.7 a	14.4 a	9.7 ab	12.7 a	5.9 b	5.3 b	5.4 b	4.3 b
Feb 2012	12.7 ab	13.5 a	14.0 a	13.4 a	7.8 b	13.6 a	0.8 c	0.8 c	0.6 c	2.5 c
Mar 2012	7.9 ab	7.9 ab	8.0 ab	8.5 a	5.6 bc	7.5 ab	6.7 ab	5.7 bc	6.7 ab	3.1 c

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

Table 6.2 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean daily evapotranspiration (ET_{GR}) out of the grapevine root zone of Shiraz/110R grapevines during the 2012/13 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	ET_{GR} ($mm.d^{-1}$)									
Sep 2012	3.6 a[(1)]	2.8 ab	2.2 b	2.1 b	2.1 b	2.4 ab	3.3 ab	2.6 ab	3.6 a	3.5 a
Oct 2012	6.6 b	8.2 a	7.0 ab	2.3 cd	2.4 c	2.4 c	1.2 d	1.7 cd	1.9 cd	1.8 cd
Nov 2012	8.7 b	8.8 b	10.4 a	5.4 c	5.2 c	5.4 c	4.1 c	4.3 c	4.4 c	4.1 c
Dec 2012	10.1 ab	9.2 b	11.3 ab	10.6 ab	11.7 a	10.5 ab	2.1 c	1.8 c	2.1 c	2.5 c
Jan 2013	8.0 a	7.9 a	7.6 a	8.5 a	8.8 a	8.1 a	3.6 b	3.5 b	4.7 b	3.7 b
Feb 2013	13.7 b	11.7 c	16.5 a	7.8 d	7.4 d	9.1 d	4.5 e	4.4 e	4.9 e	4.1 e
Mar 2013	3.2 c	3.8 abc	4 abc	5.2 a	4.8 ab	4.6 abc	3.9 abc	3.9 abc	3.9 abc	3.6 bc

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

Table 6.3 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean daily evapotranspiration (ET_{GR}) out of the grapevine root zone of Shiraz/110R grapevines during the 2013/14 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	ET_{GR} (mm.d^{-1})									
Sep 2013	2.3 a[1]	2.0 ab	2.5 a	2.1 ab	2.3 a	2.8 a	2.4 a	1.9 ab	1.2 b	2.2 ab
Oct 2013	3.0 a	3.0 a	3.0 a	1.9 bc	1.9 bc	1.6 c	1.7 bc	1.9 bc	2.2 b	2.0 bc
Nov 2013	7.5 a	7.6 a	7.6 a	4.5 b	4.7 b	4.5 b	2.3 c	2.2 c	2.5 c	2.1 c
Dec 2013	8.7 a	8.7 a	8.6 a	7.3 b	7.1 b	7.5 b	2.3 c	2.2 c	2.2 c	2.3 c
Jan 2014	9.0 a	8.5 ab	8.7 ab	8.0 b	8.7 ab	8.1 b	2.9 c	2.9 c	3.0 c	2.9 c
Feb 2014	9.8 bc	10.3 ab	10.7 a	8.4 d	8.4 d	9.1 cd	0.4 e	0.5 e	0.5 e	0.4 e
Mar 2014	7.3 a	7.3 a	7.1 a	4.7 c	5.6 b	4.6 c	1.4 d	1.4 d	1.3 d	1.6 d

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

Table 6.4 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean daily evapotranspiration (ET_{GR}) out of the grapevine root zone of Shiraz/110R grapevines during the 2014/15 growing season near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Month	ET_{GR} (mm.d^{-1})									
Sep 2014	1.7 b[(1)]	2.2 b	2.6 ab	2.3 b	2.2 b	3.3 a	1.7 b	1.8 b	2.5 ab	1.9 b
Oct 2014	4.0 b	5.0 a	5.1 a	3.3 b	4.0 b	3.7 b	1.3 c	1.2 c	1.3 c	1.1 c
Nov 2014	7.3 b	8.0 a	7.7 ab	5.5 c	5.4 c	6.1 c	0.5 d	0.5 d	0.5 d	0.5 d
Dec 2014	10.0 ab	10.8 a	10.6 a	9.6 ab	8.3 b	10.6 a	3.3 c	3.1 c	4.0 c	3.5 c
Jan 2015	9.4 abc	10.3 abc	10.7 abc	11.9 ab	11.4 ab	13.1 a	6.3 c	6.3 c	7.7 bc	6.4 c
Feb 2015	14.7 a	14.8 a	15.6 a	9.6 bc	8.6 c	10.3 b	1.0 d	1.1 d	1.3 d	1.2 d
Mar 2015	6.0 abcd	7.8 a	6.7 abc	4.8 cd	3.9 d	5.4 bcd	6.8 abc	6.5 abc	7.5 ab	5.9 abcd

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

Table 6.5 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean daily evapotranspiration (ET_{WR}) out of the work row soil volume of a Shiraz/110R vineyard during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	ET_{WR} (mm.d^{-1})		
Month	**2012/13 season**	**2013/14 season**	**2014/15 season**
September	1.29	1.42	0.60
October	0.93	0.86	0.13
November	0.03	1.41	0.64
December	1.15	0.87	0.16
January	0.20	2.38	0.11
February	0.58	0.46	0.27
March	0.26	0.51	0.03

(1) Similar trends were observed between the soil water contents of the six measuring points. Therefore, the mean monthly values are presented and no statistical analysis was done.

Table 6.6 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean daily evapotranspiration out of the whole Shiraz/110R vineyard, *i.e.* full surface (ET_{FS}), during the 2012/13 growing season near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Month	ET_{FS} (mm.d^{-1})									
Sep 2012	2.1 a[(1)]	1.8 ab	1.6 b	1.6 b	1.6 b	1.7 ab	2.0 ab	1.7 ab	2.1 a	2.0 a
Oct 2012	2.8 b	3.3 a	2.6 b	1.4 cd	1.4 c	1.4 c	1.0 d	1.2 cd	1.2 cd	1.2 cd
Nov 2012	2.9 b	3.0 b	3.5 a	1.8 c	1.8 c	1.8 c	1.4 c	1.5 c	1.5 c	1.4 c
Dec 2012	4.1 ab	3.8 b	4.5 ab	4.3 ab	4.7 a	4.3 ab	1.5 c	1.4 c	1.5 c	1.6 c
Jan 2013	2.8 a	2.8 a	2.7 a	3.0 a	3.1 a	2.8 a	1.3 b	1.3 b	1.7 b	1.4 b
Feb 2013	4.9 b	4.3 c	5.9 a	3.0 d	2.8 d	3.4 d	1.9 e	1.9 e	2.0 e	1.7 e
Mar 2013	1.2 c	1.4 abc	1.5 abc	1.9 a	1.8 ab	1.7 abc	1.5 abc	1.5 abc	1.5 abc	1.4 bc

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

Table 6.7 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean daily full surface evapotranspiration out of the whole Shiraz/110R vineyard, *i.e.* full surface (ET_{FS}), during the 2013/14 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	**ET_{FS} (mm.d^{-1})**									
Sep 2013	1.7 a[1]	1.6 ab	1.8 a	1.7 ab	1.7 a	1.9 a	1.7 a	1.6 ab	1.4 b	1.7 ab
Oct 2013	1.6 a	1.6 a	1.6 a	1.2 bc	1.2 bc	1.1 c	1.1 bc	1.2 bc	1.3 b	1.2 bc
Nov 2013	3.4 a	3.5 a	3.5 a	2.4 b	2.5 b	2.4 b	1.7 c	1.7 c	1.8 c	1.7 c
Dec 2013	3.5 a	3.5 a	3.4 a	3.0 b	2.9 b	3.1 b	1.4 c	1.3 c	1.3 c	1.3 c
Jan 2014	4.6 a	4.4 ab	4.5 ab	4.3 b	4.5 ab	4.3 b	2.6 c	2.6 c	2.6 c	2.6 c
Feb 2014	3.6 bc	3.8 ab	3.9 a	3.1 d	3.1 d	3.3 cd	0.4 e	0.5 e	0.5 e	0.4 e
Mar 2014	2.8 a	2.8 a	2.7 a	1.9 c	2.2 b	1.9 d	0.8 d	0.8 d	0.8 d	0.9 d

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

Table 6.8 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean daily full surface evapotranspiration out of the whole Shiraz/110R vineyard, *i.e.* full surface (ET_{FS}), during the 2014/15 growing season near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Month	ET_{FS} (mm.d^{-1})									
Sep 2014	1.0 b[(1)]	1.1 b	1.3 ab	1.2 b	1.1 b	1.5 a	1.0 b	1.0 b	1.2 ab	1.0 b
Oct 2014	1.4 b	1.7 a	1.8 a	1.2 b	1.4 b	1.3 b	0.5 c	0.5 c	0.5 c	0.5 c
Nov 2014	2.9 b	3.1 a	3.0 ab	2.2 c	2.2 c	2.4 c	0.6 d	0.6 d	0.6 d	0.6 d
Dec 2014	3.4 ab	3.7 a	3.6 a	3.3 ab	2.9 b	3.6 a	1.2 c	1.1 c	1.4 c	1.3 c
Jan 2015	3.2 abc	3.5 abc	3.6 abc	4.0 ab	2.5 c	4.4 a	2.2 c	2.2 c	2.6 bc	2.2 c
Feb 2015	5.1 a	5.1 a	5.4 a	3.0 bc	3.1 c	3.6 b	0.5 d	0.5 d	0.6 d	0.6 d
Mar 2015	2.0 abcd	2.6 a	2.2 abc	1.6 cd	1.3 d	1.8 bcd	2.3 abc	2.2 abc	2.5 ab	2.0 abcd

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

Table 6.9 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on total seasonal evapotranspiration out of the whole Shiraz/110R vineyard, *i.e.* full surface (ET_{FS}), during the growing seasons of the experimental period near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	Seasonal ET_{FS} ($m^3.ha^{-1}$)									
2011/12	-[(1)]	-[(1)]	-[(1)]	-[(1)]	-[(1)]	-[(1)]	-[(1)]	-[(1)]	-[(1)]	-[(1)]
2012/13	6 106 a[(2)]	6 100 a	6 156 a	4 762 b	4 769 b	4 799 b	3 116 c	3 069 c	3 391 c	3 169 c
2013/14	6 385 a	6 386 a	6 437 a	5 282 c	5 450 b	5 371 b	2 930 d	2 899 d	2 907 d	2 949 d
2014/15	5 694 ab	6 231 a	6 245 a	5 004 bc	4 366 c	5 553 ab	2 308 d	2 270 d	2 659 d	2 290 d

(1) No soil water contents were monitored within the work row soil volume during the 2011/12 season.
(2) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

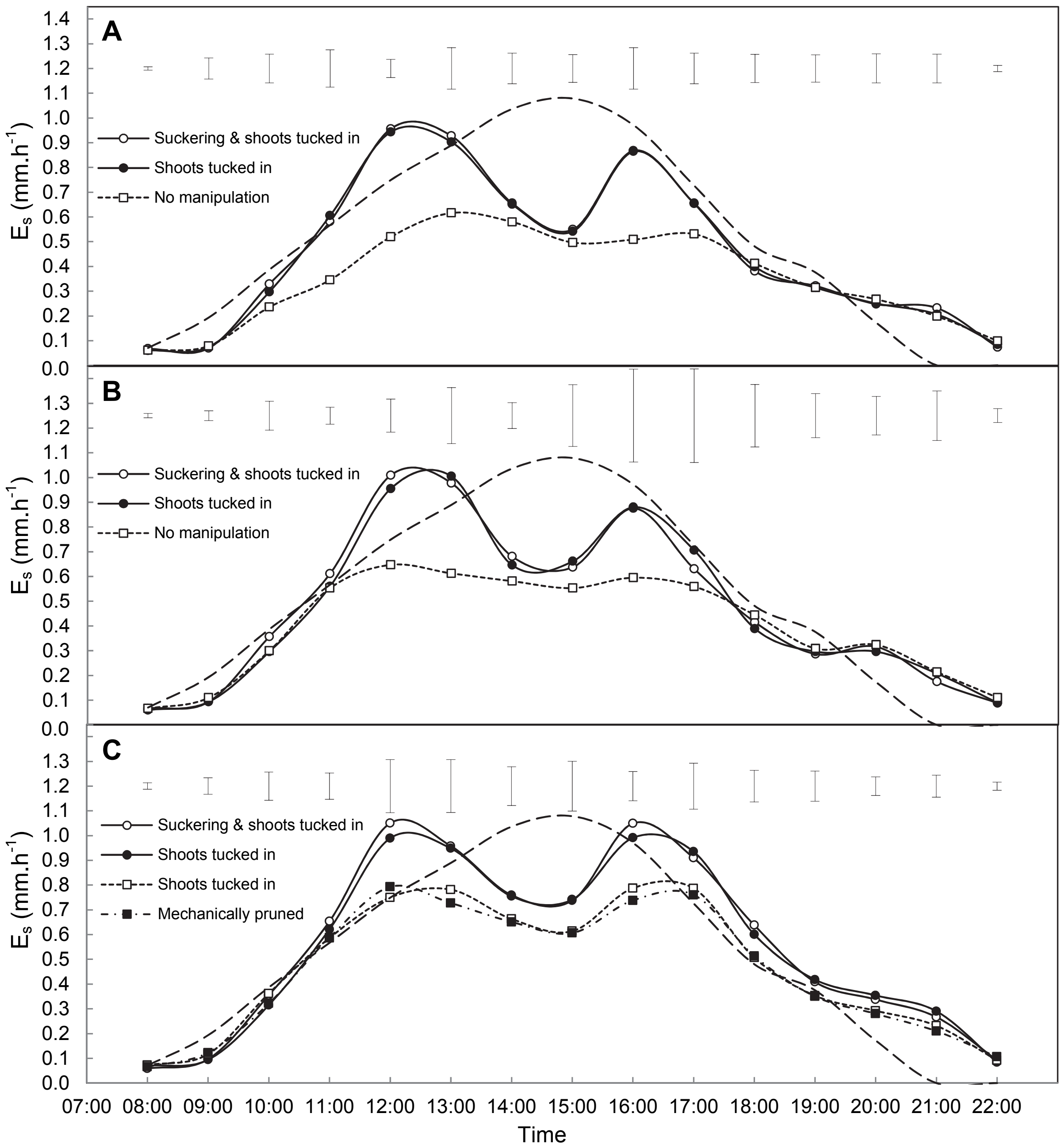

Figure 6.3 The effect of (A) *ca*. 30%, (B) *ca*. 60% and (C) *ca*. 90% plant available water depletion in combination with three canopy manipulations on evaporation from the soil (E_s) under Shiraz/110R grapevines in a fine sandy loam soil near Robertson on 13 February 2013. Vertical bars indicate least significant difference ($p < 0.05$). Dashed lines without markers (---) indicated the hourly ET_o.

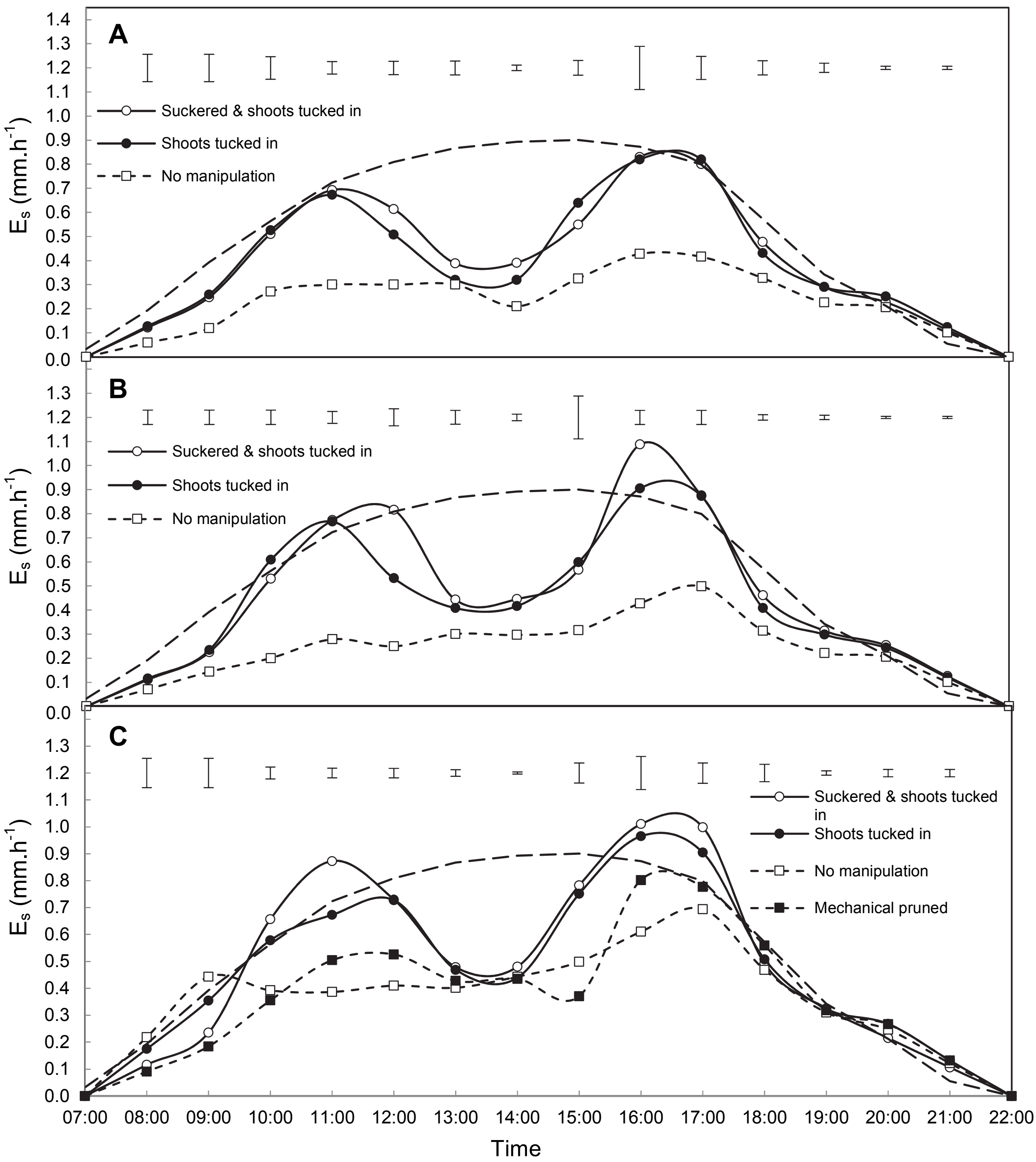

Figure 6.4 The effect of (A) *ca*. 30%, (B) *ca*. 60% and (C) *ca*. 90% plant available water depletion in combination with three canopy manipulations on evaporation from the soil (E_s) under Shiraz/110R grapevines in a fine sandy loam soil near Robertson on 18 December 2013. Vertical bars indicate least significant difference ($p < 0.05$). Dashed lines without markers (---) indicated the hourly ET_o.

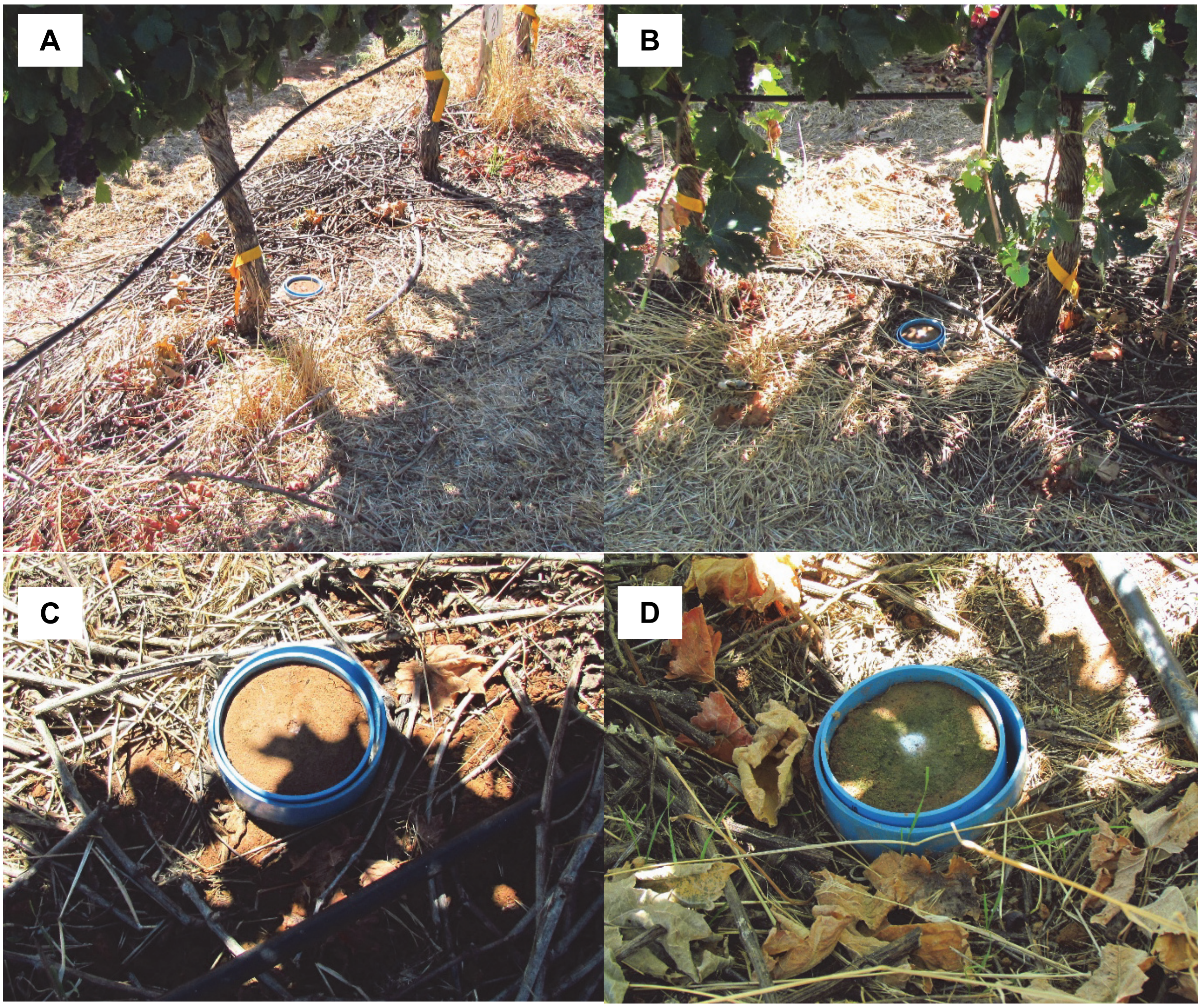

Figure 6.5 The effect of (A – 10:00; C – 12:00) tucking in of shoots and (B – 10:00; D – 12:00) sprawling grapevine canopy on the shade covering under Shiraz/110R grapevines on 13 February 2013 near Robertson.

The Beta value (β) for the specific soil was determined to be 3.849 $mm^{0.5}$ according to the slope of Figure 6.6. This compares well with values reported by Myburgh (1998) for similar textured soils near Robertson and Upington. Thus, 14.8 mm (β^2) water can be lost from the 0 to 300 mm soil depth layer before the transition from the 1st to the 2nd stage of evaporation occurs and the expected daily evaporation rate be lower than that of the ET_o (Fig 6.7).

There was a good relationship between the ΣE_s determined by means of the micro-lysimeters and the weighed gravimetric soil samples taken down to a depth of 300 mm (Fig. 6.8). After a loss of *ca*. 22 mm, the micro-lysimeter estimated E_s was less than E_s measured by means of the gravimetric soil samples.

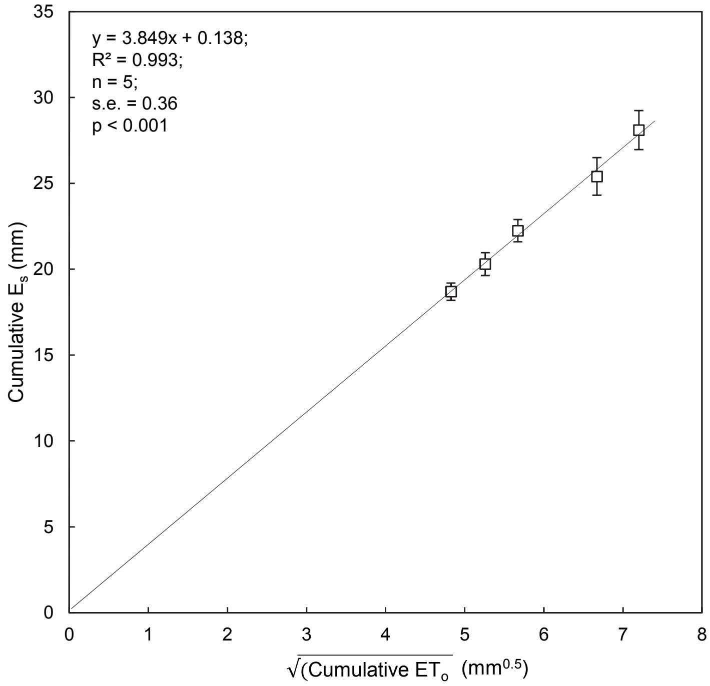

Figure 6.6 The cumulative surface evaporation (E_s) versus the square root of the cumulative reference evapotranspiration (ET_o) to determine the beta-value (slope of the curve during stage 2 of evaporation) of a fine sandy loam soil near Robertson. Values are the means of 5 replications and vertical bars indicate standard deviations.

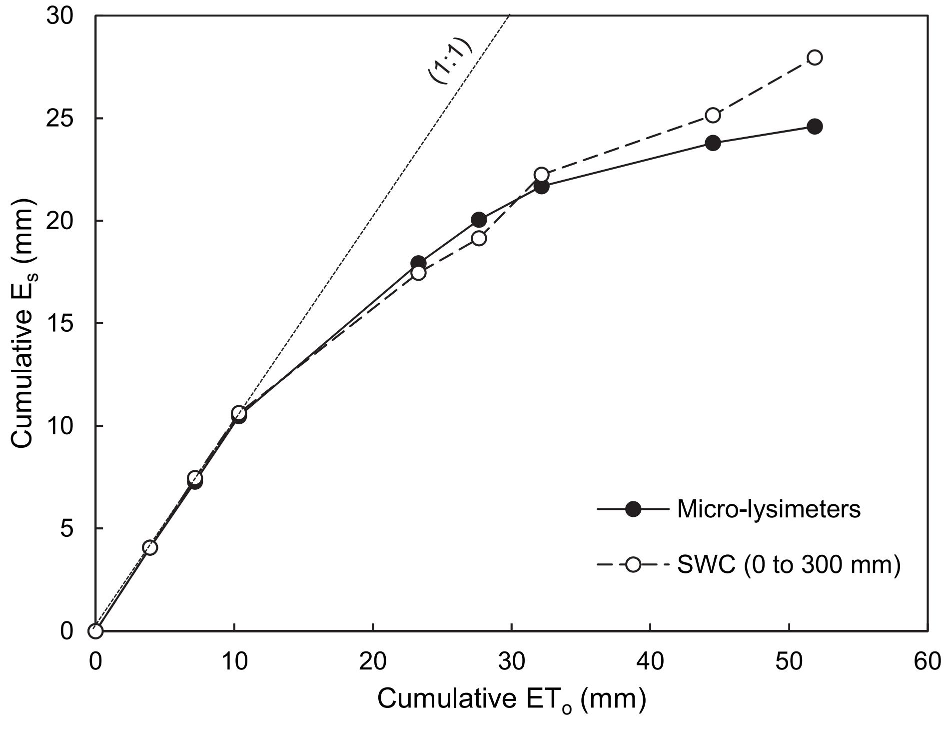

Figure 6.7 The cumulative surface evaporation (E_s) after a wetting event of a fine sandy loam soil near Robertson determined by means of micro-lysimeters (•) and weighed soil samples of 0 to 300 mm depth (○) compared to the cumulative reference evapotranspiration (ET_o) between 2 and 17 September 2014. Values are the means of 5 replications.

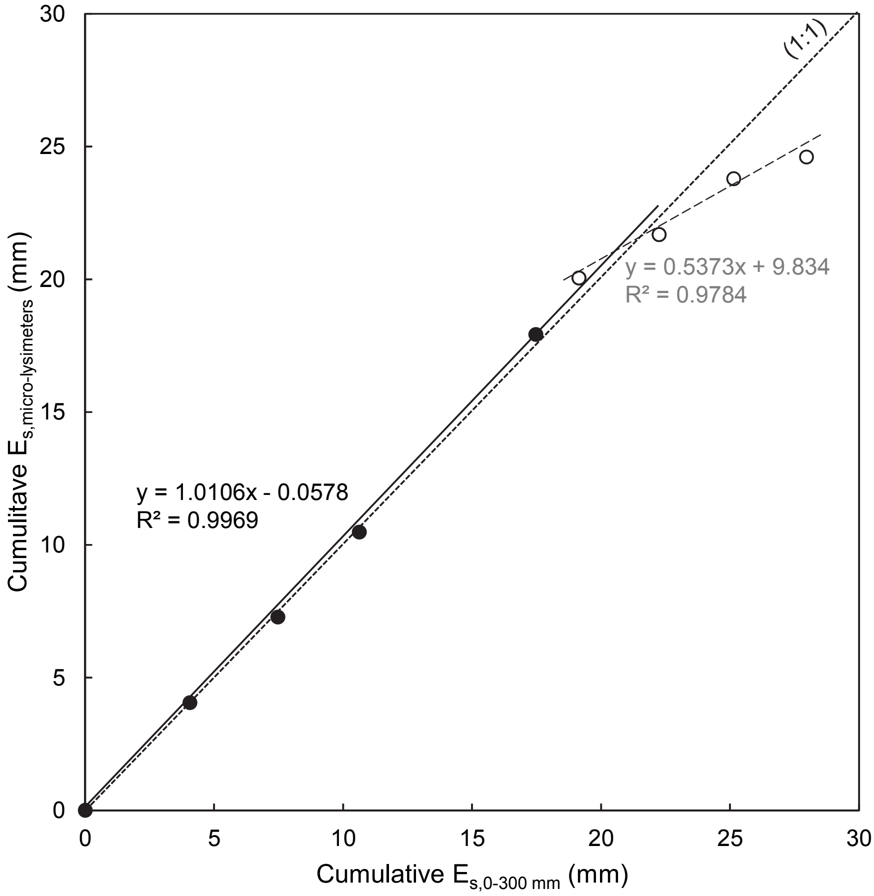

Figure 6.8 The relationship of the cumulative surface evaporation (E_s) determined by means of micro-lysimeters and weighed gravimetric soil samples of 0 to 300 mm depth of a fine sandy loam soil near Robertson determined between 2 and 17 September 2014 before bud break. Values are the means of 5 replications. The linear regression in black and the closed circles (●) represent the correlation between the two methods up to a water loss of *ca*. 22 mm, while the linear regression in grey and the open circles (○) represent the correlation after a water loss greater than *ca*. 22 mm.

Due to the fact that roots were present in the 0 to 300 mm soil layer, water losses out of this depth increment would have been due to evaporation as well as transpiration. When the 0 to 300 mm soil depth was considered during the 2013/14 growing season, the SWC of treatments irrigated at *ca*. 30% PAW depletion were always in stage 1 of evaporation (Fig. 6.9A). The SWC of grapevines irrigated at *ca*. 60% PAW depletion sometimes went into stage 2, particularly that of the sprawling canopy (Fig.6.9B). In the case of irrigation at *ca*. 90% PAW depletion, the SWC was in stage 2 for most of the season (Fig. 6.9C). Similar trends in SWC occurred in deeper soil layer within the root zone (Fig. 6.10).

The C_f of the sprawling canopies was lower than that of the VSP grapevines, irrespective of PAW depletion (Table 6.10). Less frequent irrigation increased the C_f.

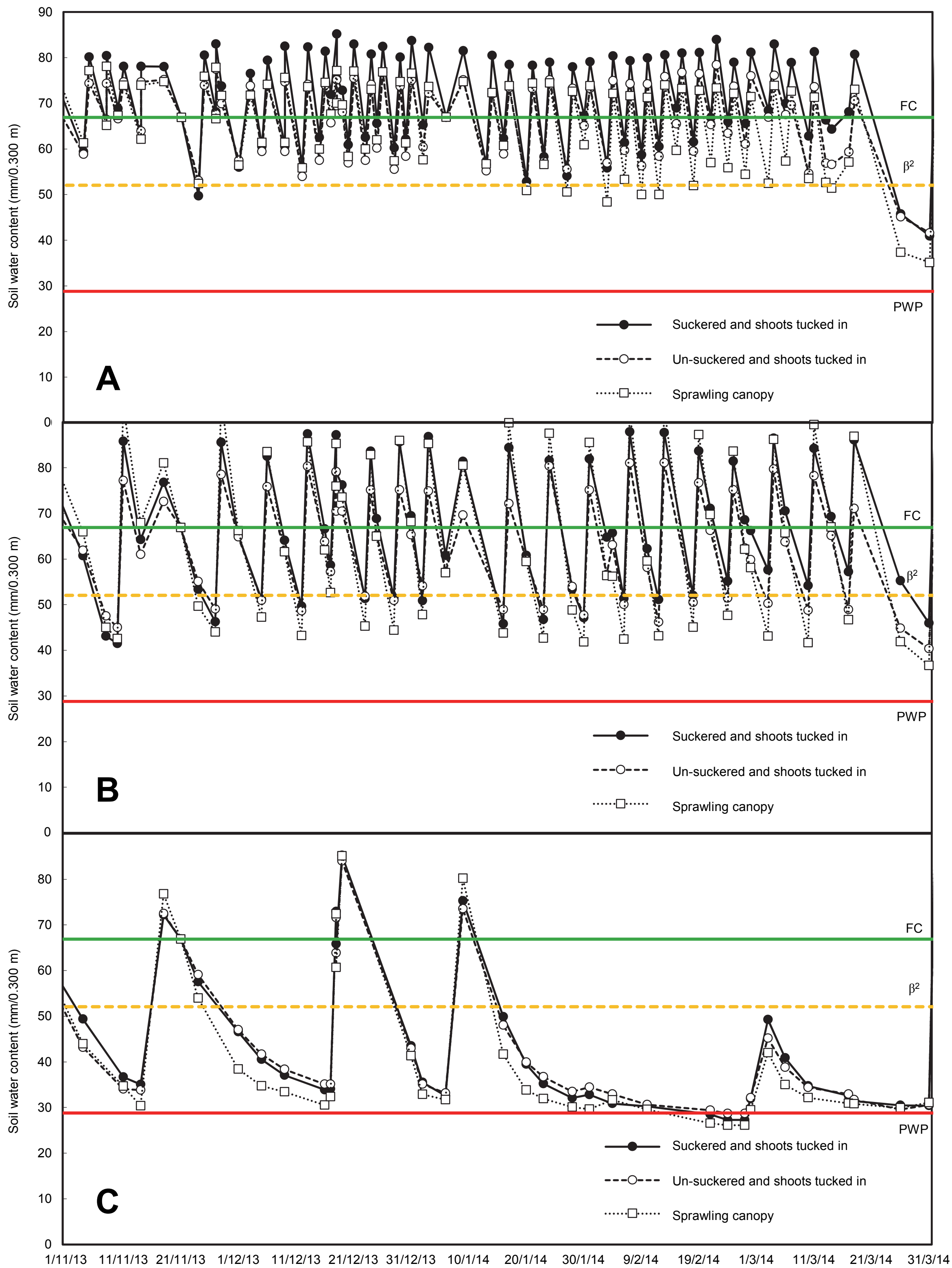

Figure 6.9 Variation in mean soil water content (SWC) of the 0 to 0.30 m soil depth under Shiraz/110R grapevines with different canopy manipulations applied and that were irrigated at (A) *ca.* 30% plant available water (PAW) depletion, (B) *ca.* 60% PAW depletion and (C) *ca.* 90% PAW depletion between 1 November 2013 and 31 March 2014 near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas β^2 indicates the SWC at which the soil evaporation transition from stage 1 to stage 2 occurs).

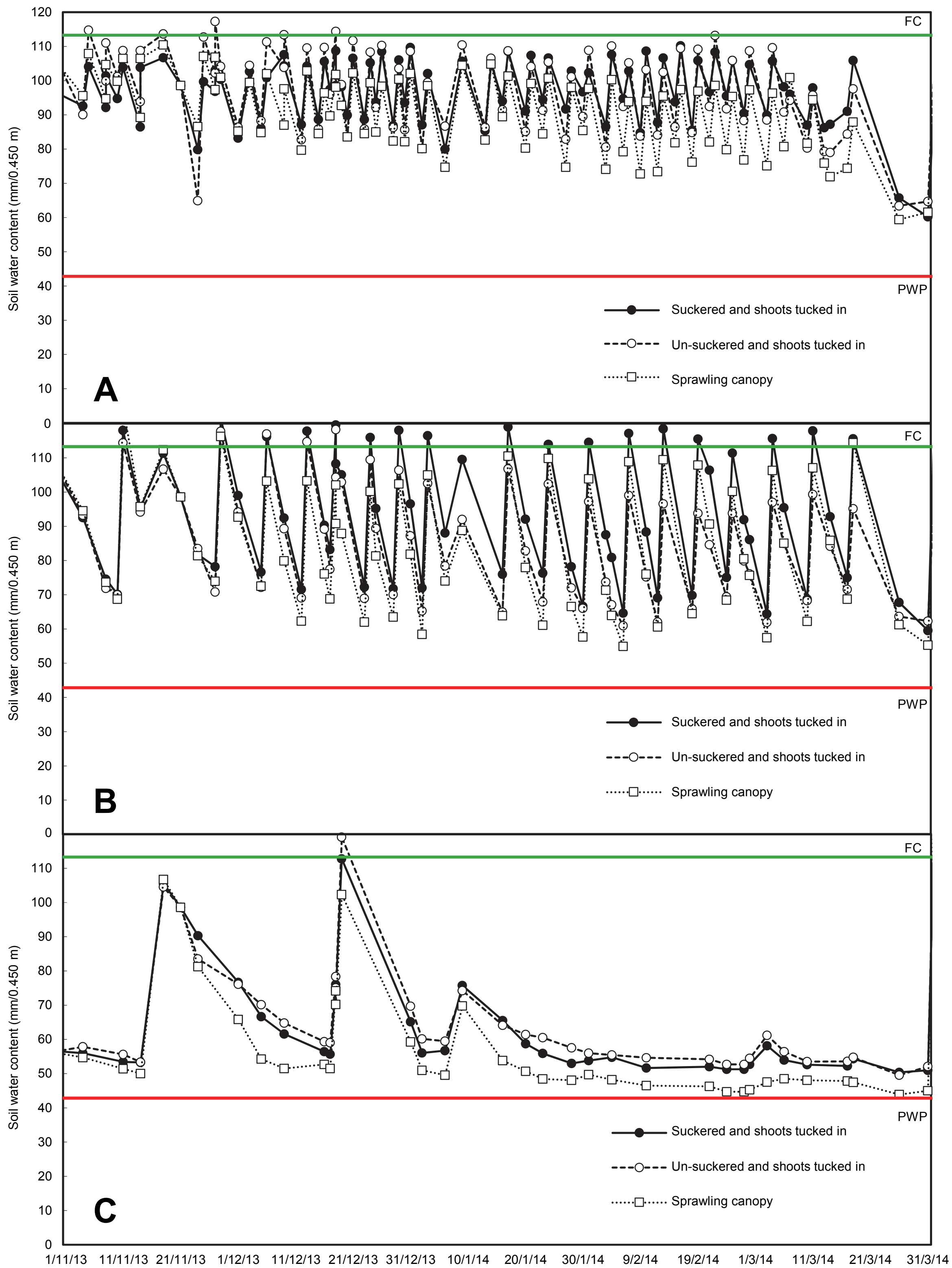

Figure 6.10 Variation in mean soil water content (SWC) of the 0.30 to 0.75 m soil depth under Shiraz/110R grapevines with different canopy manipulations applied and that were irrigated at (A) *ca*. 30% plant available water (PAW) depletion, (B) *ca*. 60% PAW depletion and (C) *ca*. 90% PAW depletion between 1 November 2013 and 31 March 2014 near Robertson (FC and PWP are field capacity and permanent wilting point, respectively.

Table 6.10 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on the evaporation canopy factor (C_f) of Shiraz/110R grapevines on evaporation during ripening of the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca*. 30% PAW depletion**			***ca*. 60% PAW depletion**			***ca*. 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	C_f									
2012/13	0.83 bc[1]	0.83 bc	0.62 d	0.96 a	0.95 a	0.76 c	0.96 a	0.96 a	0.84 b	0.84 b
2013/14	0.74 b	0.75 b	0.44 d	0.77 b	0.75 b	0.56 c	0.97 a	0.96 a	0.90 a	0.89 a
2014/15	0.90 c	0.91 c	0.67 e	0.90 c	0.92 bc	0.74 d	0.96 a	0.94 ab	0.91 c	0.91 c

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

The combined effects of LA_{CPS}, grapevine canopy volume and $CM_{grapevine}$ explained *ca.* 86% of the variation in C_f by means of multiple linear regression (Fig. 6.11) in the following equation:

$$C_f = 1.055 - 0.028 \times LA_{CPS} - 0.091 \times \text{canopy volume} - 0.119 \times CM_{grapevine}$$

($R^2 = 0.858$; se = 0.052; $p < 0.0001$) (Eq. 6.11)

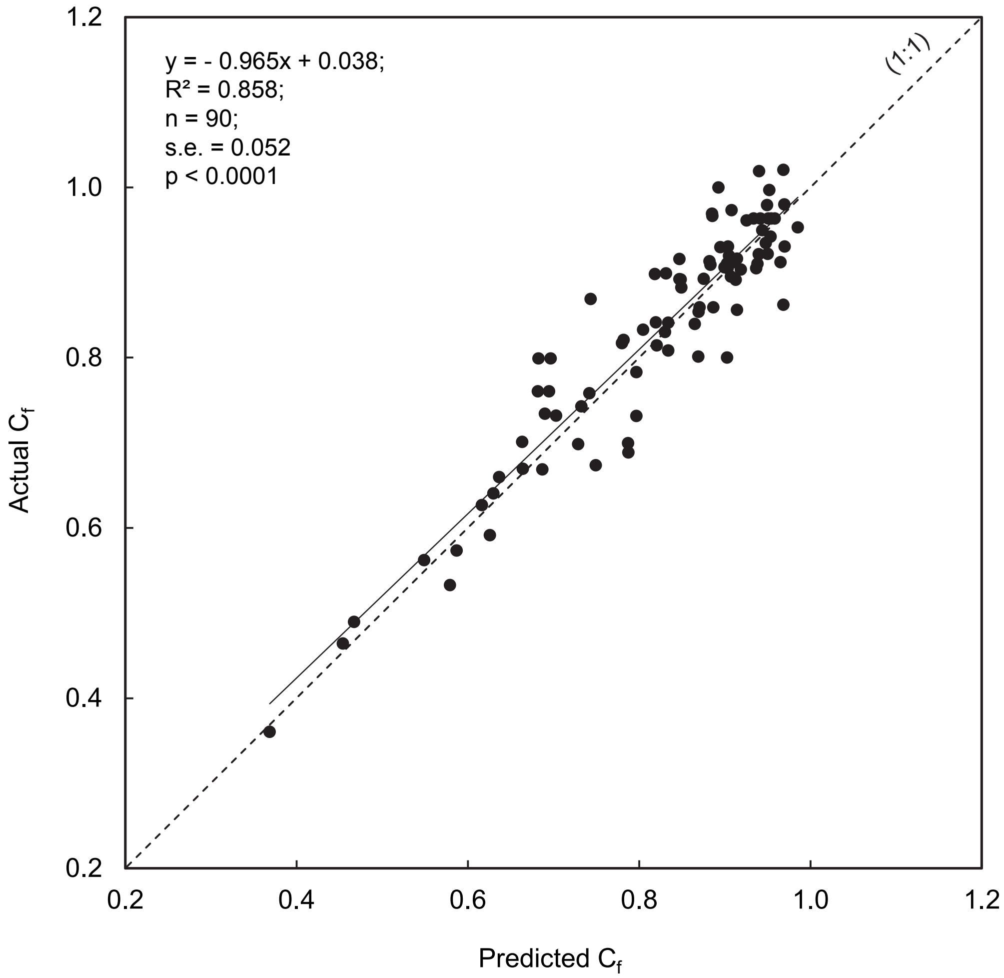

Figure 6.11 Relationship between actual evaporation canopy factor (C_f) and predicted C_f of Shiraz grapevines during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

This relationship suggested that as the grapevine vigour, as well as canopy width, height and density increases, less evaporation losses will occur from the soil surface of the wetted soil volume.

6.3.2. Crop coefficients

During the three seasons, the mean K_c for grapevines that were irrigated at *ca*. 30% PAW depletion were higher compared to those of other strategies, with those irrigated at *ca*. 90% PAW depletion being the lowest (Tables 6.11 to 6.13). The mean peak K_c was generally obtained in February of the experimental seasons for grapevines that were irrigated at *ca*.

30% PAW depletion. Where grapevines were irrigated particularly at *ca*. 30% and 60% PAW

Table 6.11 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean monthly crop coefficient for the whole Shiraz/110R vineyard, *i.e.* full surface (K_c), during the 2012/13 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	K_c									
Sep 2012	0.53 a[(1)]	0.46 ab	0.41 b	0.40 b	0.4 b	0.43 ab	0.50 ab	0.44 ab	0.53 a	0.52 a
Oct 2012	0.49 b	0.59 a	0.46 b	0.24 cd	0.25 c	0.25 c	0.18 d	0.21 cd	0.22 cd	0.22 cd
Nov 2012	0.46 b	0.46 b	0.54 a	0.28 c	0.28 c	0.28 c	0.22 c	0.23 c	0.23 c	0.22 c
Dec 2012	0.68 ab	0.63 b	0.74 ab	0.71 ab	0.77 a	0.70 ab	0.24 c	0.23 c	0.24 c	0.26 c
Jan 2013	0.41 a	0.40 a	0.39 a	0.44 a	0.45 a	0.41 a	0.19 b	0.19 b	0.25 b	0.20 b
Feb 2013	0.79 b	0.69 c	0.94 a	0.48 d	0.46 d	0.55 d	0.31 e	0.30 e	0.32 e	0.28 e
Mar 2013	0.23 c	0.26 abc	0.27 abc	0.35 a	0.32 ab	0.31 abc	0.27 abc	0.27 abc	0.27 abc	0.25 bc

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 6.12 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean monthly crop coefficient for the whole Shiraz/110R vineyard, *i.e.* full surface (K_c), during the 2013/14 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	K_c									
Sep 2013	0.44 a[(1)]	0.41 ab	0.45 a	0.42 ab	0.44 a	0.48 a	0.44 a	0.40 ab	0.35 b	0.43 ab
Oct 2013	0.31 a	0.32 a	0.32 a	0.25 bc	0.24 bc	0.22 c	0.23 bc	0.24 bc	0.26 b	0.25 bc
Nov 2013	0.68 a	0.69 a	0.69 a	0.48 b	0.50 b	0.48 b	0.34 c	0.33 c	0.35 c	0.33 c
Dec 2013	0.45 a	0.45 a	0.44 a	0.39 b	0.38 b	0.40 b	0.17 c	0.17 c	0.17 c	0.17 c
Jan 2014	0.71 a	0.69 ab	0.69 ab	0.66 b	0.7 ab	0.67 b	0.40 c	0.40 c	0.40 c	0.40 c
Feb 2014	0.56 bc	0.59 ab	0.61 a	0.49 d	0.49 d	0.53 cd	0.07 e	0.07 e	0.07 e	0.07 e
Mar 2014	0.57 a	0.57 a	0.56 a	0.39 c	0.46 b	0.39 c	0.17 d	0.17 d	0.16 d	0.18 d

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 6.13 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean monthly crop coefficient for the whole Shiraz/110R vineyard, *i.e.* full surface (K_c), during the 2014/15 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca*. 30% PAW depletion**			***ca*. 60% PAW depletion**			***ca*. 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	**K_c**									
Sep 2014	0.28 b[(1)]	0.32 b	0.35 ab	0.33 b	0.32 b	0.37 a	0.28 b	0.28 b	0.35 ab	0.29 b
Oct 2014	0.26 b	0.32 a	0.33 a	0.22 b	0.26 b	0.24 b	0.09 c	0.09 c	0.09 c	0.08 c
Nov 2014	0.47 b	0.51 a	0.5 ab	0.37 c	0.37 c	0.40 c	0.10 d	0.10 d	0.10 d	0.10 d
Dec 2014	0.51 ab	0.55 a	0.54 a	0.49 ab	0.45 b	0.54 a	0.18 c	0.17 c	0.21 c	0.19 c
Jan 2015	0.42 abc	0.47 abc	0.48 abc	0.53 ab	0.51 ab	0.59 a	0.29 c	0.29 c	0.35 bc	0.29 c
Feb 2015	0.75 a	0.75 a	0.79 a	0.49 bc	0.45 c	0.53 b	0.07 d	0.08 d	0.09 d	0.09 d
Mar 2015	0.42 abcd	0.54 a	0.46 abc	0.33 cd	0.27 d	0.37 bcd	0.47 abc	0.45 abc	0.51 ab	0.41 abcd

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

depletion, treatments with sprawling canopies tended to have higher K_c values during ripening. The lowest K_c values were obtained where grapevines were irrigated at *ca.* 90% PAW depletion in February 2014, irrespective of canopy manipulation.

The transpiration losses determined during window periods in the 2012/13, 2013/14 and 2014/15 seasons showed that as irrigation frequency increased, higher transpiration losses occurred (Table 6.14). As these window periods were normally in February, it was expected that grapevines with sprawling canopies would have higher transpiration rates. The fact that there were lower E_s losses from under the sprawling canopies may have made up for the extra water that was lost through transpiration. This was evident when the fraction of K_c contributable to evaporation (fK_e) and the fractional contribution of basal crop coefficient (fK_{cb}) of different canopies were considered (Table 6.14). Higher frequency irrigation increased the fK_e, whereas lower frequency irrigation increased the fK_{cb}.

Similar to the ET_{GR}, the crop coefficient of the irrigated volume of soil ($K_{c,GR}$) was lower than the full surface K_c (Tables 6.15 to 6.18). Although irrigation volume requirements are calculated using K_c based on the full surface needs, over-irrigation could a potential risk when making use of a partially wetted surface system such as drip irrigation as full surface evaporation would have been included in the determination of these K_c. Therefore, the $K_{c,GR}$ would be a more realistic coefficient for producers and consultants in the scheduling of irrigation requirement as the work row volume would not be irrigated and losses from this volume would be negligible.

Table 6.14 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean transpiration ($T_{grapevine}$), as well as the soil water evaporation (fK_e) and basal crop (fK_{cb}) coefficient fractions of the irrigated volume of soil's crop coefficient (K_c) of Shiraz/110R grapevines during window periods within ripening of the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca*. 30% PAW depletion**			***ca*. 60% PAW depletion**			***ca*. 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
	$T_{grapevine}$ ($L.d^{-1}$)									
2012/13[1]	1.56[4]	1.51	1.61	1.21	1.16	1.29	1.06	1.03	1.18	0.95
2013/14[2]	1.37	1.29	1.71	1.28	1.25	1.22	0.23	0.28	0.31	0.42
2014/15[3]	1.62	1.68	1.90	1.33	1.46	1.50	0.91	0.88	1.10	1.03
	fK_e									
2012/13	0.80	0.71	0.65	0.72	0.73	0.68	0.67	0.67	0.63	0.68
2013/14	0.81	0.73	0.53	0.67	0.66	0.68	0.90	0.88	0.87	0.81
2014/15	0.67	0.52	0.37	0.62	0.59	0.60	0.66	0.66	0.61	0.59
	fK_{cb}									
Feb 2013	0.20	0.29	0.35	0.28	0.27	0.32	0.33	0.33	0.37	0.32
Feb 2014	0.19	0.27	0.47	0.33	0.34	0.32	0.10	0.12	0.13	0.19
Feb 2015	0.33	0.48	0.62	0.38	0.41	0.40	0.34	0.34	0.39	0.41

(1) Cumulative evaporation determined between 12 and 25 February 2015 and used to calculate transpiration using Eq. 6.5.
(2) Cumulative evaporation determined between 27 February and 10 March 2015 and used to calculate transpiration using Eq. 6.5.
(3) Cumulative evaporation determined between 27 January and 9 February 2015 and used to calculate transpiration using Eq. 6.5.
(4) No statistical analyses were done on data.

Table 6.15 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean monthly crop coefficient ($K_{c,GR}$) of the fractional volume of soil irrigated in a Shiraz/110R vineyard during the 2011/12 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	$K_{c,GR}$									
Sep 2011	0.40 a[(1)]	0.38 ab	0.39 a	0.41 a	0.34 b	0.38 ab	0.44 a	0.39 ab	0.34 b	0.38 ab
Oct 2011	0.38 a	0.37 a	0.36 a	0.23 b	0.15 bc	0.22 b	0.06 c	0.08 c	0.08 c	0.10 c
Nov 2011	0.58 a	0.55 ab	0.53 ab	0.53 ab	0.30 bc	0.54 ab	0.22 c	0.19 c	0.22 c	0.16 c
Dec 2011	0.58 ab	0.60 a	0.63 a	0.55 abc	0.37 abcd	0.58 ab	0.32 bcd	0.26 d	0.30 cd	0.23 d
Jan 2012	0.63 a	0.63 a	0.66 a	0.65 a	0.44 ab	0.57 a	0.26 b	0.24 b	0.24 b	0.19 b
Feb 2012	0.69 ab	0.73 a	0.76 a	0.72 a	0.42 b	0.74 a	0.04 c	0.04 c	0.03 c	0.14 c
Mar 2012	0.49 ab	0.48 ab	0.49 ab	0.52 a	0.34 bc	0.46 ab	0.41 ab	0.35 bc	0.41 ab	0.19 c

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 6.16 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean monthly crop coefficient ($K_{c,GR}$) of the fractional volume of soil irrigated in a Shiraz/110R vineyard during the 2012/13 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	$K_{c,GR}$									
Sep 2012	0.39 a[1]	0.24 bc	0.19 c	0.18 c	0.18 c	0.21 bc	0.28 bc	0.22 bc	0.31 ab	0.30 ab
Oct 2012	0.38 b	0.48 a	0.35 b	0.14 cd	0.14 c	0.14 c	0.07 d	0.10 cd	0.11 cd	0.11 cd
Nov 2012	0.45 b	0.54 a	0.46 b	0.28 c	0.27 c	0.28 c	0.22 c	0.22 c	0.23 c	0.21 c
Dec 2012	0.55 ab	0.50 b	0.62 ab	0.58 ab	0.64 a	0.57 ab	0.12 c	0.10 c	0.12 c	0.14 c
Jan 2013	0.39 a	0.38 a	0.37 a	0.42 a	0.43 a	0.39 a	0.17 b	0.17 b	0.23 b	0.18 b
Feb 2013	0.73 b	0.63 c	0.88 a	0.42 d	0.39 d	0.48 d	0.24 e	0.24 e	0.26 e	0.22 e
Mar 2013	0.19 c	0.23 abc	0.24 abc	0.31 a	0.29 ab	0.28 abc	0.24 abc	0.24 abc	0.23 abc	0.22 bc

[1] Values designated by the same letter within each row do not differ significantly ($p \le 0.05$).

Table 6.17 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean monthly crop coefficient ($K_{c,GR}$) of the fractional volume of soil irrigated in a Shiraz/110R vineyard during the 2013/14 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	$K_{c,GR}$									
Sep 2013	0.20 a[(1)]	0.17 ab	0.21 a	0.18 ab	0.19 a	0.24 a	0.20 a	0.16 ab	0.10 b	0.19 ab
Oct 2013	0.20 a	0.20 a	0.20 a	0.13 bc	0.12 bc	0.11 c	0.11 bc	0.13 bc	0.15 b	0.13 bc
Nov 2013	0.49 a	0.50 a	0.50 a	0.30 b	0.31 b	0.30 b	0.15 c	0.14 c	0.16 c	0.14 c
Dec 2013	0.37 a	0.37 a	0.37 a	0.31 b	0.30 b	0.32 b	0.10 c	0.10 c	0.09 c	0.10 c
Jan 2014	0.46 a	0.44 ab	0.45 ab	0.41 b	0.45 ab	0.42 b	0.15 c	0.15 c	0.16 c	0.15 c
Feb 2014	0.52 bc	0.54 ab	0.56 a	0.44 d	0.44 d	0.48 cd	0.02 e	0.02 e	0.03 e	0.02 e
Mar 2014	0.50 a	0.50 a	0.49 a	0.32 c	0.39 b	0.32 c	0.10 d	0.10 d	0.09 d	0.11 d

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 6.18 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean monthly crop coefficient ($K_{c,GR}$) of the fractional volume of soil irrigated in a Shiraz/110R vineyard during the 2014/15 growing season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Month	$K_{c,GR}$									
Sep 2014	0.16 b[1]	0.21 b	0.24 ab	0.21 b	0.21 b	0.31 a	0.16 b	0.17 b	0.23 ab	0.18 b
Oct 2014	0.25 b	0.30 a	0.31 a	0.20 b	0.24 b	0.23 b	0.08 c	0.07 c	0.08 c	0.07 c
Nov 2014	0.40 b	0.44 a	0.43 ab	0.30 c	0.30 c	0.33 c	0.03 cd	0.03 d	0.03 d	0.03 d
Dec 2014	0.50 ab	0.54 a	0.53 a	0.48 ab	0.41 b	0.53 a	0.17 c	0.15 c	0.20 c	0.17 c
Jan 2015	0.41 bc	0.46 bc	0.47 abc	0.52 ab	0.33 c	0.58 a	0.28 a	0.28 a	0.34 bc	0.28 c
Feb 2015	0.72 a	0.72 a	0.76 a	0.47 bc	0.42 c	0.50 b	0.05 d	0.05 d	0.06 d	0.06 d
Mar 2015	0.26 d	0.33 cd	0.37 bcd	0.4 abcd	0.41 abcd	0.44 abc	0.45 abc	0.46 abc	0.51 ab	0.53 a

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

6.3.3. Comparison of measured ET values with values predicted using VINET model

When measured ET values were compared to those estimated by the VINET model, the measured ET values varied from the model (Fig 6.12). The model generally underestimated ET when higher irrigation frequencies were applied, whereas it overestimated ET when low frequency to no irrigation were applied (Appendix C).

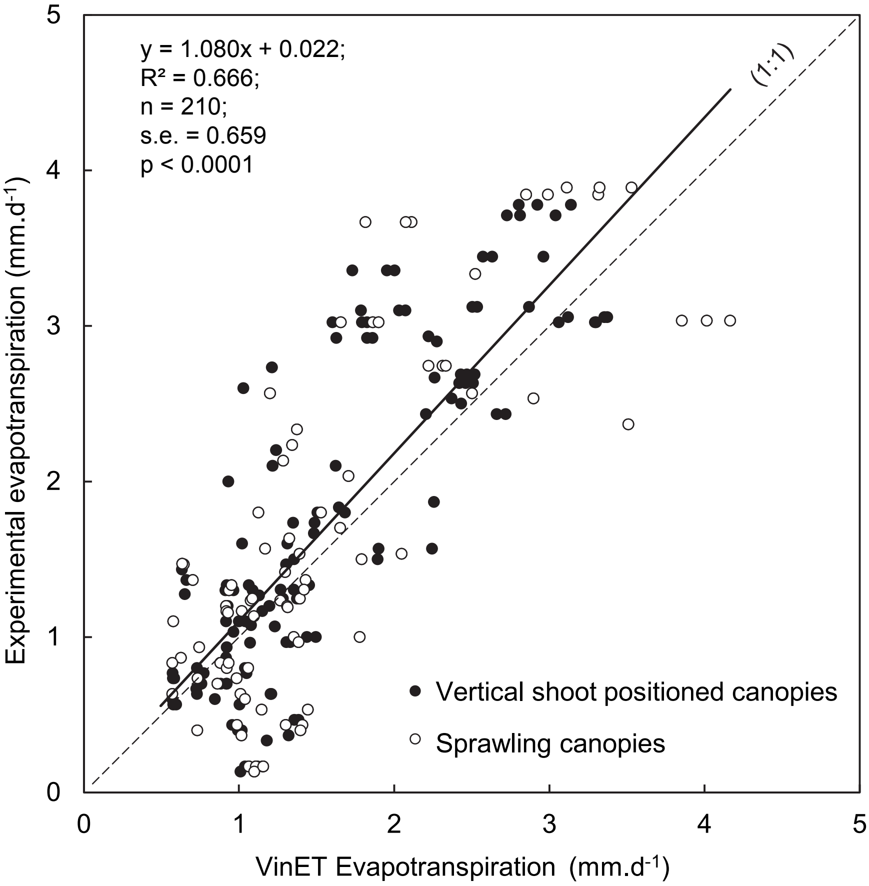

Figure 6.12 Relationship between the measured daily evapotranspiration and predicted daily evapotranspiration (mean per month), using the VINET model, for Shiraz/110R grapevines during the 2012/13, 2013/14 and 2014/15 seasons near Robertson. For variation within each treatment please refer to Appendix C.

Although a good correlation was obtained when transpiration per day was plotted against leaf area per grapevine (Fig. 6.13), it was clear that the transpiration was lower in current study compared to the mean correlation for vertical canopies reported by Myburgh (1998). Considering the relationship of the transpiration and LA_{CPS}, it was evident that the orientation of grapevine canopies could be separated into two groups, namely the VSP and sprawling canopies (Fig. 6.14). The LA_{CPS} of both groups show excellent correlation with transpiration during ripening. Future irrigation modelling should thus include not only horizontal and vertical grapevine canopies, but sprawling canopies should also be included.

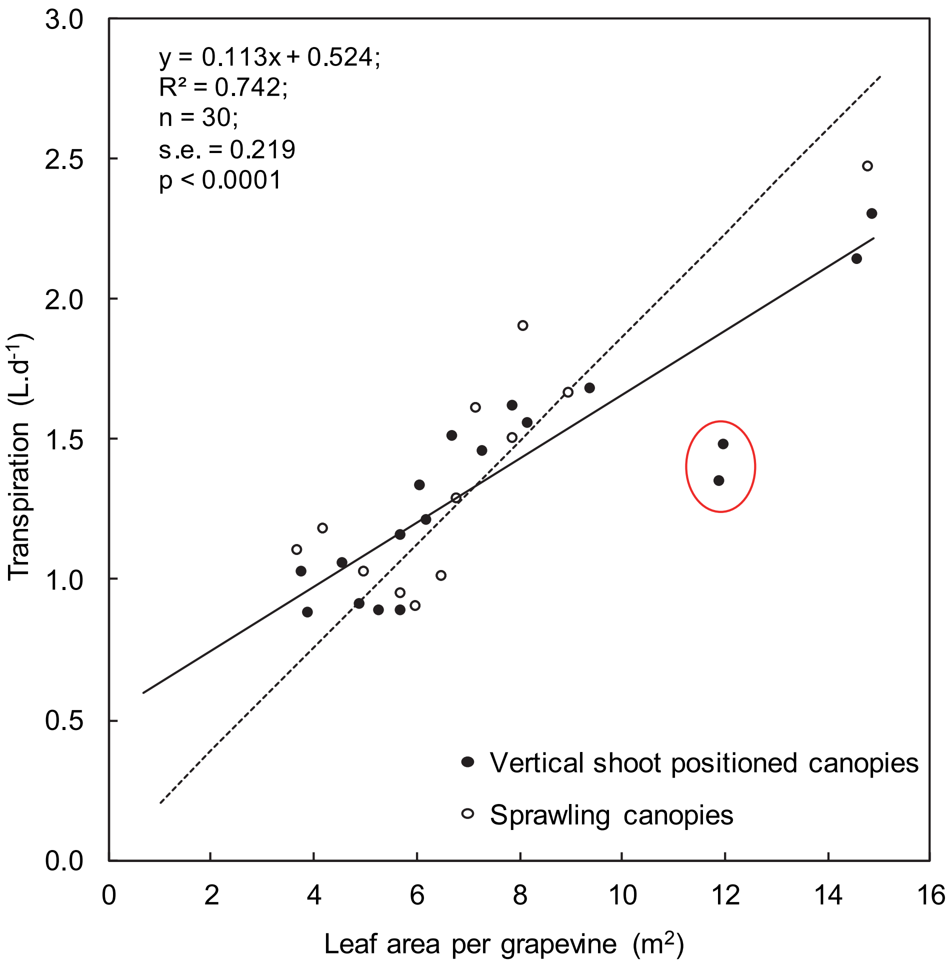

Figure 6.13 Relationship between the transpiration and the leaf area (LA) per Shiraz/110R grapevine during ripening of the 2012/13, 2013/14 and 2014/15 seasons near Robertson. The two points within the red circle were deemed to be outliers and not included in the linear regression. The dashed line represents the relationship between transpiration and LA published for vertical canopies by Myburgh (1998) and was calculated using y = 0.185x + 0.016 (R^2 = 0.873).

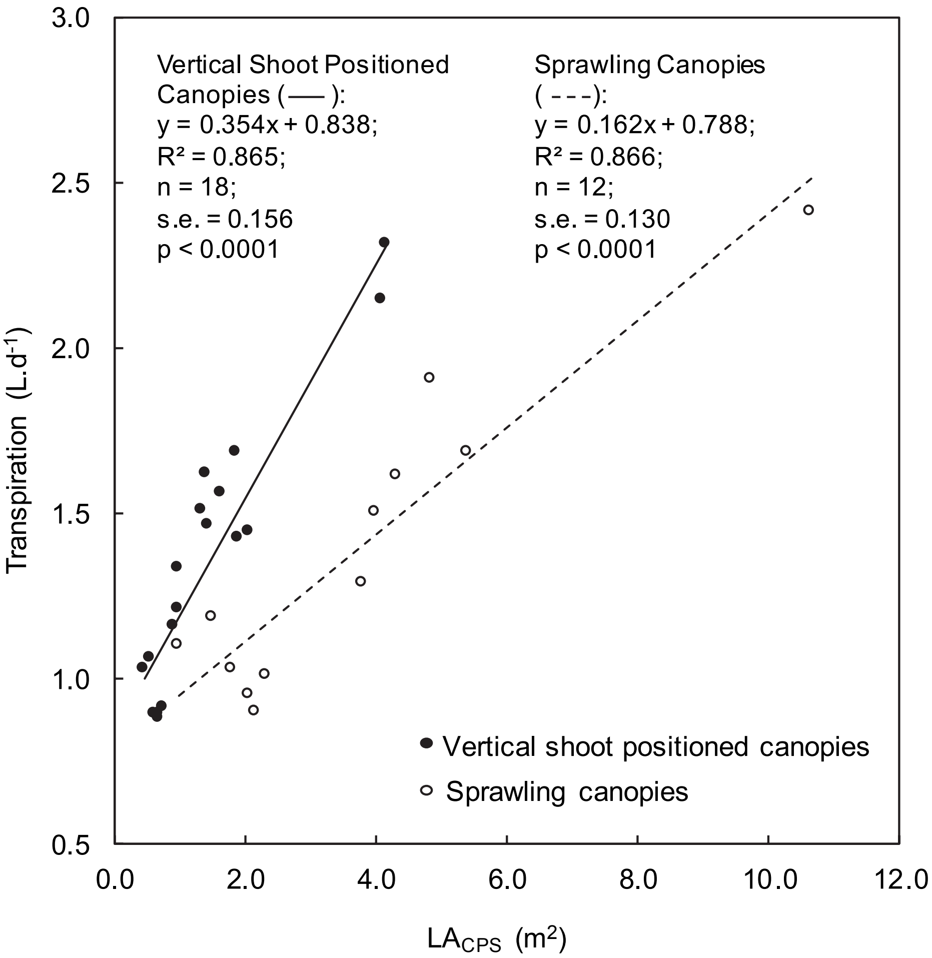

Figure 6.14 Relationship between the transpiration and the leaf area per grapevine within the fraction of soil surface area covered by the particular canopy during the solar zenith (LA_{CPS}) of different Shiraz/110R grapevine canopies with a 2.5 m × 1.22 m plant spacing during ripening of the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

The combined effects of grapevine canopy height and width, as well as the inrow plant spacing and $LA_{grapevine}$ explained *ca.* 85% of the variation in the daily transpiration rate, after grapevines were irrigated back to field capacity, by means of multiple linear regression (Fig. 6.15) in the following equation:

Transpiration = 1.144×canopy height + 0.068×$LA_{grapevine}$ + 0.221×(canopy width × plant spacing inrow) - 0.256 *(R^2 = 0.845; se = 0.180; p < 0.0001)* (Eq. 6.12)

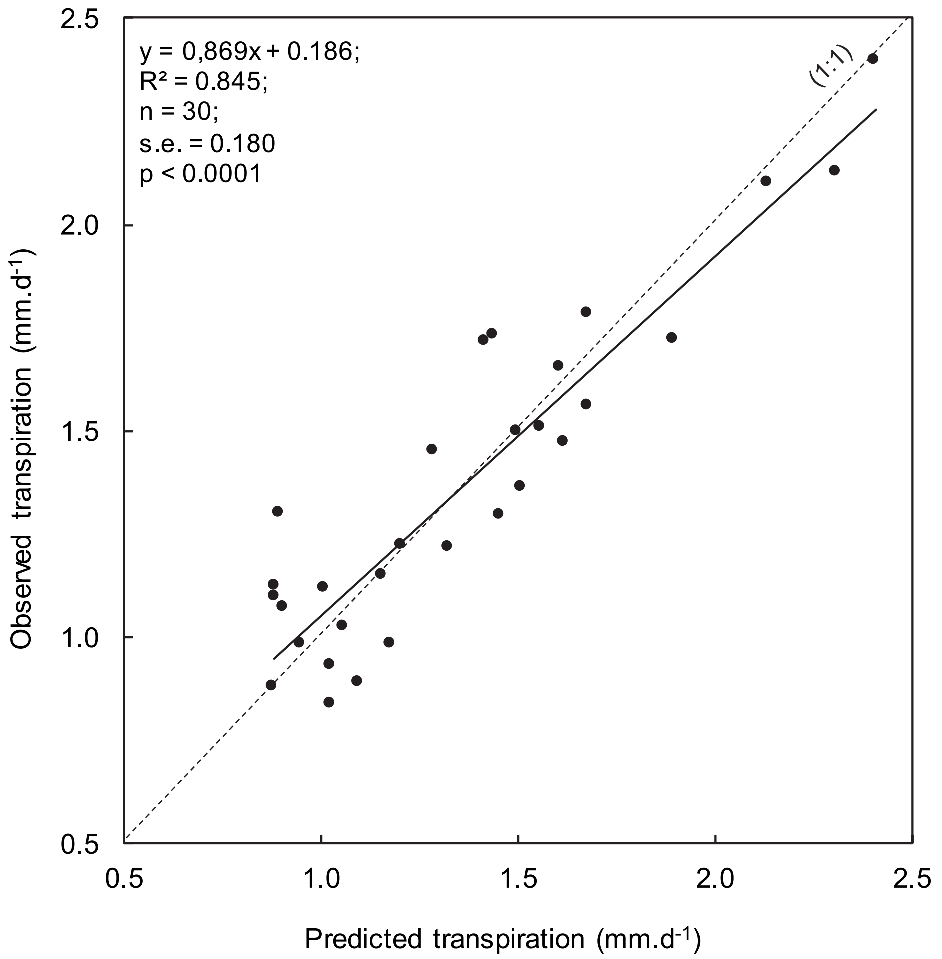

Figure 6.15 Relationship between measured transpiration and predicted transpiration of Shiraz grapevines during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

This regression suggested that as the grapevine canopy height and width, as well as the leaf area and inrow plant spacing, increases, there would be an increase in daily transpiration rates of grapevines out of the wetted soil volume.

6.4. CONCLUSIONS

Higher irrigation frequencies resulted in higher ET_{GR} losses, while losses from under sprawling canopies, particularly those irrigated at *ca*. 30% PAW depletion, tended to be higher in February than those with VSP canopies. The ET_{WR} increased in periods that followed rainfall events and was much lower than the ET_{GR}. Due to this fact, the monthly ET_{FS} was much lower than the monthly ET_{GR}. The seasonal ET_{FS} was more sensitive to irrigation frequency than to different canopy manipulations.

The diurnal and cumulative E_s losses under grapevines with sprawling canopies was lower than under VSP grapevines, irrespective of the level of PAW depletion. Higher mean leaf area per grapevine caused by more frequent irrigations resulted denser canopies. The 0 to 300 mm SWC of treatments irrigated at *ca*. 30% PAW depletion were always within stage 1 of evaporation, while that of grapevines irrigated at *ca*. 60% PAW depletion occasionally went into stage 2, particularly that of the sprawling canopies. The water content of soil under grapevines irrigated at *ca*. 90% PAW depletion spent most of the season in stage 2. The C_f of the sprawling canopies was lower than that of the VSP grapevines, irrespective of PAW depletion. Less frequent irrigation and a decrease in LA_{CPS} of experimental grapevines increased the evaporation C_f. The C_f of a recently wetted soil surface under grapevines could be predicted with 86% confidence by using leaf area and cane mass per grapevine, as well as the canopy height and -width and plant spacing.

During the three seasons, the mean K_c for grapevines that were irrigated at *ca*. 30% PAW depletion were higher compared to those of other strategies, with those irrigated at *ca*. 90% PAW depletion being the lowest. Grapevines irrigated particularly at *ca*. 30% and 60% PAW depletion, treatments with sprawling canopies tended to have higher K_c values during ripening than those with VSP canopies. The mean peak K_c was generally obtained in February of the experimental seasons for grapevines that were irrigated at *ca*. 30% PAW depletion, while the lowest K_c was found during the same period at *ca*. 90% PAW depletion irrigations. Because drip irrigation system only wets the soil volume partially during irrigation applications, the $K_{c,GR}$ would be a more realistic coefficient for producers and consultants in the scheduling of irrigation requirement.

The transpiration losses determined during ripening show that as irrigation frequency increased so did transpiration losses, with sprawling canopies tending to be higher than VSP grapevines. Higher frequency irrigation increased the $f K_e$, whereas lower frequency irrigation increased the $f K_{cb}$.

Compared to measured values, the VINET model generally underestimated ET when higher irrigation frequencies were applied, whereas it overestimated ET when very low frequency to no irrigation were applied. Transpiration of grapevines could be split into vertical canopy and sprawling canopy groups when related to the LA_{CPS}. Furthermore, daily transpiration from a recently wetted soil volume could be predicted using $LA_{grapevine}$, inrow plant spacing, canopy height and -width. Future irrigation modelling should include different canopy orientations and that of mechanical pruning grapevines.

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CHAPTER 7: EFFECT OF DIFFERENT IRRIGATION AND CANOPY MANAGEMENT STRATEGIES ON YIELD COMPONENTS

7.1. 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, 2011; Fernandes 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 deficits in this particular stage is irreversible (Ojeda *et al.*, 2002). 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 for improving yield with a reduction in water applied and compensation thereof through canopy management should be investigated.

The aim of this study was therefore to determine the combined effects of irrigation and canopy management practices on yield components of Shiraz grapevines growing in the Breede River Valley.

7.2. MATERIALS AND METHODS

7.2.1. Harvest dates

The objective was to harvest grapes when the mean total soluble solids (TSS) in the juice of all three replications reached 24˚B. The date on which each specific treatment was harvested was noted. Total soluble solids (TSS) will only be discussed in section 8.3.1.

7.2.2 Berry mass and volume

Berry mass was determined from véraison to harvest in the 2011/12 and 2012/13 seasons. Fifty-berry samples per plot were collected fortnightly until the 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 using an electronic balance. Berry volume was determined by water displacement, only in the 2011/12 season. At harvest in all four seasons, ten bunches were randomly selected using the same marked elastic band used to sample leaves (Refer to Chapter 4). These bunches were counted and transported back to Stellenbosch, where all berries were removed from the stem, counted and weighed to calculate the mean berry mass.

7.2.3. Number of bunches

At harvest, all bunches of the experimental grapevines on each plot were picked and counted using mechanical counters. The number of bunches per grapevine was calculated by dividing the total number of bunches per plot by the number of experimental grapevines per plot.

7.2.4. Bunch mass

Bunch mass was determined by dividing the total grape mass per plot by the number of bunches per plot.

7.2.5. Yield

At harvest, all the grapes were picked and weighed to obtain the total mass per experimental plot. Mean yield per grapevine was calculated and converted to tonne per hectare.

7.2.6. Production water use efficiency (WUE_P)

The effective conversion of each unit of water into mass of grapes can be expressed as the production water use efficiency (WUE_P) and can be calculated by dividing the mass of grapes produced by the seasonal evapotranspiration from bud break to harvest:

$$WUE_P = \frac{\text{Yield}}{\text{Season } ET_{FS}} \quad \text{(Eq. 7.1)}$$

where: WUE_P = production water use efficiency ($kg.m^{-3}$)

Yield = mass of grapes produced per hectare ($kg.ha^{-1}$)

Season ET_{FS} = seasonal evapotranspiration per hectare ($m^3.ha^{-1}$)

7.2.7. Potential yield losses due to sunburn and rot

To determine the incidence of grey rot (*Botrytis cinerea*), 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, grey 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, grey 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 grey 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 grey rot.

7.2.8. Statistical analyses

The data were subjected to an analysis of variance (ANOVA) by using Statgraphics®. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means, which differed at $p \leq 0.05$, were considered significantly different.

7.3. RESULTS AND DISCUSSION

7.3.1 Harvest dates

In 2011/12, grapes produced by irrigation at *ca*. 90% PAW depletion were harvested between 11 and 17 days earlier than the rest of the treatments (Table 7.1).

In the 2012/13 season, grapevines that were irrigated at *ca*. 90% PAW depletion reached the target of 24ºB TSS in the grapes 7 days before the T6 grapevines (Table 7.1). Grapevines that were suckered and had their shoots tucked into the trellis (T1 & T4) reached the target TSS 14 days after the first grapes were harvested. Grapevines that only had their shoots tucked into the trellis (T2 & T5) and grapevines irrigated at *ca*. 30% PAW depletion with sprawling canopies (T3) reached the target TSS 21 days later than the first harvest.

In 2013/14, juice TSS of grapevines with sprawling canopies irrigated at *ca*. 90% PAW depletion (T9) reached the target of 24ºB five days before the VSP grapevines irrigated at the same depletion level (Table 7.1). This was in contrast to the previous two seasons when the TSS targets of all grapevines irrigated *ca*. 90% PAW depletion were reached on the same date. The enhanced ripening of the T9 grapevines in the 2013/14 season was probably due to the wetter inter-row soil volume and larger leaf area exposed to the sun. A similar trend occurred where the grapevines were irrigated at *ca*. 30% and 60% PAW depletion (Table 7.1). Mechanical pruned grapevines (T10), those with non-suckered VSP canopies and irrigated at *ca*. 30% and 60% PAW depletion (T2 & T5), as well as those of the control treatment (T1) only reached target TSS level 21 days after the first ones.

The 2014/15 season was widely reported to be a very “early” season. Where grapevines were irrigated at *ca*. 90% PAW depletion, juice TSS reached the target of 24ºB twelve days before those irrigated *ca*. 30% and *ca*. 60 PAW depletion level (Table 7.1). Different canopy manipulations within the same irrigation depletion level, however, did not affect the harvest dates as was the case during the previous seasons.

Table 7.1 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on date when Shiraz/110R grapes reached the target total soluble solids of *ca.* 24ºB during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Season	Harvest date									
2011/12	12-03-2012	12-03-2012	06-03-2012	12-03-2012	12-03-2012	06-03-2012	24-02-2012	24-02-2012	24-02-2012	12-03-2012
2012/13	18-03-2013	25-03-2013	25-03-2013	18-03-2013	25-03-2013	11-03-2013	04-03-2013	04-03-2013	04-03-2013	04-03-2013
2013/14	27-03-2014	27-03-2014	19-03-2014	19-03-2014	27-03-2014	11-03-2014	11-03-2014	11-03-2014	06-03-2014	27-03-2014
2014/15	10-03-2015	10-03-2015	11-03-2015	10-03-2015	10-03-2015	10-03-2015	26-02-2015	26-02-2015	26-02-2015	26-02-2015

7.3.2. Berry mass and volume

Berry mass of grapevines irrigated at *ca*. 30% and *ca*. 60% PAW depletion decreased from véraison (*i.e.* the onset of ripening when berries start changing colour and softening) to harvest in 2011/12 (data not shown) and 2012/13 (Fig. 7.1). Periodical berry sampling during ripening of these seasons revealed that berry size of all treatments increased after véraison, but that those irrigated at *ca*. 30% and *ca*. 60% PAW depletion decreased during the latter part of ripening (Figs. 7.2 & 7.3). However, where grapevines were irrigated at *ca*. 90% PAW depletion, berry size increased during the ripening period, whereas that of the mechanical pruned grapevines remained the same (Fig. 7.1). In all four seasons, berry mass increased with a decrease in level of PAW depletion (Table 7.2). Furthermore, berry mass of grapevines irrigated at *ca*. 30% and *ca.* 60% PAW depletion was not affected by the different canopy manipulations (Table 7.2). However, where grapevines were irrigated at *ca*. 90% PAW depletion, the suckered VSP grapevines produced larger berries than those that were not suckered in the 2012/13 and 2014/15 seasons (Table 7.3). In the 2013/14 and 2014/15 seasons, within the *ca.* 90% PAW depletion irrigation strategy, the suckered VSP grapevines (T7) produced larger berries than those that were mechanically pruned (Table 7.3).

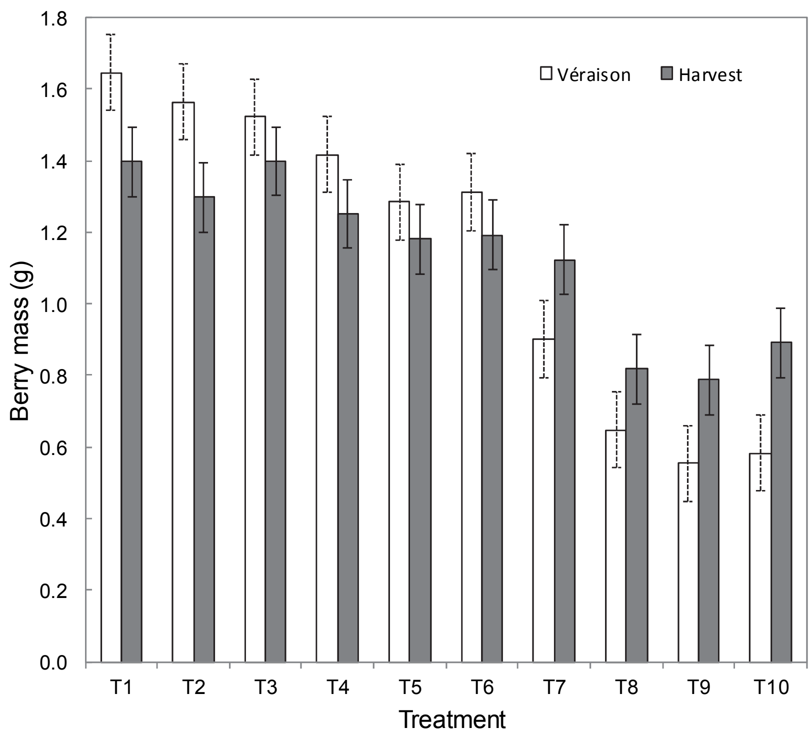

Figure 7.1 The effect of different irrigation/canopy manipulation treatments on the berry mass of Shiraz/110R in a fine sandy loam soil near Robertson at véraison and harvest in the 2012/13 season. Vertical bars indicate least significant difference per phenological phase at the 95% confidence interval. Refer to Table 2.3 for an explanation of the treatments.

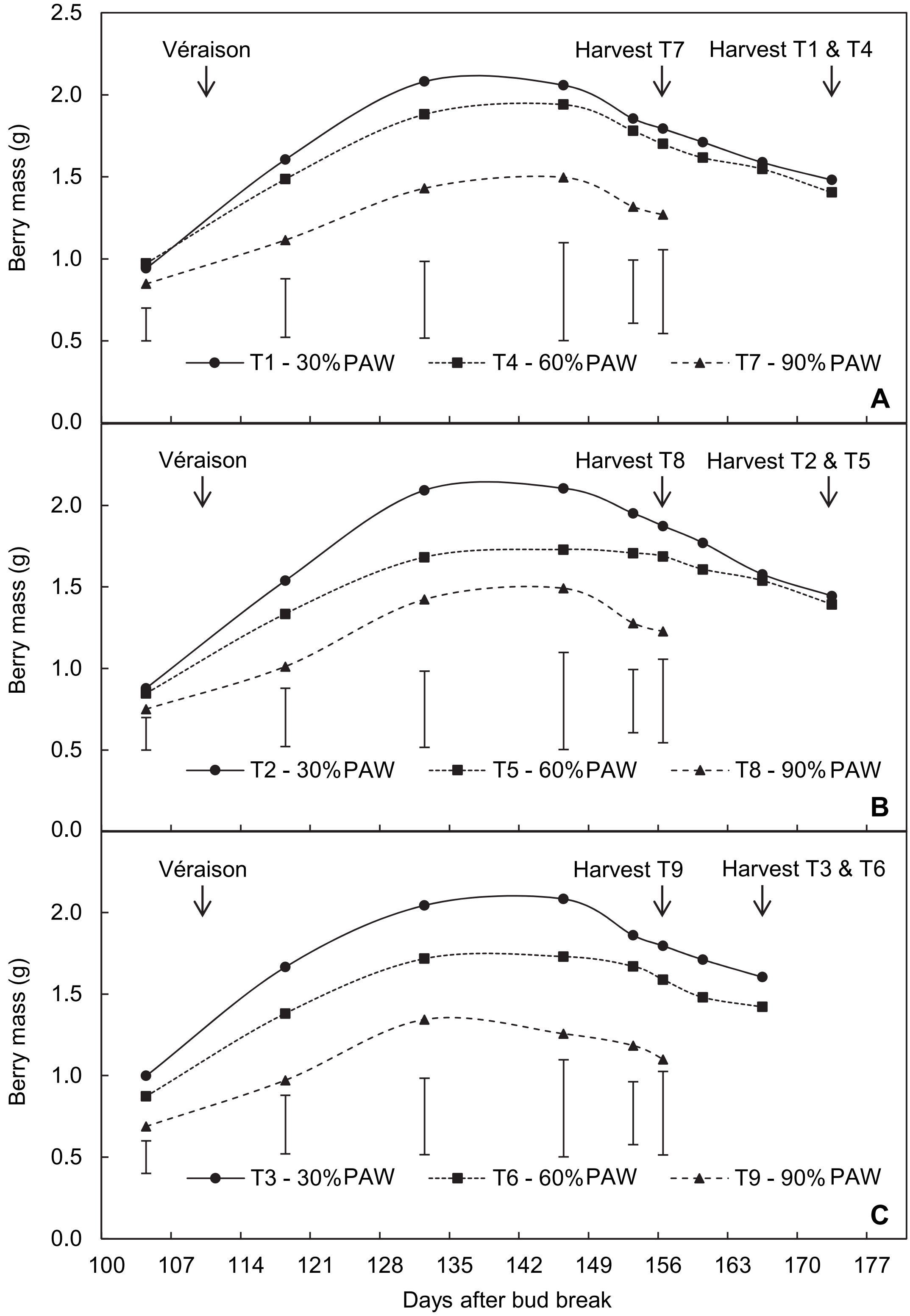

Figure 7.2 The effect of plant available water (PAW) depletion and different canopy management practices on berry mass of (A) suckered VSP, (B) non-suckered VSP and (C) sprawling canopy Shiraz/110R grapevines during the 2011/12 growing season near Robertson. Vertical bars indicate least significant difference ($p \leq 0.05$).

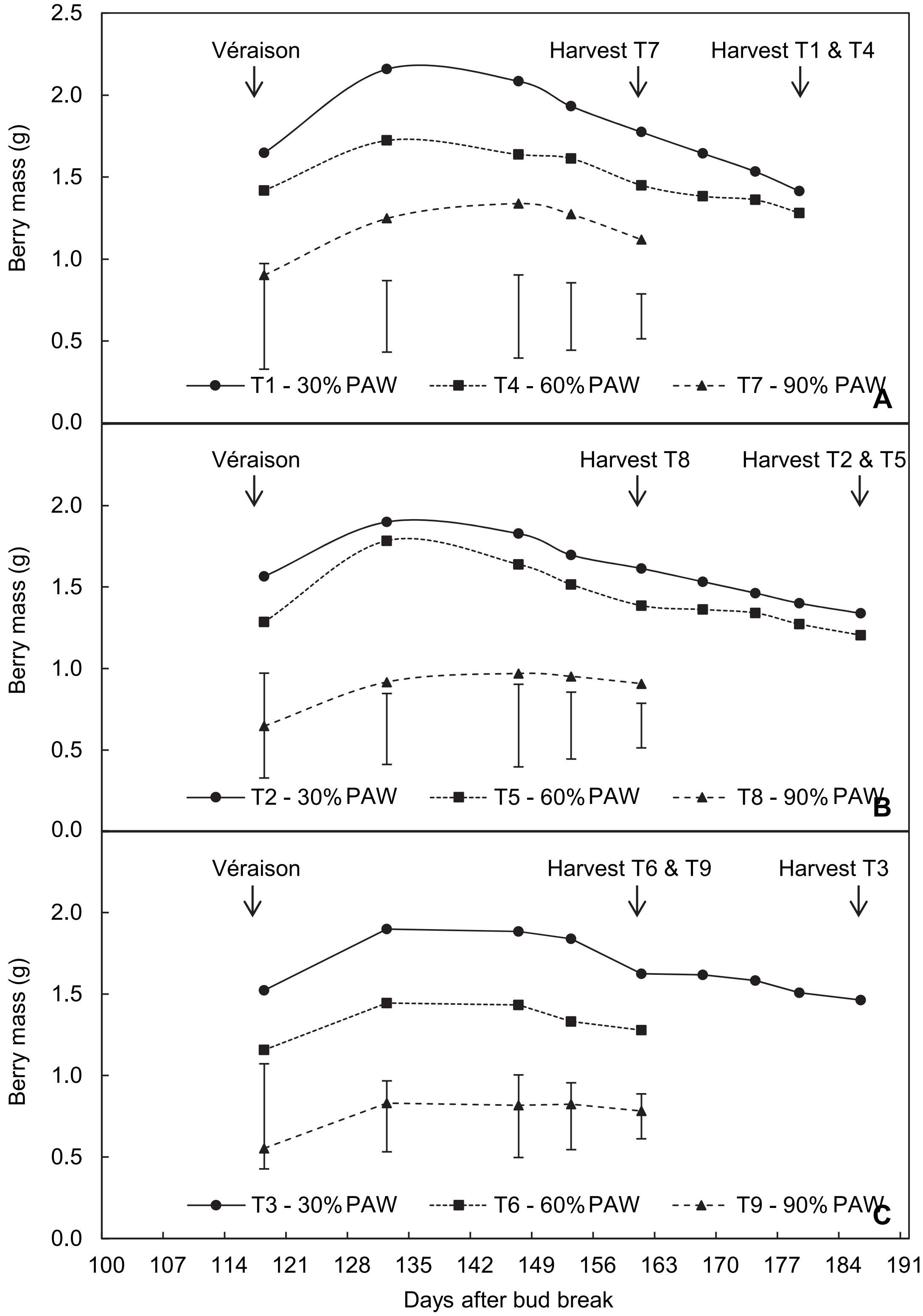

Figure 7.3 The effect of plant available water (PAW) depletion and different canopy management practices on berry mass of (A) suckered VSP, (B) non-suckered VSP and (C) sprawling canopy Shiraz/110R grapevines during the 2012/13 growing season near Robertson. Vertical bars indicate least significant difference ($p \leq 0.05$).

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 1:0.93 (Fig. 7.4). This ratio was comparable to a mean of 1:0.94 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 1:0.93 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. Determining the ratio in the earlier stages of berry development was beyond the scope of this study.

In 2011/12 and 2012/13, suckered grapevines tended to produce more berries per bunch, whereas grapevines subjected to severe water constraints produced fewer berries per bunch (Table 7.2). In contrast, in the 2013/14 season, suckering of grapevines did not increase the number of berries per bunch within the *ca.* 30% and *ca.* 60% PAW depletion irrigation strategies. Similar to the previous seasons, higher levels of PAW depletion reduced the number of berries per bunch (Table 7.2). In 2014/15, the number of berries per bunch was increased by suckering of grapevines (Table 7.2).

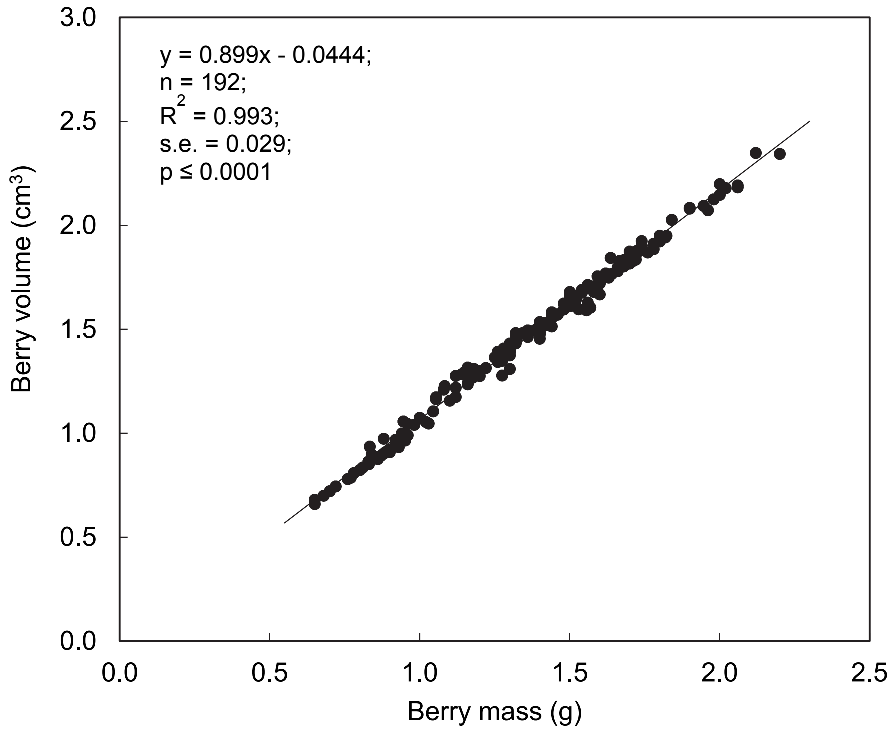

Figure 7.4 The relationship between berry volume and mass of Shiraz/110R grapevines determined during the 2011/12 growing season near Robertson.

7.3.3. Number of bunches

In 2011/12 and 2012/13, suckering reduced the number of shoots per grapevine and also reduced the number of bunches per grapevine compared to non-suckered grapevines (Table 7.4). Even though mechanically pruned grapevines produced the lowest bunch mass, they produced the highest number of bunches per grapevine of those irrigated at *ca*. 90% PAW depletion (Table 7.5). In the 2011/12 and 2012/13 seasons, suckering reduced the number of bunches produced by grapevines irrigated at *ca*. 90% PAW depletion (Table 7.5). Although suckering reduced the number of shoots per grapevine, a comparable number of bunches per grapevine was produced by the suckered VSP and sprawling canopy grapevines that were irrigated at *ca*. 30% and *ca*. 60% PAW depletion in the 2013/14 season (Table 7.4). In this particular season, the number of bunches produced by grapevines irrigated at *ca*. 90% PAW depletion was not affected by canopy management (Table 7.5). The reason for more bunches per grapevine being produced by the non-suckered VSP grapevines irrigated at *ca*. 30% and *ca*. 60% PAW depletion is unexpected, since the PAR or light intensity would be lower in these bunch zones, and could contribute to lower bud and bunch fertility. At this stage there is no explanation for this trend. Mechanically pruned grapevines produced 2.3 times more bunches per grapevine than the hand pruned grapevines that were also irrigated at *ca.* 90% PAW depletion. In 2014/15, suckering of grapevines reduced the number of shoots per grapevine and, subsequently, produced less bunches per grapevine (Table 7.4). These lower number of bunches tended to be heavier though than those produced by similar irrigated non-suckered grapevines.

As the number of bunches were related to the number of shoots per grapevine, mechanically pruned grapevines (T10) produced three times the number of bunches compared to other non-suckered grapevines, with the lowest bunch mass (Table 7.5).

Table 7.2 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean berry mass and number of berry per bunch of Shiraz/110R grapevines during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number								
	T1	T2	T3	T4	T5	T6	T7	T8	T9
	Irrigation strategy								
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion		
	Canopy management applied								
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy
Season	**Mean berry mass at harvest (g)**								
2011/12	1.43 abc[1]	1.50 a	1.46 ab	1.42 abc	1.42 abc	1.22 bcd	1.21 cd	1.14 d	1.10 d
2012/13	1.34 a	1.21 abc	1.31 ab	1.18 abc	1.11 bc	1.10 c	1.05 c	0.74 d	0.65 d
2013/14	1.43 c	1.47 bc	1.59 ab	1.48 bc	1.51 abc	1.64 a	1.45 bc	1.41 cd	1.28 d
2014/15	1.45 a	1.44 ab	1.46 a	1.28 bc	1.28 bc	1.17 cd	1.04 d	0.57 e	0.54 e
Season	**Mean number of berries per bunch**								
2011/12	158 a	136 ab	109 bc	114 bc	102 bcd	86 cd	82 cd	70 d	67 d
2012/13	171 a	137 bc	131 cd	152 b	151 b	114 de	147 bc	106 e	78 f
2013/14	149 ab	169 a	145 ab	147 ab	141 bc	116 c	128 bc	87.9 d	116 c
2014/15	124 abc	99 c	110 bc	140 ab	92 c	116 abc	143 a	114 abc	114 abc

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 7.3 The effect of four different canopy management practices on mean berry mass and number of berry per bunch of Shiraz/110R grapevines irrigated at *ca*. 90% plant available water (PAW) depletion during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number			
	T7	**T8**	**T9**	**T10**
	Irrigation strategy			
	***ca.* 90% PAW depletion**			
	Canopy management applied			
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Mean berry mass at harvest (g)**			
2011/12	1.21 a[(1)]	1.14 a	1.10 a	0.88 a
2012/13	1.05 a	0.74 b	0.65 b	0.81 ab
2013/14	1.45 a	1.41 a	1.28 a	1.08 b
2014/15	1.04 a	0.57 b	0.54 b	0.70 b
Season	**Mean number of berries per bunch**			
2011/12	82 a	70 a	67 a	106 a
2012/13	147 a	106 b	78 c	69 c
2013/14	128 a	88 b	116 a	78 b
2014/15	143 a	114 a	114 a	100 a

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

7.3.4. Bunch mass

Less bunches per grapevine tended to increase bunch mass within an irrigation strategy, with grapevines subjected to severe water constraints producing the smallest bunches (Table 7.4). In all four season, mechanically pruned grapevines produced the lowest bunch mass (Table 7.5). In Figure 7.5, examples illustrating the effect of PAW depletion and canopy management practice on bunches are presented for the 2012/13 season.

Table 7.4 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on mean bunch number per metre cordon and bunch mass per Shiraz/110R grapevines during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number								
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**
	Irrigation strategy								
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**		
	Canopy management applied								
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**
Season	**Mean number of bunches per metre cordon (bunches per grapevine divided by 1.22 m plant spacing)**								
2011/12	27 d[(1)]	42 a	39 ab	25 d	38 ab	30 cd	25 d	34 bc	38 ab
2012/13	26 d	43 b	42 b	32 c	50 a	45 ab	33 c	46 ab	50 a
2013/14	30 b	39 a	28 b	30 b	37 a	30 b	29 b	31 b	29 b
2014/15	29 b	49 a	46 a	31 b	48 a	45 a	32 b	43 a	44 a
Season	**Mean bunch mass (g)**								
2011/12	200.6 a	162.1 ab	153.9 ab	170.5 ab	144.1 bc	121.9 bcd	101.6 cde	89.1 de	69.6 e
2012/13	189.0 a	135.6 bc	139.5 bc	162.6 ab	114.9 cd	101.6 d	134.4 bc	66.9 e	52.4 e
2013/14	192.2 ab	172.6 b	201.8 a	211.1 a	172.7 b	178.5 b	170.7 b	134.4 c	133.8 c
2014/15	170.6 a	133.3 bc	164.8 a	154.7 ab	118.3 c	122.4 c	119.1 c	65.2 d	49.3 d

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

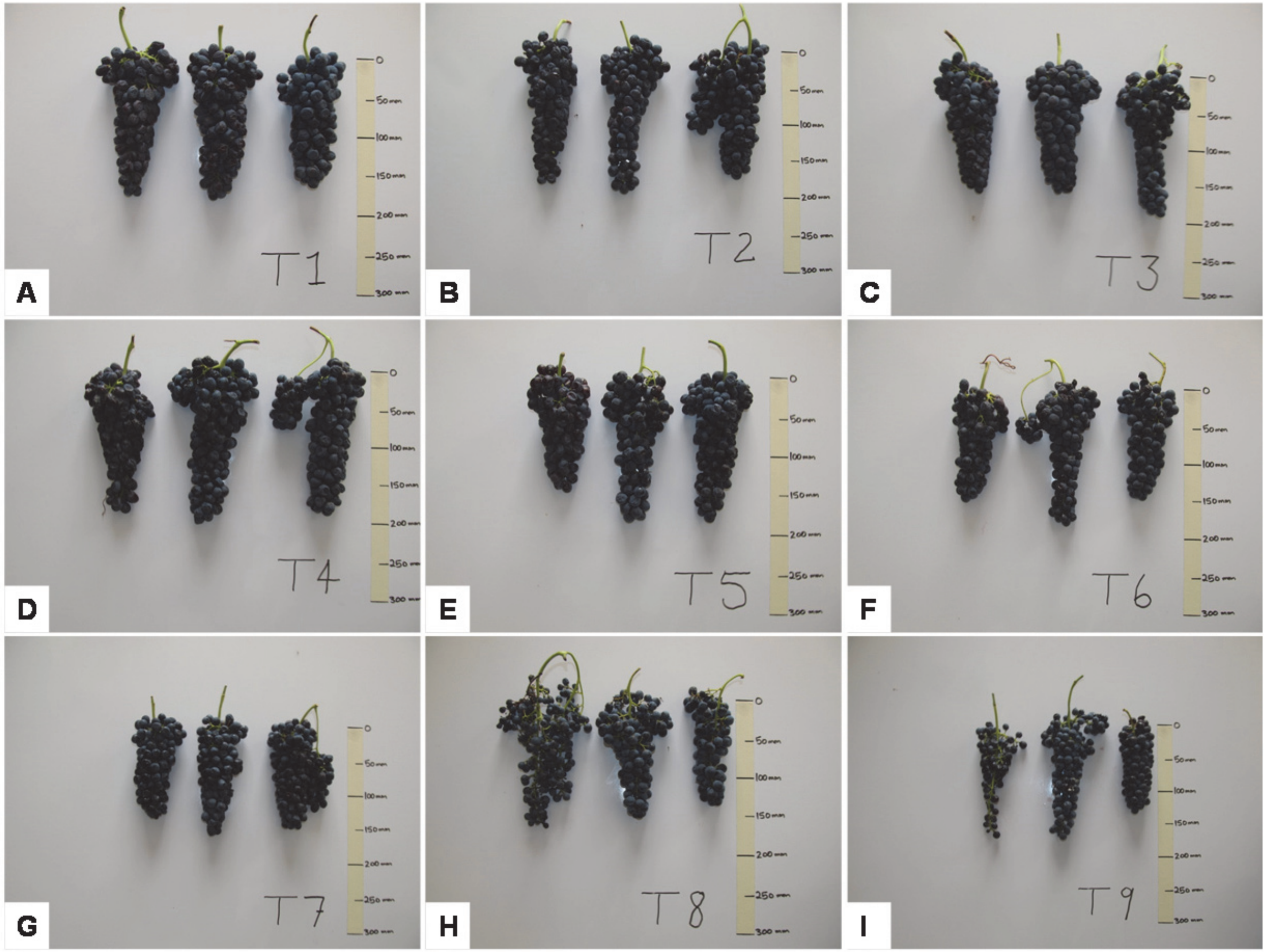

Figure 7.5 Examples illustrating the effect of irrigation at specific plant available water (PAW) depletions and canopy management practices on bunches of Shiraz/110R grapevines, where (A) is suckered VSP, (B) is non-suckered VSP and (C) is sprawling canopy grapevines irrigated at *ca.* 30% PAW depletion; (D) is suckered VSP, (E) is non-suckered VSP and (F) is sprawling canopy grapevines irrigated at *ca.* 60% PAW depletion and (G) is suckered VSP, (H) is non-suckered VSP and (I) is sprawling canopy grapevines irrigated at *ca.* 90% PAW depletion near Robertson. Photographs were taken at harvest in the 2012/13 season.

Table 7.5 The effect of four different canopy management practices on mean bunch number per metre cordon and bunch mass per Shiraz/110R grapevines irrigated at *ca*. 90% plant available water (PAW) depletion during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number			
	T7	**T8**	**T9**	**T10**
	Irrigation strategy			
	***ca.* 90% PAW depletion**			
	Canopy management applied			
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Mean number of bunches per metre cordon (bunches per grapevine divided by 1.22 m plant spacing)**			
2011/12	25 c[1]	34 b	38 b	85 a
2012/13	33 c	46 b	50 b	106 a
2013/14	29 b	31 b	29 b	80 a
2014/15	32 c	43 b	44 b	112 a
Season	**Mean bunch mass (g)**			
2011/12	101.6 a	89.1 ab	69.6 b	79.6 ab
2012/13	134.4 a	66.9 b	52.4 bc	41.0 c
2013/14	170.7 a	134.4 b	133.8 b	71.5 c
2014/15	119.1 a	64.2 b	51.5 b	39.5 b

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

7.3.5. Yield

In all four seasons, grapevine yield decreased with a decrease in irrigation volumes (Table 7.6). As expected, grapevines irrigated at *ca*. 90% PAW depletion produced the lowest yields, except for the mechanically pruned ones (T10) that produced substantially more grapes than the other treatments irrigated at *ca*. 90% PAW. In addition, in the 2011/12 season tucking shoots only into the trellis, *i.e.* without suckering (T2, T5 & T8), tended to produce the highest yields within a specific irrigation strategy (Table 7.6). The mechanically pruned grapevines (T10) produced twice the mass of grapes to those also irrigated at *ca.* 90% PAW depletion (Table 7.7). This anomaly was caused by T10 grapevines bearing similar sized bunches, but substantially more bunches compared to the other treatments (Table 7.5). The reason for the low yields produced by the non-manipulated grapevines irrigated at *ca*. 60% PAW depletion level (T6) was probably due to the lower number of shoots per grapevine which resulted in less bunches per grapevine. At this stage there is no explanation why these grapevines produced less shoots than those also not suckered and tucked into trellis wires while irrigated at the same frequency (T5).

In the 2012/13 season, tucking shoots only into the trellis, *i.e.* without suckering and non-manipulated grapevines (T2, T5 & T3), tended to produce the highest yields of the higher frequency irrigated grapevines (Table 7.6). This, however, did not seem to be the case for grapevines irrigated at *ca*. 90% PAW depletion as suckered and mechanically pruned grapevines (T7 & T10) produced the highest yields (Table 7.7). This anomaly was caused by T10 grapevines bearing smaller sized, but substantially more bunches compared to the other treatments (Table 7.5). The lower yields of mechanically pruned grapevines compared to that produced during 2011/12 was expected due a higher number of shoots and number of bunches per grapevine produced during the 2012/13 season.

In 2013/14, suckered and non-suckered VSP grapevines irrigated at *ca.* 30% depletion (T1 & T2), as well as *ca*. 60% PAW depletion (T4 & T5) tended to produce higher yields compared to the sprawling canopy grapevines (T3 & T6) (Table 7.6). However, this did not seem to be the case where grapevines were irrigated at *ca*. 90% PAW depletion, since suckered (T7) and mechanically pruned grapevines (T10) produced the highest yields (Table 7.7). As in 2012/13, this anomaly was due to T10 grapevines bearing smaller, but substantially more bunches compared to grapevines of the other treatments (Table 7.5). Yield of the mechanically pruned grapevines were similar to the 2011/12 season, and higher compared to the 2011/12 season. Overall, higher yields during the 2013/14 season was probably due to the high rainfall events during the growing season.

In the 2014/15 season, grapevines with sprawling canopies irrigated at *ca*. 30% PAW depletion produced the highest yields (Table 7.6). This was, however, not the case in the preceding three seasons and could possibly be attributed to the fact that no grey rot was present in the dry 2014/15 season. The target TSS levels were also reached *ca.* two weeks earlier than in the previous seasons and less berry weight loss occurred due to the natural maturation of berries (Ojeda *et al*., 2002; Deloire, 2010). Non-suckered grapevines produced higher yields than suckered grapevine when irrigations were applied at *ca*. 30% and *ca*. 60 PAW depletion (Table 7.6). However, this did not seem to be the case where grapevines were irrigated at *ca*. 90% PAW depletion, since suckered (T7) and mechanically pruned grapevines (T10) produced the highest yields (Table 7.7). As discussed previously, this anomaly was due to T10 grapevines bearing smaller, but substantially more bunches compared to the other treatments (Table 7.5).

Table 7.6 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on the yield and production water use efficiency (WUE_P) of Shiraz/110R grapevines during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number								
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**
	Irrigation strategy								
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**		
	Canopy management applied								
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**
Season	**Yield ($t.ha^{-1}$)**								
2011/12	21.6 bc[(1)]	27.1 a	23.9 ab	17.1 cd	22.0 bc	14.1 d	13.7 d	14.5 d	13.6 d
2012/13	19.6 bc	23.6 a	23.6 a	18.7 c	22.9 ab	18.8 c	16.5 cd	14.2 de	12.7 e
2013/14	23.4 abc	26.9 a	22.3 bc	25.0 ab	25.2 ab	21.2 bc	20.0 cd	16.5 de	15.5 e
2014/15	20.8 bc	24.4 b	29.4 a	18.1 cd	22.6 b	21.5 bc	15.2 de	11.6 ef	9.8 f
Season	**WUE_P ($kg.m^{-3}$)**								
2011/12	3.8 bc	4.3 bc	4.1 bc	3.1 c	5.4 ab	3.0 c	5.5 ab	6.9 a	5.6 ab
2012/13	3.4 f	4.1 def	4.1 de	4.3 cde	5.2 bc	4.5 cde	6.9 a	6.1 ab	4.8 cd
2013/14	3.8 c	4.3 c	3.8 c	4.9 bc	4.8 bc	4.1 c	7.5 a	6.2 ab	5.8 b
2014/15	4.2 d	4.4 cd	5.5 cd	4.2 d	6.7 bc	4.4 cd	10.1 a	7.7 b	5.2 cd

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 7.7 The effect of four different canopy management practices on the yield and production water use efficiency (WUE_P) of Shiraz/110R grapevines irrigated at *ca.* 90% plant available water (PAW) depletion during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number			
	T7	**T8**	**T9**	**T10**
	Irrigation strategy			
	***ca*. 90% PAW depletion**			
	Canopy management applied			
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Yield ($t.ha^{-1}$)**			
2011/12	13.7 b[1]	14.5 b	13.6 b	27.1 a
2012/13	16.5 ab	14.2 bc	12.7 c	17.5 a
2013/14	20.0 ab	16.5 b	15.5 b	23.0 a
2014/15	15.2 ab	11.6 ab	9.8 b	17.7 a
Season	**WUE_P ($kg.m^{-3}$)**			
2011/12	5.5 bc	6.9 b	5.6 bc	14.0 a
2012/13	6.9 ab	6.0 bc	4.8 c	7.1 a
2013/14	7.5 ab	6.2 bc	5.8 c	8.5 a
2014/15	10.09 a	7.7 b	5.2 cd	12.11 a

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$)

7.3.6. Production water use efficiency (WUE_P)

In all four seasons, irrigation at *ca.* 90% PAW depletion increased the production water use efficiency (WUE_P) substantially, *i.e.* mass grapes produced per unit irrigation water applied and rain water precipitated, if compared to the rest of the irrigation strategies (Table 7.6). In 2011/12, the WUE_P of the mechanically pruned treatment (T10) was almost double that of other treatments also irrigated at *ca*. 90% PAW depletion (Table 7.7). The WUE_P, however, did not differ for the different canopy manipulated grapevines within an irrigation strategy. In 2012/13, the WUE_P of the mechanically pruned treatment was 2.5 times that of other treatments irrigated at *ca*. 90% PAW depletion (Table 7.7). The WUE_P, however, did not differ for the different canopy manipulated grapevines within the more frequent irrigation strategies. Within the treatments that were irrigated at *ca*. 90% PAW depletion, the mechanically pruned grapevines had a higher WUE_P than those that were not suckered (Table 7.7). In 2013/14, in the case of more frequently irrigated grapevines, WUE_P did not differ between the different canopy manipulations within the same irrigation strategy, exception the lower WUE_P for sprawling canopy grapevines irrigated at *ca.* 60% PAW depletion (Table 7.6). For grapevines irrigated at *ca*. 90% PAW depletion, the WUE_P of mechanically pruned grapevines (T10) was *ca*. 1.5 times higher compared to non-suckered grapevines (T8 & T9) (Table 7.7). In 2014/15, for more frequently irrigated grapevines, WUE_P did not differ between the different canopy manipulations within the same irrigation strategy (Table 7.6). For grapevines irrigated at *ca*. 90% PAW depletion, the mechanically pruned grapevines had a *ca*. 1.5 times higher WUE_P than those that were not suckered (T8 & T9) and *ca*. three kilogram per cubic metre of water more than suckered VSP grapevines (Table 7.7).

7.3.7. Potential yield losses due to sunburn and rot

In the 2011/12 season, within the VSP grapevines regardless of suckering or no suckering, the level of PAW depletion did not affect the percentage of sunburnt berries on suckered and non-suckered VSP grapevines (Table 7.8). However, in the case of the sprawling canopy grapevines, irrigation at *ca.* 60% PAW depletion (T6) resulted in a higher percentage sunburnt berries compared to *ca.* 30% (T3) and *ca.* 90% PAW depletion (T9). At this stage there is no explanation for this trend. Where grapevines were irrigated at *ca.* 30% PAW depletion, more sunburnt berries occurred on sprawling canopy grapevines (Table 7.8). This trend also occurred where grapevines were irrigated at 60% and 90% PAW depletion. 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 of sunburnt berries (Table 7.8). In the 2012/13 season, within a given canopy management practice, the level of PAW depletion did not affect the percentage of sunburnt berries (Table 7.8). There were also more sunburnt berries on the sprawling canopy grapevines within a given level of PAW depletion (Table 7.8). In the 2013/14 season, the incidence of sunburn was very low with the exception of the mechanically pruned grapevines (Table 7.8). In the 2014/15 season, similar trends were observed to the previous seasons (Table 7.8).

The incidence of grey 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 grey rot in the Chenin blanc bunches could have been attributed to the more compact bunches (Savage & Sall, 1984; Ferreira & Marais, 1987). In the 2011/12 season, within a given level of PAW depletion, canopy management practice did not affect the incidence, severity or estimated yield losses due to grey rot, except where sprawling canopy grapevines were irrigated at *ca.* 30% PAW depletion (Table 7.9). 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 4.5), 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 7.9). In the 2012/13 season, incidence of grey rot was low (Table 7.9). As expected, in the wetter 2013/14 season, the incidence of grey rot was substantially higher than the previous two seasons where grapevines were irrigated at *ca.* 30% and *ca.* 60% PAW depletion (Table 7.9). It should be noted that for the highest level of PAW depletion there was no incidence of grey rot (Table 7.9). In the case of the *ca.* 30% PAW depletion, the incidence of grey rot was substantially more for the sprawling canopy grapevines than for the VSP grapevines (Table 7.9). In the 2014/15 season, there was no incidence of grey rot (Table 7.9). As expected, in all four seasons, estimated yield loss percentage as a result of grey rot followed similar trends as the percentage of berries infected with grey rot (Table 7.9).

Table 7.8 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on the incidence, as well as the percentage mass and yield loss of Shiraz/110R grapes due to sunburn during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Incidence (%)**									
2011/12	1.6 e[1]	2.2 de	6.6 bc	2.5 de	3.1 cde	11.4 a	1.0 e	3.5 cde	5.6 bcd	9.2 ab
2012/13	1.6 b	2.7 b	5.5 ab	3.2 b	2.3 b	5.3 ab	3 b	3.1 b	8.6 a	1.9 b
2013/14	0.8 b	0.5 b	0.5 b	0.3 b	0.7 b	0.4 b	0.1 b	0.7 b	0.6 b	2.6 a
2014/15	0.9 b	0.8 b	2.6 b	1.2 b	0.6 b	3.3 b	2.6 b	8.5 a	8.8 a	2.9 b
Season	**Percentage mass loss (%)**									
2011/12	1.3 cd	1.8 cd	4.9 bc	2.0 cd	2.6 cd	10.3 a	0.7 d	2.7 cd	4.7 bc	8.0 ab
2012/13	1.1 b	1.9 b	3.9 ab	2.2 b	1.5 b	3.9 ab	2 b	2.1 b	6.1 a	1.3 b
2013/14	0.5 b	0.4 b	0.4 b	0.2 b	0.6 b	0.3 b	0.1 b	0.5 b	0.4 b	1.9 a
2014/15	0.7 c	0.5 c	2 c	0.8 c	0.4 c	2.4 bc	1.9 c	6.3 ab	7.3 a	2.3 bc
Season	**Potential yield loss ($t.ha^{-1}$)**									
2011/12	0.3 bc	0.5 bc	1.2 ab	0.3 bc	0.6 bc	2.0 a	0.1 c	0.4 bc	0.6 bc	2.2 a
2012/13	0.4 c	1 bc	2.1 abc	0.8 bc	0.9 bc	2.3 ab	0.8 bc	1.2 bc	3.7 a	1.7 bc
2013/14	0.1 b	0.1 b	0.1 b	0.1 b	0.1 b	0.1 b	0 b	0.1 b	0.1 b	0.4 a
2014/15	0.1 c	0.1 c	0.5 ab	0.1 c	0.1 c	0.5 ab	0.3 bc	0.6 a	0.4 ab	0.4 ab

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 7.9 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on the incidence, as well as the percentage mass and yield loss of Shiraz/110R grapes due to grey rot during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Season	Incidence (%)									
2011/12	0.1 b[(1)]	0.4 b	3.7 a	0.2 b	0.5 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
2012/13	0.0 c	1.6 a	0.7 bc	0.0 c	0.8 ab	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c
2013/14	7.0 bc	7.0 bc	19.6 a	12.6 ab	12.6 ab	11.5 b	0.0 c	0.0 c	0.0 c	0.0 c
2014/15	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Season	Percentage mas loss (%)									
2011/12	0.1 b	0.2 b	2.6 a	0.1 b	0.2 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
2012/13	0.0 b	1.0 a	0.3 b	0.0 b	0.3 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
2013/14	3.7 bc	3.6 bc	9.0 a	3.6 bc	5.4 ab	7.8 ab	0.0 c	0.0 c	0.0 c	0.0 c
2014/15	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Season	Potential yield loss ($t.ha^{-1}$)									
2011/12	0.0 b	0.0 b	0.6 a	0.0 b	0.1 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
2012/13	0.0 c	0.6 a	0.4 b	0.0 c	0.2 bc	0.0 c	0.0 c	0.0 c	0.0 c	0.0 c
2013/14	0.9 ab	1.0 ab	1.7 a	0.9 ab	1.4 a	1.6 a	0.0 b	0.0 b	0.0 b	0.0 b
2014/15	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

7.4. CONCLUSIONS

Grapevines subjected to severe water constraints ripened their grapes more rapidly than those experiencing no or medium water constraints. Furthermore, grapes of sprawling canopy grapevines ripened more rapidly compared to VSP grapevines within the same level of PAW depletion. With the exception of mechanically pruned grapevines, irrigation frequency had a more pronounced impact on yield than canopy manipulation. It was evident that the higher rainfall in 2013/14 increased vegetative growth and yield compared to previous seasons. Low frequency irrigations resulted in higher WUE_P compared to medium and high frequency irrigation. Within a given canopy management practice, level of PAW depletion did not affect the percentage of sunburnt berries. In addition to this, there were also more sunburnt berries on the sprawling canopy grapevines within a given level of PAW depletion. Results showed that the incidence of grey rot was substantially higher during the wetter season of 2013/14. Grapevines with sprawling canopies tended to have higher yield losses due to sun burn and even more so as irrigation was less frequent. Highest incidences and yield loss to grey rot was where grapevines were left un-suckered and irrigated at *ca.* 30 PAW depletion. Irrigation at *ca.* 90 PAW depletion resulted in the absence of grey rot.

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CHAPTER 8: EFFECT OF DIFFERENT IRRIGATION AND CANOPY MANAGEMENT STRATEGIES ON JUICE AND WINE CHARACTERISTICS

8.1. INTRODUCTION

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, 2001; Ashley, 2004). However, using either method, sugar accumulation differences between treatments can be identified. Juice total titratable acidity (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).

The anthocyanin concentration in Shiraz berries is most sensitive to a very high availability of water during ripening (Ojeda *et al*., 2002). The highest phenolic concentrations in Shiraz grape juice are obtained by no to little irrigation during ripening (Petrie *et al.*, 2004). Similarly, anthocyanin concentrations in Pinotage wines tended to be higher in wines made from grapes irrigated at 80% RAW depletion grapevines compared to ones irrigated at 50% readily available water (RAW) depletion (Myburgh, 2006). It was found that highest concentrations of phenolics and anthocyanins in Shiraz wines were obtained with non-irrigated grapevines compared to ones receiving drip irrigation with crop coefficients of 0.2 or 0.4, respectively (McCarthy *et al.*, 1983). Where Shiraz canopies were managed to allow high bunch exposure to sunlight, grapevines that received excessive water during the growing season produced wines containing only 70% of the total anthocyanins and tannins compared to wines where grapevines were subjected to water deficits (Ristic *et al*., 2010).

In a study on the effect of irrigation in a warm climate on grape juice flavour and aroma as perceived by tasting panels, non-irrigated grapevines produced juice containing higher levels of potential volatile terpenes (McCarthy & Coombe, 1984). Non-irrigated grapevines also produced wines of higher sensorial quality (McCarthy *et al.*, 1986). Cabernet Sauvignon growing in sandy soils in a hot climate produced wines with the highest berry character and overall quality when adequate irrigation water was applied during the growing season (Bruwer, 2010). In cooler climates or in loamy soils with higher soil water holding capacities, better cultivar character and overall quality can be expected when medium to high water constraints occur in Cabernet Sauvignon grapevines (Bruwer, 2010). During dry growing seasons, Merlot grapevines produced better wine colour, cultivar character and overall wine quality when three irrigations were irrigations were applied to restore the soil to field capacity (FC) in the Coastal region of South Africa (Myburgh, 2011d). In these dry growing seasons, particularly ones following low rainfall winters, non-irrigated grapevines were exposed to excessive water constraints and produced inferior wines. Wine colour and overall quality was negatively affected when more than three irrigations were applied per season. Pinotage and Sauvignon blanc grapevines in the semi-arid Breede River Valley, irrigated at 80% RAW depletion during ripening, produced the best overall quality wines (Myburgh, 2011b; Myburgh, 2011c). Where canopy management were applied so that the bunches were either fully shaded, moderately exposed or fully exposed to sunlight, high frequency irrigated Shiraz grapevines produced wines characterised by herbaceous and straw aromas (Ristic *et al.*, 2010). On the other hand, wines had a dominant liquorice (spicy) character aroma where grapevines were subjected to soil water deficits, and bunches were fully exposed. Neither irrigation, nor canopy management had an effect on the berry aroma (raspberry and cherry) in the wines (Ristic *et al.*, 2010).

The aim of this study was to determine the combined effects of irrigation and canopy management practices on juice and wine quality characteristics of Shiraz grapevines growing in the Breede River Valley.

8.2. MATERIALS AND METHODS

8.2.1. Juice components

The TSS, TTA and pH in the juice were determined according to standard procedures of the Infruitec-Nietvoorbij Institute of the Agricultural Research Council (ARC) near Stellenbosch. The TSS was determined using a digital refractometer (Pocket PAL-1, Atago U.S.A. inc., Bellevue, WA, U.S.A.). The TTA and pH in the juice was measured using an automatic titrater (Metrohm 785 DMP Tritino, Metrohm AG, Herisau, Switzerland), against sodium hydroxide (NaOH) at a concentration of 0.33 mol.kg^{-1}.

8.2.2. Wine characteristics

Forty kilograms of harvested grapes from each of the thirty experimental plots were transported to the research winery of ARC Infruitec-Nietvoorbij to be micro-vinified. After the grapes were crushed 50 $mg.kg^{-1}$ SO_2 was added. Skin contact was allowed for at least one hour before the crushed grapes were inoculated with a commercial wine yeast (VIN 13, Anchor Biotechnologies), at a concentration of 30 $g.hL^{-1}$. A volume of 50 $g.hL^{-1}$ diammonium phosphate (DAP) was then added. Fermentation was conducted on the skins at 25°C and the cap was punched down three times a day. The must was fermented down to sugar content was below 5°B. Following this, the skins were separated and pressed at *ca.* 0.2 MPa. The pressed wine was added to the free run-off wine and fermented at 25°C until dry. As soon as fermentation was completed, the wine was racked, the SO_2 adjusted to a total of 85 $mg.L^{-1}$ (in accordance with the analysis) and cold stabilised at 0°C for at least two weeks. After cold stabilisation the wine was filtered by using sterile mats (K900 and EK), as well as a 0.45 μm membrane and bottled into nitrogen filled bottles at room temperature. The total SO_2 was adapted during bottling to ensure that it was not less than 85 $mg.L^{-1}$. The bottled wines were stored at 14°C until the sensorial evaluation in August of the harvest year.

After harvest in the 2011/12 season, grapes were delivered to the research winery for the preparation of the experimental wines. After the standard wine making procedure described above, wine chemical analyses of all 30 wines in August 2012 indicated that very high volatile acidity (VA) concentrations were present in the majority of the wines (data not shown). The VA concentration in wine is affected by the production of acetic acid when grape juice and/or wine is contamination with acetic acid bacteria and lactic acid bacteria (Ferreira *et al.*, 2006). A VA concentration of higher than 0.76 $g.L^{-1}$ is sensorially perceivable (Ribéreau-Gayon *et al.*, 2006) and the legal concentration for commercial wines is 1.2 $g.L^{-1}$ (Du Toit & Lambrechts, 2002). Of the 30 wines prepared, 21 were higher that the sensorial perceivable VA concentration. Twelve of these 21 wines were also over the legal VA concentration limit. Despite the unnatural high VA levels, all 30 wine were evaluated for their sensorial characteristics by a tasting panel of experts in September 2012. However, after thorough data perusal, no treatment trends could be observed. This can be attributed to the high VA contents of the wines, and was confirmed by most of the wine judges who indicated high VA aroma and tastes on their evaluation sheets.

Wines were subjected to sensorial evaluation by a panel of at least 12 experienced wine tasters. The primary sensorial wine characteristics were colour, flavour and overall wine quality. Flavour characteristics consisted of (i) berry aroma, *i.e.* blackberry, raspberry, strawberry and black currant, and (ii) spicy aroma, *i.e.* black pepper, cloves, liquorice, and aniseed. Wine characteristics were scored by means of a 100 mm long unmarked line scale.

Selected chemical analyses of the experimental wines were done at a commercial laboratory. Following tasting, the alcohol, extract, residual sugar, volatile acidity, tartaric acid, malic acid, total acidity and pH of the wines were analysed by a commercial laboratory (Koelenhof winery, Stellenbosch) as described by Schoeman (2012) for any wine abnormalities that can be attributed to wine making mistakes or errors. In order to quantify wine colour, light absorbance of the wines was measured at 420 nm and 520 nm using a spectrophotometer. Wine samples were digested by adding concentrated nitric acid, allowing it to stand overnight and then adding perchloric acid to determine wine K. Following the nitric acid/perchloric acid digestion, wine K was determined using an inductively coupled plasma emission spectrometer (Liberty 200 ICP AES, Varian, Australia).

8.2.3. Statistical analyses

The data were subjected to an analysis of variance (ANOVA) by using Statgraphics®. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means, which differed at $p \leq 0.05$, were considered significantly different.

8.3. RESULTS AND DISCUSSION

8.3.1. Total soluble solids

Grapes were harvested as close to the target TSS level of 24ºB as logistically possible (Table 8.1). Although the TSS levels differed between some treatments, it would probably not affect the sensorial wine evaluation, since alcohol contents in the wines would be comparable. In 2012/13, grapes of treatments irrigated at *ca*. 90% PAW depletion had an unforeseen TTS increase of *ca*. 3°B in the last week of February. Consequently, these grapes were harvested 7 to 21 days earlier than the rest of the treatments (Table 7.1).

8.3.2. pH

In 2011/12 and 2013/14, juice pH of grapevines irrigated at *ca*. 90% PAW depletion tended to be lower than that of grapevines subjected to less water constraints (Table 8.1). At this stage it is unclear why T2 grapevines produced juice with the lowest pH in the 2011/12 season. In the 2012/13 season, there were no consistent trends in juice pH with regard to irrigation strategy or canopy manipulation (Table 8.1). There was no clear difference between juice from grapevines that were irrigated at *ca*. 30% and 60% PAW depletion, irrespective of thedifferent canopy manipulations that were applied (Table 8.1). In the 2014/15 season, juice pH was neither affected by irrigation nor canopy manipulation strategy.

8.3.3. Total titratable acidity

In 2011/12, grapes produced by irrigation at *ca*. 90% PAW depletion were harvested between 11 and 17 days earlier than the rest of the treatments (Table 7.1), and had the highest juice TTA content (Table 8.1). Furthermore, within a specific PAW depletion level, juice TTA contents was affected by the different canopy manipulations. As mentioned previously, in the 2012/13 season, the unforeseen rapid increase in TSS of the grapes of treatments that were irrigated at *ca*. 90% PAW depletion resulted in the harvest of these particular treatments between 7 and 21 days earlier than the rest of the vineyard (Table 7.1). Consequently, the juice had the highest juice TTA content (Table 8.1). As in the previous season, canopy manipulations did not affect juice TTA contents within a specific PAW depletion level (Table 8.1). In the 2013/14 season, grapes produced by irrigation at *ca*. 90% PAW depletion also had the highest juice TTA content (Table 8.1). There was no clear difference between juice from grapevines that were irrigated at *ca*. 30% and *ca.* 60% PAW depletion, irrespective of the different canopy manipulations that were applied (Table 8.1). In 2014/15, trends observed for juice TTA were similar to trends observed in the previous three seasons

8.3.4. Chemical wine analysis

In the 2012/13 season, there was a low mean VA concentration of 0.24±0.07 $g.L^{-1}$ in the experimental wines, which was substantially lower than 0.76 $g.L^{-1}$, the threshold for sensorial detectability for VA (data not shown). In general, 1.2 $g.L^{-1}$ is the maximum allowable concentration in natural wine. This was in sharp contrast to the unacceptably high VA concentrations measured in the faulty 2011/12 wines due to improper winery procedures, as mentioned in Deliverable 3. Based on the low VA levels, there were no faulty wines in the 2012/13 season. Alcohol levels in wines irrigated at *ca.* 90% PAW depletion were higher compared to wines produced where grapevines were irrigated at lower PAW depletion levels (Table 8.2). Due to logistic constraints, the grapevines irrigated at *ca.* 90% PAW depletion could only be harvested at a higher sugar contents than the target of 24ºB. Consequently, the higher sugar contents fermented to produce higher wine alcohol levels. Therefore, the higher wine alcohol levels could not be attributed to level of PAW depletion or canopy management practice. The results of the spectrophotometric readings indicated that more frequent irrigation tended to decrease light absorption, *i.e.* the wine colour was lighter (Table 8.2).

Table 8.1 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on the total soluble solids (TSS), total titratable acidity (TTA) and pH of grape juice at harvest of Shiraz/110R grapevines during ripening of the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	TSS (°B)									
2011/12	25.0 a[(1)]	23.5 b	23.9 ab	24.0 ab	23.8 ab	23.4 b	24.0 ab	24.5 ab	24.8 a	23.9 ab
2012/13	23.8 cd	23.8 cd	23.5 d	23.6 d	23.5 d	24.2 cd	24.8 bc	25.6 ab	26.1 a	25.4 ab
2013/14	24.4 ab	24.0 ab	23.8 ab	23.4 b	23.8 ab	23.7 ab	23.9 ab	24.6 a	23.8 ab	23.5 ab
2014/15	24.6 a	24.7 a	23.7 ab	22.9 b	23.6 ab	23.4 b	23.8 ab	23.3 b	23.7 ab	23.9 ab
Season	TTA ($g.L^{-1}$)									
2011/12	4.9 bc	5.1 b	5.0 b	4.9 bc	4.8 bc	4.8 bc	6.6 a	6.4 a	6.3 a	4.3 c
2012/13	3.9 c	4.0 bc	4.1 ab	3.9 c	4.0 bc	4.0 bc	3.9 c	4.0 bc	4.2 a	3.9 c
2013/14	4.8 bc	4.4 cd	4.4 cd	4.0 de	4.4 cd	5.2 ab	5.3 a	4.6 c	5.4 a	3.7 e
2014/15	5.1 ab	5.1 ab	5.0 abc	5.0 abc	5.7 a	4.5 cde	4.5 cde	4.7 bc	3.8 e	4.2 de
Season	pH									
2011/12	3.94 abcd	3.77e	3.89 bcde	3.99 a	3.97 abc	3.98 ab	3.83 de	3.85 cde	3.85 cde	3.94 abcd
2012/13	5.07 ab	4.90 b	4.40 c	4.30 c	4.35 c	4.10 c	5.15 ab	5.27 ab	5.37 a	4.90 b
2013/14	4.33 a	4.29 ab	4.26 ab	4.25 ab	4.24 ab	4.12 bc	4.02 c	4.04 c	3.83 d	4.06 c
2014/15	3.75 ef	3.88 d	3.87 de	3.66 f	3.23 a	3.97 cd	3.99 bcd	3.99 bcd	3.05 bc	3.09 b

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 8.2 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on selected chemical characteristics of Shiraz/110R wine during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Season	**Alcohol (%)**									
2012/13	13.6 cd[(1)]	13.2 d	13.6 cd	13.7 cd	13.1 d	14.1 bcd	15.0 ab	15.0 ab	15.3 a	14.5 abc
2013/14	13.7 a	13.8 a	13.5 a	13.5 a	13.8 a	13.4 a	13.8 a	13.8 a	13.2 a	13.4 a
2014/15	13.8 ab	14.1 ab	13.6 ab	13.8 ab	13.6 ab	13.9 ab	13.6 ab	14.7 a	14.1 ab	13.2 b
Season	**Light absorbance (420 nm)**									
2012/13	1.36 de	0.80 e	1.19 e	1.60 de	1.10 e	2.85 bc	2.26 cd	3.49 ab	4.32 a	3.43 ab
2013/14	2.45 a	1.67 a	1.48 a	1.40 a	1.90 a	1.36 a	1.81 a	2.07 a	2.28 a	2.24 a
2014/15	1.86 c	1.91 c	2.01 c	2.07 c	1.94 c	2.01 c	2.01 c	3.98 ab	4.44 a	3.31 b
Season	**Light absorbance (520 nm)**									
2012/13	1.36 cd	0.74 d	1.36 cd	1.70 cd	1.06 cd	3.64 ab	2.04 c	3.21 b	4.54 a	3.28 b
2013/14	2.59 ab	1.73 ab	1.61 ab	1.38 b	1.85 ab	1.47 ab	2.10 ab	2.41 ab	2.97 a	2.55 ab
2014/15	2.41 c	2.65 c	2.95 c	2.87 c	2.73 c	2.69 c	2.95 c	5.74 ab	6.52 a	4.97 b
Season	**K ($mg.L^{-1}$)**									
2012/13	1 369 a	1 120 a	1 205 a	1 282 a	1 047 a	1 192 a	1 177 a	1 197 a	1 319 a	1 208 a
2013/14	1 248 a	1 358 a	1 253 a	1 257 a	1 187 a	1 163 a	1 123 a	1 197 a	1 201 a	1 235 a
2014/15	1 135 a	1 268 a	1 187 a	1 168 a	1 128 a	1 057 a	1 098 a	1 059 a	1 117 a	1 136 a

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Wines produced from non-suckered VSP grapevines irrigated at *ca.* 30% and *ca.* 60% PAW depletion tended to have lower light absorption at both wavelengths compared to wines produced from suckered VSP and sprawling canopy grapevines within the same irrigation strategy.

In contrast, wines produced from the non-suckered VSP grapevines irrigated at *ca.* 90% PAW depletion did not show this trend. Neither level of PAW depletion, nor canopy management affected wine K concentrations (Table 8.2). This was to be expected since juice pH levels did not differ at harvest in March 2013 (Table 8.1). Wine pH, malic acid, tartaric acid and polyphenol concentrations were not affected by level of PAW depletion or canopy management practice (data not shown). Wine pH, malic acid, tartaric acid and polyphenol concentrations were 3.96±0.14, 1.43±0.54 $g.L^{-1}$, 0.24±0.07 $g.L^{-1}$and 61.31±10.53 $g.L^{-1}$, respectively. It must be noted that the wine pH was generally higher than 3.5, *i.e.* the level at which colour stability in red wine is expected to be reduced.

The VA concentration in the experimental wines of the 2013/14 season was 0.04±0.16 $g.L^{-1}$, which was lower 1.2 $g.L^{-1}$ than 0.76 $g.L^{-1}$ which is the threshold for sensorial detectability for VA. In general, is the maximum allowable concentration in natural wine. This was in sharp contrast to the unacceptably high VA concentrations measured in the faulty 2011/12 wines as discussed previously. There were no differences in alcohol levels in the experimental wines (Table 8.3) as all the grapes were harvested near the target sugar contents of 24ºB. There were no clear trends in the spectrophotometric measurements of absorbance at 420 nm and 520 nm, and reflected in the poor colour of the wine (Table 8.2). Neither level of PAW depletion nor canopy management affected wine K concentrations (Table 8.2). This was to be expected since juice pH levels did not differ at harvest in March 2013. Wine pH, malic acid, tartaric acid and polyphenol concentrations were not affected by level of PAW depletion or canopy management practice (data not shown). Wine pH, malic acid, tartaric acid and polyphenol concentrations were 4.00±0.32, 1.04±0.73 $g.L^{-1}$, 1.47±0.26 $g.L^{-1}$ and 47.49±4.22 $g.L^{-1}$, respectively. It must be noted that the wine pH was generally higher than 3.5.

Results indicated a low mean VA concentration of 0.14±0.02 $g.L^{-1}$ in the experimental wines of the 2014/15 season. Due the fact that grapes were harvested near the target sugar contents of 24ºB, no substantial differences in alcohol content were expected (Table 8.2). Within the same irrigation strategy, grapevines with sprawling canopies produced wines with higher colour intensity, while those irrigated at higher depletion levels had more intense colouration compared to those irrigated at *ca.* 30% and *ca.* 60% PAW depletion (Table 8.2).

Neither level of PAW depletion nor canopy management affected wine K concentrations (Table 8.3). This was to be expected since juice pH levels did not differ at harvest in March 2015 (Table 8.1). Wine pH, malic acid, tartaric acid and polyphenol concentrations were not affected by level of PAW depletion or canopy management practice and were similar to that of the previous season. It must be noted that the wine pH was once more higher than 3.5.

8.3.5. Sensorial wine characteristics

In 2012/13, wines produced from non-suckered VSP grapevines irrigated at *ca.* 30% and *ca.* 60% PAW depletion (T2 & T5) had poorer wine colour, berry and spicy characteristics compared to wines produced from suckered VSP and sprawling canopy grapevines (Table 8.3). In contrast, wines produced from the non-suckered VSP grapevines irrigated at *ca.* 90% PAW depletion did not show this trend. The foregoing indicated that the standard ARC sensorial wine colour showed the same responses to level of PAW depletion and canopy management as the spectrophotometric results. In fact, sensorial wine colour correlated well with light absorbance at 520 nm and the relationship was non-linear (Fig. 8.1). The non-linearity indicated that the sensorial evaluation became less sensitive to differences as wine colour increased. Overall quality of wines produced from the non-suckered VSP grapevines was poorest, whereas wines produced from sprawling canopy grapevines were rated best where irrigation was applied at *ca.* 30% and *ca.* 60% PAW depletion (Table 8.3). However, this was not the case when grapevines were irrigated at *ca.* 90% PAW depletion since non-suckered VSP, sprawling and mechanically pruned grapevines produced grapes with the potential to make wines of superior quality. Wines produced during the 2013/14 season had poorer wine colour, berry and spicy characteristics and overall wine quality, compared to wines produced during the 2012/13 season (Table 8.3). Although overall wine quality was poorer, similar trends to the previous season were observed with grapevines irrigated at higher PAW depletion levels producing better wines.

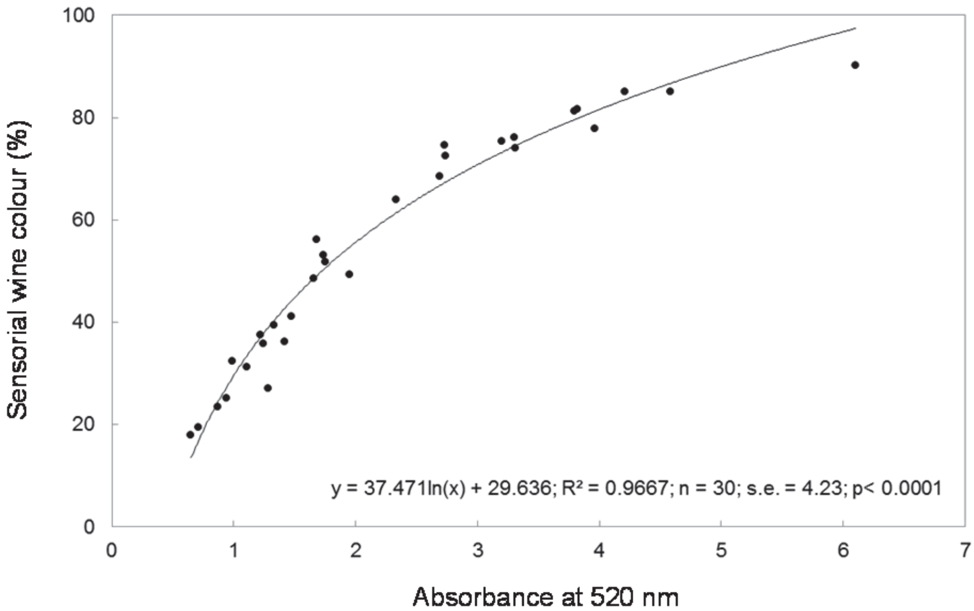

Figure 8.1 Relationship between sensorial wine colour and light absorbance at 520 nm for Shiraz/110R wine determined during the 2012/13 season near Robertson.

The reason for the lower overall wine quality in 2013/14 compared to 2012/13 can be attributed to the high rainfall during ripening (January to March). As explained in section 2.1, the rainfall during the 2013/14 season was 119 mm higher than the LTM. In a previous study, grapevines irrigated at low PAW depletion levels during ripening produced inferior wine quality, irrespective of the PAW depletion level before véraison, compared to those irrigated at a high depletion level during ripening (Lategan, 2011). The 2013/14 season had the second highest rainfall in January and the third highest rainfall for January and February (ripening) since 1901 (Appendix A). The 2013/14 vintage was generally expected to be a bad season for wine quality (B. Stipp, Personal communication).

Wines of the 2014/15 season had better wine colour, berry and spicy characteristics and overall wine quality, compared to wines produced during the 2013/14 season (Table 8.3). Similar trends were observed to the previous season with grapevines irrigated at higher PAW depletion levels producing better wines. Furthermore, where grapevines irrigated were irrigated at *ca*. 30% and *ca.* 60% PAW depletion, sprawling canopies improved overall wine quality (Table 8.3).

Table 8.3 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on sensorial characteristics of Shiraz/110R wines during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**				***ca.* 90% PAW depletion**		
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Colour (%)**									
2012/13	35.9 c[1]	20.3 d	40.6 bc	52.1 b	31.2 cd	79.7 a	52.7 b	74.6 a	83.1 a	73.9 a
2013/14	25.8 e	33.8 cde	32.1 de	31.9 de	32.3 de	31.8 de	47.7 bc	51.3 ab	42.0 bcd	63.0 a
2014/15	38.1 c	39.3 c	44.6 c	46.5 c	43.5 c	53.3 bc	63.9 ab	74.4 a	68.9 ab	70.3 ab
Season	**Berry character (%)**									
2012/13	46.4 d	33.7 e	53.5 bcd	56.1 abcd	45.8 d	60.8 ab	48.6 cd	64.9 a	62.8 ab	59.1 abc
2013/14	33.7 e	40.3 cde	42.9 abc	45.1 abc	41.1 bc	38.4 de	42.8 abc	45.6 ab	46.0 ab	48.9 a
2014/15	48.6 ab	39.1 b	38.7 b	45.8 ab	44.4 ab	44.8 ab	51.8 a	44.1 ab	47.3 ab	46.0 ab
Season	**Spicy character (%)**									
2012/13	30.9 cde	21.5 f	31.8 cd	32.4 cd	25.3 ef	41.6 ab	29.8 de	43.3 a	41.4 ab	36.0 bc
2013/14	27.5 d	34.2 abcd	30.1 cd	32.7 abcd	36.1 abc	37.6 abc	40.3 a	38.0 ab	31.3 bcd	36.7 abc
2014/15	34.3 c	33.6 c	36.4 bc	35.9 bc	33.9 c	36.7 bc	35.7 bc	45.5 ab	48.5 a	37.7 bc
Season	**Overall quality (%)**									
2012/13	38.5 de	33.1 e	43.1 cd	50.0 bc	33.4 e	55.2 ab	48.5 bc	61.4 a	60.0 a	59.3 a
2013/14	30.5 d	34.3 cd	37.6 bc	36.8 bc	39.0 abc	39.4 abc	44.3 a	43.9 a	42.2 ab	43.8 a
2014/15	45.0 c	36.1 d	43.8 c	45.9 c	43.6 c	54.7 ab	53.1 bc	55.0 ab	59.6 a	56.5 ab

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

8.4. CONCLUSIONS

Grapes were harvested as close to the target TSS level of 24ºB as possible. Where severe water constraints enhanced berry maturation, juice TTA was higher and pH lower compared to grapes that were harvested later. Within a given PAW depletion level, canopy manipulations did not affect juice TTA contents. Irrigation applied at a higher PAW depletion level, *i.e. ca.* 90%, improved overall wine quality compared to more frequent irrigation. Within the lower levels of PAW depletion levels, *i.e. ca.* 30% and *ca.* 60%, non-suckered VSP grapevines produced wines of the poorest overall quality. Highest overall wine quality was obtained where non-suckered VSP, sprawling canopy and mechanically pruned grapevines were irrigated at *ca.* 90% PAW depletion. Wine alcohol content, pH, K, malic and tartaric acids and polyphenol concentrations were not affected by level of PAW depletion or canopy management practice.

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CHAPTER 9: EFFECT OF DIFFERENT IRRIGATION AND CANOPY MANAGEMENT STRATEGIES ON ECONOMIC VIABILITY OF SHIRAZ GRAPE PRODUCTION

9.1. INTRODUCTION

The positive and negative effects of water constraints on grapevines have been reported on numerous occasions. However, most of the irrigation research in South Africa on wine grapes was carried out in flood or micro-sprinkler irrigated vineyards (Van Zyl, 1984; Myburgh, 2005; Myburgh, 2006; Myburgh, 2007; Myburgh, 2011). Although the positive effects of canopy manipulation on the quality aspect of wine have been reported, all grapevines of the canopy treatments received the same irrigation volumes (strategies) and irrigation applications were indicated very vaguely or not at all (Hunter, 2000; Hunter & Volschenk, 2001; Volschenk & Hunter, 2001; Archer & Van Schalkwyk, 2007). Thus, there is no knowledge regarding the effect that different irrigation strategies and canopy management combinations will have on water requirements, vegetative growth, yield, labour inputs and wine quality of grapevines, and the economic implications thereof.

Canopy management also requires a lot of labour inputs (Volschenk & Hunter, 2001; Archer & Van Schalkwyk, 2007) and variations in the amount of labour necessary to apply different grapevine canopy manipulations can be expected (Volschenk & Hunter, 2001). Grapevines that were manipulated intensively and irrigated frequently during the season were easier to harvest and prune compared to those which were not intensively manipulated. This can be explained not only by the fact that canopies were more open due to less shoots per grapevine and the bunches being more readily harvestable, but also because less grapes were produced by these intensively manipulated grapevines (Volschenk & Hunter, 2001). The application of the more intensive grapevine canopy manipulations resulted in 32% higher labour expenses per hectare. The cost to apply mechanical pruning can vary between R669.ha^{-1} and R972.ha^{-1}, depending on the row spacing and the type of pruning machine, a double sided or single sided pruning, being used (Le Roux, 2009). A double sided pruning machine can prune grapevines at *ca*. 2.2 hours.ha^{-1} while it will take double the time to prune a hectare of grapevines using a single sided pruning machine (Le Roux, 2009). Thus, by applying mechanical pruning and no other canopy management practices, the cost of canopy manipulation can be drastically cut, without influencing the wine quality. In 2010, it was reported that labour costs accounted for 41% of the total production of wine grapes (Van Wyk & Le Roux, 2011)

The aim of this study was to determine the combined effects of irrigation and canopy management practices on economic viability of Shiraz grape production in the Breede River

Valley. This knowledge will enable farmers and growers to plan and apply a different irrigation and canopy management for their individual vineyard needs, and in doing so managing limited and expensive resources, i.e. water and electricity, to produce the best possible wine quality. Knowledge could also aid viticulturists in their classification of vineyards for a specific wine style class and irrigation consultants in their recommendations for scheduling individual vineyard blocks.

9.2. MATERIAL AND METHODS

9.2.1. Discussion Group Meetings

An initial discussion group meeting was held on 11 September 2013 between the project team and viticulturists from the Robertson area. The objective of the meeting was to determine whether the field experimental data could be seen as representative of that of the rest of the area. The group consisted of the following individuals:

Mr Vink Lategan	Project leader	ARC Infruitec-Nietvoorbij
Dr Philip Myburgh	Soil Scientist/Researcher	ARC Infruitec-Nietvoorbij
Mr Briaan Stipp	Viticulturist	Robertson Winery
Mr Jaco Lategan	Viticulturist	Roodezandt Winery
Mr Johannes Mellet	Viticulturist	Vinpro
Mr Willem Botha	Viticulturist/Irrigation	Netafim
Dr Willem Hoffmann	Agricultural economist	Stellenbosch University
Mr Victor Louw	Agricultural economist	Stellenbosch University

The group agreed that although the yield potential of the soil in which the field trial was done was towards the higher potential compared to the majority of the soils in the area, the trends within the data, particularly yield and growth, were as expected. The soil in the field trial has medium to high yield potential and represent 12.3% of the surveyed soils in the Breede River Valley (Oberholzer & Schloms, 2011). The group agreed that the experimental dependent attributable costs and the methods proposed by the project team would be representative of that occurring in the rest of the area.

A second discussion group meeting was held on 18 June 2014. The objective of this meeting was, amongst others, to determine the mean farm demographics and to compare the *non*-experimental dependent attributable costs, calculated from the Vinpro 2014/15 cost guide (Van Niekerk & Van Zyl, 2014), to the actual costs experienced by producers. The following individuals attended the meeting:

Mr Vink Lategan	Project leader	ARC Infruitec-Nietvoorbij
Dr Philip Myburgh	Soil Scientist/Researcher	ARC Infruitec-Nietvoorbij
Mr Briaan Stipp	Viticulturist	Robertson Winery
Mr Jaco Lategan	Viticulturist	Roodezandt Winery
Mr Willem Botha	Viticulturist/Irrigation	Netafim
Dr Willem Hoffmann	Agricultural economist	Stellenbosch University
Mr Victor Louw	Agricultural economist	Stellenbosch University
Mr Hannes Beukman	Producer	
Mr Daan Louw	Producer	
Mr Febbie van der Merwe	Producer	
Mr Le Febre van der Merwe	Producer	
Mr Schalk Wentzel	Producer	

9.2.2. Experimental attributable costs

9.2.2.1. Labour input requirements

Different pre-determined canopy manipulations were applied as and when it was necessary throughout the experimental seasons (Table 2.3). The same two individuals were used to do all the canopy manipulation actions throughout for consistency purposes. The time required to apply the different canopy manipulations was recorded using a stop watch and converted to man hours per hectare for the particular manipulation:

$$\text{Labour input requirement (man hours.ha}^{-1}\text{)} = \frac{\left(\frac{t}{n_{labourers}}\right)}{A_{plot}} \qquad \text{(Eq. 9.1)}$$

where: t = time required to complete the input (h)

$n_{labourers}$ = number of labourers applying the labour input

A_{plot} = area of experimental plot (ha)

The minimum wage of R12.41 per hour (Van Niekerk & Van Zyl, 2014) was multiplied with the labour requirement to calculate the cost per hectare of the summer canopy manipulation actions, as well as harvesting and winter pruning costs.

9.2.2.2. Irrigation cost breakdown

It was agreed in discussion group meeting on 18 June 2014 that the mean farm size in the area was 80 ha of which only 70 ha were arable (Louw, 2015). Of this 70 ha, 21 ha would be utilised for canning fruit production and the other 49 ha used for grape production (Louw, 2015).

The electricity in the area in which the field experiment was done is supplied by the Langeberg Municipality. The majority of producers have a three-phase conventional metering supply of 51 to 100 kVA. The basic electricity cost charged by Langeberg Municipality of R 1 211.70 per month had to be divided by 70 to determine the basic electricity charge distribution per hectare, while the usage cost for the 2012/13 season were 100.76 $c.kWh^{-1}$. A representative energy requirement per hectare (3.5 kW) was used for determining the electricity costs of treatments (Louw, 2015). The number of irrigation hours applied per treatment was multiplied with the standard pump size and a power factor, *i.e.* ratio of the real power used to do the work and the apparent power that is supplied to the circuit, of 0.85 (B. Marais, personal communication, 2012; Louw, 2015) to calculate the amount of kilowatt hours (kWh) necessary to irrigate each treatment. Each of these kWh values were then multiplied by the cost per electricity unit ($c.kWh^{-1}$) to calculate the variation in irrigation costs of the different treatments:

$$\text{Irrigation cost} = \left(\frac{\text{Langeberg Municipality basic cost}}{A_{\text{Arable}}} \times A_{\text{Wine grapes}}\right) + \left(\frac{E_{ha}}{PF} \times h\right) \times C_{eu} \qquad \text{(Eq. 9.2)}$$

where: A_{Arable} = area of arable land (ha)

$A_{\text{Wine grapes}}$ = area planted with wine grapes (ha)

E_{ha} = energy requirement for irrigation per hectare (kW)

PF = power factor

h = amount of irrigation hours applied per treatment per season (h)

C_{eu} = electricity usage cost ($c.kWh^{-1}$)

9.2.2.3. Grape transport cost

During the discussion group meeting held on 18 June 2014 with producers, it was agreed that a 6 tonne truck is the standard size truck used to transport grapes from farms to the wineries.

The grape transport costs were calculated by first determining the number of truck loads (6 tonnes) needed to transport the total mass of grapes produced to the winery. The typical distance from farm to winery (d_{winery}) was set as 10 km and the truck's total operating costs are fixed at R4.86 per km (Van Niekerk & Van Zyl, 2014). The mean traveling speed of the truck was estimated as 30 $km.h^{-1}$. Considering that the truck would have to come back to the farm after delivering the grapes to the winery, the following equation was used to calculate the truck component of the grape transport cost:

$$\text{Truck cost component} = (d_{winery} \times 2 \times \text{operating cost}) \times \frac{\text{Yield}}{6\text{ ton}} + (\text{labour cost} \times \frac{d_{winery}}{\text{traveling speed}}) \quad \text{(Eq. 9.3)}$$

Tractor transport cost components that made the transfer of the grapes from the vineyard to the truck were also taken into account. It was estimated that a trip per tractor was 15 minutes to transport grapes to the truck. The time factor was against a total tractor (41 kW) and wagon (4 tonnes) mechanisation of R104 calculated per hour, plus the labour cost of the tractor driver, to determine the total grape transport costs for each treatment (Van Niekerk & Van Zyl, 2014). Thus, the tractor cost component and total transport cost were calculated using the following equations:

$$\text{Tractor cost component} = (\text{mechanisation cost} \times 0.25 \times \frac{\text{Yield}}{4\text{ ton}}) + (\text{labour cost} \times 0.25 \times \frac{\text{Yield}}{4\text{ ton}}) \quad \text{(Eq. 9.3)}$$

$$\text{Grape transport cost} = \text{Truck cost component} + \text{Tractor cost component} \quad \text{(Eq. 9.4)}$$

9.2.3. Non-experimental attributable costs

Non-experimental dependent costs consisted of costs not directly measured during the field trial. These costs are part of direct attributable variable costs in wine grape cultivation. Costs include, amongst others, fertilizers (inorganic and organic), pest and disease control, weed control (herbicides), repair and maintenance costs, water costs, labour for pest control and irrigation, and mechanization. The labour component involved in pest control represented the labour cost component on mechanized operations. Labour costs in irrigation were related to maintenance and regular maintenance of irrigation systems. Assumptions relating to these costs were made by the VinPro annual study group and operating costs assumptions were also determined (Van Niekerk & Van Zyl, 2014).

9.2.4. Potential commercial wine classification

Grapes generally would be classed in a specific category during the season. This would not only enable wineries to manage grapes with similar quality characteristics during the vinification process, but also affect the price that the winery pays the grower for the grapes. The categories for Shiraz wine, their descriptions and mean wine prices for 2013 are presented in Table 9.1 (T. Loubser, personal communication, 2013). Robertson and Roodezandt wineries process *ca.* a third of the grapes produced in the Robertson area (Louw, 2015). In December 2013, all experimental wines of the 2012/13 season that were sensorially evaluated in the preceding August, were classed by nine winemakers from Robertson and Roodezandt wineries according to their potential commercial category to enable the project team to determine a price point per tonne of grapes delivered.

Table 9.1 Four different Shiraz wine class categories, descriptions and price for the Robertson area in 2013.

Wine class category	Description of wine class	Selling price[1] per wine class ($R.L^{-1}$)
Class 1	Specially selected single vineyard wine	R 10.00
Class 2	Single cultivar wine	R 7.70
Class 3	Dry red blend wine	R 6.00
Class 4	Rosé	R 4.60

[1] Mean selling price per class for Robertson and Roodezandt wineries in 2013.

It must be noted that due to the fact that experimental wines of the 2012/13 season were classed and compared to sensorial evaluated wines, all experimental attributable costs were calculated using 2012/13 season data to compare seasons with one another.

9.2.5. Gross income

After producers have been compensated, the wineries add a general processing cost of R 1 600 per 1 000 kg of grapes, while it is generally accepted that 700 L of wine are produced per tonne of grapes (J. Lategan, personal communication, 2013; T. Loubser, personal communication, 2013; B. Stipp, personal communication, 2013). Depending on in what category a specific vineyard's grapes were classed, the pay point per tonne of grapes delivered to the winery by producers were calculated using the following equation:

$$P_{grapes} = (P_{wine} \times 1000) \times 0.7 - C_p \qquad \text{(Eq. 9.5)}$$

where: P_{grapes} = producers' gross income per tonne of grapes delivered ($R.ton^{-1}$)

P_{wine} = selling price of specific wine category ($R.L^{-1}$)

C_p = winery processing cost per ton of grapes (R)

9.2.6. Gross margin analyses

All treatment affected input costs that were determined was used in a gross margin analyses per treatment and done according to methods described by Backeberg and Bronkhorst (1990), *i.e.* gross income minus the experimental attributable and non-attributable costs.

9.2.7. Gross margin water use efficiency (WUE_{GM})

The gross margin obtained from each unit of water can be expressed as the gross income water use efficiency (WUE_{GM}) and can be calculated by dividing the gross income by the seasonal evapotranspiration (ET) from the full surface during the growing season, *i.e.* bud break to harvest:

$$WUE_{GM} = \frac{\text{Gross margin}}{\text{Season } ET_{FS}} \qquad \text{(Eq. 9.6)}$$

where: WUE_{GM} = gross margin water use efficiency ($R.m^{-3}$)

Gross margin = gross income minus the experimental attributable and non-attributable costs per hectare ($R.ha^{-1}$)

Season ET_{FS} = seasonal evapotranspiration per hectare ($m^3.ha^{-1}$)

9.2.8. Statistical analyses

The data were subjected to an analysis of variance (ANOVA) by using Statgraphics®. Least significant difference (LSD) values were calculated to facilitate comparison between treatment means. Means, which differed at $p \leq 0.05$, were considered significantly different.

9.3. RESULTS AND DISCUSSION

9.3.1. Experimental attributable costs

9.3.1.1. Labour input requirements

In 2011/12, the highest irrigation frequency (T1) required more labour inputs to remove unwanted shoots (suckering) compared to those irrigated less frequently (T7) (Table 9.2). The tucking of shoots into the trellis was less time consuming where grapevines were irrigated less frequently compared to the more frequently irrigated ones (Table 9.2). More frequent irrigation also increased the time required for topping of growing shoots (Table 9.3). The reason for the high topping input requirements during the 2011/12 seasons was because during this season this action was performed by making use of hand secateurs, whereas in the other seasons hedge clippers were used.

Similarly, less shoots per grapevine increased topping inputs, since this practice stimulated more secondary growth. This was probably due to less competition between the lower number of shoots produced. Where grapevine canopies were manipulated similarly, the total summer canopy management input decreased when irrigations were less frequently applied (data not shown).

Although the summer canopy management inputs of non-suckered grapevines were lower, manual harvesting of non-suckered grapevines was more time consuming than for suckered grapevines (Table 9.3) as they bore more bunches per grapevine which had to be handled (Table 7.4). More frequently irrigated grapevines tended to required more pruning labour inputs compared to less frequently irrigated grapevines (Table 9.3). The sprawling grapevines tended to need higher labour inputs during winter pruning compared to those that had their shoots tucked into trellis wires.

The combined effects of the number of shoots per grapevine and mean shoot weight explained 81% of the variation in labour input requirement for winter pruning by means of multiple linear regression in the following equation:

$$LI_p = -78.40 + 4.40 \times n_{ps} + 2513.51 \times M_s \quad (R^2 = 0.8090;\ se = 13.9;\ p < 0.001) \qquad \text{(Eq. 9.7)}$$

where LI_p = labour input requirements during pruning (man hours.ha^{-1}),

n_{ps} = mean number of primary shoots per grapevine

M_s = mean mass per shoot (kg).

In the 2012/13 season, irrigation frequency did not affect the required labour inputs to remove unwanted shoots (Table 9.2). The tucking of shoots into the trellis wires was less time consuming where grapevines were irrigated less frequently compared to the more frequently irrigated ones (Table 9.2). More frequent irrigation also increased the time required for topping of growing shoots (Table 9.3). Where grapevine canopies were manipulated similarly, the total summer canopy management input decreased when irrigations were less frequently applied (data not shown). Although the summer canopy management inputs of non-suckered grapevines were lower, manual harvesting of these grapevines tended to be more time consuming than the harvesting of suckered grapevines (Table 9.3). This can be attributed to the fact that these grapevines bore more bunches per grapevine which had to be handled and made manual harvest difficult particularly in the case of open canopies. On a farm scale, the harvest input and cost could be reduced by mechanical harvesting. Sprawling canopy grapevines tended to require higher labour inputs for winter pruning compared to other canopy management practices within the same irrigation strategy (Table 9.3).

Table 9.2 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on labour input requirements for cleaning of trunks, suckering and tucking in of shoots during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Season	**Cleaning of trunks (man hours.ha^{-1})**									
2011/12	26.4 abc[1]	28.6 ab	31.2 a	26.4 abc	25.7 abc	22.2 c	26.4 abc	27.7 abc	23.3 bc	25.6 abc
2012/13	21.4 a	21.0 ab	18.9 abc	18.0 bcd	16.1 cde	16.5 cde	17.0 cde	12.9 f	14.6 ef	15.8 def
2013/14	23.5 ab	21.6 ab	25.3 a	21.8 ab	22.3 ab	21.3 ab	20.7 b	21.0 b	20.4 bc	16.6 c
2014/15	19.5 a	16.7 b	15.0 cd	19.9 a	15.3 bc	14.7 cd	17.6 b	15.8 b	13.9 d	13.6 d
Season	**Suckering (man hours.ha^{-1})**									
2011/12	82.5 a	-[2]	-[2]	71.3 b	-[2]	-[2]	61.6 c	-[2]	-[2]	-[2]
2012/13	87.4 a	-[2]	-[2]	75.3 a	-[2]	-[2]	83.7 a	-[2]	-[2]	-[2]
2013/14	75.8 a	-[2]	-[2]	57.6 b	-[2]	-[2]	50.0 b	-[2]	-[2]	-[2]
2014/15	72.9 a	-[2]	-[2]	71.1 a	-[2]	-[2]	68.2 a	-[2]	-[2]	-[2]
Season	**Tucking in of shoots (man hours.ha^{-1})**									
2011/12	222.3 a	239.7 a	-[3]	179.2 b	173.6 b	-[3]	134.6 c	131.6 c	-[3]	-[3]
2012/13	276.1 a	225.2 b	-[3]	154.1 c	162.4 c	-[3]	90.2 d	140.8 c	-[3]	-[3]
2013/14	175.9 abc	187.9 ab	-[3]	156.9 abc	205.3 a	-[3]	131.7 bc	125.8 c	-[3]	-[3]
2014/15	238.8 a	209.4 a	-[3]	143.3 b	151.0 b	-[3]	78.3 c	87.6 c	-[3]	-[3]

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).
[2] No suckering action was applied.
[3] No tucking of shoots into trellis wires was applied.

Table 9.3 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on the labour input requirements for topping of shoots, harvesting and winter pruning during the 2011/12, 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca*. 30% PAW depletion**			***ca*. 60% PAW depletion**			***ca*. 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Topping of shoots (man hours.ha^{-1})**									
2011/12	113.8 a[1]	107.7 ab	88.2 bc	86.8 bcd	73.2 cde	56.0 ef	64.6 def	48.6 f	50.9 ef	64.2 def
2012/13	31.9 a	30.3 a	33.3 a	20.1 b	14.3 bc	21.2 b	12.1 c	8.6 c	9.4 c	8.1 c
2013/14	72.3 a	59.4 ab	75.1 a	60.8 ab	53.8 b	43.0 b	14.9 c	21.4 c	14.9 c	12.8 c
2014/15	29.7 ab	28.2 b	31.0 a	18.7 c	13.3 d	19.7 c	11.3 d	8.0 e	8.7 e	8.7 e
Season	**Harvesting by hand (man hours.ha^{-1})**									
2011/12	148.2 de	231.8 b	209.0 bc	117.5 e	165.9 cde	126.1 e	141.9 de	170.8 cde	201.3 bcd	307.7 a[2]
2012/13	180.4 cd	218.7 bc	201.2 bcd	173.8 d	188.1 bcd	223.8 b	176.2 d	211 bcd	185.6 bcd	446.9 a
2013/14	184.5 bcd	232.8 b	203.5 bc	186.2 bcd	206.8 bc	195.9 bcd	168.7 cd	173 cd	146.3 d	349.7 a
2014/15	137.8 cd	194.4 b	215.6 b	109.3 e	154.3 c	145.4 c	132 cde	140.2 cd	117.3 de	399.9 a
Season	**Winter pruning (man hours.ha^{-1})**									
2011/12	140.4 b	145.4 b	180.9 a	130.9 b	132.7 b	141.4 b	99.7 c	128.0 b	132.4 b	203.2 a[3]
2012/13	83.1 bcde	116.8 a	99.3 abc	57.9 e	104.2 ab	78.1 bcde	56.9 e	70.4 cde	61.7 de	88 abcd
2013/14	149.0 ab	160.1 ab	177.2 a	126.2 abc	112.8 bcd	133.2 abc	69.3 d	87.2 cd	93.8 cd	96.7 cd
2014/15	88.2 cd	131.4 a	123.5 ab	74.1 de	97.2 c	105.6 bc	58.1 e	75.7 de	78.6 d	70.8 de

(1) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).
(2) Harvested by hand. On a commercial scale this action would be applied mechanically.
(3) Pruned by hand. On a commercial scale this action could be applied mechanically.

Grapevines irrigated at *ca*. 30% PAW depletion required more labour to remove unwanted shoots, compared to those irrigated at *ca*. 60% and *ca.* 90% PAW depletion in the 2013/14 season (Table 9.2). In this season, tucking in of shoots was less time consuming where grapevines were irrigated at *ca*. 90% PAW depletion compared to the more frequently irrigated ones (Table 9.2). Non-suckered grapevines irrigated at *ca*. 30% and *ca*. 60% PAW depletion required more inputs during the tucking in of shoots than the suckered VSP ones (Table 9.2). More frequent irrigation also tended to increase the time required for topping of actively growing shoots. (Table 9.3). Although the summer canopy management labour inputs of non-suckered grapevines were lower, manual harvesting of these grapevines tended to be more time consuming than the harvesting of suckered grapevines (Table 9.3). This can be attributed to the fact that non-suckered grapevines bore more bunches per grapevine that had to be picked. Furthermore, the additional shoots tucked into the trellis was an obstruction when the grapes of the non-suckered grapevine were harvested. Likewise, open canopies made manual harvesting difficult, but to a lesser extent where grapevines were irrigated at *ca*. 90% PAW depletion (Table 9.3). In practice, harvest labour input, and subsequently cost, could be reduced by mechanical harvesting. Sprawling canopy grapevines tended to require higher labour inputs for winter pruning compared to other canopy management practices within the same irrigation strategy (Table 9.3).

In the 2014/15 season, the time taken to remove unwanted shoots from trunks, as well as cordons of suckered grapevines was similar for all three irrigation depletion levels (Table 9.2). Tucking in of shoots was less time consuming as level of PAW depletion increased (Table 9.2). The suckering action, however, did not result in a lower input requirement for tucking in of shoots within the same irrigation strategy (Table 9.2). More frequent irrigation also tended to increase the time required for topping of growing shoots (Table 9.3). Although the summer canopy management labour inputs of non-suckered grapevines were lower, manual harvesting of these grapevines tended to be more time consuming than the harvesting of suckered grapevines (Table 9.3). This can be attributed to the fact that non-suckered grapevines bore more bunches per grapevine that had to be handled and the obstructions created by the extra shoots tucked into the trellis wires being. Likewise, open canopies made manual harvesting difficult, but to a lesser extent when irrigated at *ca*. 90% PAW depletion. At the farm level, harvest labour input, and subsequently cost, could be reduced by mechanical harvesting. Grapevines with un-suckered canopies tended to require higher labour inputs for winter pruning, compared to other canopy management practices within the same irrigation strategy (Table 9.3).

9.3.1.2. Viticultural labour input costs

All labour costs were calculated based on the minimum wage for 2013 of R12.41 per hour. The reason for the use of this specific year's minimum wage rate was due to the fact that wine prices, and thus grape price point payouts for the same period, were supplied by wineries in Robertson and was to be utilised during the gross margin analyses.

The total annual canopy management labour cost, *i.e*. viticultural labour inputs, within the same canopy management practice decreased with an increase in level PAW depletion, *i.e*. less frequently irrigated required less labour inputs (Table 9.4). Within the same irrigation strategy, the total viticultural labour costs were lowest for sprawling canopy grapevines and highest for suckered VSP grapevines (Table 9.4). There were no substantial differences between the labour costs of the seasons, with sprawling canopy grapevines being the most economical management option.

9.3.1.3. Irrigation cost breakdown

As expected, pump costs increased with an increase in irrigation frequency (Table 9.4). However, the differences between the highest and lowest pumping cost per hectare was *ca*. R1 400, *ca*. R1 600 and *ca*. R1 100 for the 2012/13, 2013/14 and 2014/15 seasons, respectively. Pumping costs made out a smaller fraction of the total experimental attributable costs that the viticultural labour input cost.

9.3.1.4. Grape transport cost

Within the scenario used in the study, transport costs did not differ substantially across the treatments and was marginally higher during the 2013/14 season (Table 9.4). Transport costs made out only *ca*. 5% and *ca* 10% of the total experimental attributable costs.

Table 9.4 The mean experimental attributable costs of ten different irrigation strategy and canopy management combinations applied to Shiraz/110R grapevines during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca.* 60% PAW depletion			*ca.* 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Experimental attributable costs (R.ha^{-1})										
2012/13 season										
Viticultural labour inputs	R8 438 a[(1)]	R7 557 ab	R4 343 e	R6 275 cd	R6 026 cd	R4 205 ef	R5 435 d	R5 556 d	R3 367 f	R6 898 b
Pump cost (electricity)	R2 057 b	R2 169 a	R2 169 a	R1 432 d	R1 495 c	R1 373 e	R809 f	R809 f	R809 f	R809 f
Grape transport cost	R611 ab	R676 a	R611 ab	R579 bc	R611 ab	R579 bc	R514 cd	R514 cd	R481 d	R546 bcd
Total	**R11 106 a**	**R10 401 a**	**R7 123 c**	**R8 286 b**	**R8 131 b**	**R6 157 d**	**R6 758 cd**	**R6 879 cd**	**R4 657 e**	**R8 254 b**
2013/14 season										
Viticultural labour inputs	R7 766 a	R7 533 a	R5 970 bc	R6 860 ab	R6 369 b	R4 883 de	R5 022 cde	R4 768 e	R3 417 f	R5 903 bcd
Pump cost (electricity)	R2 046 a	R2 046 a	R2 046 a	R1 619 b	R1 619 b	R1 619 b	R488 d	R488 d	R488 d	R506 c
Grape transport cost	R643 ab	R708 a	R643 ab	R676 ab	R676 ab	R611 bc	R611 bc	R546 cd	R481 d	R643 ab
Total	**R10 455 a**	**R10 287 a**	**R8 660 b**	**R9 154 b**	**R8 664 b**	**R7 113 c**	**R6 122 cd**	**R5 803 d**	**R4 387 e**	**R7 052 c**
2014/15 season										
Viticultural labour inputs	R7 284 a	R7 199 a	R4 778 d	R5 416 c	R5 351 c	R3 542 f	R4 534 de	R4 062 e	R2 708 g	R6 118 b
Pump cost (electricity)	R1 843 a	R1 843 a	R1 843 a	R1 432 b	R1 432 b	R1 432 b	R704 c	R704 c	R704 c	R704 c
Grape transport cost	R611 bcd	R676 b	R773 a	R579 cde	R643 bc	R611 bcd	R514 ef	R449 fg	R417 g	R546 de
Total	**R9 739 a**	**R9 718 a**	**R7 394 b**	**R7 427 b**	**R7 426 b**	**R5 585 cd**	**R5 752 c**	**R5 215 d**	**R3 829 e**	**R7 368 b**

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

9.3.2. Non-experimental attributable costs

The same total non-experiment dependent costs of R9 300 per hectare were used for all the treatments (Table 9.5).

Table 9.5 The non-experimental attributable costs for the production of wine grapes in the Breede River Valley region according to the VinPro Cost Guide 2014/15[(1)].

Non-experimental attributable costs	
Specific input	**Cost ($R.ha^{-1}$)**
Fertilizers and organic material	R2 210
Pest and disease control	R2 057
Herbicide	R651
Repair and maintenance cost	R325
Water cost	R984
Pest management and irrigation labour	R993
Mechanisation	R2 080
Total	**R9 300**

[(1)] According to Van Niekerk and Van Zyl (2014).

9.3.3. Potential commercial wine classification and price point per tonne of grapes produced

The different price points per wine class category was calculated using eg. 9.5 and the different prices given in Table 9.6.

Table 9.6 Four different Shiraz wine class categories, descriptions and calculated price per ton of grapes paid to producers in the Robertson area during 2012/13 season.

Wine class category	Description of wine class	Price per tonne of grapes ($R.ton^{-1}$)
Class 1	Specially selected single vineyard wine	R5 400
Class 2	Single cultivar wine	R3 790
Class 3	Dry red blend wine	R2 600
Class 4	Rosé	R1 620

A good relationship was found between the potential wine commercial class that was determined during the wine evaluation in December 2013 held in Robertson, and the sensorial wine quality evaluation held in Stellenbosch in August 2013 (Fig.9.1). Wine price class was class 4 if the mean sensorial overall wine quality was ≤ ca.37%, class 3 between *ca*.37% and *ca*. 52%, class 2 between *ca*.52% and *ca.* 67% and class 1 above *ca.* 67%.

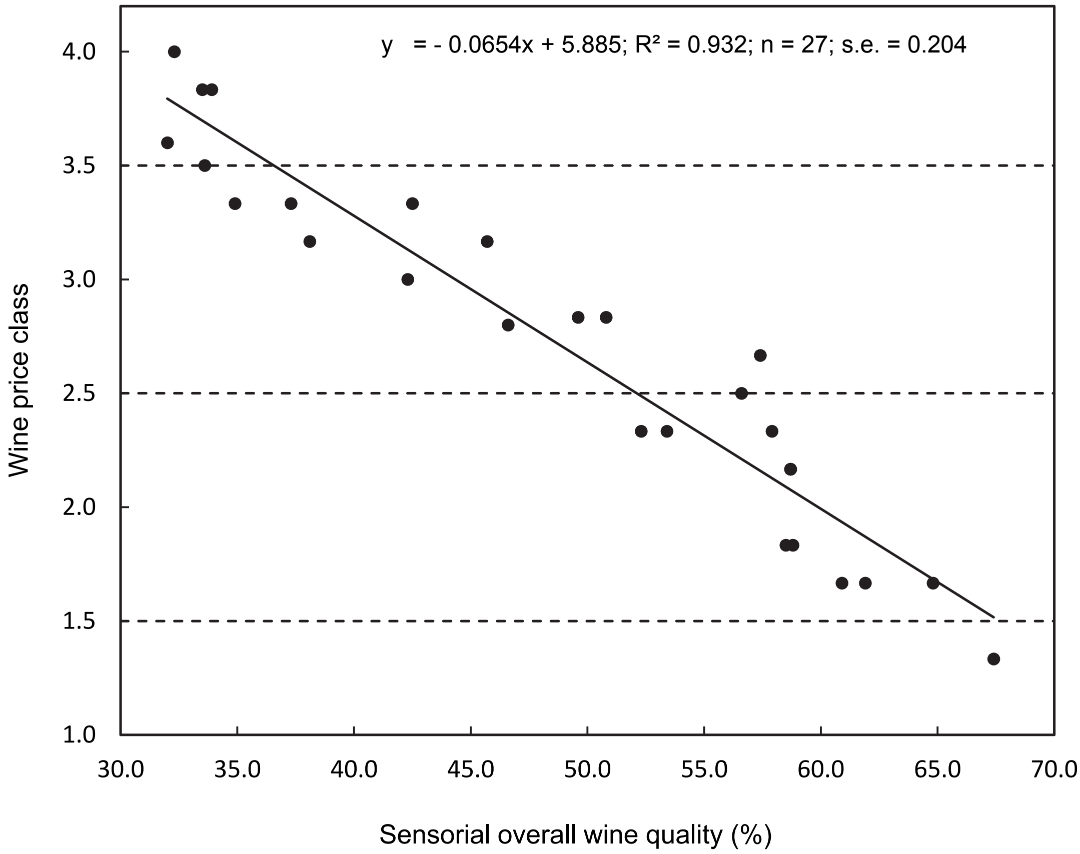

Figure 9.1 Relationship between potential commercial wine class and sensorial overall wine quality of micro-vinified Shiraz from the 2012/13 season near Robertson.

Higher frequency irrigation applications resulted in wines within a higher potential commercial wine class, thus with a lower price point per tonne of grapes during the 2012/13 and 2014/15 seasons (Table 9.7). However, during the 2013/14 season wine classification was similar for all the treatments regardless of the irrigation strategy and/or canopy manipulation applied. This was due to the exceptionally high rainfall during the season, and particularly during ripening (Appendix A). The overall wine quality within the region was expected to be poorer for the 2013/14 vintage (B. Stipp, personal communication, 2014).

Table 9.7 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on the potential commercial wine classification and variation in gross income per tonne of grapes for Shiraz/110R.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Season	**Potential commercial wine score[1]**									
2012/13	3.4 ab[2]	3.7 a	3.1 bc	2.6 cd	3.7 a	2.3 de	2.7 cd	1.9 e	2.0 e	2.0 e
2013/14	3.5 bc	3.3 bcd	3.4 bc	3.9 a	3.6 ab	3.4 bc	3.0 d	3.0 d	3.1 cd	3.0 d
2014/15	2.9 b	3.5 a	3.0 b	2.9 b	2.8 b	2.3 cd	2.4 c	2.3 cd	2.0 d	2.2 cd
Season	**Gross income per tonne of grapes (R.ton^{-1})**									
2012/13	R 2 602[3]	R 1 623	R 2 602	R 2 602	R 1 623	R 3 791	R 2 602	R 3 791	R 3 791	R 3 791
2013/14	R 1 623	R 2 602	R 2 602	R 1 623	R 1 623	R 2 602	R 2 602	R 2 602	R 2 602	R 2 602
2014/15	R 2 602	R 1 623	R 2 602	R 2 602	R 2 602	R 3 791	R 3 791	R 3 791	R 3 791	R 3 791

(1) Different wine classes are presented in Tables 9.1 and 9.6.
(2) Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).
(3) No statistical analysis was performed on this data as this was based on mean potential commercial wine class and the expected price per tonne of grapes presented in Table 9.6 .

9.3.4. Gross margin analyses

The grapevines irrigated at *ca*. 60% PAW depletion with sprawling canopies tended to generate the highest gross income calculated from the yield and price point per tonne of grapes (Tables 9.8 to 9.10). Due to the generally poorer wine quality produced by all the treatments during the 2013/14 season (Table 9.7), the gross income was affected the predominantly by the differences in the yields produced and the highest gross income was obtained by grapevines with non-suckered VSP canopies and irrigated at *ca*. 30% PAW depletion (Table 9.9).

The total experimental attributable costs was increased by the application of suckering and tucking in of shoots into trellis wires, as well as higher irrigation frequencies (Tables 9.8 to 9.10).

During seasons with low to normal rainfall, grapevines with sprawling canopies that were irrigated at *ca*. 60% PAW depletion produced the highest gross margins, followed by box pruned grapevines irrigated at *ca*. 90% PAW depletion (Tables 9.8 & 9.10). In the season that was characterised by high summer rainfall, box pruned grapevines irrigated at *ca*. 90% PAW depletion, as well as non-suckered VSP canopies irrigated at *ca*. 30% PAW depletion had the highest gross margins (Table 9.9). The gross incomes related well when it was correlated to the gross margins, indicating that a specific treatment combination's gross margin was strongly dependent on the gross income (Fig. 9.2). Thus, in normal rainfall seasons grapevines with sprawling canopies, particularly those irrigated *ca*. 60% PAW depletion, produced the best balance between yield and quality, thereby insuring the best gross margin.

Table 9.8 The gross margin analysis of ten different irrigation strategy and canopy management combinations applied to Shiraz/110R grapevines during the 2012/13 season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Gross production value ($R.ha^{-1}$)										
Gross income	R44 313 cd[(1)]	R38 213 d	R61 765 ab	R56 306 abc	R37 107 d	R71 258 a	R49 721 bcd	R61 413 ab	R48 022 bcd	R66 152 a
Total experimental attributable cost	R11 106 a	R10 401 a	R7 123 c	R8 286 b	R8 131 b	R6 157 d	R6 758 cd	R6 879 cd	R4 657 e	R8 254 b
Total non-experimental attributable cost	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300
Total expenses	-R20 406 a	-R19 701 a	-R16 423 c	-R17 586 b	-R17 431 b	-R15 457 d	-R16 058 cd	-R16 179 cd	-R13 957 e	-R17 554 b
Gross margin ($R.ha^{-1}$)	**R23 906 cd**	**R18 512 d**	**R45 343 ab**	**R38 720 bc**	**R19 675 d**	**R55 801 a**	**R33 662 bcd**	**R45 233 ab**	**R34 065 bcd**	**R48 599 ab**

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 9.9 The gross margin analysis of ten different irrigation strategy and canopy management combinations applied to Shiraz/110R grapevines during the 2013/14 season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Gross production value (R.ha^{-1})										
Gross income	R53 507 abc[(1)]	R62 292 a	R54 299 abc	R40 549 c	R40 853 c	R47 832 abc	R52 311 abc	R43 146 bc	R40 529 c	R60 220 ab
Total experimental attributable cost	R10 455 a	R10 287 a	R8 660 b	R9 154 b	R8 664 b	R7 113 c	R6 122 cd	R5 803 d	R4 387 e	R7 052 c
Total non-experimental attributable cost	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300
Total expenses	-R19 755 a	-R19 587 a	-R17 960 b	-R18 454 b	-R17 964 b	-R16 413 c	-R15 422 cd	-R15 103 d	-R13 687 e	-R16 352 c
Gross margin (R.ha^{-1})	**R33 752 ab**	**R42 705 a**	**R36 339 ab**	**R22 095 b**	**R22 889 b**	**R31 420 ab**	**R36 889 ab**	**R28 043 ab**	**R26 842 ab**	**R43 867 a**

[(1)] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

Table 9.10 The gross margin analysis of ten different irrigation strategy and canopy management combinations applied to Shiraz/110R grapevines during the 2014/15 season near Robertson.

	Treatment number									
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**
	Irrigation strategy									
	***ca.* 30% PAW depletion**			***ca.* 60% PAW depletion**			***ca.* 90% PAW depletion**			
	Canopy management applied									
	Suckered and shoots tucked in	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Suckered and shoots tucked in**	**Shoots tucked in**	**Sprawling canopy**	**Mechanical/ Box pruned**
Gross production value (R.ha^{-1})										
Gross income	R54 533 cde[1]	R55 834 cde	R79 597 ab	R47 431 def	R59 343 cd	R81 637 a	R44 919 ef	R43 958 ef	R36 968 f	R66 895 bc
Total experimental attributable cost	R9 739 a	R9 718 a	R7 394 b	R7 427 b	R7 426 b	R5 585 cd	R5 752 c	R5 215 d	R3 829 e	R7 368 b
Total non-experimental attributable cost	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300	R9 300
Total expenses	-R19 039 a	-R19 018 a	-R16 694 b	-R16 727 b	-R16 726 b	-R14 885 cd	-R15 052 c	-R14 515 d	-R13 129 e	-R16 668 b
Gross margin (R.ha^{-1})	**R35 494 de**	**R36 816 cde**	**R62 903 ab**	**R30 705 de**	**R42 617 cd**	**R66 752 a**	**R29 867 de**	**R29 443 de**	**R23 839 e**	**R50 226 bc**

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

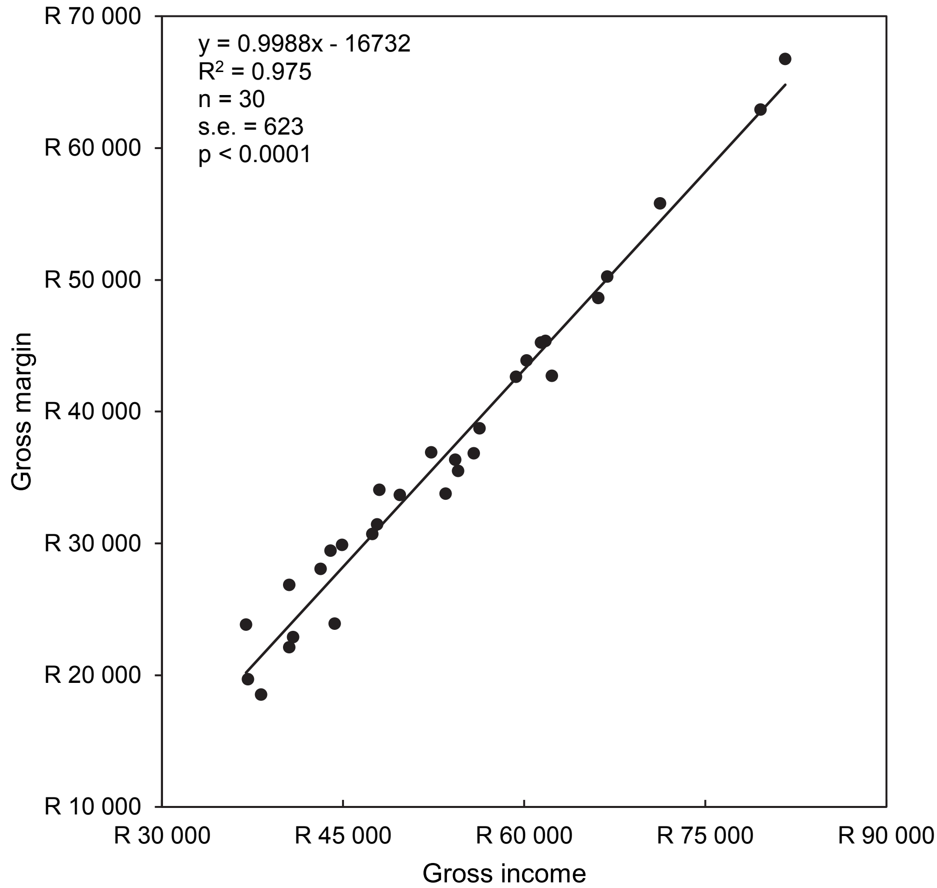

Figure 9.2 Relationship between mean gross margin and the mean gross income of different irrigation strategies and canopy manipulation combinations during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

9.3.5. Gross margin water use efficiency

The WUE_{GM} increased with a decrease in irrigation frequency in the 2012/13 and 2014/15 seasons (Table 9.11). Where grapevines were irrigated at *ca*. 30% and *ca*. 60% PAW depletion, those with sprawling canopies tended to result in higher WUE_{GM}. The lower WUE_{GM} obtained by the grapevines irrigated at *ca*. 60% PAW depletion during the 2013/14 season can be attributed to the poorer wine quality, compared to that of the other seasons, resulting in lower gross income per tonne of grapes. The box pruned grapevines irrigated at *ca*. 90% PAW depletion consistently produced the highest WUE_{GM}.

Table 9.11 The effect of irrigation at specific plant available water (PAW) depletion levels and different canopy management practices on the gross margin water use efficiency (WUE_{GM}) of Shiraz/110R grapes during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

	Treatment number									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
	Irrigation strategy									
	ca. 30% PAW depletion			*ca*. 60% PAW depletion			*ca*. 90% PAW depletion			
	Canopy management applied									
	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Suckered and shoots tucked in	Shoots tucked in	Sprawling canopy	Mechanical/ Box pruned
Season	WUE_{GM} ($R.m^{-3}$)									
2012/13	4.17 de	3.23 e	7.84 de	8.82 cd	4.47 de	13.23 bc	13.7 b	18.85 a	13.08 bc	19.57 a
2013/14	5.44 e	6.90 cde	5.82 e	4.34 e	4.37 e	6.07 de	13.81 ab	10.60 bc	10.11 bcd	16.31 a
2014/15	6.8 d	7.06 d	7.15 d	11.45 cd	11.94 cd	12.67 cd	13.76 bc	19.41 b	19.54 b	34.28 a

[1] Values designated by the same letter within each row do not differ significantly ($p \leq 0.05$).

9.4. CONCLUSIONS

Less frequent irrigations reduced summer canopy management requirements. However, grapevines bearing more shoots required higher labour inputs at harvest. Pruning labour input requirements seems to be affected by the number of shoots produced per grapevine, as well as mass per individual shoot. Within the same irrigation strategy, sprawling canopy grapevines tended to require more labour inputs during winter pruning, compared to other canopy management practices. The total seasonal canopy management labour inputs decreased as the volume of irrigation water applied decreased. Sprawling canopy grapevines generally required less labour costs. Pump costs were affected by the frequency of irrigation applications, while transport costs of grapes differed minimally between treatments.

During seasons with low to normal rainfall, grapevines with sprawling canopies that were irrigated at *ca*. 60% PAW depletion produced the highest gross margins, followed by box pruned grapevines irrigated at *ca*. 90% PAW depletion. In seasons characterised by high summer rainfall, box pruned grapevines irrigated at *ca*. 90% PAW depletion, as well as non-suckered VSP canopies irrigated at *ca*. 30% PAW depletion had the highest gross margins. This was due to the gross margin being strongly determined by the gross income. In general, grapevines with sprawling canopies, particularly those irrigated *ca*. 60% PAW depletion, produced the best balance between yield and quality, thereby ensuring the best gross margin. The WUE_{GM} increased with an increase in PAW depletion level, *i.e.* a decrease in irrigation water applied, with box pruned grapevine consistently having the highest WUE_{GM}.

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CHAPTER 10: GENERAL CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH

10.1. GENERAL CONCLUSIONS

Irrigation applied at low PAW depletion levels more than doubled irrigation volumes compared to grapevines irrigated at high PAW depletion levels. Due to accelerated sugar accumulation which resulted in different harvest dates, canopy management practice indirectly reduced pre-harvest irrigation volumes. In the area in which the field experiment was done, grapevines will need irrigation applications until *ca*. May that follows the growing season. Even though grapevines received the irrigation at the same depletion level during the post-harvest period, grapevines irrigated at low frequencies during the season had lower irrigation requirement compared to those irrigated at higher frequencies.

Under the given conditions, the different canopy manipulations did not affect total leaf area per grapevine within an irrigation strategy. Non-suckered grapevines produced more shoots, which increased the number of bunches per grapevine, compared to suckered ones. More frequent irrigation of grapevines caused more vigorous shoot growth. Within the same irrigation strategy, non-suckered VSP grapevines tended to produce lower cane mass compared to suckered VSP and sprawling canopy grapevines. The LA_{CPS} give a better indication of canopy orientation, -volume and -density than the LAI alone. By measuring the plant spacing, canopy width and PAR interception, the LA_{CPS} can be estimated. Winter pruned cane mass can be estimated by non-destructive measurements of primary and secondary shoots. This would enable a viticulturist, producer or irrigation consultant to use the VINET model in during ripening to predict grapevine water requirements.

Mid-day Ψ_L and Ψ_S in grapevines within the same irrigation strategy did not differ, irrespective of the canopy manipulations applied. However, sprawling canopy grapevines tended to have lower mid-day Ψ_L and Ψ_S than the VSP grapevines. Grapes on grapevines subjected to severe water constraints ripened more rapidly than those experiencing no or medium water constraints. Low frequency irrigation, *i.e.* 90% PAW depletion, increased grapevine water constraints compared to high frequency irrigation, *i.e.* 30% PAW depletion. Results from the diurnal Ψ_L cycles showed that grapevines with sprawling canopies tended to have lower Ψ_L than the VSP grapevines after 18:00 and throughout the night. This indicated that the water status in the sprawling canopy grapevines could not recover during the night to the same extent as VSP grapevines.

Grapevines subjected to severe water constraints ripened their grapes more rapidly than those experiencing no or medium water constraints. Furthermore, grapes of sprawling canopy grapevines ripened more rapidly compared to VSP grapevines within the same level of PAW depletion. With the exception of mechanically pruned grapevines, irrigation frequency had a more pronounced impact on yield than canopy manipulation. It was evident that the higher rainfall in 2013/14 increased vegetative growth and yield compared to previous seasons. Low frequency irrigations resulted in higher WUE_P compared to medium and high frequency irrigation. Within a given canopy management practice, level of PAW depletion did not affect the percentage of sunburnt berries. In addition to this, there were also more sunburnt berries on the sprawling canopy grapevines within a given level of PAW depletion. Results showed that the incidence of grey rot was substantially higher during the wetter season of 2013/14.

Higher irrigation frequencies resulted in higher ET_{GR} losses, while losses from under sprawling canopies, particularly those irrigated at *ca*. 30% PAW depletion, tended to be higher in February than those with VSP canopies. The ET_{WR} increased in periods that followed rainfall incidences and was much lower than the ET_{GR}. Due to this fact the monthly ET_{FS} was much lower than the monthly ET_{GR}. The seasonal ET_{FS} was more sensitive to irrigation frequency than to different canopy manipulations. The diurnal and cumulative E_s losses under grapevines with sprawling canopies was lower than under VSP grapevines, irrespective of the level of PAW depletion. As higher mean leaf area per grapevine caused by more frequent irrigations caused denser canopies surface. The 0 to 300 mm SWC of treatments irrigated at *ca*. 30% PAW depletion were always in stage 1 of evaporation, while that of grapevines irrigated at *ca*. 60% PAW depletion occasionally went into stage 2, particularly that of the sprawling canopy. The water content of soil under grapevines irrigated at *ca*. 90% PAW depletion spend most of the season in stage 2. The C_f of the sprawling canopies was lower than that of the VSP grapevines, irrespective of PAW depletion. Less frequent irrigation decreased LA_{CPS} of experimental grapevines and increased the evaporation C_f.

During the three seasons, the mean K_c for grapevines that were irrigated at *ca*. 30% PAW depletion were higher compared to those of other strategies, with those irrigated at *ca*. 90% PAW depletion being the lowest. Grapevines irrigated particularly at *ca*. 30% and 60% PAW depletion, treatments with sprawling canopies tended to have higher K_c values during ripening than those with VSP canopies. The mean peak K_c was generally obtained in February of the experimental seasons for grapevines that were irrigated at *ca*. 30% PAW depletion, while the lowest K_c was found during the same period at *ca*. 90% PAW depletion irrigations. Because drip irrigation system only wet the soil volume partially during irrigation applications, the $K_{c,GR}$ would be a more realistic coefficient for producers and consultants in the scheduling of irrigation requirement. The transpiration losses determined during ripening show that as irrigation frequency increased so did transpiration losses, with sprawling canopies tending to be higher than VSP grapevines. Higher frequency irrigation increased the fK_e, whereas lower frequency irrigation increased the fK_{cb}. Compared to measured values, the VINET model generally underestimated ET when higher irrigation frequencies were applied, whereas it overestimated ET when very low frequency to no irrigation were applied. Transpiration of grapevines could be split into vertical canopy and sprawling canopy groups when related to the LA_{CPS}.

Grapes were harvested as close to the target TSS level of 24ºB as possible. Where severe water constraints enhanced berry maturation, juice TTA was higher and pH lower compared to grapes that were harvested later. Within a given PAW depletion level, canopy manipulations did not affect juice TTA contents. Irrigation applied at a higher PAW depletion level, *i.e. ca.* 90%, improved overall wine quality compared to more frequent irrigation. Within the lower levels of PAW depletion levels, *i.e. ca.* 30% and *ca.* 60%, non-suckered VSP grapevines produced wines of the poorest overall quality. Highest overall wine quality was obtained where non-suckered VSP, sprawling canopy and mechanically pruned grapevines were irrigated at *ca.* 90% PAW depletion. Wine alcohol content, pH, K, malic and tartaric acids and polyphenol concentrations were not affected by level of PAW depletion or canopy management practice.

Less frequent irrigations reduced summer canopy management requirements. However, grapevines bearing more shoots required higher labour inputs at harvest. Pruning labour input requirements seems to be affected by the number of shoot produced per grapevine and the individual mass per shoot. Within the same irrigation strategy, sprawling canopy grapevines tended to require more labour inputs during winter pruning, compared to other canopy management practices. The total seasonal canopy management labour inputs decreased as the volume of irrigation water applied decreased. Sprawling canopy grapevines generally required less labour costs. Pump costs were affected by the frequency of irrigation applications, while transport costs of grape differed minimally between treatments. During seasons with low to normal rainfall, grapevines with sprawling canopies that were irrigated at *ca*. 60% PAW depletion produced the highest gross margins, followed by box pruned grapevines irrigated at *ca*. 90% PAW depletion. In seasons characterised by high summer rainfall, box pruned grapevines irrigated at *ca*. 90% PAW depletion, as well as non-suckered VSP canopies irrigated at *ca*. 30% PAW depletion would have highest gross margins. This was due to the gross margin being strongly determined by the gross income. In general, grapevines with sprawling canopies, particularly those irrigated *ca*. 60% PAW depletion, produced the best balance between yield and quality, thereby insuring the best gross margin. The WUE_{GM} increased with an increase in PAW depletion level, *i.e.* a decrease in irrigation water applied, with box pruned grapevine consistently having the highest WUE_{GM}.

10.2. RECOMMENDATIONS

Based on the project results, the following criteria should be considered when deciding on what irrigation and canopy management strategies to apply to vineyards:

(i) Since irrigation at high frequencies increased yield substantially, it can be recommended under comparable conditions if high grape yields are the objective, *i.e*. if producers are not compensated for higher quality, irrigation should be applied at *ca*. 30% to *ca*. 60% PAW depletion;

(ii) Since irrigation at lower frequencies increased wine colour and quality substantially, it can be recommended under comparable conditions where the objective is to produce good wine quality or to minimize viticultural labour inputs, irrigation should be applied at *ca*. 80% to *ca*. 90% PAW depletion;

(iii) Low frequency irrigation can be applied to enhance berry ripening, thereby also obtaining higher juice TTA;

(iv) Sprawling canopy grapevines might not be suitable for cultivars that are susceptible to sunburn, particularly if irrigation is applied at a low frequency. Under such conditions it would be preferable to tuck shoots into trellis wires;

(v) Sprawling canopy grapevines might not be suitable for cultivars, *i.e*. Chenin blanc, that are very susceptible to rot, particularly if grapevines have low cordon heights (lower than 1.2 m) and irrigation is applied at a high frequency;

(vi) In summer rainfall regions, higher trained cordons should be established if grapevines are not suckered and shoots left to sprawl to decrease the incidence of rot; and

(vii) Considering the gross margin analyses, the most consistent economically viable production of red wine grapes in the Robertson area would be when grapevines are not suckered, shoots left to sprawl open and where irrigation is applied at *ca*. 60% PAW depletion or alternatively, grapevines box pruned and irrigated at *ca*. 90% PAW depletion.

10.3. FUTURE RESEARCH

Although the research project has yielded novel, important information on the combined effects of irrigation and canopy management practices on vegetative growth, yield, juice and wine characteristics as well as profitability, there are still aspects that need to be investigated such as:

(i) The response of different cultivars;

(ii) Responses under different climatic conditions and different soil types;

(iii) Grapevine physiology, *i.e.* photosynthesis and transpiration responses;

(iv) Canopy micro-climate conditions of differently irrigated grapevines;

(v) Evaporation from the soil surface of different soils to determine the β-values of different textured soils;

(vi) 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;

(vii) Effects of level of PAW depletion on mechanical pruning with regard to grapevine physiology, as well as vegetative growth, yield and wine quality; and

(viii) Future irrigation modelling should include different canopy orientations and that of mechanical pruning grapevines.

APPENDIX A: THE MONTHLY SUMMER RAINFALL FROM 1900 UNTIL 2015 FOR THE ROBERTSON AREA

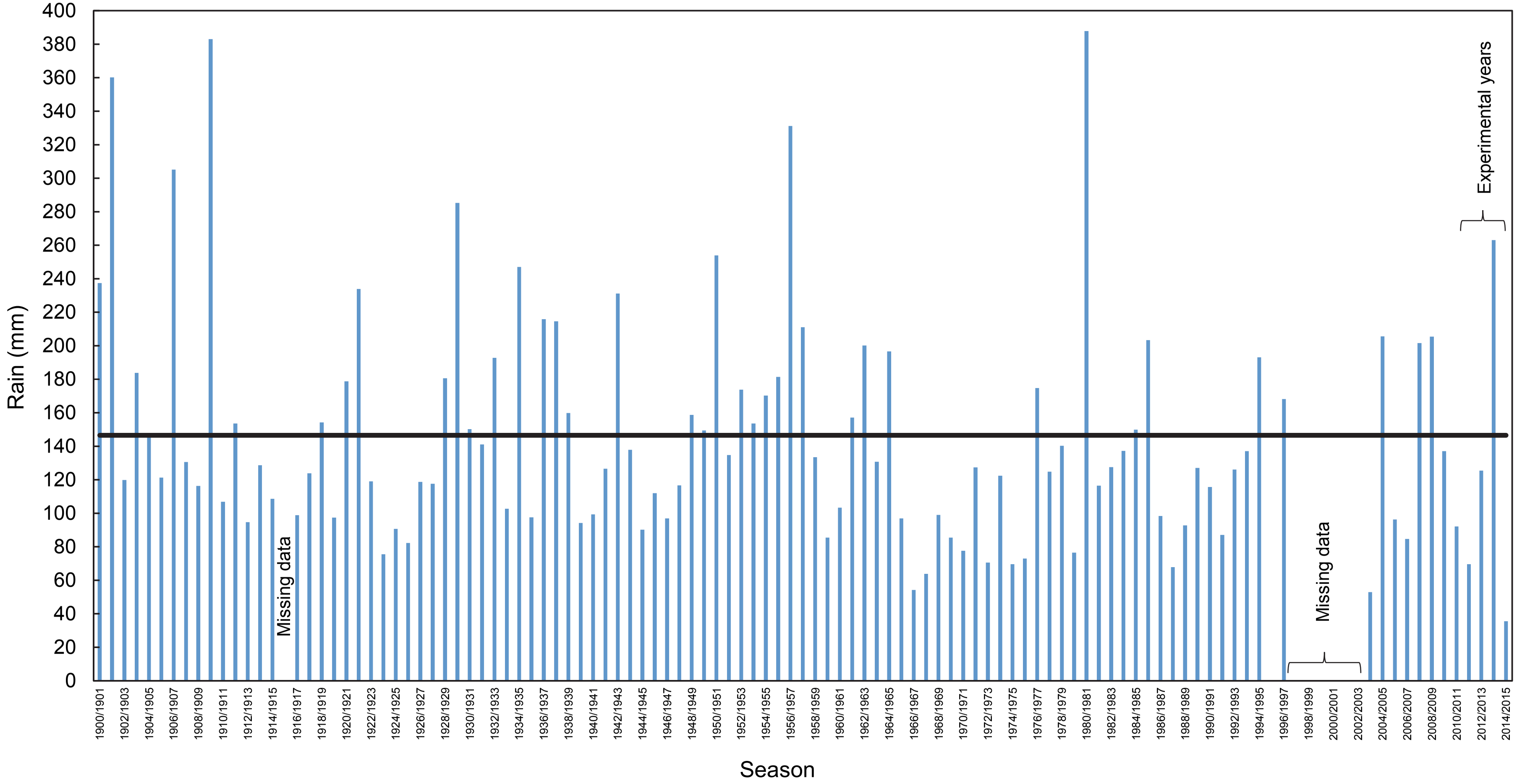

Figure A.1 The monthly rainfall for September to March (*ca*. Shiraz growing season, *i.e.* bud break until harvest) from 1900 until 2015 for Robertson. No data was available for 1915 and 1995, as well as 1998 to 2003. The long term mean (LTM) rainfall is presented by the black line.

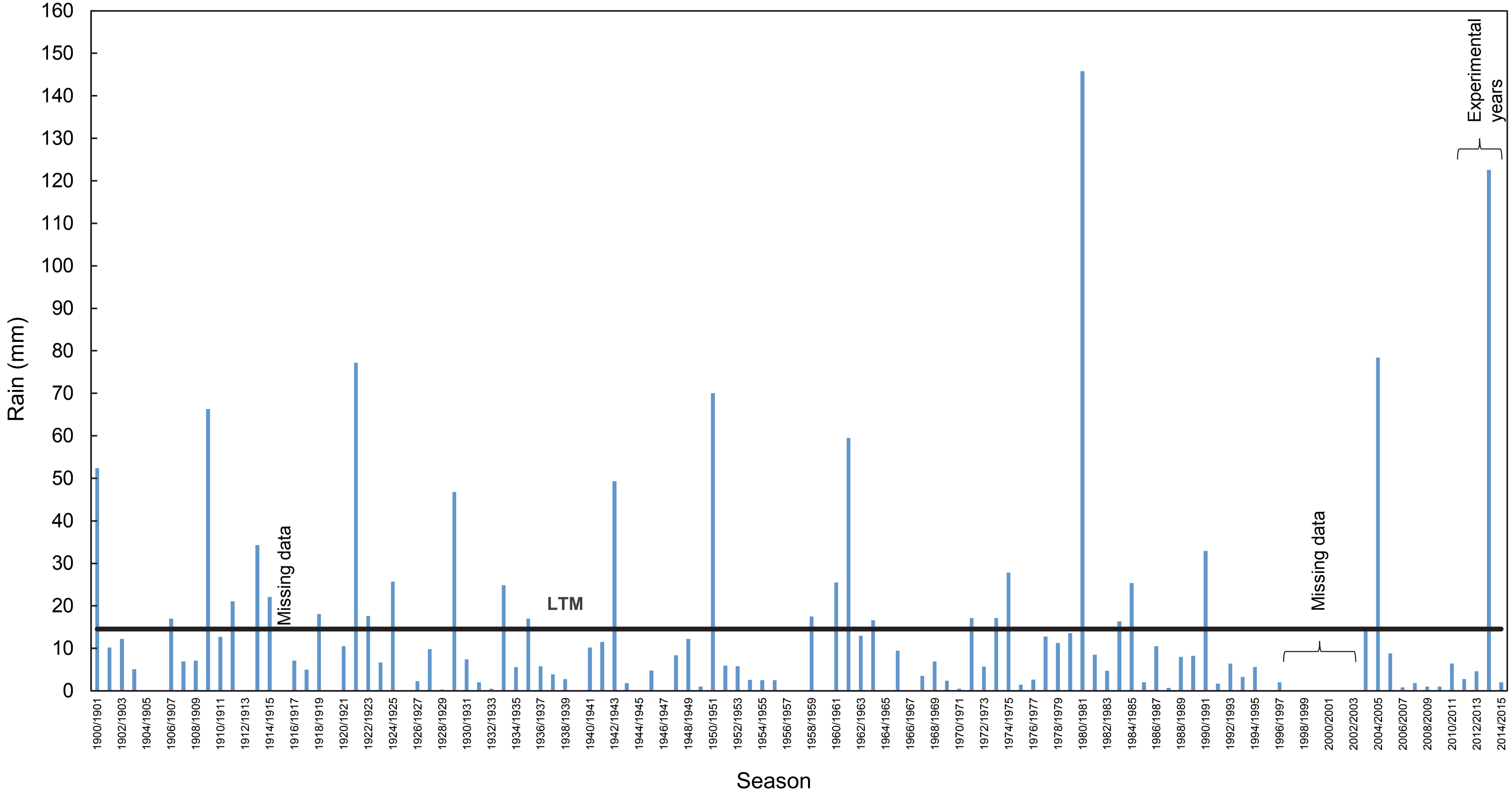

Figure A.2 The monthly rainfall for January (*ca*. Shiraz véraison, *i.e.* start of ripening) from 1901 until 2015 for Robertson. No data was available for 1915 and 1995, as well as 1998 to 2003. The long term mean (LTM) rainfall is presented by the black line.

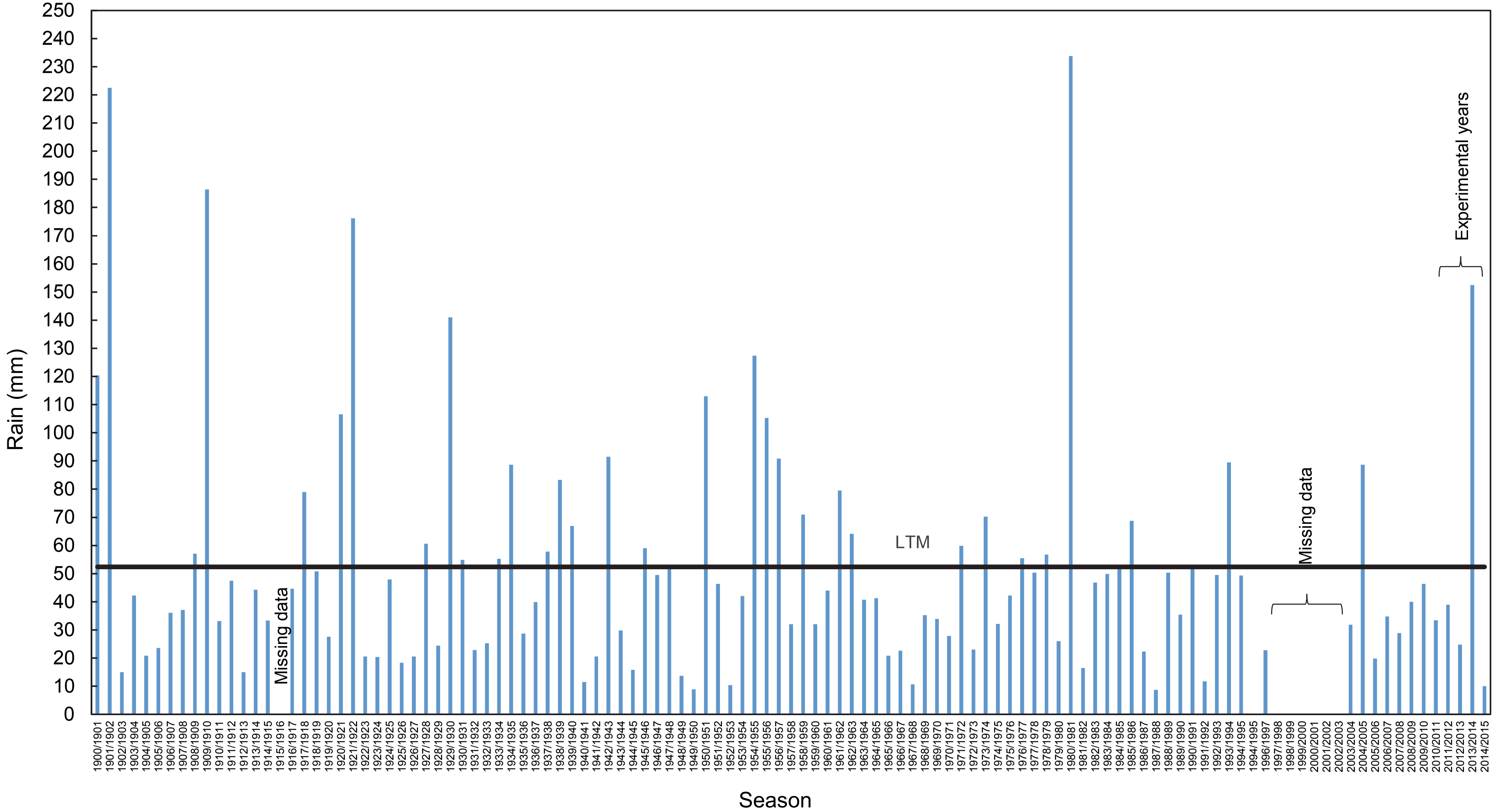

Figure A.3 The monthly rainfall for January to March (*ca.* Shiraz ripening, *i.e.* véraison until harvest) from 1900 until 2015 for Robertson. No data was available for 1915 and 1995, as well as 1998 to 2003. The long term mean (LTM) rainfall is presented by the black line.

APPENDIX B: VARIATION IN MEAN SOIL WATER CONTENT UNDER SHIRAZ/110R GRAPEVINES EXPOSED TO DIFFERENT IRRIGATION STRATEGIES AND CANOPY MANIPULATIONS

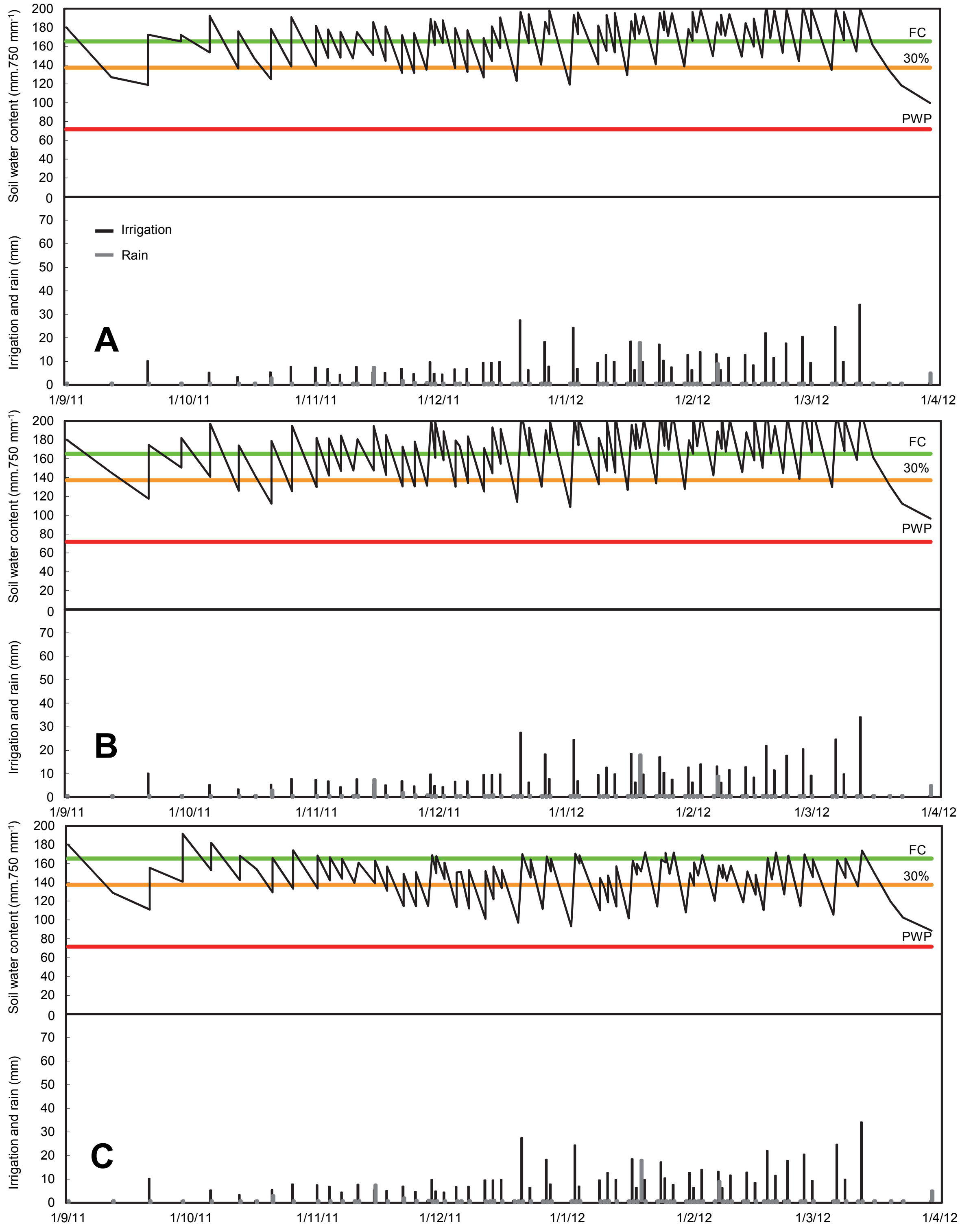

Figure B.1 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 30% plant available water (PAW) depletion and canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during 2011/12 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

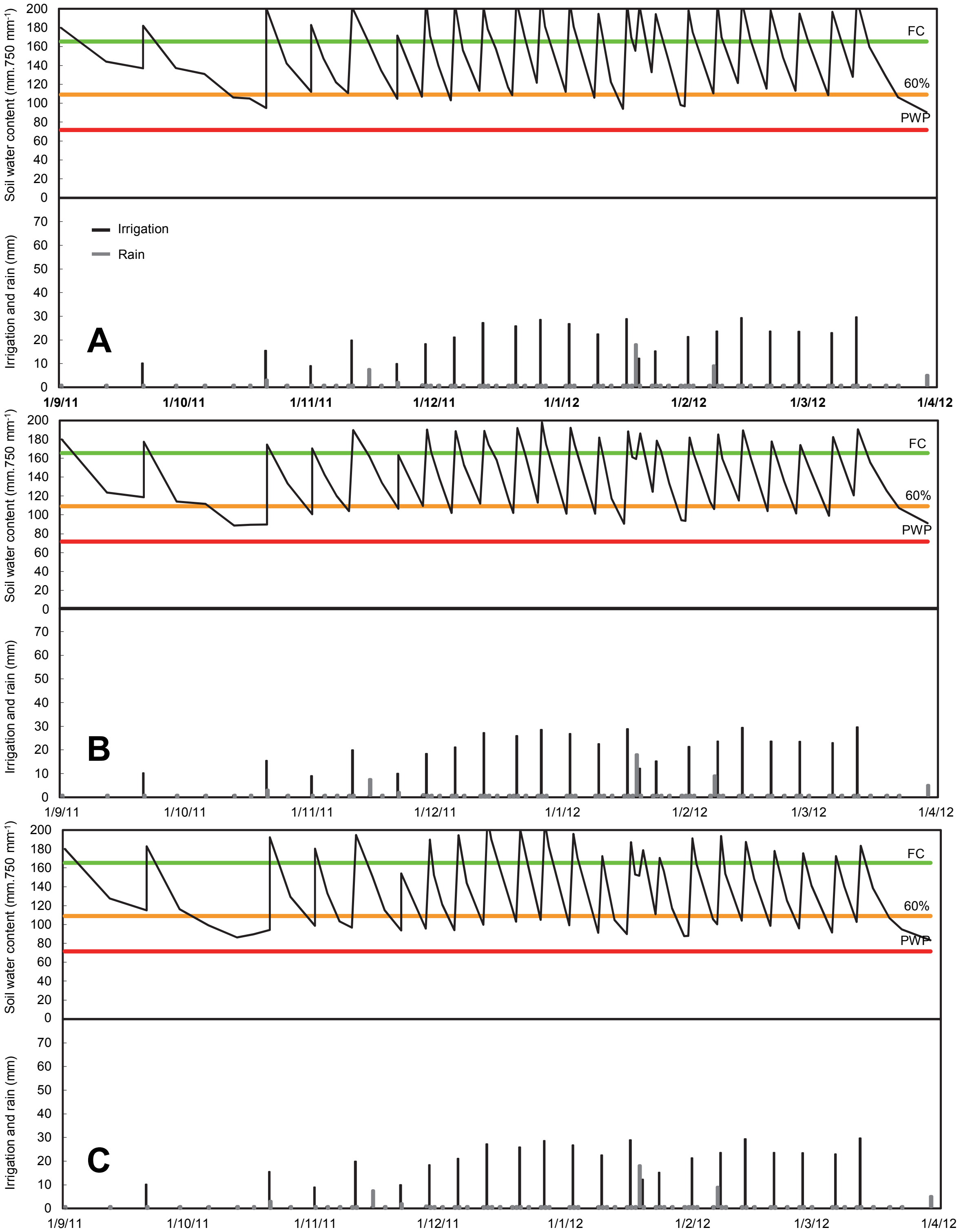

Figure B.2 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca.* 60% plant available water (PAW) depletion and canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during 2011/12 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

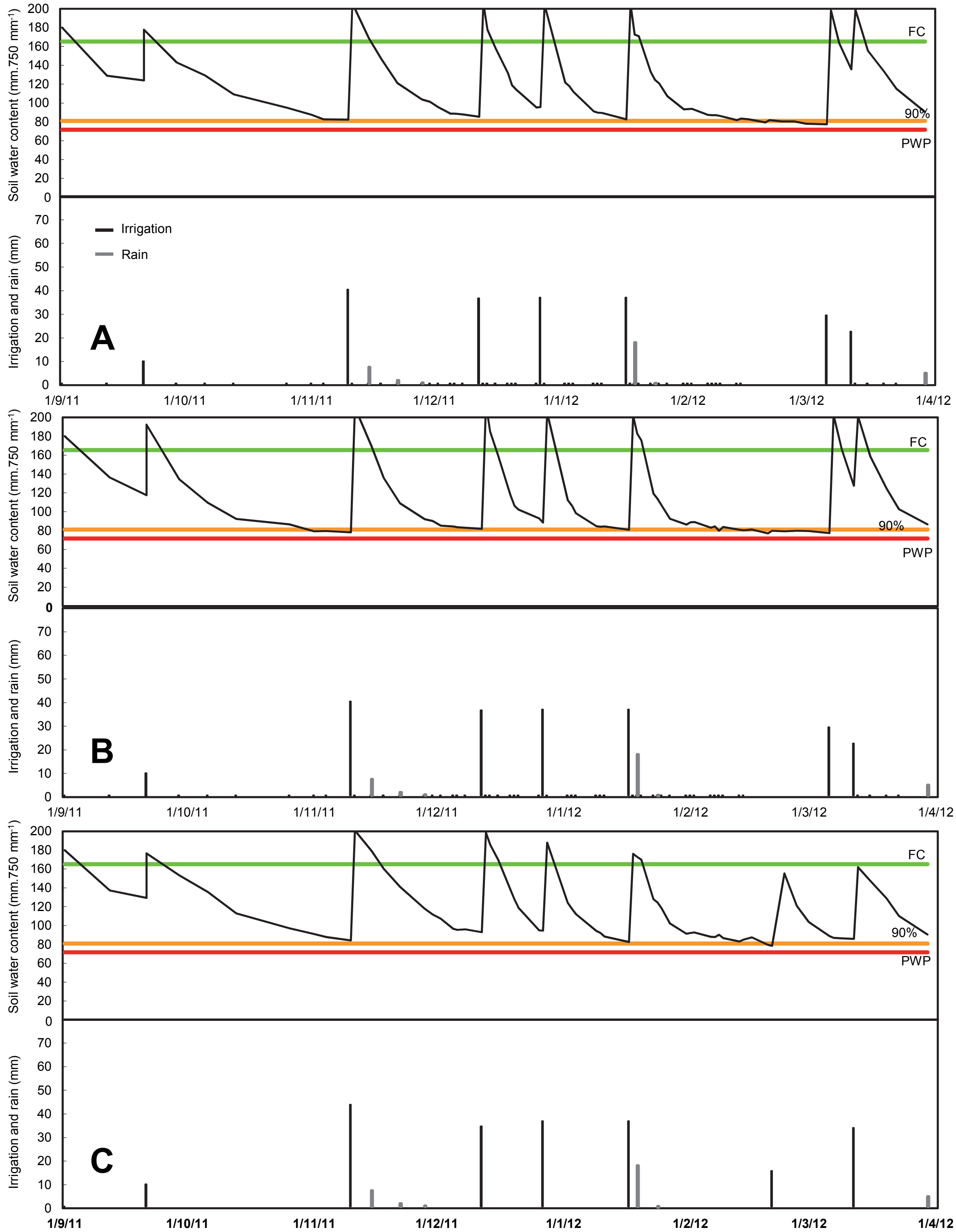

Figure B.3 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 90% plant available water (PAW) depletion and canopies (A) un-suckered and shoots tucked in, (B) canopies left un-suckered and sprawling and (C) grapevines box pruned and canopies left sprawling during 2011/12 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

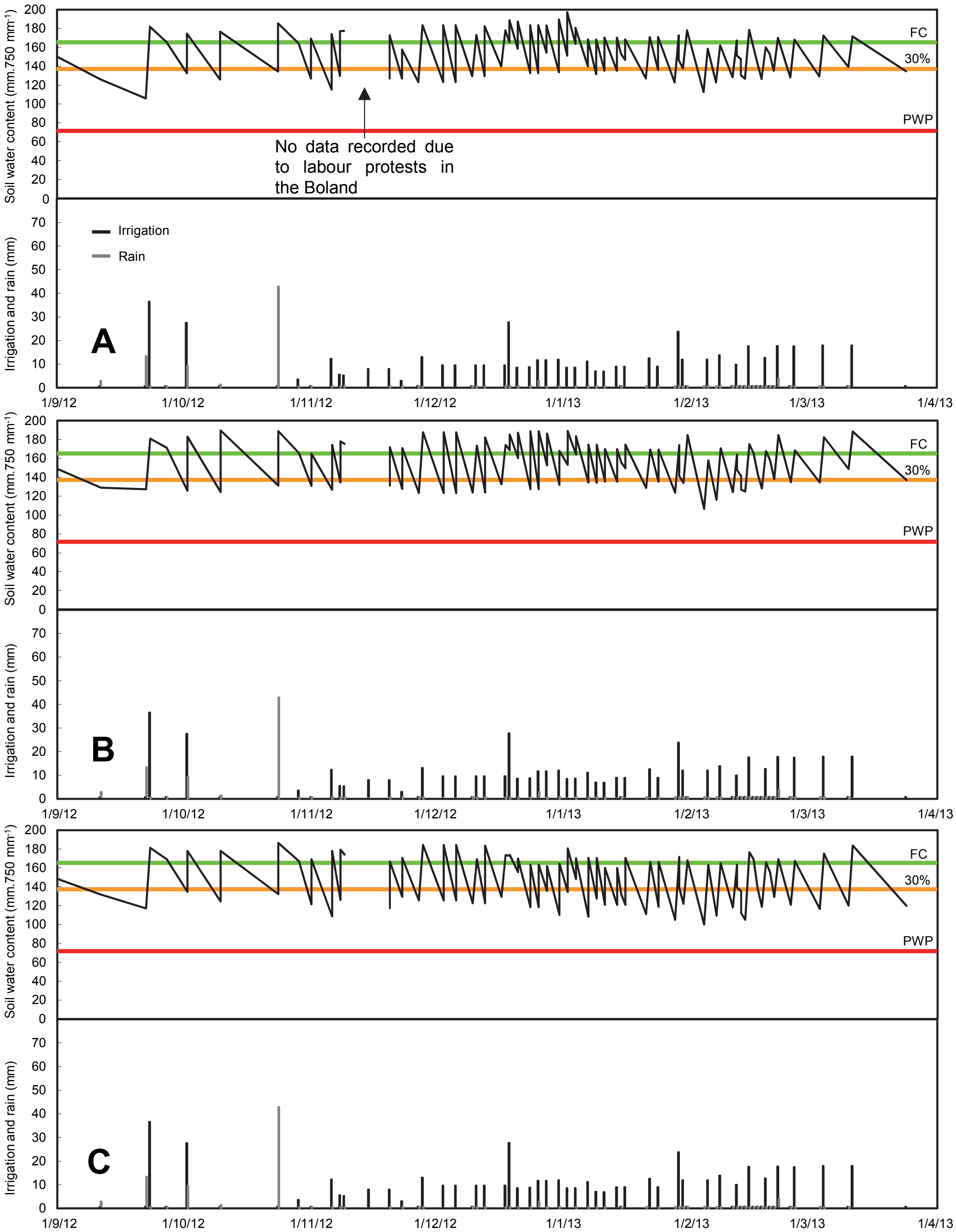

Figure B.4 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 30% plant available water (PAW) depletion and canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during 2012/13 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

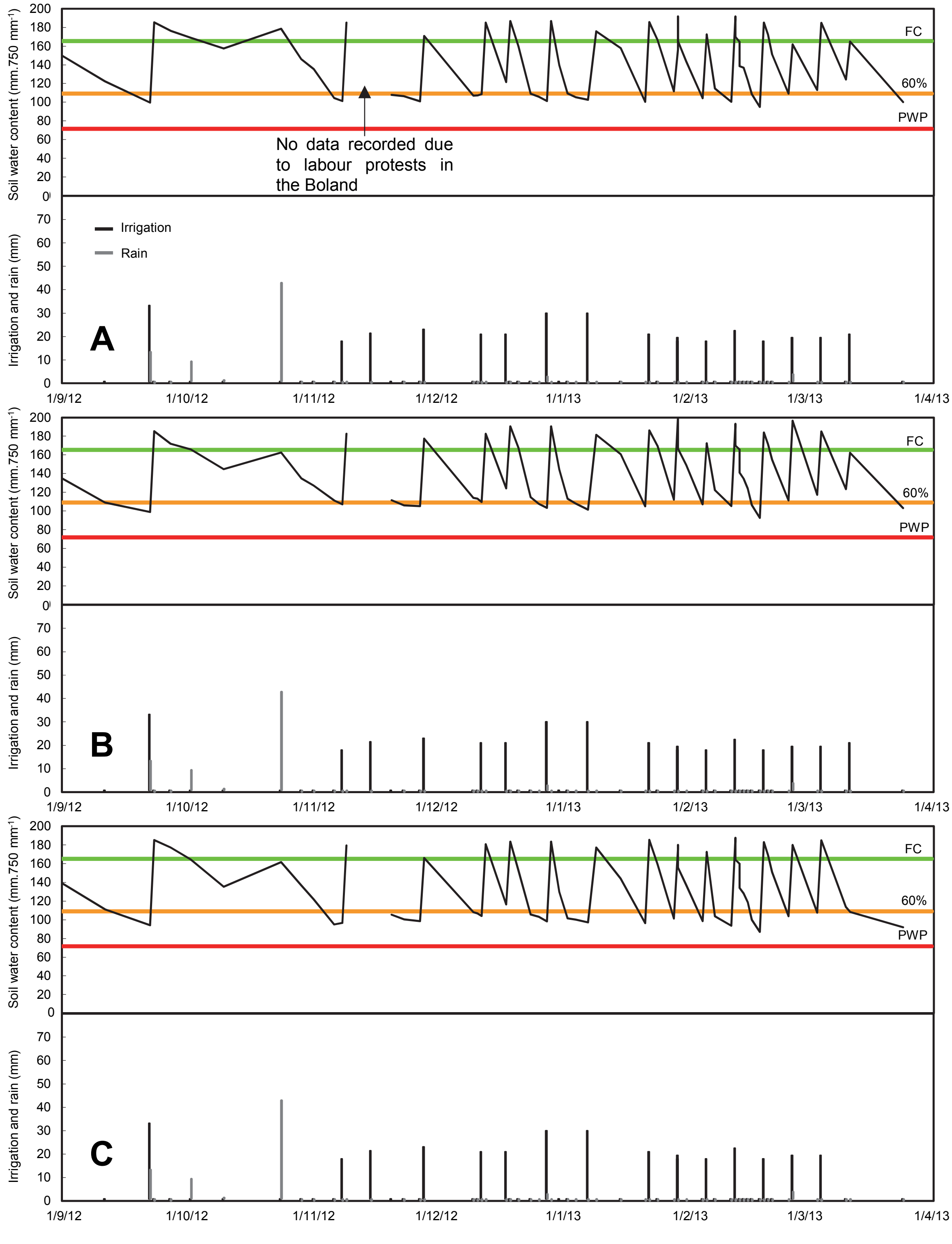

Figure B.5 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 60% plant available water (PAW) depletion and canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during 2012/13 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

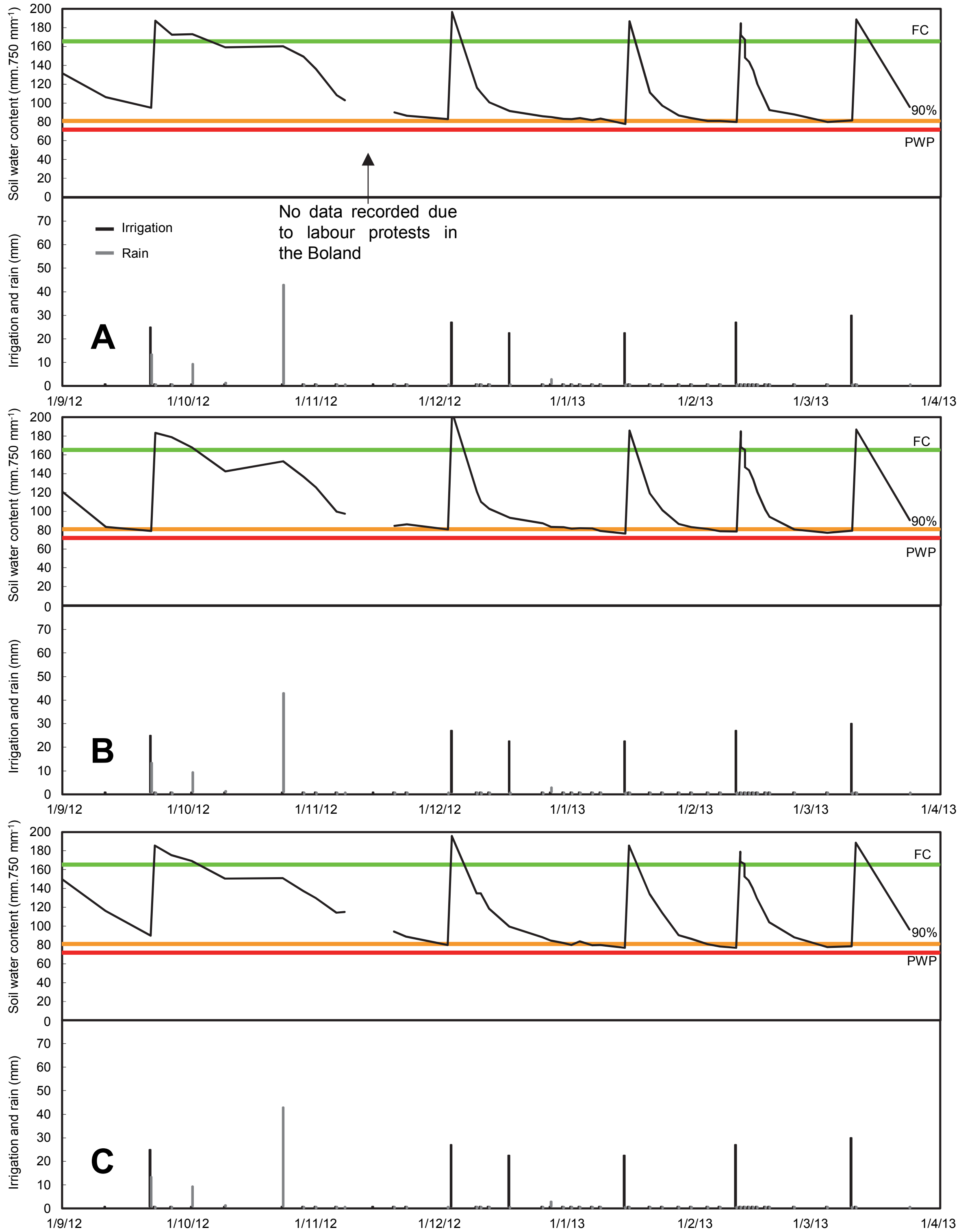

Figure B.6 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 90% plant available water (PAW) depletion and canopies (A) un-suckered and shoots tucked in, (B) canopies left un-suckered and sprawling and (C) grapevines box pruned and canopies left sprawling during 2012/13 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

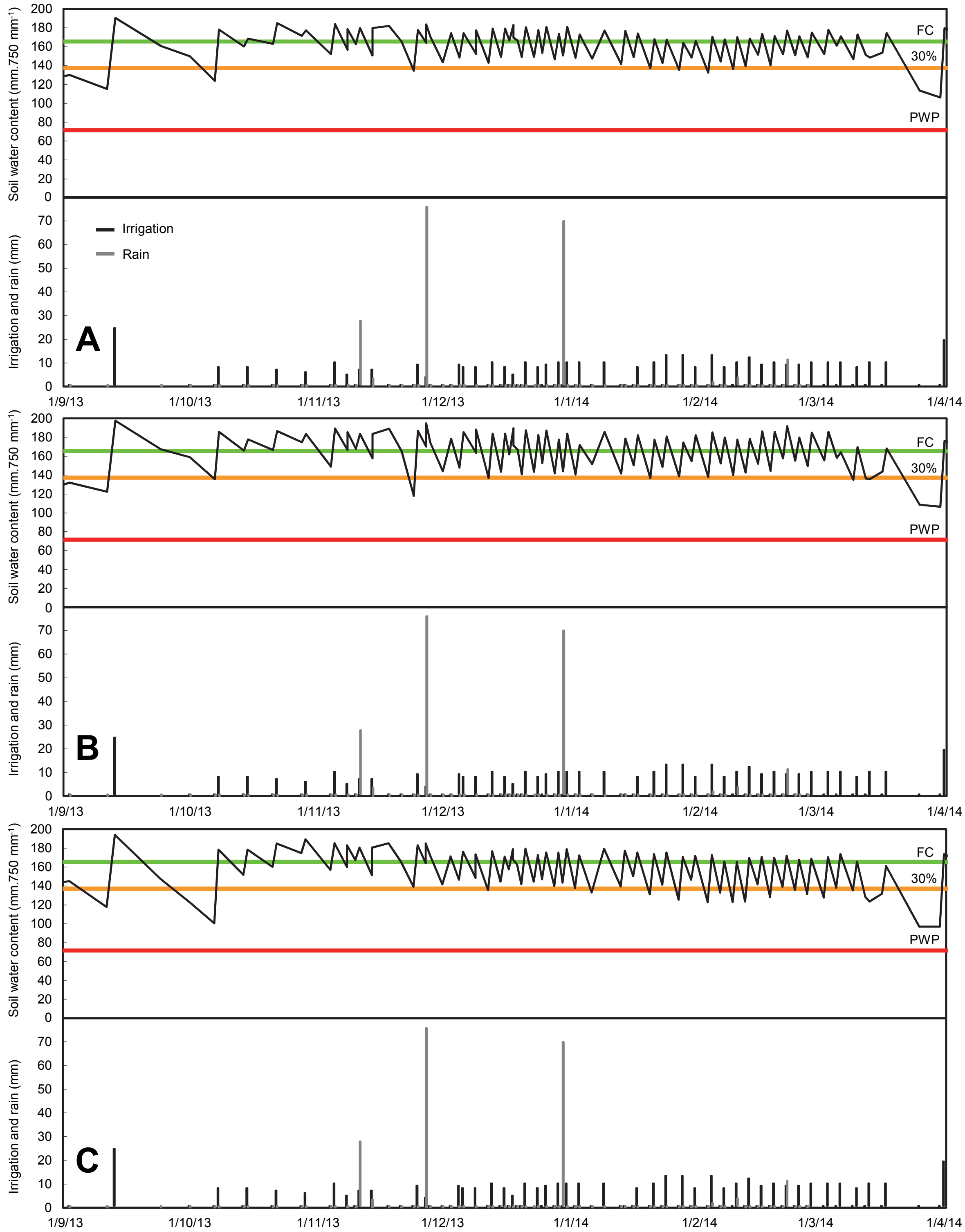

Figure B.7 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 30% plant available water (PAW) depletion and canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during 2013/14 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

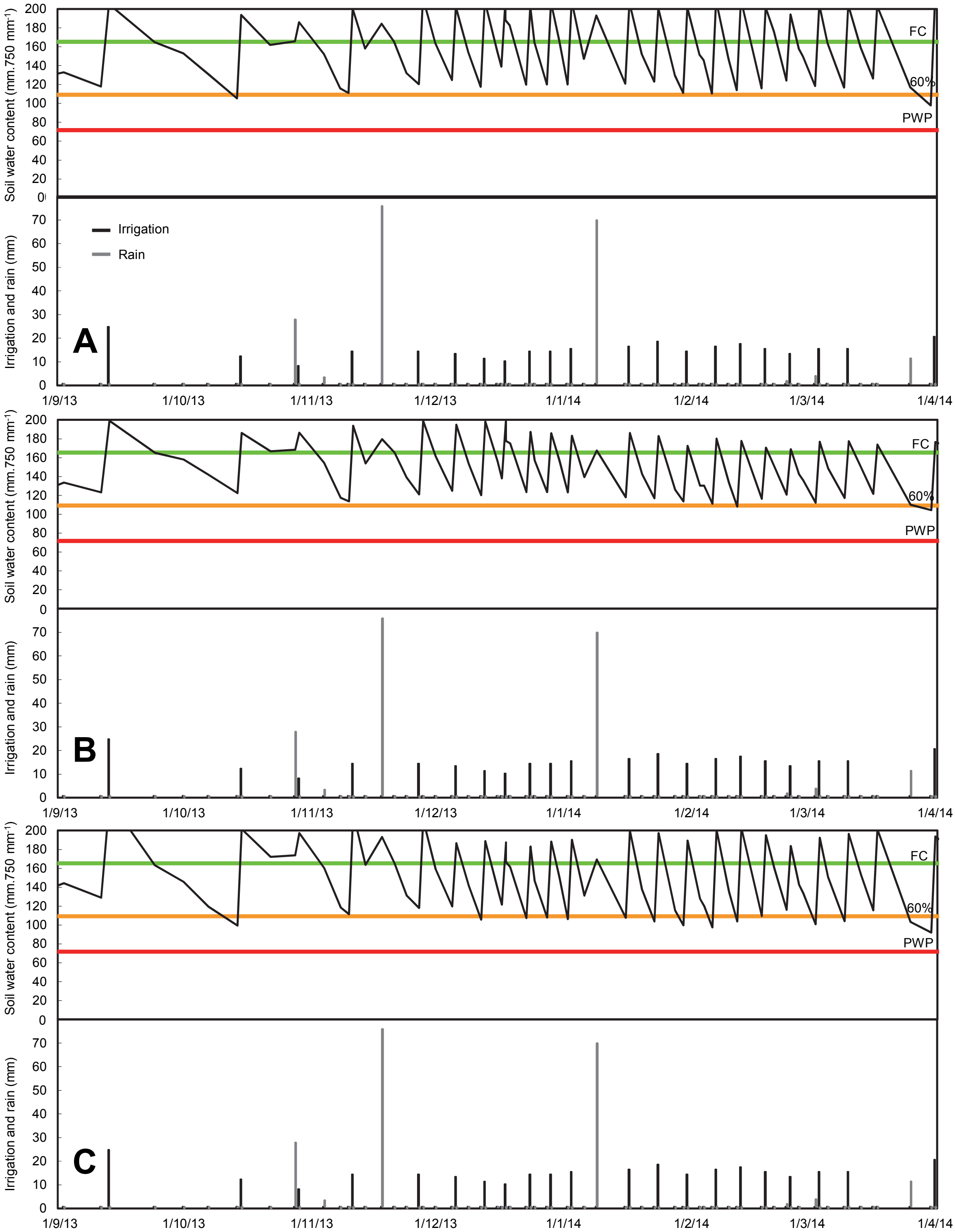

Figure B.8 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 60% plant available water (PAW) depletion and canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during 2013/14 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

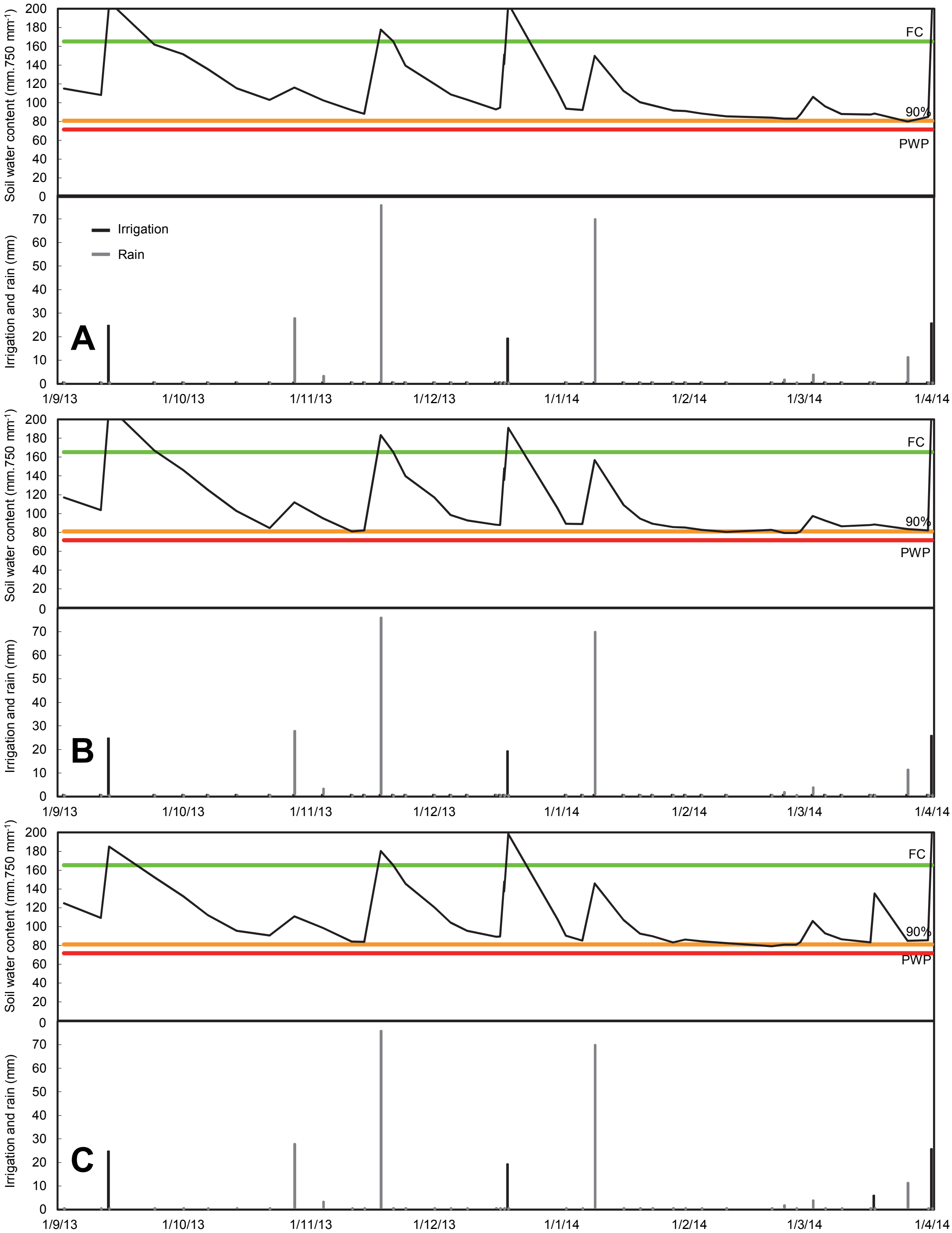

Figure B.9 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 90% plant available water (PAW) depletion and canopies (A) un-suckered and shoots tucked in, (B) canopies left un-suckered and sprawling and (C) grapevines box pruned and canopies left sprawling during 2013/14 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

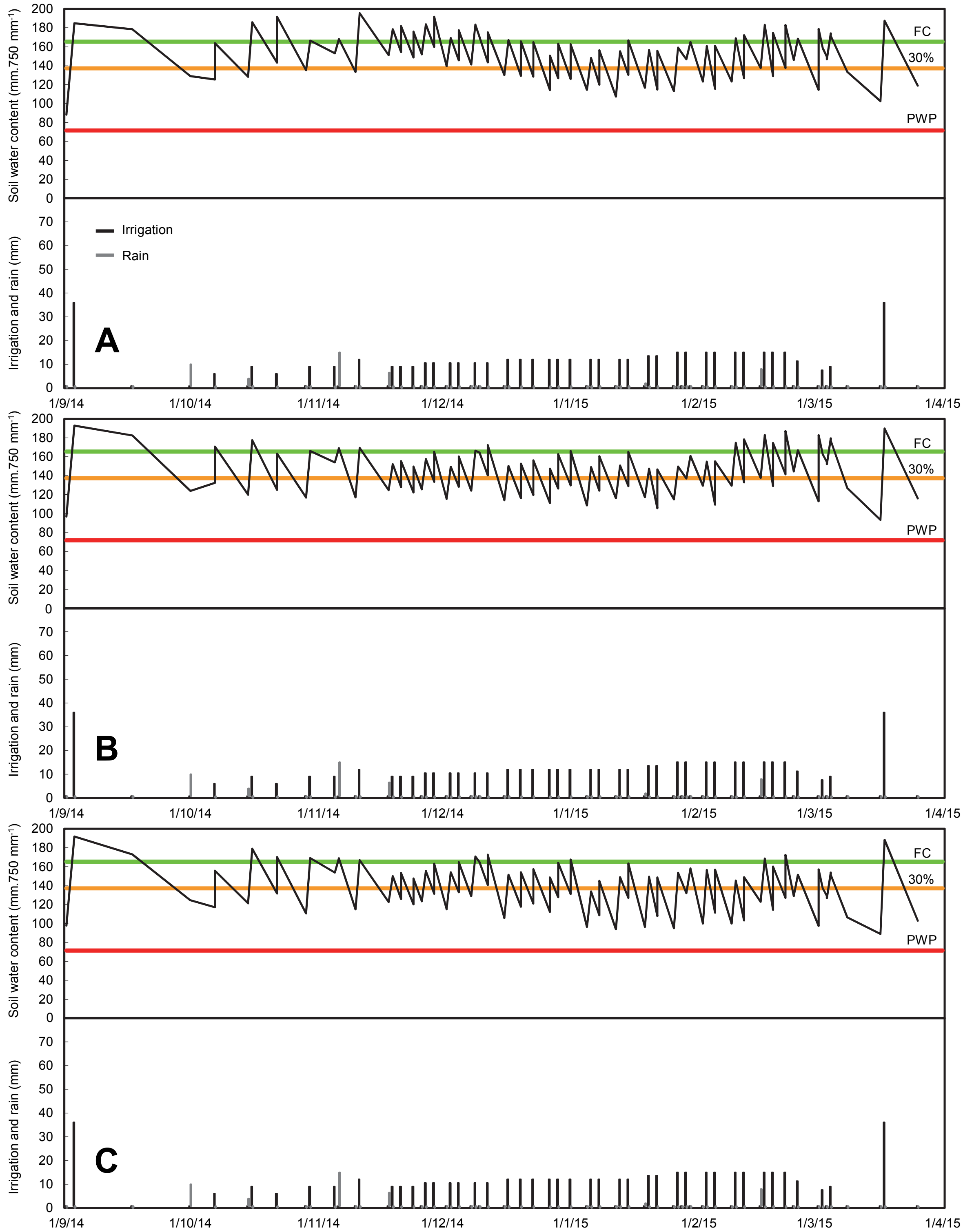

Figure B.10 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 30% plant available water (PAW) depletion and canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during 2014/15 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical bars indicate irrigation volumes and rain, respectively.

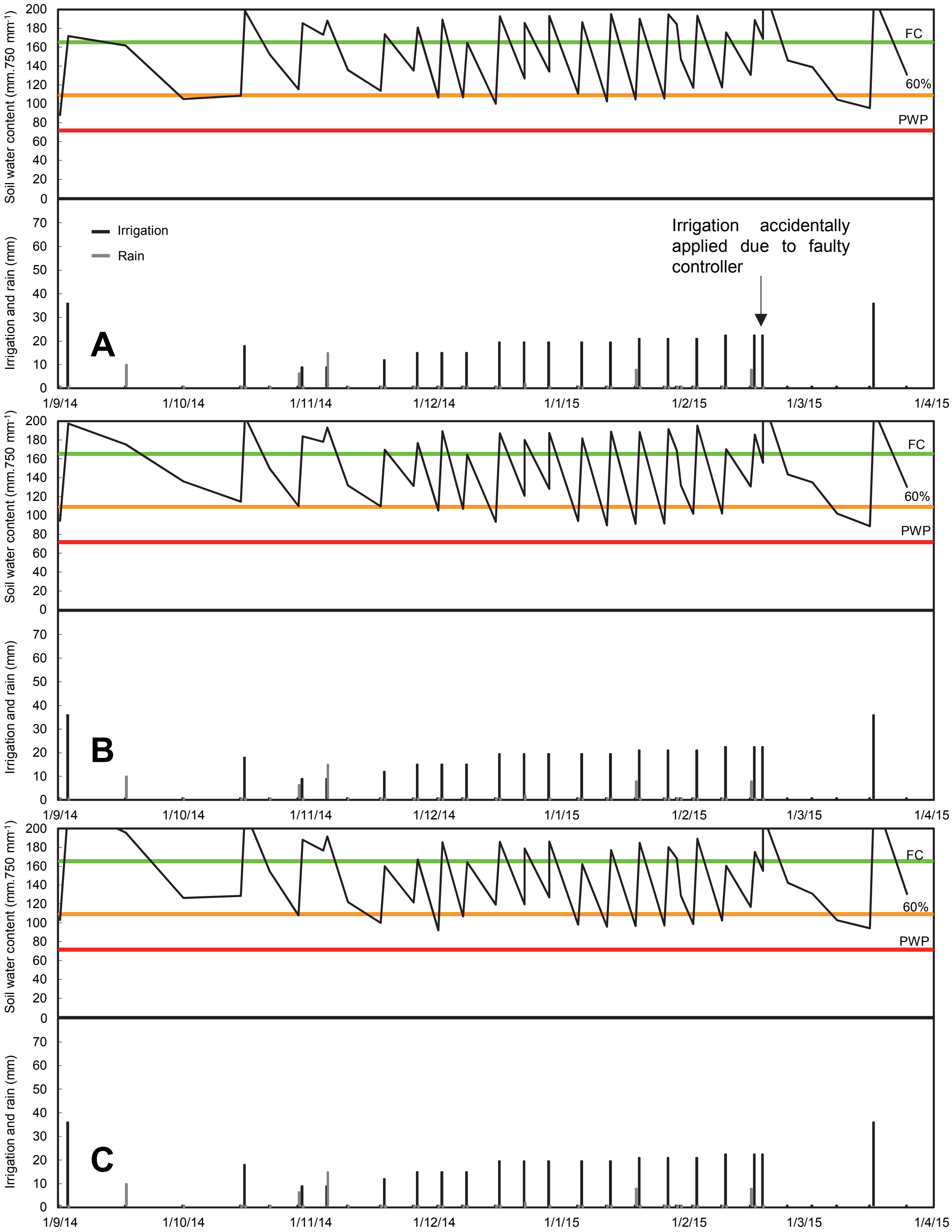

Figure B.11 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca*. 60% plant available water (PAW) depletion and canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during 2014/15 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical lines indicate irrigation volumes and rain, respectively.

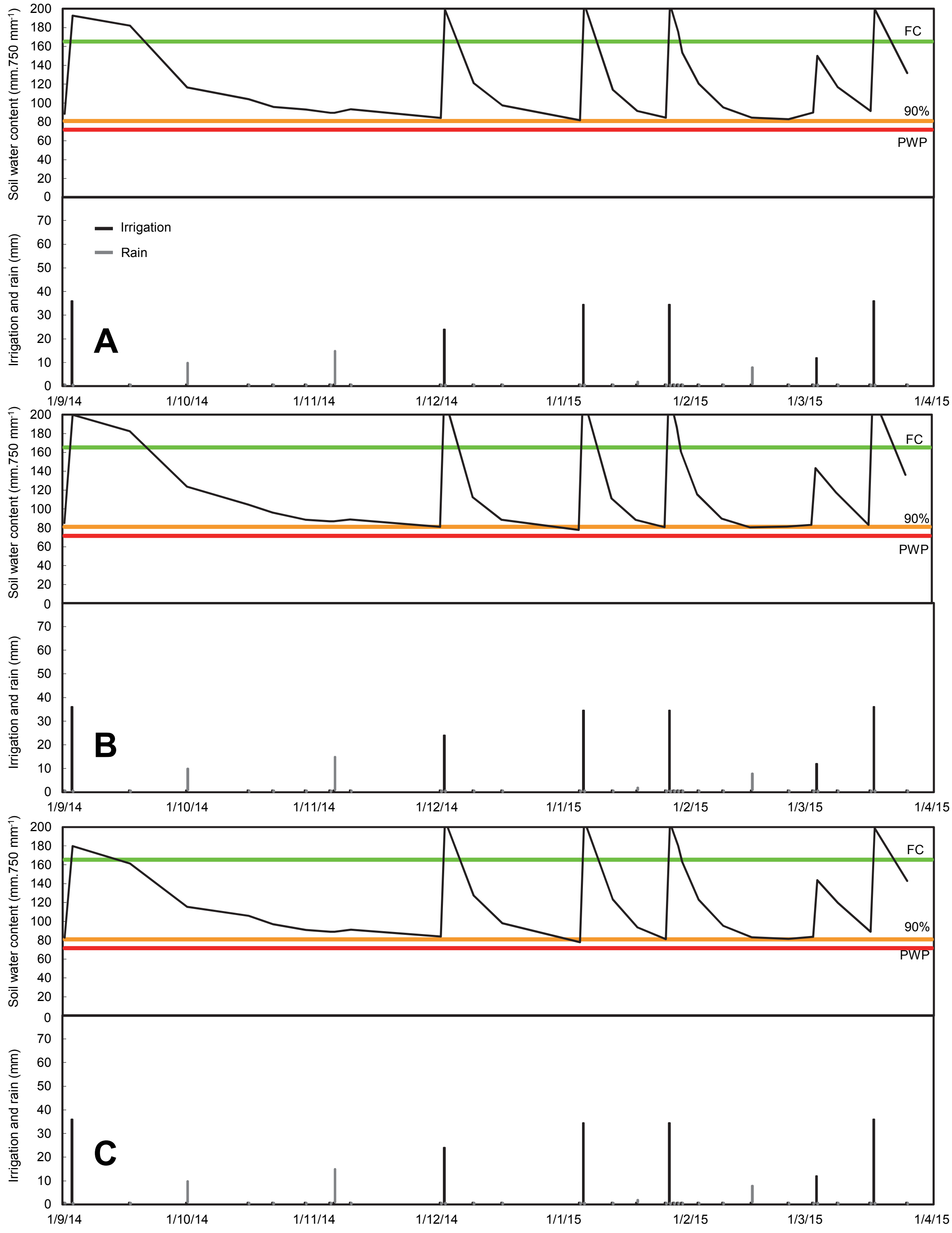

Figure B.12 Variation in mean soil water content under Shiraz/110R grapevines that were irrigated at *ca.* 90% plant available water (PAW) depletion and canopies (A) un-suckered and shoots tucked in, (B) canopies left un-suckered and sprawling and (C) grapevines box pruned and canopies left sprawling during 2014/15 season near Robertson (FC and PWP are field capacity and permanent wilting point, respectively, whereas percentage values on the right-hand axis indicate the target PAW depletion levels). Vertical lines indicate irrigation volumes and rain, respectively.

APPENDIX C: COMPARISON BETWEEN THE MEASURED MEAN DAILY EVAPOTRANSPIRATION AND PREDICTED DAILY EVAPOTRANSPIRATION PER MONTH, USING THE VINET MODEL, OF DIFFERENT IRRIGATED AND CANOPY MANIPULATED SHIRAZ/110R GRAPEVINES

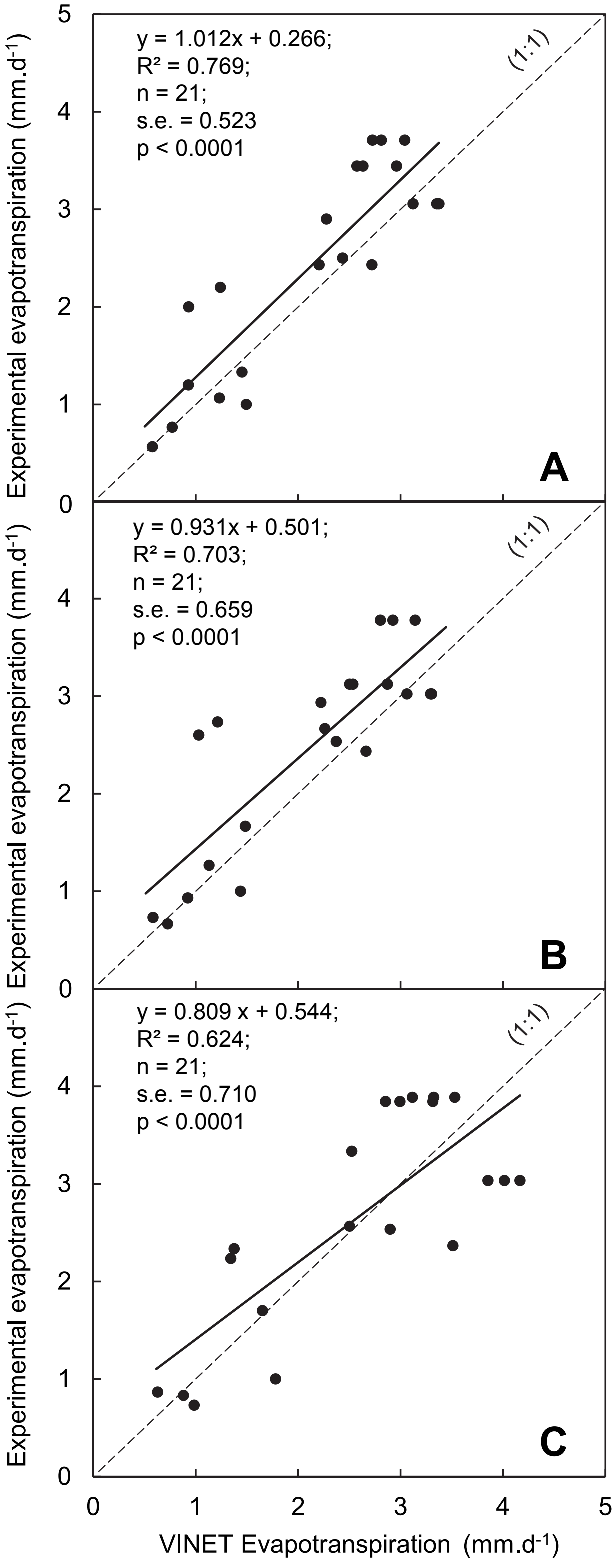

Figure C.1 Relationship between the measured mean daily evapotranspiration and predicted daily evapotranspiration per month, using the VINET model, for Shiraz/110R grapevines that were irrigated at *ca*. 30% plant available water depletion and had their canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

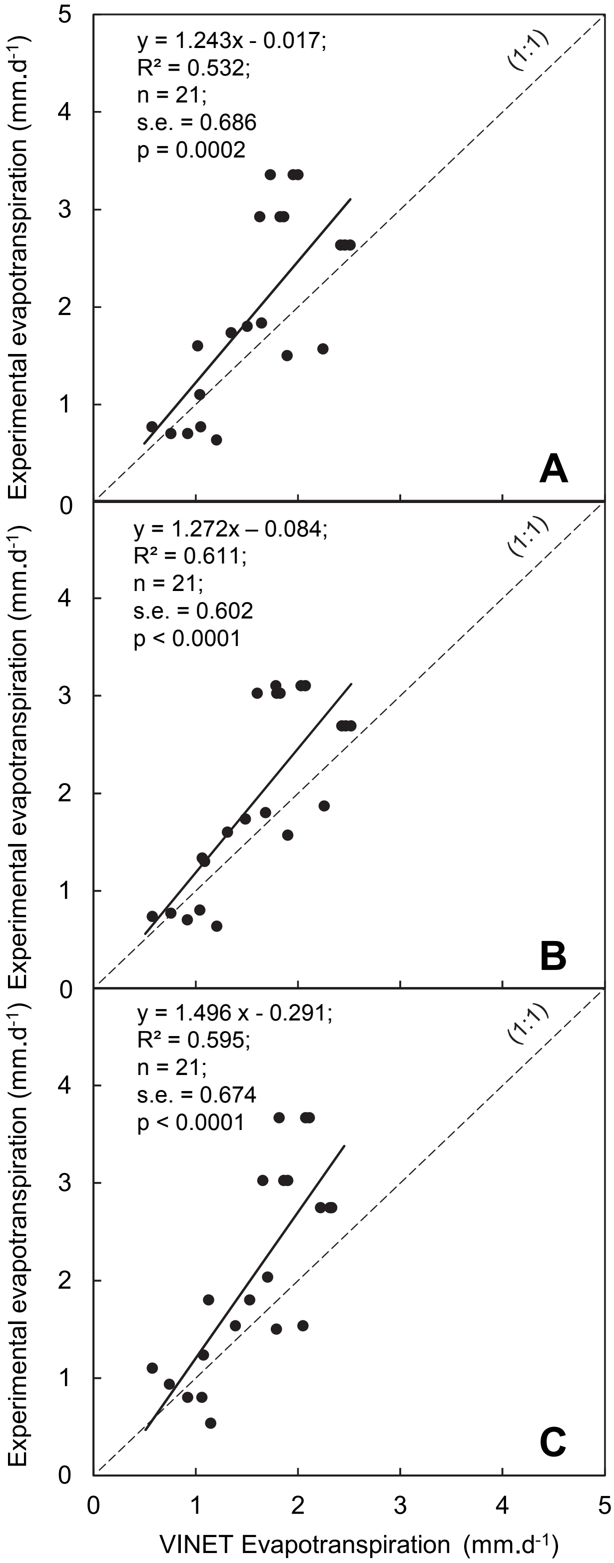

Figure C.2 Relationship between the measured mean daily evapotranspiration and predicted daily evapotranspiration per month, using the VINET model, for Shiraz/110R grapevines that were irrigated at *ca*. 60% plant available water depletion and had their canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

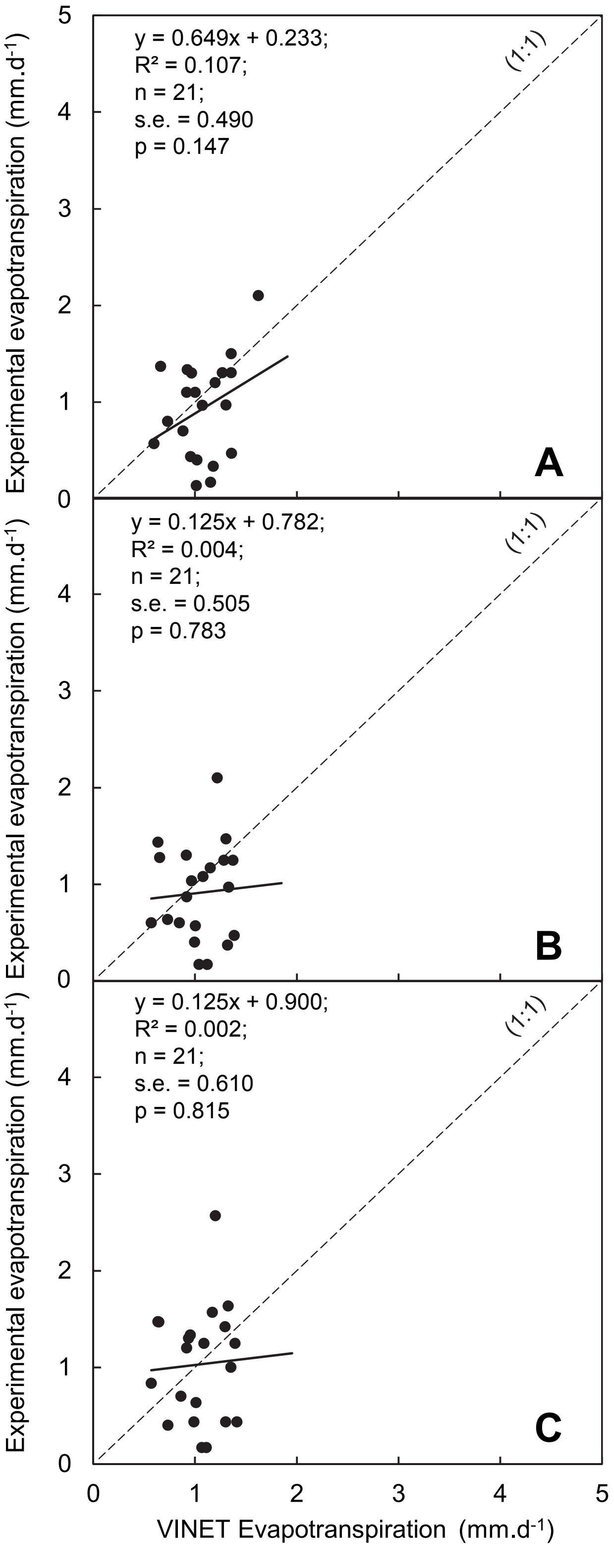

Figure C.3 Relationship between the measured mean daily evapotranspiration and predicted daily evapotranspiration per month, using the VINET model, for Shiraz/110R grapevines that were irrigated at *ca*. 90% plant available water depletion and had their canopies (A) suckered and shoots tucked in, (B) un-suckered and shoots tucked in and (C) canopies left un-suckered and sprawling during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

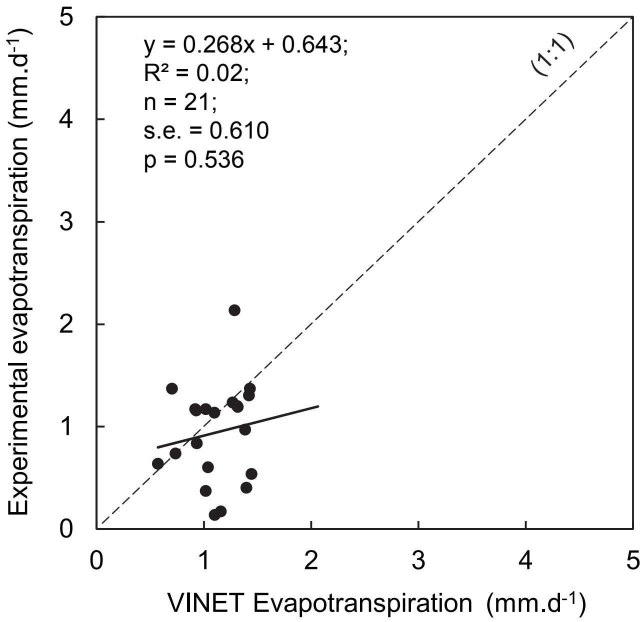

Figure C.4 Relationship between the measured mean daily evapotranspiration and predicted daily evapotranspiration per month, using the VINET model, for Shiraz/110R grapevines that were irrigated at *ca*. 90% plant available water depletion, were box pruned and had their canopies left un-suckered and sprawling during the 2012/13, 2013/14 and 2014/15 seasons near Robertson.

APPENDIX D: CAPACITY BUILDING REPORT

APPENDIX D: CAPACITY BUILDING REPORT

The data and information generated during the timespan of the project and presented in this report will be used by Mr E.L. Lategan (Project leader) for his PhD Agric study, for which he has already registered at Stellenbosch University's Department of Soil Science.

The following students, namely Messrs Robert Amundus Stolk and Victor De Wet Louw made invaluable contributions to the project as part of their post-graduate studies at Stellenbosch University, while Messrs J.C. Erasmus (Viticulture) and Philip Viljoen (Soil Science) did compulsory practical work during the December 2012 and December 2013 university recesses, respectively. Mr Stolk received his MSc Agric (Viticulture) degree in 2014, whereas Mr Louw received his MSc Agric (Agricultural Economics) degree in 2015.

Please see more detail, titles and summaries from their respective theses:

D.1. R.A. STOLK

MSc Agric (Viticulture) *Cum Laude* – 2014

Supervisor:	Dr P.A. Myburgh
Co-supervisors:	Mr E.L. Lategan
	Dr A.E. Strever

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

Available for download: http://hdl.handle.net/10019.1/86470

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.

D.2. V.D. LOUW

MSc Agric (Agricultural Economics) – 2015

Supervisor: Dr W.H. Hoffmann

Co-supervisor: Mr E.L. Lategan

FINANSIËLE IMPLIKASIES VAN BESPROEIING, GEÏNTEGREER MET LOWERBESTUUR, VIR ROOI WYNDRUIWE IN DIE ROBERTSON-WYNVALLEI

Available for download: http://hdl.handle.net/10019.1/96806

SUMMARY

The financial decision-making environment within which wine-grape producers function is challenging because of the complex interrelationships between yield, product price and input requirements. The complexity of farm systems is increased because production and financial decisions are necessarily made under uncertainty. Various issues influence the resilience of the wine industry. The goal of this study is to determine the financial implications of irrigation, integrated with canopy management practices on red wine cultivars in the Robertson area.

Canopy management and irrigation cost play an important role within the multi-faceted farm system regarding yield, quality and input cost. This necessitates that research be carried out within the context of a systems approach. In this manner the interdependence among the various components of the farm system, and the associated synergies can be captured. Farm management, as a field of research, is dependent on other disciplines that present an alternative perspective to the research problem.

Viticulture trials specifically focused on the impact of various irrigation and canopy management activities is being done on Wansbek farm. Nine treatments were tested at various combinations of soil water depletion levels and canopy management strategies. The farm is situated in Agterkliphoogte, an area in the Robertson Valley. A multi-disciplinary

group discussion was held to firstly obtain insight in the complex working of a farm. Secondly the group discussion was used to gain insight into the application of the Wansbek trial data and the setting of guidelines as to its application to determine the expected farm level financial implications of the treatments. Dealing with complexity necessitates insight form various areas of expertise, which is achieved time efficiently within expert group discussions.

A quantitative method is required to reflect the interrelatedness and dynamics of a whole farm system in a user-friendly manner. Multi-period budget models present the ability to accommodate the complexity associated with a farm through a sequence of mathematical and accounting equations. The physical/biological interrelations and structure of the farm can be modelled while the financial performance of various irrigation and canopy management strategies can be determined.

Farm-level profitability is especially sensitive to yield and price of farm products. The treatments that showed the highest expected profitability, return relatively high yields and prices at relatively low production costs. The sprawling canopy management treatment at *ca.* 60% and *ca.* 30% plant available water depletion levels returned the highest and second highest profitability at both gross margin per hectare and whole farm level. Scenarios were incorporated to illustrate the expected impact of key variables and the capability of the model. Key factors associated with the success of specific treatments could be identified. Results showed throughout that the balance between yield, price and input cost are the determining factor to profitability, rather than a focus on any particular one of these factors.

APPENDIX E: TECHNOLOGY TRANSFER AND PUBLICATIONS

APPENDIX E: TECHNOLOGY TRANSFER AND PUBLICATIONS

E.1. TECHNOLOGY TRANSFER

The information generated by the Project was disseminated to the different stakeholders *via* information sessions, *i.e.* producers' and Winetech meetings, as well as scientific oral and presentations at national conferences as listed below:

LATEGAN E.L., 2012. Water requirement of grapevines: Factors that affect it (Afrikaans). Netafim field day for viticulturists and farmers. 5 June 2012

LATEGAN E.L., 2012. Water requirement of grapevines: Factors that affect it (Afrikaans). SASEV Winter Assembly 2012. South African Society for Enology and Viticulture. 20 July 2012.

LATEGAN E.L., 2013. Investigating the possible improvement of water use efficiency and decrease canopy management inputs by applying deficit irrigation (Afrikaans). Le Chasseur and Agterkliphoogte Farmers Union meeting, Wansbek. 11 September 2013.

LATEGAN E.L., 2013. IRRIGATION OF RED WINE GRAPES: How irrigation volumes affect yields and quality (Afrikaans)? Breedekloof Viticultural study group, Botha Winery, Worcester. 16 October 2013.

LATEGAN E.L., 2013. Evaluating the possibility of reducing canopy management inputs by means of deficit irrigation – *Preliminary results*. 35th Conference of the South African Society for Enology and Viticulture (Workshop format). South African Society for Enology and Viticulture. Somerset West. 13 November 2013.

LATEGAN E.L., 2014. Investigating the possible improvement of water use efficiency and decrease canopy management inputs by applying deficit irrigation (Afrikaans). Water Research Commission Information and Field Experiment Day, Wansbek. 29 January 2014.

LATEGAN E.L., 2014. The effect of different canopy orientations on the water use of grapevines (Afrikaans) WINETECH/VINPRO Information day, Malmesbury. 11 June 2014.

LATEGAN E.L., 2014. The effect of different canopy orientations on the water use of grapevines (Afrikaans) WINETECH/VINPRO Information day, Nelson Estate, Paarl. 25 June 2014.

LATEGAN E.L., 2014. IRRIGATION VS CANOPY MANIPULATIONS: Water usage of different canopy types/sizes (Afrikaans). VINPRO Western Cape Viticulture Committee Meeting, Paarl. 12 September 2014.

LATEGAN E.L., 2014. The effect of different canopy management actions and irrigation strategy combinations on growth, yield and quality of wine grapes (Shiraz) (Afrikaans). Roodezandt Members Meeting, Robertson. 23 September 2014.

LATEGAN E.L., 2015. The effect of different canopy management actions and irrigation strategy combinations on growth, yield and quality of Shiraz (Afrikaans). WINETECH/VINPRO Information day, Montagu. 04 June 2015.

LATEGAN E.L., 2015. How can we produce more grapes with the same amount of water by increasing water use efficiency? WINETECH/VINPRO Leaf roll Virus and Irrigation Roadshow, Kingna Disstery, Montagu. 15 September 2015.

LATEGAN E.L., 2015. How can we produce more grapes with the same amount of water by increasing water use efficiency? WINETECH/VINPRO Leaf roll Virus and Irrigation Roadshow, Robertson. 15 September 2015.

LATEGAN E.L., 2015. How can we produce more grapes with the same amount of water by increasing water use efficiency? WINETECH/VINPRO Leaf roll Virus and Irrigation Roadshow, Aan de Doorns Winery, Worcester. 16 September 2015.

LATEGAN E.L., 2015. How can we produce more grapes with the same amount of water by increasing water use efficiency? WINETECH/VINPRO Leaf roll Virus and Irrigation Roadshow, Nelson Wine Estate, Paarl. 16 September 2015.

LATEGAN E.L., 2015. How can we produce more grapes with the same amount of water by increasing water use efficiency? WINETECH/VINPRO Leaf roll Virus and Irrigation Roadshow, J.C. Le Roux Wine Estate, Stellenbosch. 17 September 2015.

LATEGAN E.L., 2015. How can we produce more grapes with the same amount of water by increasing water use efficiency? WINETECH/VINPRO Leaf roll Virus and Irrigation Roadshow, Vredendal. 13 October 2015.

E.2. PUBLICATIONS

Some of the information have also been disseminated through the following publications:

- Stolk, R.A., 2014. 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. Thesis, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa.

- Louw, V.D.W., 2014. Finansiële implikasies van besproeiing, geïntegreer met lowerbestuur, vir rooi wyndruiwe in die Robertson-wynvallei. Thesis, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa.

The following publications are planned after completion of the project:

- Mr E.L. Lategan's PhD Agric dissertation (Stellenbosch University);
- The effect of irrigation and canopy management on irrigation requirements, soil water status, grapevine evapotranspiration and crop coefficients;
- The effect of irrigation and canopy management on vegetative growth responses of grapevines;
- The effect of irrigation and canopy management on yield, juice and wine quality responses of grapevines; and
- Financial implications of the interactive effect of irrigation and canopy manipulations on red wine grape production;

E.3. DATA AVAILABILITY

The raw, unprocessed data are available on compact disk from ARC Infruitec-Nietvoorbij. Direct enquiries with a short motivation to:

The Programme Manager
Soil and Water Science
ARC Infruitec-Nietvoorbij
Private Bag X5026
Stellenbosch
7599
South Africa
Telephone: +27 21 809 3100
Fax: +27 21 809 3002