0CFPA Canning Fruit Producers' Assoc. Submit to: Wiehahn Victor PO Box 426 Paarl, 7620 Tel: +27 (0)21 872 1501 inmaak@mweb.co.za	DFPT Deciduous Fruit Producers' Trust Submit to: Louise Liebenberg Suite 275, Postnet X5061 Stellenbosch, 7599 Tel: +27 (0)21 882 8470/1 **louise@dfptresearch.co.za**	DFTS Dried Fruit Technical Services Submit to: Dappie Smit PO Box 426 Paarl, 7620 Tel: +27 (0)21 872 1501 **dappies@dtd.co.za**	Winetech Submit to: Jan Booysen PO Box 825 Paarl, 7624 Tel: +27 (0)21 807 3324 **booysenj@kwv.co.za**
			X

Indicate (X) client(s) to whom this progress report is submitted.
Replace any of these with other relevant clients if required.

FINAL PROGRESS REPORT
FOR 2008/2009

PROGRAMME & PROJECT LEADER INFORMATION

	Programme leader	Project leader
Title, initials, surname	Dr J Steenkamp	Dr JJ Hunter
Present position	Research Leader: Viticulture	Specialist Scientist
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PROJECT INFORMATION

Project number	WW 12/25

Project title	Relationship between Shiraz/R99 water relations and physiological and developmental changes in the berry

Industry programme	**CFPA**	
	DFPT	
	DFTS	
	Winetech	Viticulture : Cultivation of winegrapes & Optimal grape composition for different wine objectives
	Other	

Fruit kind(s)	Winegrapes

Start date (dd/mm/yyyy)	01/04/2004	**End date** (dd/mm/yyyy)	31/03/2009

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Industry programme leader	
Specialist committee	
Meeting date	
Amount awarded	

SUMMARY OF FINAL PROGRESS REPORT FOR 2008/09

PROGRAMME & PROJECT LEADER INFORMATION

	Programme leader	Project leader
Title, initials, surname	Dr J Steenkamp	Dr JJ Hunter
Institution	ARC Infruitec-Nietvoorbij	ARC Infruitec-Nietvoorbij
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Fruit kind(s)	Winegrapes

Start date (dd/mm/yyyy)	01/04/2004	**End date** (dd/mm/yyyy)	31/03/2008

The regulation of grapevine water status is critical in obtaining a quality product and to fully explore vineyard and grape potential. The objective of this investigation was to determine the effect of plant water status and ripeness level on grape structure and composition in view of the factors involved in source:sink mechanisms, sugar accumulation and physical changes. Combined effects of water status and ripeness level and specifically in a Mediterranean high winter rainfall area, have not yet been systematically investigated in terms of the induction of morphological, structural, and physiological changes in the grapevine and grapes and the eventual impact on wine. The vine physiological, viticultural and oenological differences induced by variation in plant water status were quantified at different ripeness levels and recommendations on management required to obtain different styles of grape and wine composition under varying vine water status levels were made. Studies at different ripeness levels add a further dimension to management effects and our quest for finding top quality, and different styles, of wine.

A seven year old *Vitis vinifera* L. cv. Shiraz (clone SH1A) vineyard, grafted onto Richter 99 (*Vitis Berlandieri* x *Vitis rupestris*) (clone RY2A), was used. The vineyard was located on the Experiment Farm of ARC Infruitec-Nietvoorbij in Stellenbosch, Western Cape, South Africa. The area is under the influence of a Mediterranean climate with high rainfall in winter. The vines were spaced 2.75 m × 1.5 m on a Glenrosa soil with western aspect (26° slope) and trained onto a 7-wire (cordon wire and three sets of movable wires spaced 15 cm) lengthened Perold (VSP) trellising system with cordon wire at 60 cm. Vines were pruned to two-bud spurs with a spur spacing of approximately 15 cm. Canopies were suckered, shoot positioned and tipped/topped. No leaf removal was done in the canopies. Micro-sprinkler irrigation was applied. Rye was sowed (at 80 kg/ha) between the rows in autumn to serve as cover crop during winter. The cover crop was killed in spring before bud burst and left as mulch on the ground during the summer. Fifteen treatments, comprising single and combined irrigations which differed in volume of water supplied and stage/s of application, were applied. Three water levels, i.e. no irrigation (0%), soil volume filled to 75% of field water capacity, and soil volume filled to 100% of field water capacity, were implemented. Each irrigation treatment comprised either a single or different combinations of irrigations at different stages (berry set, pea size berry, véraison, and post-véraison). Véraison represented at least 75% of grape colouring. Post-véraison refers to three weeks after véraison. The treatments were applied in summer for four years continually. The treatments were completely randomised in two blocks (representing two replications), with a buffer row on each side of a treatment row and two buffer vines on each side of a treatment plot within the row. Thirty vines per replicate were used. Measurements were done at berry set, pea size berry, véraison, post-véraison and at three ripeness levels. Soluble solid contents were used as indicator for ripeness level, i.e. 23 ^{0}B, 25 ^{0}B and 27 ^{0}B (approximately 14 days between ripeness levels, corresponding to the beginning, middle and end of March). Mean values of the last two years of the experiment (2006/2007 and 2007/2008) are presented. At any given measurement stage, soil water determinations, physiological measurements, vegetative and reproductive growth sampling, as well as harvesting for winemaking were completed during the course of two days, after which irrigation was applied as required for the different treatments.

The Glenrosa soil used is classified as a predominantly sand-clay-loam soil and has an average field water capacity (FWC) of approximately 17% (dry mass basis). The FWC of the different soil layers was similar. The soil compaction index (measured as bulk density) of the different soil layers slightly exceeded the critical value of 1.5 g/cm^3. Resistance of the soil increased with increasing depth, whereas P, K and Ca decreased. Except for Fe, contents of the micro-elements and carbon as well as the texture of the soil also decreased with depth. Gravimetric and neutron moisture probe soil water results, for the purpose of calibration, showed an extremely poor relationship. This aspect has serious implications for producers relying solely on neutron moisture probe results for irrigation scheduling. Gravimetric measurements were used to determine soil water contents and calculate irrigation volumes. A reduction in soil water apparently mostly stemmed from a loss of added water and the base soil water fraction stayed largely intact. A relatively high soil water content was found for the non-irrigated treatment, particularly in the deepest soil layer and at the last harvest stage. The soil clearly had a high water holding capacity and buffer capacity against favourable evapotranspiration conditions, even with western aspect and being subjected to a long and relatively dry season with frequent occurrence of high temperatures and grapevines with fully developed canopies.

The water potential data showed clear trends. In general, an increasing water stress seemed evident from berry set stage until the last harvest stage. Although the soil water contents showed a decreasing trend from the first to the second harvest stage, the water relations of the vines clearly increased during this time as a result of the rainfall just before the second harvest stage. Primary and secondary leaves and stem water potential displayed similar patterns. Fully irrigated vines, and vines irrigated at post-véraison, and in combination with earlier stages, clearly responded to more or less water, in line with the soil water contents. It seems, however, that non-irrigated vines and vines irrigated only during pre-véraison (at pea size) developed an adaptive behaviour towards lower soil water contents and diurnal environmental stress. Both level of irrigation and stage of irrigation effects were evident at all stages. The water relations of vines, irrespective of treatment, generally followed soil water content patterns. Continuously irrigated vines maintained reasonably high water potential during the season. From after véraison until the second harvest stage, apical primary leaves and secondary leaves displayed generally higher photosynthetic activity than primary basal leaves. After the second harvest stage (and despite rainfall just prior), a general drop in photosynthetic activity occurred. Noticeably, vines were not highly stressed and non-irrigated vines maintained comparatively high photosynthetic activity. Decreasing water potentials occurring for irrigated and non-irrigated vines during grape ripening were probably mainly imposed by lack of continued high water absorption by roots. This would have been enhanced by a senescing canopy and prevailing cooler day and night temperatures, impacting on water potential gradients and source:sink relationships. A larger secondary leaf area component would contribute significantly to photosynthetic capacity. Non-irrigated vines maintained surprisingly high leaf area, most probably because of the relatively high base soil water content.

Berries reached highest mass approximately three weeks after véraison. Berry size was increased by pre-véraison high-volume irrigation, but the effect was only evident at the first harvest stage. High base soil water under the conditions of the study prevented classic water deficit berry size reduction effects. Bunch mass and volume started to decrease already from post-véraison, whereas the rachis reached highest mass only at the first harvest stage, after which it decreased. The rachis largely contributed to maintenance of bunch mass with further ripening; this has implications for both winery and producer. Results seemed to indicate independent development and/or senescence for berry and rachis during ripening. Soil water contents, leaf and stem water potential, photosynthetic activity and bunch and berry mass seemed concerted during the last ripening stages. A build-up of sucrose in primary and secondary leaves during late ripening, i.e. an over-supply of sucrose, may nullify potential negative effects that re-growth of secondary shoots or even tertiary shoot initiation after late-season irrigation may have on grape ripening. A sudden build-up of sucrose in the rachis during ripening has value as indicator of optimal ripeness and harvest potential of grapes.

A higher irrigation volume resulted in generally lower initial (first harvest stage) soluble solid concentrations for all treatments. At the other two harvest stages differences were more variable, but the general trend of more water, less soluble solid concentration was still evident. This trend was much more evident and stable for treatments receiving irrigation up to véraison stage. Non-irrigated vines seemed not able to reach similar soluble solid concentrations than the irrigated vines. Vines seemed to display an independence of soil water during ripening. This became more pronounced as ripening proceeded. The senescing canopy produced less and hoarded more sucrose and the berries lost more water than it could gain by water potential gradients. No clear evidence could be found that even high volumes of water (to 100% FWC) during ripening could sustain berry volume, indicating that the berry was not only insensitive to water deficit during ripening, but it also seemed not to be affected by high volumes of water during this time. Neither evapotranspiration nor phloem or the partly dysfunctional xylem flow seems to be able to sustain inflow during late ripening and maintain berry turgor. Xylem backflow to the parent vine may have contributed to a better sustained rachis mass. The shrinking process may perhaps be considered physical, at least during the final stages before the berry reach raisin status. This does not refrain from the complex physical or physiological regulatory processes involved in berry development. Demand for sucrose by the rest of the plant, including the berry, seemed to continue after leaves already had lost most of their activity, but a point was reached where active demand was terminated. It seems reasonable to assume that during late ripening the changing environmental conditions, the senescing canopy, a lower evaporative demand, a lower photosynthetic output and concomitant transpirational loss, a decrease in sink demand on the canopy, the build-up of sucrose in leaves and the recuperating canopy in terms of water relations, would lead to a reduction in the water potential gradient between the canopy/conduits of the parent plant and the berry pericarp and that water flow and concomitant transport of sucrose to the berry would diminish, even under visually normal, intact bunch stem, rachis and pedicel occurrence.

The °B:TA ratios, indicating quality standards for Shiraz, showed that ratios were generally higher with less irrigation volume. The ratios were only inside criteria for quality wine styles at the first and second harvest stages. At the third harvest, ratios were outside the range for quality wine potential and grapes were clearly over-ripe. Delayed ripening of vines irrigated at all stages was evident at the third harvest stage. Although non-irrigated vines showed delayed soluble solid contents and low acidity at the last harvest stage, no seasonal irrigation had no marked effect on °B:TA ratios. Treatments receiving only post véraison irrigation seemed to have enhanced grape ripening, having high-quality ratios already at around 23 °B. Skin anthocyanin and phenolic contents indicated that development of colour was already almost complete approximately three weeks/one month after véraison at a soluble solid concentration of approximately 18 – 20 °B. Skin colour was generally highest at the first harvest stage, where after it decreased until the last harvest stage. Soluble solid concentration and skin anthocyanin contents moved in opposite directions as ripening proceeded. Extractability of berries increased with ripening. The extractability index (difference between results at pH 1.0 and pH 3.2) was low at the third harvest. This could be another indicator for harvest and wine style differences and could significantly affect decisions during the fermentation process in terms of duration, frequency and intensity of pump-over, temperature control and enzyme/tannin addition. A late harvest may result in wines slightly better coloured, but highly alcoholic and tannic. Similar trends to what were found with skin colour and phenolic contents were also evident in the wine colour and phenolic profiles.

The organoleptic wine quality and wine style data corresponded with the grape and wine composition data. The 75% pea size, post-véraison irrigation, and 75% pea size+post-véraison irrigation consistently resulted in high quality wines at all stages. Different wine styles were, however, found at each stage and between stages. At the first harvest stage, exceptional wines were obtained by irrigating to 75% FWC at post-véraison, to 100% FWC at post-véraison, to 75% FWC at pea size + at véraison combined, and to 75% FWC at pea size + at post-véraison combined. At the second harvest stage, exceptional wines were obtained by irrigating to 75% FWC at pea size, and to 75% FWC at post-véraison. At the third harvest stage, exceptional wines were obtained by irrigating to 75% FWC at post-véraison, and to 100% FWC at post-véraison. The group of treatments that performed best seemed to be that which included post-véraison (three weeks to one month after véraison) irrigation. Although irrigation at such late stage to 100% FWC, especially when in combination with irrigation earlier during the season (up to véraison), may present a risk of too much re-growth under fertile soil conditions, slight re-growth, which may occur under different conditions, should nevertheless not be judged as detrimental to grape ripening and eventual wine quality. It is clear that irrigation in terms of volume and stage may also under Mediterranean conditions, such as in the Western Cape, contribute largely to a required style of wine.

Treatment effects were generally reduced at a late harvest stage (third harvest stage in this study). Overripe grapes therefore seem to minimise the opportunity for the making of a unique or even terroir specific, wine. It would also to a large extent minimise the effect of any special cultivation practices followed during the season. Over-ripeness seems to have an equalising effect. Harvesting at optimal ripeness or within a window that allows the effects of terroir and vineyard-specific practices to surface is therefore critical.

The project was done over a period of four growth seasons. The water holding capacity of the soil and change in summer rainfall patterns from year to year within the Mediterranean climate certainly impacted on the reaction of the vines to treatments, complicating the data set and deductions. Vines were apparently not overly stressed. This is in line with relatively high basic soil water fractions of mostly more than 50% of FWC. Yet, additional water was certainly required in order to obtain the best grape and wine quality. Basic trends were in accordance to those found in other studies, whereas new information was obtained on the inter-relationships between the behaviour of the canopy and that of the grapes during ripening. The physical and compositional changes in the berry during late ripening were clarified further. Definitive guidelines regarding stage and volume of low intensity (supplementary) irrigation under Mediterranean climate and medium potential soil conditions on grape composition and wine quality and style were found. It certainly also has significance for other terroirs. It seems reasonable to assume that Shiraz/Richter 99 vines and other cultivar-rootstock combinations with similar environment requirements or abiotic resistance, specifically drought resistance, and ecophysiological reaction would react similar under similar terroir conditions.

FINAL PROGRESS REPORT

1. Problem identification and objectives

Shortly state the problem being addressed and the ultimate aim of the project.
State the objectives for the current year and for the following year.

PROBLEM ADDRESSED/EVENTUAL OBJECTIVE

1. Determine the effect of varying vine water status in combination with ripeness level on morphological, structural and physiological changes in vegetative and reproductive organs and on wine quality.
2. Shed light on the physiological mechanism involved during the last stages of the ripening period in the ostensible switching of the berry from a complete, primarily water- and sugar-importing, organ to a metabolic unit that is apparently functioning with greater independence from the mother plant and where physical changes seem to have a great impact on the eventual quality potential for winemaking.
3. Determine the significance of vine water status on the length of the ripening period and the type of grape and wine style as related to optimal ripeness.
4. Make recommendations regarding the relationship between berry condition (physical and physiological) and wine quality and style.
5. Promote collaboration between research institutions in South Africa, France, Italy and Spain.

OBJECTIVES CURRENT YEAR

1.	Taste wines.	**August 2008**
2.	Write a final report.	**May - June 2009**

OBJECTIVES FOLLOWING YEAR

1. None

2. Amended workplan (materials & methods)

Give the proposed workplan for continuation **if changes are proposed to the original workplan**.

Materials and Methods

Vineyard

A seven year old *Vitis vinifera* L. cv. Shiraz (clone SH1A) vineyard, grafted onto Richter 99 (*Vitis Berlandieri* x *Vitis rupestris*) (clone RY2A), was used. The vineyard was located on the Experiment Farm of ARC Infruitec-Nietvoorbij in Stellenbosch, Western Cape, South Africa. The area is under the influence of a Mediterranean climate with high winter rainfall. The vines were spaced 2.75 m × 1.5 m on a Glenrosa soil with western aspect (26^{o} slope) and trained onto a 7-wire (cordon wire and three sets of movable wires spaced 15 cm) lengthened Perold (VSP) trellising system with cordon wire at 60 cm. Vines were pruned to two-bud spurs with a spur spacing of approximately 15 cm. Canopies were suckered (judicious removal of infertile shoots not located on spurs before and/or at approximately 30 cm primary shoot length), shoot positioned (shoots picked up to a vertical position by means of movable wires and then positioned by hand in line with their corresponding spurs – practice repeated as required) and tipped/topped [tipping (removal of primary shoot tips) and topping (removal of primary shoot apical portions to 30 cm above the top wire) was done as required during the period berry set to pea size]. No leaf removal was done in the canopies. Shoots growing laterally were tucked into the canopy and positioned vertically between the wires. Micro-sprinkler irrigation was applied according to levels and stages indicated in Table 1. Rye was sowed (at 80 kg/ha) between the rows in autumn to serve as cover crop during winter. The cover crop was killed in spring before bud burst and left as mulch on the ground during the summer.

Treatments & Layout

Fifteen treatments, comprising single and combined irrigations which differed in volume of water supplied and stage/s of application, were applied (Table 1). Three water levels, i.e. no irrigation (0%), soil volume filled to 75% of field water capacity, and soil volume filled to 100% of field water capacity, were implemented. Each irrigation treatment comprised either a single or different combinations of irrigations at different stages (berry set, pea size berry, véraison, and post-véraison). Véraison represented at least 75% of grape colouring. Post-véraison refers to three weeks after véraison. The treatments were applied in summer for four years continually. The treatments were completely randomised in two blocks (representing two replications), with a buffer row on each side of a treatment row and two buffer vines on each side of a treatment plot within the row. Thirty vines per replicate were used. Measurements were done at berry set, pea size berry, véraison, post-véraison and at three ripeness levels. Soluble solid contents were used as indicator for ripeness level, i.e. 23 ^{0}B, 25 ^{0}B and 27 ^{0}B (approximately 14 days between ripeness levels, corresponding to the beginning, middle and end of March). Mean values of the last two years of the experiment (2006/2007 and 2007/2008) are presented.

Measurements

Field water capacity and bulk density (at 10 cm, 40 cm and 70 cm) of the soil were determined by standard methods between the vineyard rows in six locations distributed at random in the experiment block. Both these soil parameters were used to calculate the volume of water needed to adjust the soil water content to either 75% or 100% of field water capacity at the different stages. Soil water contents were determined gravimetrically as well as by neutron moisture probe at 30 cm, 60 cm and 90 cm depth, respectively, at each measurement stage. Samples for soil analyses were taken at the same depths.

Seven shoots (including bunches) per vine were sampled in order to determine total leaf area, primary and secondary leaf area, number of primary leaves, number of secondary leaves and shoots, shoot lengths, bunch mass, and berry mass and volume. Berry skins were separated from the pulp, fresh and dry mass determined, and the water content calculated.

Leaf area was determined by means of a LICOR Model 3100 area meter. Light intensity in the bunch zone of the canopy was measured during mid-morning by means of a LICOR Line Quantum Sensor and expressed as a percentage of ambient light level determined in the vine row. Photosynthetic activity of leaves on primary and secondary shoots in the basal and apical parts of the canopy was measured during mid-morning using an open system ADC portable photosynthesis meter (The Analytical Development Co., Ltd., England). Leaf and stem water potential of mature leaves was determined from early to mid-afternoon using a Scholander pressure chamber (Scholander *et al*., 1965).

Soluble solids (^{0}Balling), titratable acidity, and pH of the grape must were determined in the cellar by standard methods after crushing of the grapes for winemaking. Individual sugars in the leaves, rachis, whole berry and pulp were extracted and analysed at all measurement stages by GLC (after silylation), as described by Hunter & Ruffner (2001). Whole berries were analysed for total anthocyanins (potential and extractable), total tannins, total seed tannins, total phenolic index, and total phenolics (A_{280}) (Ribéreau-Gayon *et al*., 2000). Berries were also analysed for flavan-3-ol monomers and oligomers by the DMAC method according to Vivas *et al*. (1994) and for proanthocyanins according to Ojeda *et al.* (2002). Berry skin total anthocyanins (A_{520}) and total phenolics (A_{280}) were determined according to Hunter *et al*. (1991).

Grapes of all harvests were cooled to the same temperature (20 ºC) before processing. Grapes were destemmed, crushed and the pomace inoculated with commercial yeast (VIN 13). Alcoholic fermentation took place at a controlled temperature of 24 ºC (di-ammonium phosphate and SO_2 were added). The skins were pushed through three times per day. Fermentation on the skins averaged five days, after which the pomace was pressed and the wines stabilised and bottled. Total phenolics (A_{280}) and total anthocyanins (A_{520}) of the bottled wines were determined. Wines were sensorially analysed by a trained panel of eight judges from the SA Wine Industry approximately four months after bottling. A unstructured line-scale method was used (Jackson, 2002).

At any given measurement stage, soil water determinations, physiological measurements, vegetative and reproductive growth sampling, as well as harvesting for winemaking were completed during the course of two days, after which irrigation was applied as required for the different treatments.

Table 1. Irrigation treatments applied to the Shiraz/Richter 99 vineyard.

Irrigation Treatment	**Berry set**	**Pea size**	**Véraison**	**Post-véraison**
1. No irrigation (NI)	O	O	O	O
2. 75% All stages (75% All stages)	¾X	¾X	¾X	¾X
3. 100% All stages (All stages)	X	X	X	X
4. 75% Pea size (75% PS)	O	¾X	O	O
5. 100% Pea size (PS)	O	X	O	O
6. 75% Véraison (75% V)	O	O	¾X	O
7. 100% Véraison (V)	O	O	X	O
8. 75% Post-véraison (75% PV)	O	O	O	¾X
9. 100% Post-véraison (PV)	O	O	O	X
10. 75% Pea size & véraison (75% PS+V)	O	¾X	¾X	O
11. 100% Pea size & véraison (PS+V)	O	X	X	O
12. 75% Pea size & post-véraison (75% PS+PV)	O	¾X	O	¾X
13. 100% Pea size & post-véraison (PS+PV)	O	X	O	X
14. 75% Véraison & post-véraison (75% V+PV)	O	O	¾X	¾X
15. 100% Véraison & post-véraison (V+PV)	O	O	X	X

Véraison = at least 75% colouring of grapes
Post-véraison = 3 weeks after véraison
O = No irrigation, ¾X = irrigation to 75% field water capacity, X = irrigation to 100% field capacity

3. Performance chart, results and discussion

Referring to the objectives, state results obtained to date and list any current benefits to the industry. Include a short discussion if applicable to your results. Please limit this discussion to essential information.

Milestone	**Achievement**
1. Application of treatments	Done
2. Measurements & analyses	Done
Response of vines to irrigation volume and timing	Clear trends regarding impact on growth, grape composition, wine quality and wine style found. Statistical analyses (Student's t-LSD test) still to be completed.

Introduction

The physiological functioning of the vine and capacity of the vine to buffer stressful conditions are an integrated expression of the terroir conditions and cultivation practices such as soil preparation, mulching, plant density, trellising and cultivar-rootstock combination (Smart & Coombe, 1983; Hunter & Myburgh, 2001; Hunter & Archer, 2001a, 2001b; Hunter & Bonnardot, 2002; Carey & Bonnardot, 2004; Deloire *et al.*, 2005; Vadour & Shaw, 2005; Novello, 2005). Selection of terroir and long and short term cultivating conditions that would stimulate physiological activity and increase priority of reproductive sinks in relation to vegetative sinks are of primary importance in our quest for improving yield and quality of grapes and wine (Hunter, 2000; Hunter & Archer, 2001a, 2001b; Hunter & Ruffner, 2001; Cloete *et al*., 2005; Hunter & Bonnardot, 2004; Hunter *et al*., 2004a; Pisciotta *et al*., 2004a, 2004b). Together with temperature, plant water status is generally recognised as one of the most critical factors impacting on the performance of the grapevine (Coombe, 1987; Hunter & Myburgh, 2001; Hunter & Bonnardot, 2002). The gradual depletion of soil water during the growth season normally results in increasing water stress experienced by vineyards. Considering the vegetative and reproductive growth patterns of the grapevine, it follows logical that the availability of water in terms of volume, accessibility, and growth stage during the season, may have differential effects on growth and grape and wine quality *per se*, but also on the length of the ripening period (harvesting window). This would impact on the level of ripeness that may be achieved and the potential for different styles of wine on a particular terroir (Ojeda *et al*., 2002; Hunter *et al*., 2004; Hunter & Deloire, 2005). A thorough understanding of physiological changes during both green berry and ripening period (and in response to environment changes) seems necessary. Strong indications exist that manipulation by means of water stress (and canopy management) during the pre-véraison period is critical in the regulation of berry size and eventual berry composition at ripeness (Ojeda *et al*., 2002). Water relations during the post-véraison period also clearly impact on grape composition. In addition, studies showed that the ripeness level at which grapes are harvested is critical in the determination of wine quality and style (Hunter *et al*., 2004a, 2004b; Hunter & Deloire, 2006; Nadal & Hunter, 2007). Optimum irrigation strategies that allow timely stress in order to curb vegetative growth, but at the same time maintain a good canopy capacity and microclimate, and which benefit grape composition and wine quality (as depicted by different wine styles), are therefore still pursued.

The stimulation of growth, supply and loading of sugar by sources, sink hierarchy, phloem transport and unloading in sinks after partitioning, and metabolisation of sugar in sinks are critical events in grapevine growing and the quality of the eventual product. Despite attempts based on methods such as berry dimensions (after transport disruption by means of girdling and heat treatment) (Lang & Thorpe, 1989; Greenspan *et al.,* 1994; Greenspan *et al*., 1996), water soluble dyes (Düring *et al*., 1987; Findlay *et al*., 1987; Creasy *et al*., 1993; Rogiers *et al*., 2001), monitoring of xylem and phloem mobile mineral transport (Creasy *et al*., 1993; Rogiers *et al*., 2000; Etchebarne *et al*., 2008), hydraulic conductance measurements (Tyerman *et al*., 2004), berry turgor (Tyler *et al*., 2006) and xylem tracheary element analyses (Chatelet *et al*., 2008), the mechanisms involved in the regulation of sugar and water import as well as berry shrinkage at a specific ripeness level, particularly for Shiraz, are not resolved. Indications are that sugar (sucrose – the origin of most quality-contributing compounds) and water accumulation in the grapes is regulated by a combination of photosynthesis, osmotically driven transport, berry evapotranspiration, sucrolytic enzyme activity, membrane degeneration/permeability and a change in the ratio of xylem:phloem import, primarily after véraison (Dreier *et al*., 1998; Lang & Düring, 1991; Greenspan *et al*., 1994; Rebucci *et al*., 1997; Dreier *et al*., 2000). However, many aspects, such as cellular compartmentation and xylem embolism have been disputed (Tyler *et al*., 2006; Chatelet *et al*., 2008). According to Bondada *et al.* (2005) a loss in appropriate driving force or hydrostatic gradient may be involved in the loss of active xylem function after véraison. Furthermore, xylem backflow from the berries back to the parent vine during late ripening stages has been proposed by many (Lang & Thorpe, 1989; Schaller *et al*., 1992; Greenspan *et al*., 1996; McCarthy & Coombe, 1999; Rogiers *et al*., 2006; Tilbrook & Tyerman, 2009). A resumption of xylem inflow during late ripening stages has also been suggested, presumably to match the diminishing phloem flow (Schaller *et al*., 1992; Rogiers *et al*., 2006). Etcheban *et al.* (2008) argued that the increase in calcium found during post-véraison under sufficient water supply may be taken as an indication that there is partial functioning of the xylem (transport) after véraison. A migration of calcium and potassium between berry compartments (from seeds/flesh to skins) also seem to occur during this time. This may have been a normal migration according to the loss of water from the berry. A continuation of post-véraison berry peripheral xylem development seems evident (Chatelet *et al*., 2008), but whether this is involved in post-véraison water translocation into the berry is still debatable. Improper sucrose and potassium phloem unloading at enzyme, transporter and carrier level have been suggested (Davies *et al*., 1999; Fillion *et al*., 1999; Pratelli *et al*., 2002) as reasons for the apparent termination of transport into berries. A decline in membrane hydraulic conductance seems evident and significant during ripening (Tyerman *et al*., 2004) and lower activity of aquaporins responsible for membrane water permeability have been implicated (Tyerman *et al*., 2002; Tyerman *et al*., 2004; Delrot *et al*., 2001).

The challenge lies in finding the relation that these changes in canopy and berries have with the readiness of the latter for harvesting and potential wine style/s that can be expected. Attention to both volume and developmental stage of water supply are required. In order to fully quantify the importance of water relations in grape composition and it's suitability for a specific wine objective, grapes that are subjected to various vine water status levels should be monitored at different ripeness levels. Changes during ripening should be quantified and the water status-grape ripening interrelationship be optimized to the benefit of yield, grape and wine quality and classification of different wine styles (Hunter & Deloire, 2005; Deloire *et al*., 2005). To our knowledge, this aspect has not been systematically investigated. This would provide a further dimension to grapevine water relation effects on grape and wine quality, further insight into physical and physiological changes and relationships during ripening and new perspectives on how to manage the time of harvesting under varying vine water status. The focus of this study was on quantifying changes during the last stages of ripening under different vine water status levels, introduced at different stages during the growth season as single or multiple applications. An ultimate aim would be to determine wine quality and style on the basis of soil and plant water relations, canopy appearance, berry physical structure, and berry composition at any given time during ripening.

Results and Discussion

The Glenrosa soil used is classified as a predominantly sand-clay-loam soil (Table 2) and has an average field water capacity (FWC) of approximately 17% (dry mass basis), which is lower than expected. The FWC of the different soil layers was similar. The soil compaction index (measured as bulk density) of the different soil layers slightly exceeded the critical value of 1.5 g/cm^3, beyond which root penetration is believed to decline (Richards (1983). Resistance of the soil increased with increasing depth, whereas P, K and Ca decreased. Except for Fe, contents of the micro-elements and carbon as well as the texture of the soil also decreased with depth (Tables 3a & 3b).

Table 2. Physical analyses of the soil.

Depth (cm)	Clay (%)	Silt (%)	Sand (%)				Classification*	Bulk density (g/cm^3)	Field water capacity
			Fine	Medium	Coarse	Total			
0-30	21.60	12.44	49.35	8.99	7.62	65.96	Sa-Cl-Lm	1.62	17.20
30-60	25.58	10.60	48.67	8.69	6.46	63.82	Sa-Cl-Lm	1.60	16.92
60-90	28.56	10.64	45.95	8.44	6.42	60.80	Sa-Cl-Lm	1.60	17.37

*Sa-Cl-Lm = Sand-clay-loam soil

Table 3a. Chemical analyses of the soil.

Depth	pH	Resistance	H	Stone	P Bray II	K	Exchangeable cations (cmol(+)/kg)			
(cm)	(KCl)	(Ohm)	(cmol/kg)	(Vol %)	(mg/kg)		Na	K	Ca	Mg
0-30	5.8	2160	0.46	16.0	6.0	131.0	0.12	0.34	2.62	0.92
30-60	5.7	2520	0.39	19.5	3.0	62.0	0.10	0.16	2.25	0.54
60-90	5.5	2960	0.42	12.0	2.5	51.5	0.11	0.13	1.85	0.82

Table 3b. Chemical analyses of the soil.

Depth (cm)	Cu	Zn	Mn	B	Fe	C	Na	K	Ca	Mg	T-value (cmol/kg)
	(mg/kg)					(%)					
0-30	1.17	2.25	19.00	0.15	3.11	0.94	2.55	4.44	59.06	20.72	4.44
30-60	0.97	0.60	9.90	0.08	4.44	0.41	2.91	3.44	65.43	15.67	3.44
60-90	0.70	0.30	6.45	0.07	4.55	0.17	3.31	3.32	56.24	23.22	3.32

Soil water contents are given only at the different harvest times (rest of data not shown) (Fig. 1a). Gravimetric and neutron moisture probe soil water results, for the purpose of calibration, showed an extremely poor relationship (Fig. 1b) and gravimetric measurements were therefore used to determine soil water contents and calculate irrigation volumes. This aspect has serious implications for producers relying solely on neutron moisture probe results for irrigation scheduling. Though the familiar trend of increasing soil water content with increasing soil depth was evident, it is interesting that similar treatment effects occurred in the different soil layers. The drainage, accumulation and withdrawal dynamics of water in the different soil layers were therefore similar. With few exceptions, the soil water content (on a dry mass basis) stayed above 50% FWC. A decreasing trend was, however, noticeable from the first to the third harvest stage, the water loss between the first two stages being the most noticeable (Fig. 1a), irrespective of rainfall just prior to the second harvest stage in both 2006/07 and 2007/08 (Figs. 2a & 2b). Despite the relatively regular rainfall during the active growth period and the ripening period (Figs. 2a & 2b), treatments with soil water adjusted to 100% FWC, at all stages (control) and noticeably at post-véraison, and at post-véraison and earlier stages combined, showed elevated soil water contents in all soil layers and at the different harvest stages. The treatments were therefore successful in reaching deeper soil layers, despite the increase in clay content with depth and the soil compaction which may have affected soil porosity in particularly the top soil layer (Table 2). It seems that the reduction in soil water mostly stemmed from a loss of added water and that the base soil water fraction stayed largely intact (Fig. 1a). This is also evident from the relatively high soil water content of the non-irrigated treatment, particularly in the deepest soil layer and at the last harvest stage. The treatment effects on soil water content progressively diminished from the first to the third ripeness stage. It can be accepted that the water tension in the soil increased during the later stages of the growth season, but that the impact of transpiration would have been reduced because of a senescing canopy and reduced phloem water gradient between the berry and the parent plant during this time (Lang & Thorpe, 1989; Schaller *et al.*, 1992; Greenspan *et al.*, 1996; McCarthy & Coombe, 1999; Dreier *et al.*, 2000; Hunter *et al.*, 2004; Tyerman *et al.*, 2004; Rogiers *et al.*, 2006).

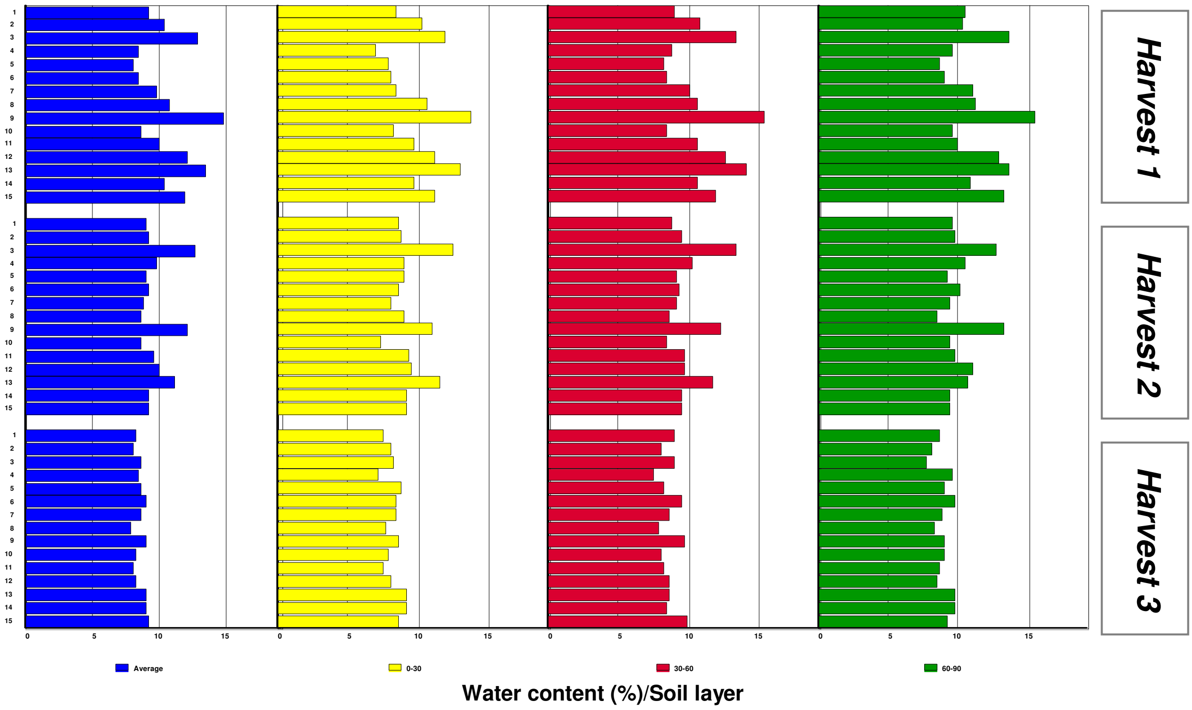

Fig. 1a. Effect of level and stage of irrigation (number refers to the treatment as depicted in Table 1) on soil water content, measured in three layers and at three ripeness stages in the Shiraz/Richter 99 vineyard.

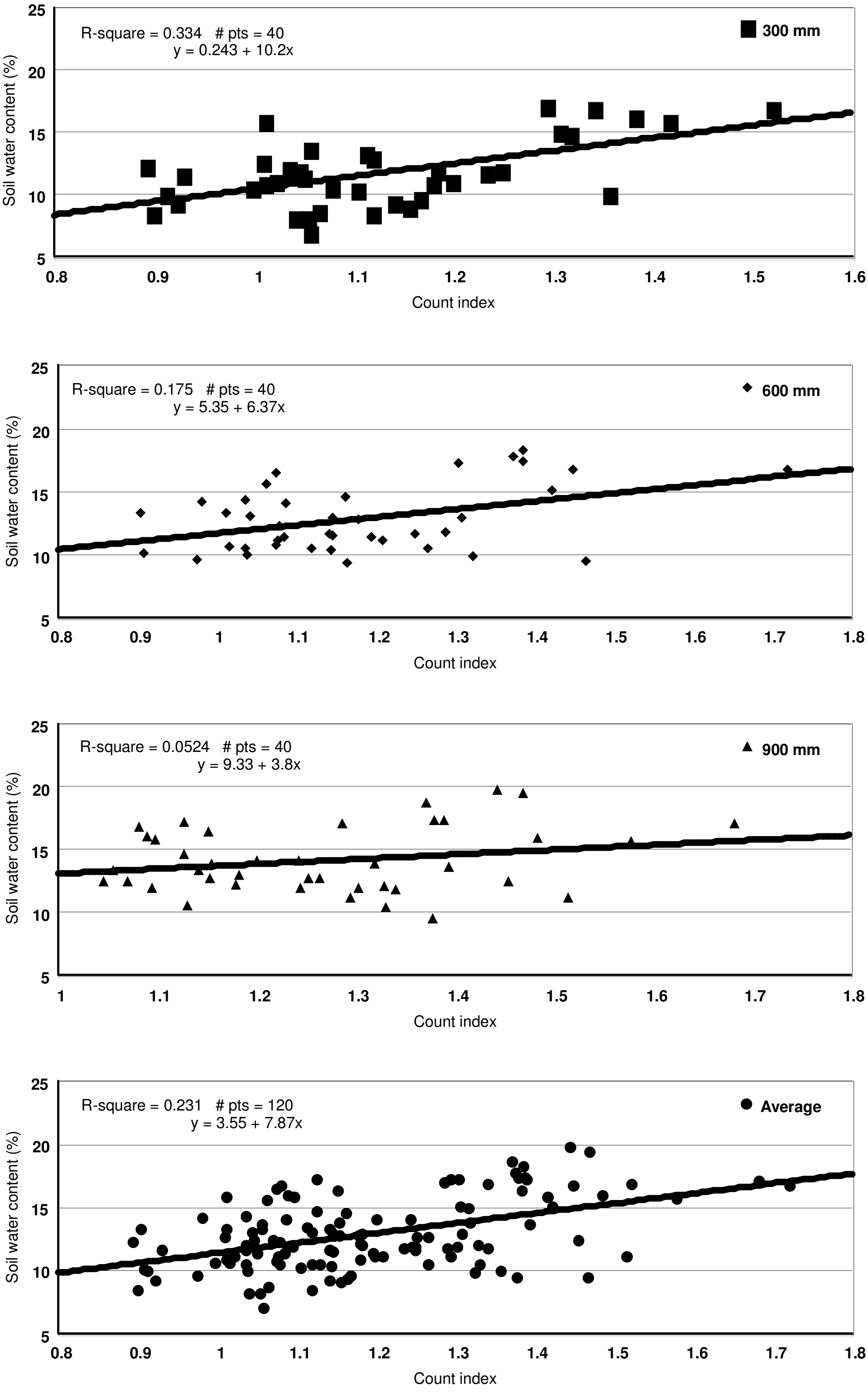

Fig. 1b. Relationship between gravimetric and neutron moisture probe soil water contents in three layers and over a surface of approximately 0.8 ha in the Shiraz/Richter 99 vineyard.

The soil clearly has a high water holding capacity and buffer capacity against favourable evapotranspiration conditions, even with western aspect and being subjected to a long and relatively dry season with frequent occurrence of high temperatures (Figs. 2a & 2b) and grapevines with canopies fully developed on the trellising system. It is unlikely that the root system composition (in terms of root thickness) and distribution in the different soil layers could have been similar. It may be assumed that the root system would have grossly been distributed in the top 0 – 80 cm layer and fine root presence would have been higher in at least the top soil layers, mostly the 0 – 30 cm layer, similar to what had been found for different cultivars in different soils (Swanepoel & Southey, 1989; Hunter *et al*., 1995; Hunter, 1998a, and references therein).

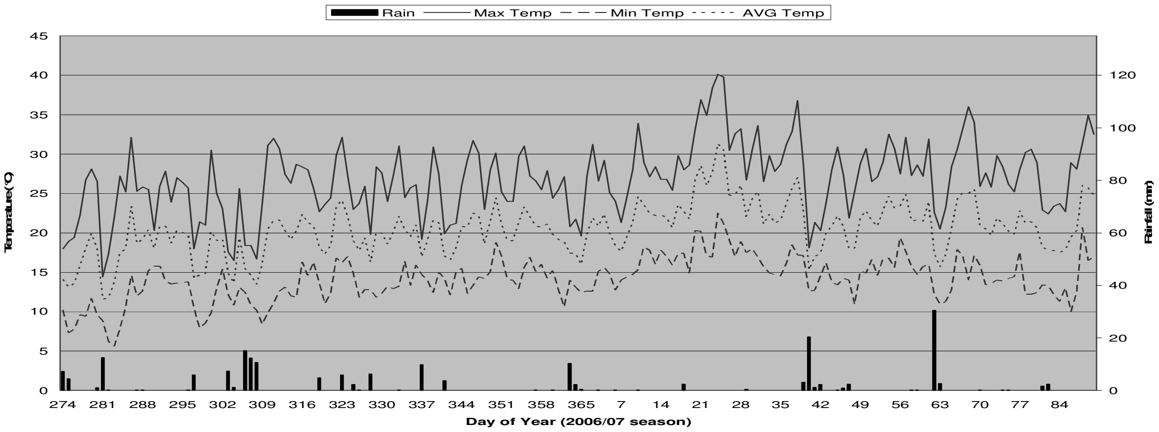

Fig. 2a. Temperature and rainfall patterns for the 2006/2007 season at the experiment location.

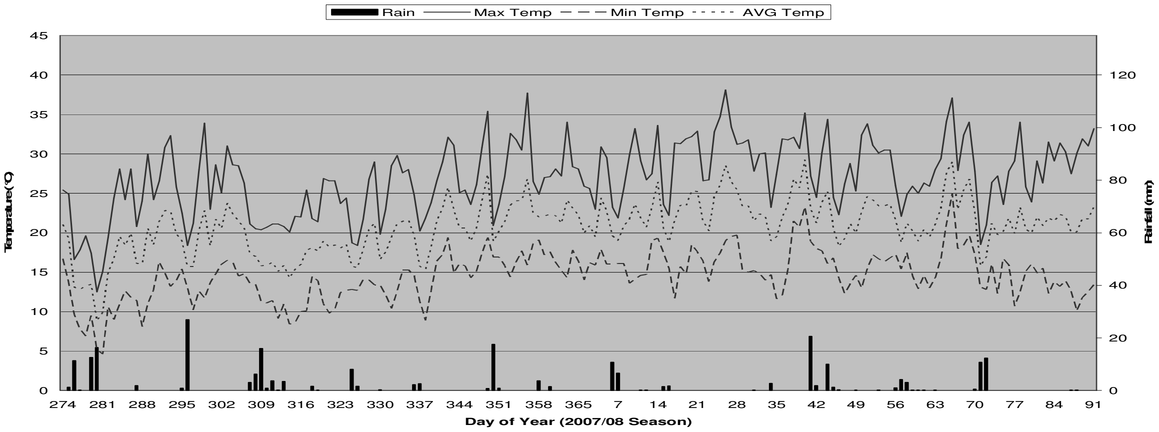

Fig. 2b. Temperature and rainfall patterns for the 2007/2008 season at the experiment location.

The water potential data are showing clear trends (Table 4). In general, an increasing water stress seemed evident from berry set stage until the last harvest stage. Although the soil water contents showed a decreasing trend from the first to the second harvest stage (Fig. 1a), the water relations of the vines clearly increased during this time as a result of the rainfall just before the second harvest stage (Figs. 2a & 2b). The general impression is that vines were not overly stressed. This is in line with relatively high basic soil water fractions of mostly more than 50% of FWC (Fig. 1a). Primary and secondary leaves and the internal hydraulic conductivity in the trunk and shoot (as measured by stem water potential), displayed similar patterns. Water potential of primary and secondary leaves was not much different. Stem water potential was generally higher than leaf water potential. This is commonly found (Choné *et al*., 2001; Di Lorenzo *et al*., 2005). It also indicates that leaf water potential over mid-day is more sensitive to environmental changes in e.g. light, temperature and wind. However, the drier the conditions, the less the difference seemed to be. This tendency was also noticed under extreme hot conditions (data not shown). Differences in stem water potential between treatments were more noticeable (Table 4).

Non-irrigated, pea size irrigated (75% and 100%) and pea size+véraison irrigated (75%) vines behaved similarly, generally displaying lower leaf water potentials.

Table 4. Effect of level and stage of irrigation on leaf and stem water potential, measured in the bunch zone and apical zone of the canopy of Shiraz/Richter 99.

Stage	**Irrigation Treatment (stage + level)**	**Water potential (- kPa)**					
		Primary leaves		**Secondary leaves**		**Stem**	
		ψ	**Trm. av.**	**Ψ**	**Trm. Av.**	**ψ**	**Trm. av.**
BS	**Before I**	683.3	683.3	687.5	687.5	587.5	587.5
PS	**NI**	956.3	956.3	868.8	868.8	775.0	775.0
	75All stages	743.8		825.0		706.3	
	100All stages	668.8	706.3	812.5	818.8	593.8	650.0
V	**NI**	1081.3	1081.3	800.0	800.0	956.3	988
	75All stages	950.0		931.3		746.9	
	100All stages	968.8	959.4	937.5	934.4	687.5	717.2
	75PS	1187.5		1125.0		1025.0	
	100PS	943.8	1065.6	943.8	1034.4	837.5	931.3
PV	**NI**	1268.8	1268.8	1331.3	1331.3	1087.5	1087.5
	75All stages	1106.3		1218.8		1037.5	
	100All stages	931.3	1018.8	1125.0	1171.9	868.8	953.1
	75PS	1362.5		1400.0		1300.0	
	100PS	1425.0	1393.8	1418.8	1409.4	1300.0	1300.0
	75V	1275.0		1356.3		1062.5	
	100V	1087.5	1181.3	1112.5	1234.4	912.5	987.5
	75PS+V	1337.5		1487.5		1206.3	
	100PS+V	1050.0	1193.8	968.8	1228.1	831.3	1018.8
H1	**NI**	1187.5	1187.5	1075.0	1075.0	1087.5	1087.5
	75All stages	887.5		950.0		787.5	
	100All stages	825.0	856.3	825.0	887.5	687.5	737.5
	75PS	1175.0		1237.5		1175.0	
	100PS	1287.5	1231.3	1275.0	1256.3	1212.5	1193.8
	75V	1137.5		1237.5		1137.5	
	100V	1087.5	1112.5	1112.5	1175.0	975.0	1056.3
	75PV	937.5		900.0		775.0	
	100PV	787.5	862.5	812.5	856.3	555.0	665.0
	75PS+V	1312.5		1337.5		1250.0	
	100PS+V	1025.0	1168.8	912.5	1125.0	850.0	1050.0
	75PS+PV	1025.0		1037.5		912.5	
	100PS+PV	825.0	925.0	800.0	918.8	750.0	831.3
	75V+PV	1037.5		1037.5		1000.0	
	100V+PV	850.0	943.8	787.5	912.5	737.5	868.8
H2	**NI**	950.0	950.0	912.5	912.5	925.0	925.0
	75All stages	862.5		975.0		850.0	
	100All stages	862.5	862.5	837.5	906.3	750.0	800.0
	75PS	1050.0		1025.0		950.0	
	100PS	1087.5	1068.8	1037.5	1031.3	987.5	968.8
	75V	1012.5		1075.0		925.0	
	100V	1037.5	1025.0	962.5	1018.8	937.5	931.3
	75PV	1037.5		1025.0		937.5	
	100PV	837.5	937.5	962.5	993.8	650.0	793.8
	75PS+V	1087.5		1062.5		1012.5	
	100PS+V	862.5	975.0	900.0	981.3	812.5	912.5
	75PS+PV	1050.0		1112.5		1000.0	
	100PS+PV	925.0	987.5	825.0	968.8	762.5	881.3
	75V+PV	1050.0		1075.0		912.5	
	100V+PV	900.0	975.0	1012.5	1043.8	750.0	831.3
H3	**NI**	1037.5	1037.5	1112.5	1112.5	1062.5	1062.5
	75All stages	912.5		925.0		887.5	
	100All stages	962.5	937.5	950.0	937.5	850.0	868.8
	75PS	1012.5		1100.0		1037.5	
	100PS	1075.0	1043.8	1025.0	1062.5	975.0	1006.3
	75V	1175.0		1275.0		1125.0	
	100V	1275.0	1225.0	1237.5	1256.3	1125.0	1125.0
	75PV	1325.0		1225.0		1162.5	
	100PV	1100.0	1212.5	1175.0	1200.0	1025.0	1093.8
	75PS+V	1275.0		1187.5		1250.0	
	100PS+V	950.0	1112.5	925.0	1056.3	850.0	1050.0
	75PS+PV	1387.5		1312.5		1362.5	
	100PS+PV	1137.5	1262.5	1062.5	1187.5	1025.0	1193.8
	75V+PV	1225.0		1137.5		1187.5	
	100V+PV	1012.5	1118.8	1025.0	1081.3	1025.0	1106.3

BS = Berry set; PS = Pea size; V = Véraison; PV = Post-véraison; 75 = irrigation to 75% field water capacity; 100 = irrigation to 100% field water capacity; NI = No irrigation; Trm. av. = Treatment average; H1 = Harvest 1; H2 = Harvest 2; H3 = Harvest 3; Before (I) irrigation = Means of measurements at berry set

Fully irrigated vines, and vines irrigated at post-véraison, and in combination with earlier stages, clearly responded to more or less water (Table 4), in line with the soil water contents (Fig. 1a). It seems, however, that non-irrigated vines and vines irrigated only during pre-véraison (at pea size) developed an adaptive behaviour towards lower soil water contents and diurnal environmental stress. According to Patakas & Noitsakis (1999), an active osmotic adjustment may occur during the day under drought conditions. This would enable vines to maintain turgor. Both level of irrigation and stage of irrigation effects were evident at all stages. The water relations of vines, irrespective of treatment, generally followed soil water content patterns. The decrease in water potential at the last two harvests seemed more pronounced for wetter and post-pea size irrigated vines, a pattern which coincides with soil water patterns shown in Fig.1a. This decrease in water potential nevertheless was too excessive to judge as being solely resulting from a decrease in soil water. Behaviour of pre-véraison irrigated vines and non-irrigated vines is discernable from that of post-véraison irrigated vines, the first-mentioned group apparently lifting their internal water relations, whereas the latter group continued to lose water after irrigation. Continuously irrigated vines maintained reasonably high water potential during the season. From after véraison until the second harvest stage, apical primary leaves and secondary leaves displayed generally higher photosynthetic activity than primary basal leaves (Table 5). Being younger, apical and secondary leaves generally responded better to decreasing photosynthetic active radiation during ripening. They would be more involved in metabolic processes to satisfy sucrose and osmotic balance demands during this time (Hunter *et al.*, 1994; Hunter & Ruffner, 2001; Hunter *et al.*, 2004) and thus would have been more affected by environmental fluctuations and less affected by abiotic influences on senescing processes, compared to primary leaves. According to Patakas *et al.* (1997) the capability for osmo-regulation was almost the same in mature and immature leaves, but decreased with age. Immature leaves have more elastic cell walls rendering them an ability to maintain positive cell turgor under lower leaf water conditions. Secondary leaves may thus have a better ability to buffer the impact of unfavourable environmental conditions, e.g. high temperatures, on grape development and ripening (Hunter, 2000; Hunter *et al.*, 2004; Novello & Hunter, 2004). In addition to water management (and appropriate fertilization programmes), it is important that initiation and development of secondary leaves are stimulated pre-véraison by judicious canopy management (Hunter, 2000). After the second harvest stage (and despite rainfall just prior – Figs. 2a & 2b), a general drop in photosynthetic activity occurred (Table 5). This may be indicative of senescence of the whole canopy, but may also be evidence that sucrose built up in leaves as a result of reduced demand from the rest of the vine, including berries (Hunter *et al.*, 1994; Hunter *et al.*, 2004). Noticeably, vines were not highly stressed and non-irrigated vines maintained comparatively high photosynthetic activity. A decrease in photosynthetic efficiency (indicated by photosynthesis:transpiration ratio) occurred as the season progressed. Decreasing water potentials occurring for irrigated and non-irrigated vines during grape ripening were probably mainly imposed by lack of continued high water absorption by roots, possibly under influence of so-called stress hormones, e.g. abscisic acid (Hunter, 1998b; Lovisolo *et al.*, 2002; Patakas *et al.*, 2005). This would have been enhanced by a senescing canopy and prevailing cooler day and night temperatures, impacting on water potential gradients and source:sink relationships. A natural decrease in primary and secondary leaf area occurred during berry ripening from at least post-véraison stage (Fig. 3, Tables 6a & 6b). This was also found for Cabernet Sauvignon (Hunter & Visser, 1990). Development of secondary leaf area was stimulated by early-season irrigation (up to pea size berry). However, late season, high volume irrigation (to 100% FWC) in combination with earlier stages, tended to stimulate secondary leaf area development during late ripening. It is unlikely that late season initiated primary or secondary leaves would reach sucrose-export age and still significantly contribute to grapes (Hunter & Visser, 1988), but they may contribute to reserve accumulation after harvest. Re-growth may also be an indication of a still active canopy, which may extend the harvesting window by continued translocation/contribution to grapes by existing exporting leaves. A larger secondary leaf area component would contribute significantly to photosynthetic capacity (Hunter, 2000; Vasconcelos & Castagnoli, 2000). Non-irrigated vines maintained surprisingly high leaf area

(Fig. 3), most probably because of the relatively high base soil water content (Fig. 1a). They also generally displayed lowest primary:secondary leaf area ratios. Pre-véraison irrigation seemed to result in lowest ratios at the three harvest stages, mostly because of early stimulation of secondary leaf area development.

Table 5. Effect of level and stage of irrigation on photosynthetic activity of leaves of Shiraz/Richter 99.

Stage	Irrigation Treatment (stage + level)	Photosynthetic activity (PS) (µmole/m^2/s)/Transpiration (T) (mmole/m^2/s)											
		Primary leaves						Secondary leaves					
		Basal			Apical			Basal			Apical		
		PS	T	PS:T	PS	T	PS:T	PS	T	PS:T	PS	T	PS:T
PS	NI	14.3	5.2	2.8	9.9	3.7	2.6	12.6	4.41	2.9	8.9	3.9	2.3
	75All stages	13.7	5.1	2.7	11.2	4.2	2.6	10.0	4.14	2.4	9.6	3.9	2.5
	100All stages	15.0	5.4	2.8	8.9	3.7	2.4	11.5	4.61	2.5	8.8	3.9	2.3
V	NI	10.1	4.6	2.2	8.7	5.4	1.6	10.9	4.69	2.3	12.8	5.5	2.3
	75All stages	6.6	3.8	1.8	9.6	5.0	1.9	9.8	4.94	2.0	10.9	6.7	1.6
	100All stages	6.0	5.0	1.2	4.3	4.5	2.3	5.7	4.71	1.2	12.5	5.9	2.1
	75PS	7.6	3.6	2.1	4.2	2.4	1.7	6.6	3.22	2.0	7.7	3.6	2.2
	100PS	8.4	3.9	2.1	9.1	5.6	1.6	6.1	5.81	1.0	11.7	5.4	2.2
PV	NI	7.0	3.3	2.1	10.9	4.6	2.4	7.3	3.89	1.9	8.2	4.1	2.0
	75All stages	4.9	3.9	1.3	11.7	6.0	1.9	9.0	4.99	1.8	12.0	5.5	2.2
	100All stages	9.6	5.8	1.7	12.0	6.1	2.0	9.8	5.51	1.8	12.8	6.4	2.0
	75PS	8.3	3.8	2.2	7.9	4.6	1.7	6.0	3.47	1.7	10.8	5.2	2.1
	100PS	4.3	2.8	1.5	9.1	4.5	2.0	6.2	3.75	1.7	6.9	4.4	1.6
	75V	9.7	5.5	1.7	11.4	6.1	1.9	9.6	5.00	1.9	10.8	6.0	1.8
	100V	4.8	5.1	0.9	10.3	5.6	1.8	5.2	5.33	1.0	10.9	6.2	1.8
	75PS+V	6.1	4.3	1.4	6.6	4.9	1.3	9.7	4.30	2.3	7.5	4.9	1.5
	100PS+V	8.1	4.8	1.7	11.3	6.0	1.9	6.5	5.53	1.2	7.1	5.0	1.4
H1	NI	8.4	6.7	1.3	9.4	6.6	1.4	5.5	6.27	0.9	5.6	7.1	0.8
	75All stages	2.8	4.6	0.6	6.2	7.1	0.9	9.1	6.55	1.4	9.9	7.0	1.4
	100All stages	7.7	6.4	1.2	12.4	7.5	1.7	7.7	7.40	1.0	6.2	6.8	0.9
	75PS	3.6	4.3	0.8	8.7	5.2	1.7	9.0	5.40	1.7	10.6	5.6	1.9
	100PS	5.5	4.3	1.3	5.0	3.9	1.3	5.2	3.98	1.3	6.7	4.3	1.6
	75V	4.0	4.3	0.9	8.6	5.0	1.7	7.5	4.81	1.6	8.9	5.9	1.5
	100V	7.0	6.8	1.0	6.4	6.3	1.0	6.9	6.46	1.1	10.9	6.7	1.6
	75PV	6.3	6.3	1.0	9.3	6.4	1.5	10.2	6.58	1.5	9.4	6.5	1.4
	100PV	9.0	5.4	1.7	9.9	5.5	1.8	5.2	6.06	0.9	3.1	6.8	0.5
	75PS+V	2.9	3.2	0.9	6.3	4.4	1.4	4.4	3.33	1.3	5.5	4.0	1.4
	100PS+V	9.2	6.2	1.5	9.2	6.7	1.4	8.3	5.81	1.4	10.0	6.0	1.7
	75PS+PV	6.6	5.4	1.2	7.5	6.2	1.2	2.7	6.32	0.4	4.6	6.5	0.7
	100PS+PV	5.9	5.6	1.1	9.4	7.4	1.3	8.7	6.42	1.4	10.9	6.7	1.6
	75V+PV	9.1	6.3	1.5	10.9	6.4	1.7	12.0	7.11	1.7	12.3	6.9	1.8
	100V+PV	9.5	6.4	1.5	11.7	7.0	1.7	8.0	6.27	1.3	9.4	6.6	1.4
H2	NI	8.5	4.8	1.8	9.5	5.4	1.7	9.7	5.37	1.8	11.9	5.7	2.1
	75All stages	6.8	4.8	1.4	7.1	4.0	1.8	8.1	4.05	2.0	12.6	6.0	2.1
	100All stages	7.3	4.8	1.5	9.8	5.8	1.7	12.6	5.87	2.1	10.4	6.0	1.7
	75PS	4.1	2.6	1.6	7.1	4.4	1.6	7.6	3.81	2.0	8.4	4.0	2.1
	100PS	4.9	3.0	1.6	8.2	4.3	1.9	3.6	2.85	1.3	6.9	3.8	1.8
	75V	3.6	2.4	1.5	8.0	3.7	2.2	10.6	4.85	2.2	10.1	4.3	2.3
	100V	4.5	3.9	1.2	10.8	5.0	2.2	8.0	4.44	1.8	5.6	5.4	1.0
	75PV	9.1	5.1	1.8	7.3	4.8	1.5	11.5	5.32	2.2	11.4	5.1	2.2
	100PV	7.7	4.2	1.8	9.2	4.6	2.0	8.9	4.24	2.1	13.5	5.0	2.7
	75PS+V	4.5	2.8	1.6	5.3	3.1	1.7	4.4	2.85	1.5	8.0	4.5	1.8
	100PS+V	6.4	4.6	1.4	6.5	4.3	1.5	8.5	4.60	1.8	13.8	6.2	2.2
	75PS+PV	5.6	3.4	1.6	10.7	4.8	2.2	12.7	5.57	2.3	12.7	5.7	2.2
	100PS+PV	5.6	3.7	1.5	10.3	5.3	1.9	11.1	5.29	2.1	9.7	5.5	1.8
	75V+PV	7.2	3.9	1.8	8.7	4.6	1.9	11.5	5.28	2.2	10.7	5.1	2.1
	100V+PV	5.8	3.8	1.5	10.9	5.2	2.1	8.3	4.62	1.8	12.1	5.7	2.1
H3	NI	4.6	3.0	1.5	5.3	3.1	1.7	4.8	3.20	1.5	7.2	4.2	1.7
	75All stages	4.7	4.0	1.2	7.6	5.0	1.5	2.7	2.93	0.9	4.4	4.5	1.0
	100All stages	5.4	4.0	1.3	6.4	4.5	1.4	4.1	3.31	1.2	8.8	5.1	1.7
	75PS	3.7	2.5	1.5	5.9	3.4	1.7	4.6	2.65	1.7	3.6	3.5	1.0
	100PS	3.7	2.6	1.4	6.4	4.1	1.5	2.5	2.09	1.2	6.0	3.5	1.7
	75V	5.6	3.2	1.7	6.1	3.6	1.7	3.3	2.12	1.6	7.2	3.6	2.0
	100V	3.7	3.1	1.2	5.3	3.3	1.6	5.6	3.40	1.7	6.1	3.5	1.8
	75PV	2.5	2.4	1.1	7.6	4.1	1.8	2.8	2.02	1.4	6.5	4.0	1.6
	100PV	8.0	3.8	2.1	10.7	4.4	2.4	7.9	3.76	2.1	9.8	4.3	2.3
	75PS+V	2.8	1.7	1.6	6.0	4.3	1.4	4.4	2.53	1.7	3.5	2.2	1.6
	100PS+V	2.3	2.6	0.9	6.3	4.2	1.5	5.2	3.77	1.4	5.4	4.0	1.4
	75PS+PV	3.4	2.0	1.7	8.9	3.8	2.3	5.0	2.44	2.0	8.1	3.6	2.2
	100PS+PV	3.8	3.0	1.3	7.1	4.1	1.7	6.6	4.27	1.5	7.8	4.8	1.6
	75V+PV	2.4	1.8	1.3	3.7	3.4	1.1	5.5	3.19	1.7	6.7	3.4	2.0
	100V+PV	4.5	3.6	1.2	6.8	4.6	1.5	6.2	4.27	1.5	6.1	4.7	1.3

BS = Berry set; PS = Pea size; V = Véraison; PV = Post véraison; 75 = irrigated to 75% field water capacity; 100 = irrigated to 100% field water capacity; NI = No irrigation; H1 = Harvest 1; H2 = Harvest 2; H3 = Harvest 3

Berries reached highest mass approximately three weeks after véraison (Table 7). This is in agreement with earlier findings (Hunter *et al.*, 2004). Berry size was increased by pre-véraison high-volume irrigation, but the effect was only evident at the first harvest stage. High base soil water under the conditions of the study prevented classic water deficit berry size reduction effects (Williams & Matthews, 1990; McCarthy, 2000; Ojeda *et al.*, 2002; Roby & Matthews, 2004; Myburgh, 2005). Bunch mass and volume started to decrease already from post-véraison, whereas the rachis reached highest mass only at the first harvest stage, after which it decreased (Fig. 4). Although response to treatment was similar, bunch mass and volume and berry mass and volume continued to decrease during all ripening stages, whereas rachis mass kept stable from the second to third harvest stage. The rachis therefore largely contributed to maintenance of bunch mass with further ripening; this has implications for both winery and producer. Appearance of the rachis may not be an indication of berry condition. Results seem to indicate independent development and/or senescence for berry and rachis during ripening. Soil water contents (Fig. 1a), leaf and stem water potential (Table 4), photosynthetic activity (Table 5) and bunch and berry mass (Table 7) seem concerted during the last ripening stages. This is in line with a senescing canopy (Fig. 3, Tables 6a & 6b). Sucrose concentrations in leaves reached peak values between post-véraison and the first harvest stage, after which a general decline occurred (Fig. 5), in line with general senescence of the canopy during the latter period. It was previously found that sucrose built up in primary and secondary leaves during late ripening (Hunter *et al.*, 1994; Hunter *et al.*, 2005). This was also evident in this study (Fig. 5), particularly in secondary leaves, and coincided with the decrease in water potential of leaves (Table 4). This build-up of sucrose in the leaves, i.e. an over-supply of sucrose, may also nullify potential negative effects that re-growth of secondary shoots or even tertiary shoot initiation after late-season irrigation may have on grape ripening, as discussed earlier. Parallel to sucrose concentrations in leaves, sucrose concentrations in the skin (which is assumed to be mainly fed by berry peripheral phloem) also seem to peak between post-véraison and the first harvest stage (Fig. 6). In contrast, lowest sucrose concentrations in the pulp seemed to occur around the first harvest stage, where after it increased, and kept stable after that. This increase coincided with lowest concentrations in the rachis, which then increased again. Sucrose concentrations in the skin and pulp therefore followed similar patterns up to post-véraison, where after it increased in the skin and decreased in the pulp up to the second harvest stage; after this, a stable trend was evident in the pulp, but a decreasing trend in the skin. Given the low water potential in the canopy, build-up of sucrose in leaves, a more stable rachis mass, a reduction in berry size and the decreasing trend in the skin during this time, it is possible that the increase in sucrose in the rachis may indicate a point where phloem unloading into the berry is affected by water potential gradients as well as metabolic activity in berries. The increase in sucrose content of the rachis suggests that transport to berries became restricted during this time, despite a favourable sucrose gradient from rachis to berry and a decreasing osmotic potential in the berry. This also confirms that rachis and berry behaviour are not concerted during ripening, the rachis displaying more typical vegetative tissue characteristics. A sudden build-up of sucrose in the rachis during ripening certainly has value as indicator of optimal ripeness and harvest potential of grapes.

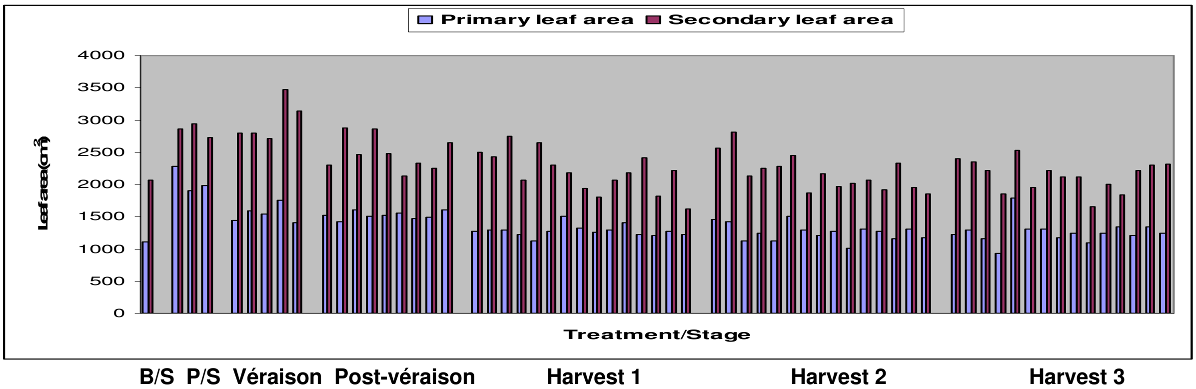

Fig. 3. Effect of level and stage of irrigation on vegetative growth of Shiraz/Richter 99.

Table 6a. Effect of level and stage of irrigation on vegetative growth (primary shoots) of Shiraz/Richter 99.

Stage	Irrigation Treatment (stage + level)	Leaves/shoot		Leaf mass		Leaf area/shoot		Shoot length	
		Number	Trm. av.	(g)	Trm. av.	(cm^2)	Trm. av.	(cm)	Trm. av.
BS	**Before irrigation**	10.3	10.3	2.8	2.8	1112.0	1112.0	90.1	90.1
PS	**NI**	12.6	12.6	2.9	2.9	2281.8	2281.8	103.0	103.0
	75All stages	13.1		2.9		1907.8		107.3	
	100All stages	13.4	13.3	2.5	2.7	1978.6	1943.2	101.3	104.3
V	**NI**	12.0	12.0	2.8		1439.2	1439.2	90.8	90.8
	75All stages	13.8		2.6		1579.8		116.9	
	100All stages	15.5	14.7	2.3	2.4	1538.4	1559.1	101.1	109.0
	75PS	14.7		2.8		1752.3		112.9	
	100PS	12.7	13.7	2.7	2.7	1400.6	1576.5	108.0	110.4
PV	**NI**	13.2	13.2	2.6	2.6	1519.5	1519.5	112.6	112.6
	75All stages	13.4		2.5		1416.4		109.5	
	100All stages	16.3	14.9	2.3	2.4	1606.6	1511.5	120.4	115.0
	75PS	15.3		2.2		1501.8		116.4	
	100PS	13.4	14.4	2.7	2.4	1519.6	1510.7	109.2	112.8
	75V	15.7		2.3		1554.0		106.2	
	100V	13.5	14.6	2.6	2.4	1475.3	1514.7	103.8	105.0
	75PS+V	14.6		2.3		1488.3		105.9	
	100PS+V	15.6	15.1	2.6	2.5	1611.5	1549.9	110.2	108.0
H1	**NI**	9.5	9.5	3.3	3.3	1266.8	1266.8	103.0	103.0
	75All stages	11.0		2.8		1296.3		110.6	
	100All stages	13.5	12.3	2.3	2.6	1292.2	1294.2	105.0	107.8
	75PS	12.0		2.2		1221.6		109.2	
	100PS	10.1	11.1	2.6	2.4	1117.7	1169.7	105.5	107.3
	75V	9.6		3.2		1273.0		101.6	
	100V	12.0	10.8	2.9	3.1	1508.3	1390.7	104.6	103.1
	75PV	11.5		2.6		1317.0		110.0	
	100PV	11.6	11.6	2.3	2.5	1263.3	1290.2	100.2	105.1
	75PS+V	10.9		2.8		1285.4		106.1	
	100PS+V	12.9	11.9	2.7	2.8	1403.7	1344.5	108.8	107.4
	75PS+PV	9.5		3.1		1228.5		102.3	
	100PS+PV	9.9	9.7	3.0	3.0	1202.5	1215.5	96.1	99.2
	75V+PV	9.1		3.4		1264.5		97.8	
	100V+PV	11.6	10.4	2.6	3.0	1230.5	1247.5	93.3	95.6
H2	**NI**	12.7	12.7	2.5	2.5	1452.2	1452.2	112.1	112.1
	75All stages	12.8		2.6		1420.2		110.0	
	100All stages	11.5	12.2	2.3	2.5	1119.5	1269.9	98.7	104.3
	75PS	13.2		2.3		1245.3		107.6	
	100PS	10.4	11.8	2.4	2.4	1129.7	1187.5	100.6	104.1
	75V	12.2		3.1		1503.2		116.7	
	100V	11.3	11.8	2.8	2.9	1288.9	1396.1	100.0	108.3
	75PV	10.5		2.7		1211.9		106.4	
	100PV	11.1	10.8	2.7	2.7	1269.0	1240.5	108.5	107.4
	75PS+V	9.0		2.6		1006.5		93.6	
	100PS+V	11.5	10.3	2.6	2.6	1300.9	1153.7	103.4	98.5
	75PS+PV	11.5		2.8		1266.6		109.6	
	100PS+PV	11.4	11.5	2.5	2.6	1156.3	1211.5	101.3	105.4
	75V+PV	12.1		2.6		1309.9		109.1	
	100V+PV	10.8	11.5	2.7	2.6	1176.8	1243.3	98.8	104.0
H3	**NI**	10.7	10.7	2.6	2.6	1217.8	1217.8	102.5	102.5
	75All stages	11.0		2.7		1294.7		104.8	
	100All stages	11.3	11.2	2.3	2.5	1156.9	1225.8	108.5	106.6
	75PS	10.8		1.9		929.7		102.7	
	100PS	14.4	12.6	2.1	2.0	1779.1	1354.4	126.4	114.6
	75V	11.5		2.6		1313.1		107.7	
	100V	10.9	11.2	2.7	2.6	1303.6	1308.4	116.4	112.1
	75PV	9.0		3.0		1173.0		104.6	
	100PV	11.4	10.2	2.5	2.7	1236.9	1204.9	96.8	100.7
	75PS+V	11.3		2.2		1096.0		109.1	
	100PS+V	10.6	11.0	2.8	2.5	1246.1	1171.1	107.5	108.3
	75PS+PV	11.9		2.6		1346.6		117.8	
	100PS+PV	9.7	10.8	3.1	2.8	1210.3	1278.4	107.9	112.8
	75V+PV	9.0		3.1		1344.9		105.7	
	100V+PV	11.2	10.1	3.0	3.0	1237.5	1291.2	99.0	102.4

BS = Berry set; PS = Pea size; V = Véraison; PV = Post véraison; 75 = irrigated to 75% field water capacity; 100 = irrigated to 100% field water capacity; NI = No irrigation; Trm. av. = Treatment average; H1 = Harvest 1; H2 = Harvest 2; H3 = Harvest 3; Before irrigation = Means of measurements at berry set

Table 6b. Effect of level and stage of irrigation on vegetative growth (secondary shoots) and the ratio of primary:secondary leaf area of Shiraz/Richter 99.

Stage	Irrigation Treatment (stage + level)	Shoots/Prim. Shoot		Leaf mass/Prim. Shoot		Leaf area/Prim. shoot		Prim. Leaf area/Sec. leaf area	
		Number	Trm. av.	(g)	Trm. av.	(cm^2)	Trm. av.	(cm)	Trm. av.
BS	Before irrigation	7.5	7.5	33.6	33.6	2062.1	2062.1	0.56	0.56
PS	NI	9.8	9.8	42.2	42.2	2854.2	2854.2	0.80	0.80
	75All stages	10.2		42.4		2943.6		0.68	
	100All stages	9.2	9.7	31.2	36.8	2731.8	2837.7	0.80	0.74
V	NI	8.9	8.9	48.0	48.0	2801.3	2801.3	0.52	0.52
	75All stages	12.4		52.4		2793.3		0.65	
	100All stages	13.4	12.9	47.0	49.7	2712.7	2753.0	0.61	0.63
	75PS	12.8		50.8		3472.8		0.48	
	100PS	11.7	12.3	317.5	184.2	3137.5	3305.2	0.49	0.48
PV	NI	10.9	10.9	40.5	40.5	2299.3	2299.3	0.67	0.67
	75All stages	10.8		52.0		2884.1		0.53	
	100All stages	11.4	11.1	53.5	52.7	2455.4	2669.7	0.93	0.73
	75PS	12.0		51.9		2855.7		0.56	
	100PS	10.2	11.1	45.4	48.6	2478.7	2667.2	0.67	0.62
	75V	10.5		38.9		2137.7		0.84	
	100V	11.0	10.8	42.3	40.6	2323.4	2230.5	0.78	0.81
	75PS+V	11.0		41.0		2244.6		0.73	
	100PS+V	11.2	11.1	47.4	44.2	2645.4	2445.0	0.61	0.67
H1	NI	9.2	9.2	45.6	45.6	2501.4	2501.4	0.54	0.54
	75All stages	9.9		44.9		2422.2		0.55	
	100All stages	13.5	11.7	52.4	48.6	2741.6	2581.9	0.51	0.53
	75PS	10.6		38.4		2065.6		0.62	
	100PS	10.3	10.4	48.9	43.7	2647.2	2356.4	0.44	0.53
	75V	8.8		43.8		2303.3		0.56	
	100V	9.7	9.2	44.8	44.3	2186.1	2244.7	0.56	0.56
	75PV	10.0		35.1		1938.4		0.76	
	100PV	9.7	9.8	32.9	34.0	1799.0	1868.7	0.78	0.77
	75PS+V	8.8		39.5		2065.1		0.66	
	100PS+V	11.7	10.2	40.7	40.1	2187.5	2126.3	0.75	0.71
	75PS+PV	9.3		44.5		2416.5		0.53	
	100PS+PV	8.9	9.1	33.3	38.9	1822.7	2119.6	0.67	0.60
	75V+PV	9.9		41.3		2208.1		0.59	
	100V+PV	9.3	9.6	31.0	36.1	1614.2	1911.1	0.86	0.73
H2	NI	10.8	10.8	44.4	44.4	2568.4	2568.4	0.60	0.60
	75All stages	11.3		52.9		2816.6		0.67	
	100All stages	11.5	11.4	39.5	46.2	2124.7	2470.7	0.62	0.64
	75PS	11.7		43.2		2242.9		0.59	
	100PS	10.6	11.2	42.7	43.0	2286.4	2264.6	0.50	0.54
	75V	11.7		46.1		2454.5		0.59	
	100V	9.4	10.5	37.2	41.6	1861.1	2157.8	0.88	0.73
	75PV	9.3		40.8		2162.7		0.65	
	100PV	10.8	10.0	39.8	40.3	1964.9	2063.8	0.72	0.68
	75PS+V	9.4		38.6		2016.4		0.62	
	100PS+V	11.1	10.3	35.2	36.9	2066.7	2041.6	0.69	0.65
	75PS+PV	9.6		35.4		1922.3		0.73	
	100PS+PV	10.4	10.0	44.1	39.8	2335.0	2128.6	0.60	0.67
	75V+PV	9.6		38.1		1950.9		0.79	
	100V+PV	9.3	9.5	35.0	36.5	1859.5	1905.2	0.90	0.85
H3	NI	9.1	9.1	44.1	44.1	2392.1	2392.1	0.56	0.56
	75All stages	10.0		44.4		2349.5		0.59	
	100All stages	12.1	11.0	39.3	41.8	2209.1	2279.3	0.55	0.57
	75PS	10.0		33.8		1847.1		0.56	
	100PS	12.3	11.2	44.2	39.0	2533.4	2190.3	0.72	0.64
	75V	10.3		33.6		1949.8		0.77	
	100V	11.4	10.8	40.6	37.1	2214.0	2081.9	0.68	0.73
	75PV	8.9		34.3		2116.0		0.64	
	100PV	10.3	9.6	38.6	36.5	2112.3	2114.1	0.68	0.66
	75PS+V	10.3		28.9		1647.3		0.71	
	100PS+V	9.1	9.7	35.5	32.2	1993.3	1820.3	0.72	0.71
	75PS+PV	9.9		33.2		1832.5		0.83	
	100PS+PV	10.3	10.1	40.4	36.8	2218.0	2025.2	0.63	0.73
	75V+PV	9.7		42.2		2292.5		0.66	
	100V+PV	8.8	9.3	43.6	42.9	2307.0	2299.7	0.78	0.72

BS = Berry set; PS = Pea size; V = Véraison; PV = Post véraison; Prim. = Primary; 75 = irrigated to 75% field water capacity; 100 = irrigated to 100% field water capacity; NI = No irrigation; Trm. av. = Treatment average; H1 = Harvest 1; H2 = Harvest 2; H3 = Harvest 3; Before irrigation = Means of measurements at berry set

Table 7. Effect of level and stage of irrigation on reproductive growth of Shiraz/Richter 99.

Stage	Irrigation Treatment	Bunch no./ shoot	Bunch				Rachis		Berry			Bunch: Rachis mass
			Mass (g)	Vol. (cm^3)	Length (cm)	Width (cm)	Mass (g)	Vol. (cm^3)	Mass (g)	No./ bunch	Vol. (cm^3)	
BS	**Before I**	1.45	5.35	5.1	11.20	3.41	1.74	1.88	0.05	*	0.05	3.1
PS	**NI**	1.46	63.21	57.9	15.83	6.01	4.75	4.89	0.67	75.0	0.67	13.3
	75AII	1.68	65.46	64.0	13.98	6.29	4.50	4.62	0.75	77.3	0.74	14.5
	100AII	1.50	61.56	58.0	13.00	5.64	4.89	4.68	0.68	79.7	0.68	12.6
V	**NI**	1.57	191.67	165.9	15.90	8.64	6.61	6.41	1.81	111.5	1.71	29.0
	75AII	1.96	151.85	143.6	15.05	7.54	5.58	5.28	1.71	97.0	1.61	27.2
	100AII	1.64	148.07	141.1	14.65	7.77	5.66	5.34	1.60	95.0	1.49	26.1
	75PS	1.64	148.76	138.9	14.76	8.08	5.31	5.07	1.68	95.9	1.59	28.0
	100PS	1.68	173.26	155.3	16.28	8.60	6.81	6.66	1.67	115.4	1.56	25.5
PV	**NI**	1.71	131.48	118.6	14.48	6.80	5.05	7.40	1.81	78.0	1.66	26.0
	75AII	1.93	158.95	134.5	14.44	7.37	5.28	5.44	1.89	91.9	1.74	30.1
	100AII	1.57	151.50	140.2	13.69	6.88	5.28	5.76	1.86	96.3	1.65	28.7
	75PS	1.75	150.90	133.5	16.74	6.90	5.46	5.21	1.84	90.4	1.68	27.6
	100PS	1.86	174.29	152.1	15.04	7.74	6.49	6.41	1.84	101.7	1.68	26.9
	75V	1.54	143.54	133.2	14.23	7.27	5.74	7.33	1.77	90.6	1.63	25.0
	100V	1.57	180.25	149.0	14.85	8.11	7.22	7.24	1.83	104.5	1.68	25.0
	75PS+V	1.64	157.76	140.4	15.42	7.64	6.46	6.64	1.82	97.1	1.65	24.4
	100PS+V	1.86	171.81	154.1	15.22	7.69	7.15	6.71	1.84	102.9	1.67	24.0
H1	**NI**	1.50	162.27	146.0	15.44	7.60	6.62	5.83	1.79	108.6	1.62	24.5
	75AII	1.54	132.59	127.6	14.04	6.83	6.09	4.61	1.67	92.3	1.57	21.8
	100AII	1.54	130.76	119.3	14.22	7.12	6.00	5.20	1.83	88.6	1.64	21.8
	75PS	1.61	137.93	123.0	14.93	7.30	5.95	5.41	1.72	95.2	1.53	23.2
	100PS	1.43	150.51	109.0	14.71	7.37	6.54	5.81	1.73	114.7	1.51	23.0
	75V	1.50	136.64	127.4	14.42	7.45	5.80	5.29	1.68	94.4	1.52	23.6
	100V	1.50	172.51	154.8	15.49	8.08	7.25	8.91	1.77	107.8	1.61	23.8
	75PV	1.64	143.36	129.7	14.56	7.20	6.74	5.82	1.65	101.1	1.46	21.3
	100PV	1.57	132.46	125.6	13.99	6.63	6.32	5.36	1.60	92.6	1.43	20.9
	75PS+V	1.68	130.56	118.6	13.77	6.83	5.71	5.32	1.67	94.0	1.50	22.9
	100PS+V	1.64	165.41	150.9	14.96	7.04	7.48	6.68	1.82	101.2	1.66	22.1
	75PS+PV	1.57	136.88	130.6	13.99	7.28	5.97	5.59	1.58	97.0	1.41	22.9
	100PS+PV	1.64	157.51	137.2	14.03	6.70	7.19	6.62	1.71	108.4	1.49	21.9
	75V+PV	1.75	143.08	130.3	13.83	6.78	6.15	5.27	1.67	93.0	1.50	23.3
	100V+PV	1.82	129.40	116.9	14.19	6.71	6.41	5.75	1.58	86.8	1.44	20.2
H2	**NI**	1.79	135.71	124.0	15.77	9.01	6.17	5.73	1.59	99.9	1.43	22.0
	75AI	1.64	155.61	140.1	16.34	8.25	7.33	6.27	1.41	103.7	1.38	21.2
	100AII	1.43	129.69	117.6	14.57	7.38	5.63	5.01	1.48	96.4	1.45	23.0
	75PS	1.70	112.59	100.7	14.23	7.01	5.32	4.63	1.45	86.2	1.29	21.2
	100PS	1.43	163.20	127.9	15.57	7.61	6.20	5.28	1.52	105.0	1.37	26.3
	75V	1.82	133.06	121.1	16.15	7.49	6.21	5.38	1.49	102.1	1.34	21.4
	100V	1.64	148.63	134.5	16.28	7.85	6.40	6.05	1.55	107.3	1.38	23.2
	75PV	1.57	135.56	120.7	16.02	7.75	6.27	5.74	1.46	108.3	1.30	21.6
	100PV	1.54	108.76	97.6	14.37	7.19	5.74	4.85	1.49	86.4	1.32	18.9
	75PS+V	1.54	117.85	105.0	15.49	7.22	5.41	5.29	1.45	95.7	1.28	21.8
	100PS+V	1.64	126.99	117.7	14.90	7.14	5.72	5.15	1.56	92.2	1.40	22.2
	75PS+PV	1.71	130.99	115.2	15.13	8.05	6.12	5.38	1.45	101.7	1.29	21.4
	100PS+PV	1.68	141.54	126.7	15.63	7.33	6.81	6.43	1.41	99.5	1.36	20.8
	75V+PV	1.64	151.75	135.0	16.47	8.01	6.76	6.10	1.51	113.9	1.36	22.5
	100V+PV	1.29	107.96	97.9	13.78	6.75	5.36	4.72	1.39	87.3	1.24	20.1
H3	**NI**	1.64	107.27	93.6	14.41	6.17	5.20	4.94	1.42	94.3	1.23	20.6
	75AII	1.71	115.92	104.7	15.05	7.70	5.62	4.44	1.46	97.2	1.29	20.6
	100AII	1.36	124.21	105.5	15.29	6.86	6.15	5.49	1.49	102.6	1.33	20.2
	75PS	1.46	87.32	79.4	12.85	5.90	4.48	3.77	1.32	83.8	1.15	19.5
	100PS	1.79	125.75	113.1	15.48	7.49	6.37	5.40	1.34	105.2	1.18	19.7
	75V	1.64	106.93	96.0	15.14	7.11	5.35	5.18	1.43	94.4	1.26	20.0
	100V	1.71	114.75	105.1	15.29	7.34	5.71	4.85	1.48	98.2	1.29	20.1
	75PV	1.79	105.29	95.3	14.76	7.34	5.54	4.61	1.42	95.0	1.26	19.0
	100PV	1.75	101.89	92.2	13.93	6.78	5.46	4.95	1.40	84.6	1.24	18.6
	75PS+V	1.48	95.88	84.2	14.29	6.50	4.99	4.32	1.26	89.6	1.13	19.2
	100PS+V	1.61	124.18	113.3	14.22	7.20	6.38	5.55	1.45	105.4	1.30	19.5
	75PS+PV	1.86	104.54	94.6	15.02	6.99	5.82	5.58	1.31	86.8	1.16	18.0
	100PS+PV	1.68	110.41	99.8	14.19	6.74	6.25	5.73	1.31	92.5	1.15	17.7
	75V+PV	1.71	112.04	101.4	14.80	7.13	5.75	5.26	1.44	99.7	1.27	19.5
	100V+PV	1.75	116.72	102.1	15.56	7.19	6.24	5.59	1.42	103.7	1.28	18.7

BS = Berry set; PS = Pea size; V = Véraison; PV = Post véraison; Trm. av. = Treatment average; 75 = 75% field water capacity irrigation; 100 = 100% field water capacity irrigation; NI = No irrigation; H1 = Harvest 1; H2 = Harvest 2; H3 = Harvest 3; Before irrigation (I) = Means of measurements at berry set

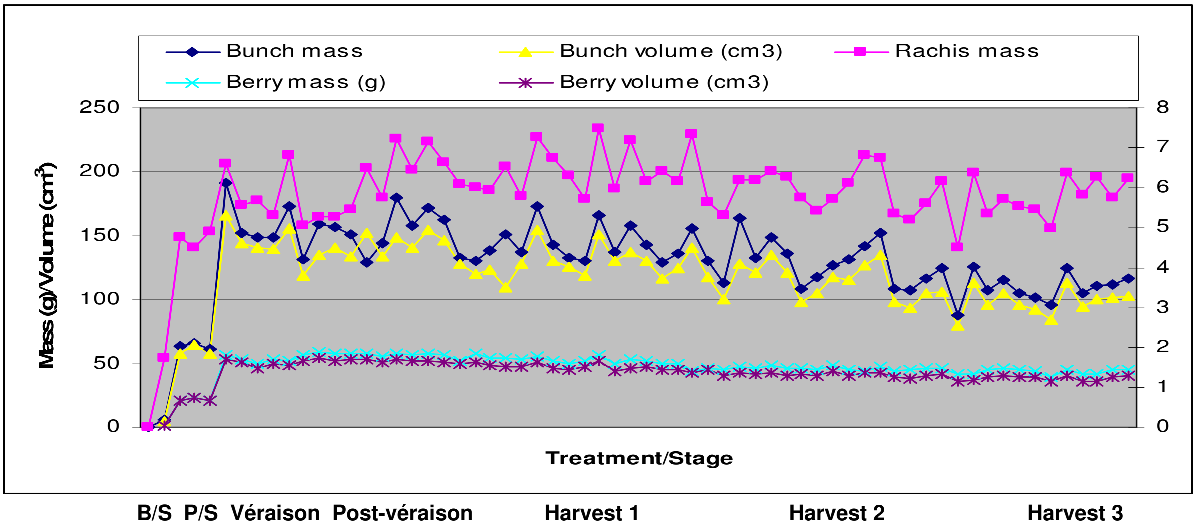

Fig. 4. **Trends of the effect of level and stage of irrigation on bunch, rachis and berry parameters of Shiraz/Richter 99.**

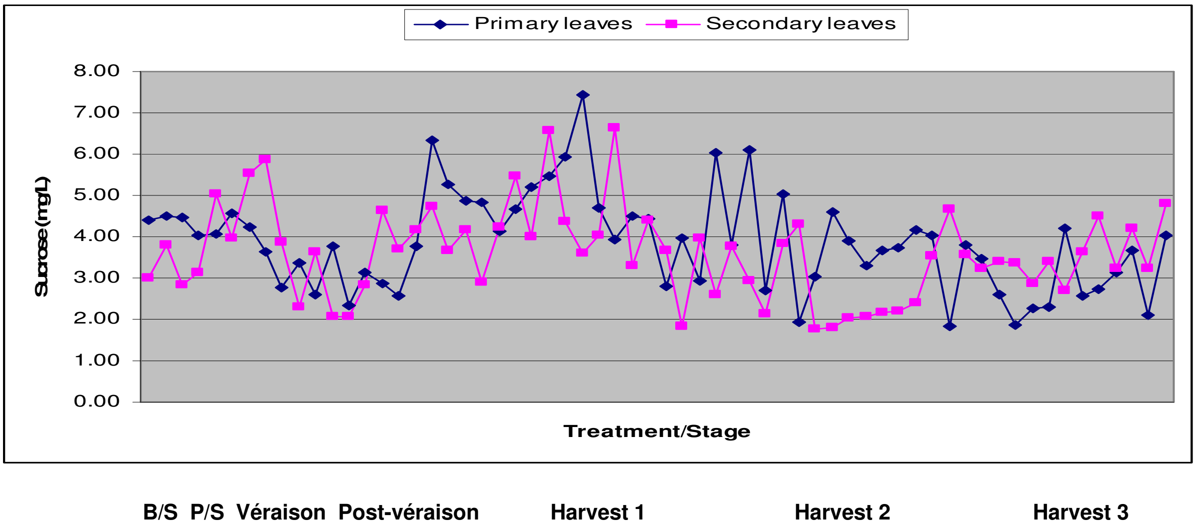

Fig. 5. Trends of the effect of level and stage of irrigation on sucrose contents of primary and secondary leaves of Shiraz/Richter 99.

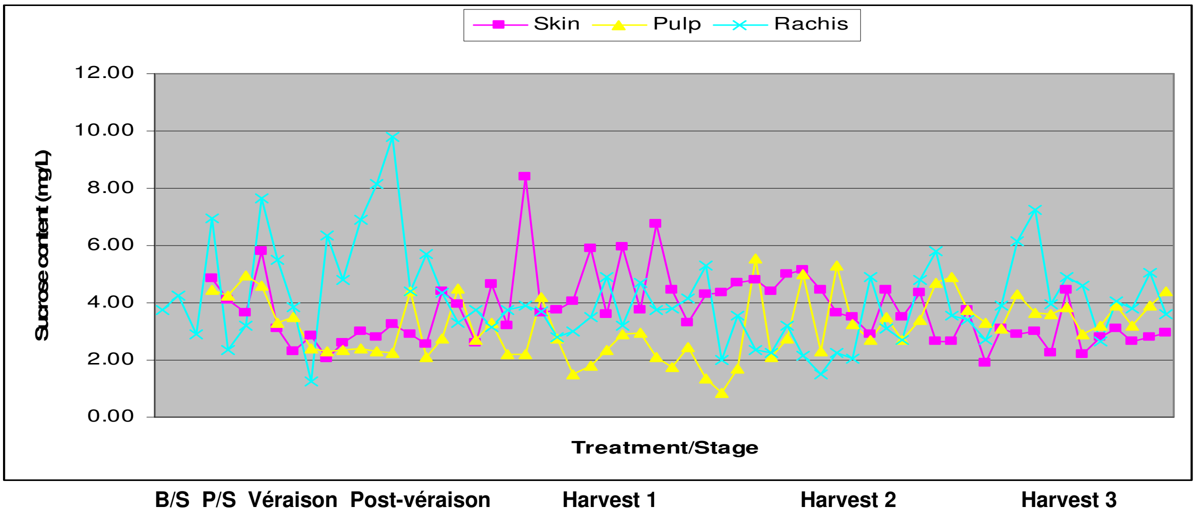

Fig. 6. **Trends of the effect of level and stage of irrigation on sucrose contents of bunch parameters of Shiraz/Richter 99.**

A higher irrigation volume resulted in generally lower initial (first harvest stage) soluble solid concentrations for all treatments (Table 8). At the other two harvest stages differences were more variable, but the general trend of more water, less soluble solid concentration was still evident. This trend was much more evident and stable for treatments receiving irrigation up to véraison stage. The non-irrigated vines seemed not able to reach similar soluble solid concentrations than the irrigated vines. As referred to earlier, vines seemed to display an independence of soil water during ripening. This became more pronounced as ripening proceeded. The senescing canopy produced less and hoarded more sucrose and the berries lost more water than it could gain by water potential gradients. Although the soluble solid contents increased with further ripening, the sugar transport was reduced and the linear relationship broken earlier under conditions of soil water reduction (Figs. 7 & 8) (Hunter & Deloire, 2005). The berry therefore concentrated, but at the same time lost, mass as a result of reduced phloem sugar and water transport. From Fig. 9 it is clear that the general rachis:pulp+skin sucrose ratio (over all treatments) increased with ripening, especially at the last harvest stage, indicating restricted transport to the berry.

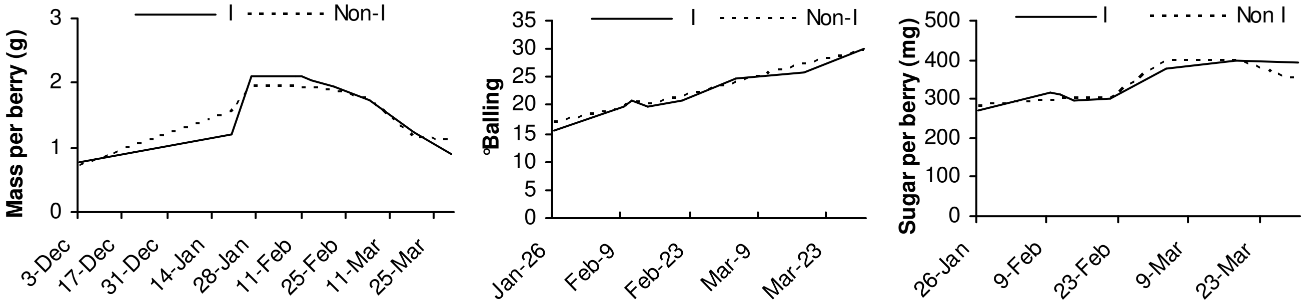

Fig. 7. Berry mass, ^{0}Balling and sugar per berry of irrigated (I) and non-irrigated (Non-I) treatments (2004/05 season)

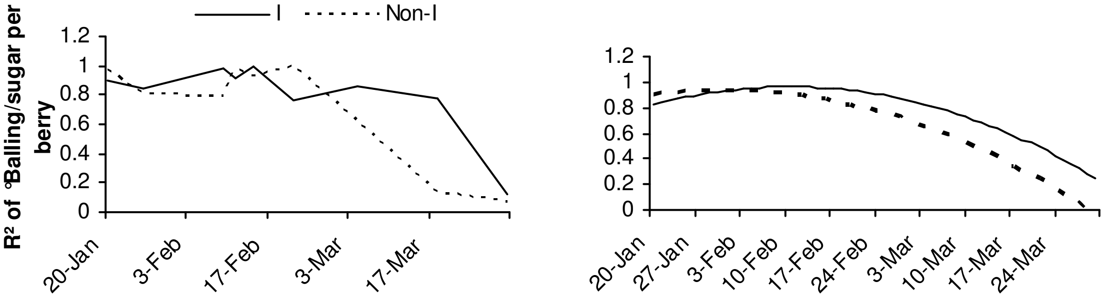

Fig. 8. Linear relationship (R^2) between ^{0}Balling and sugar per berry of irrigated (I) and non-irrigated (Non-I) treatments (2004/05 season)

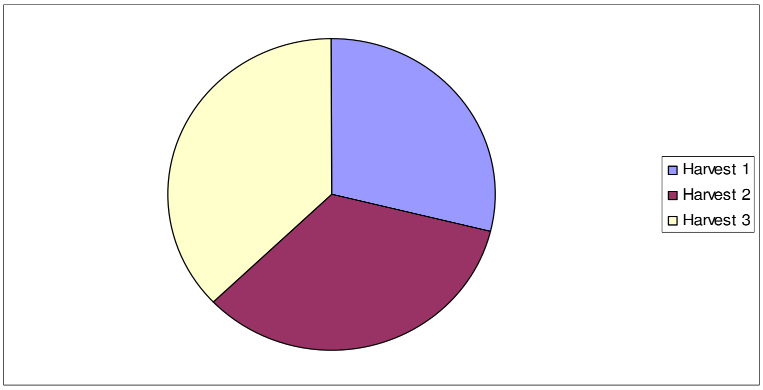

Fig. 9. General effect of level and stage of irrigation on the rachis:pulp+skin sucrose ratio of Shiraz/Richter 99.

For Shiraz at least, shrinkage of the berries therefore continued during ripening, irrespective of highly negative water potentials prevailing in the berry at late ripening stages, as found by Rogiers *et al.* (2006). The critically low turgor status of the pericarp cells is apparently not transmitted to the parent vine (including the pedicel) and the berry seems to become at least partly isolated at such time. No clear evidence could be found that even high volumes of water (to 100% FWC) during ripening could sustain berry volume, indicating that not only is the berry less sensitive to water deficit during ripening (as compared to the pre-véraison period – Greenspan *et al*., 1994, 1996), but it seems also not to be affected by high volumes of water during this time. This is partly in line with findings of Keller *et al.* (2006). However, they deducted from their studies that watering during ripening would prevent further shrinkage of the berries. In our study, berries continued to lose water irrespectively. Although it is acknowledged that the field conditions of this study may not be considered ideal for studying basic physiological processes, clear trends were found. If accepted that the cell can only regulate its water balance (turgor) by actively regulating the osmotic potential, solute accumulation and metabolism must have a significant role to play. In addition, the water potential gradients and hydraulic conductivity of the transport pathway are critical in the influx of water and thus sustaining of turgor. Neither evapotranspiration nor phloem or the partly dysfunctional xylem flow (Lang & Düring, 1991; Greenspan *et al*., 1994; Rebucci *et al*., 1997) seems to be able to sustain inflow during late ripening and maintain berry turgor. Xylem backflow to the parent vine seems a real accompanying possibility (Tyerman *et al*., 2004), at least through the central xylem bundles (Düring *et al*., 1987; Findlay *et al*., 1987; Lang & Thorpe, 1989). This may even have contributed to a better sustained rachis mass as found in this study. This process may perhaps rightly so be considered physical (Dreier *et al*., 2000), at least during the final stages before the berry reach raisin status. This does not refrain from the complex regulatory processes involved in berry development, be it physical or physiological.

In a study linking canopy activity and water relations with berry composition of Shiraz, a physiological endpoint regarding sucrose demand by the berry seemed to occur during late ripening (Hunter *et al*., 2004). This was accompanied by a build-up of sucrose in the leaves, and pre-ceded by a phloem-supported sucrose drain from the leaves and a physiological endpoint regarding active leaf function. Demand for sucrose by the rest of the plant, including the berry, seemed to continue after the leaves already lost most of their activity, but a point was also clearly reached where active demand was terminated. The build-up of sucrose in the leaves could have been the result of a low, but continuing, largely maintenance-orientated photosynthetic rate, and a largely inactive sucrose hydrolyzing enzyme pool in senescing tissue (Ruffner *et al*., 1990; Hunter *et al*., 1994; Hunter & Ruffner, 2001). Environmental conditions are changing late during ripening, the senescing canopy has a lower evaporative demand during this time, photosynthetic output and concomitant transpirational loss are diminishing, sink demand on the canopy decreases, sucrose builds up in leaves and the vine generally seems to recuperate in terms of water relations (Hunter *et al*., 1994; Hunter & Ruffner, 2001; Hunter *et al*., 2004). It seems reasonable to assume that these events would lead to a reduction in the water potential gradient between the canopy/conduits of the parent plant and the berry pericarp and that water flow and concomitant transport of sucrose to the berry would diminish, even under visually normal, intact bunch stem, rachis and pedicel occurrence. Sucrose loading as well as downloading are bound to be affected. An osmotic gradient driven mass transport to the berry (based on the hypothesis of passive phloem transport - Münch, 1930), created by osmotic differences between the vascular tissue and the berry mesocarp (see also Hunter & Ruffner, 2001), may well be diminishing during late ripening in particular. This hypothesis describes an influx and efflux of water with a bulk flow of solution from source to sink that tends to balance solute concentrations through the passive mediation of water. It is argued that an apoplastic route of sugar unloading is realised in ripening berries (Patrick, 1990). However, under circumstances of saturated membrane transport (high sucrose concentrations in the free space), both apoplastic and symplastic routes may be operative, simultaneously or sequentially, depending on the conditions (Ho, 1988). The turnover rates of sucrolysis, particularly the various forms of invertase, may be critical to sustain transfer of sucrose from sieve element/companion cell complexes in the berry brush (Hawker, 1985; Ruffner *et al.*, 1990). To prevent dampening of phloem pressure and hence import into the berry, depletion of apoplasmic sucrose must be offset by the maintenance of apoplasmic osmolality (Brown & Coombe, 1985; Lang & Düring, 1991; Patrick, 1997). The downloading of sucrose into the berry apoplast would raise the osmotic pressure, causing water efflux from the phloem. This would in turn release the pressure in the phloem at the unloading site and phloem influx would result. The water released from the phloem would need to be evapotranspired at a rate that would sustain gradients. When during late ripening the rate of evapotranspiration of the berry is dampened, the lack of strong gradients would most likely reduce sucrose loading (in the leaves into the phloem) and downloading at the sink (berry), despite the senescing canopy and the ostensible ample availability of sucrose in the leaves (see also Hunter *et al.*, 2004). Evapotranspiration seems, however, to still outweigh the influx of sucrose, hence the continued shrinking of the berry. The relationship during early ripening between water influx (primarily *via* the phloem) and water efflux (*via* evapotranspiration) apparently became weaker during late ripening (see also Etchebarne *et al.*, 2007).

It seems reasonable to assume that the vines in this study were not highly stressed and that ample water was still available to sustain demands on the soil and plant water sources. The berry seems to go through phases during the ripening period which resembles a change from a high to a low sucrose plus water transport:berry evapotranspiration ratio (Hunter *et al.*, 2004). Active transport seems to be followed by passive transport, which finally ceases under the ultimate influence of a diminishing driving force combining lower sucrose supply, lower phloem sucrose concentration, low sucrose demand, decreasing sucrose metabolism/compartmentation, low water potential gradients, reducing canopy and berry evapotranspiration and changing (decreasing) atmospheric vapour pressure deficit. A continued evaporative loss of water from the berry finally leads to a reduction in both mass and volume. Late during ripening, berry size reduction is not sufficient to compensate for the diminishing inflow of sugar to the berry, leading to declining rates of soluble solid accumulation. It seems evident that the berry water relations are largely independent of those of the parent plant, at least during late ripening (see also Chatelet *et al.*, 2008). The water relations of the parent plant seem to be focused on maintenance and recovery requirements as well as transport to reserve building areas during this time. This is further accentuated by a lack of active demand by the berries.

The °B:TA ratios, indicating quality standards for Shiraz (Hunter *et al.*, 2004), showed that ratios were generally higher with less irrigation volume. The ratios were only inside the criteria for quality wine styles at the first and second harvest stages. At the third harvest, ratios were outside the range for quality wine potential and grapes were clearly over-ripe. A delayed ripening of vines irrigated at all stages was evident at the third harvest stage. Although the non-irrigated vines showed delayed soluble solid contents and low acidity at the last harvest stage, no seasonal irrigation had no marked effect on °B:TA ratios. Strangely, treatments receiving only post véraison irrigation seemed to have enhanced grape ripening, having high-quality ratios already at around 23 °B. It is possible that the additional, rather late, irrigation may have helped to maintain the sugar flow to the berries (even if photosynthetic activity continued at a low level for metabolic maintenance purposes) and actually contributed to a more efficient distribution of available sucrose to areas of reserve accumulation and areas of reproductive growth. It may also represent a physical water gradient facilitated flow of water (and concomitant sucrose flow in the phloem) to the reproductive area, the berry being the most probable organ for water loss during this time.

Skin anthocyanin and phenolic contents indicated that development of colour was already almost complete approximately three weeks/one month after véraison at a soluble solid concentration of approximately 18 – 20 °B (Table 8). This is in agreement with results found previously (Hunter *et al.*, 2004; Nadal & Hunter, 2007) and with detailed anthocyanin and tannin composition studies by Fournand *et al.* (2006). Skin colour was generally highest at the first harvest stage, where after it decreased until the last harvest stage (also Fig. 10), which may suggest a change from free anthocyanins to derivatised anthocyanins (Fournand *et al.,* 2006). At the latter stage, grapes were overripe. From Fig. 10 it is clear that the soluble solid concentration and the skin anthocyanin contents moved in opposite directions as ripening proceeded, similar to the results found by Fournand *et al.* (2006). The improvement in skin colour from véraison was accompanied by a loss in skin water content (Table 8). From the post-véraison stage a steady loss of water from the skins occurred for all treatments, but least for the vines irrigated throughout the season at all stages. None of the treatments were, however, markedly successful in maintaining higher skin water contents. Skin colour as well as total phenolic contents were particularly stimulated by 75% pea size irrigation, post-véraison irrigation and 75% pea size+post-véraison irrigation, until the last harvest stage; the véraison and 75% pea size+véraison irrigation seemed reasonably successful at the first harvest stage. Other than the general believe, treatments that included post-véraison irrigation seemed not negative in terms of ripening parameters.

Although the expression of anthocyanin on a whole berry basis was at least two times higher at pH 1.0 (total available anthocyanin) than at pH 3.2 (average wine medium), the trends were similar and showed a general increase until the last harvest stage (Table 9), parallel to soluble solid accumulation (Figs. 11 & 12). This is in agreement with results found by Guidoni & Argamante (2003). It also shows that the extractability increased with ripening – the extractability index (difference between results at pH 1.0 and pH 3.2) was therefore low at the third harvest (Fig. 13). This could be another indicator for harvest and wine style differences. In fact, it could significantly affect decisions during the fermentation process in terms of duration, frequency and intensity of pump-over, temperature control and enzyme/tannin addition (Romero-Cascales *et al*., 2005).

Trends regarding the treatment effects on whole berries were similar to those found in the skins. The total tannin contents, seed tannins and total phenolics also increased with the development of the berry and as ripening progressed. In contrast, the total flavan-3-ol monomer levels (tannin monomers expressed as catechin) decreased until post-véraison and then kept reasonably stable until the last harvest stage. In most cases, anthocyanin extractability was reasonably stable from the first to the second harvest stage, where after it increased. Given the reduction in skin anthocyanin content (Table 8), it seems reasonable to assume that this mainly resulted from the decrease in berry mass (and concomitant higher skin:pulp ratio, favouring extraction from the skins) (Table 7). However, the major reduction in berry mass occurred from the first to the second harvest stage. This is also evident from the relationship between must soluble solids and whole berry anthocyanin contents (Figs. 11 & 12). It therefore seems more likely that the general increase found at the last harvest stage is an indication of increased extractability and could be the result of a loss in cellular integrity during the softening and shrinking process (a change in cell wall polysaccharides possibly brought about by cell wall enzymes such as, amongst others, hydrolase and endo-polygalacturonase) (Dreier *et al*., 1998; Nunan *et al*., 1998). This is in line with the reduction in sucrose contents in the skin (Fig. 6). On a physical level, the low skin water contents (Table 8) may have further concentrated the extraction. A late harvest (as represented here by the third harvest stage) would therefore result in wines slightly better coloured, but highly alcoholic and tannic, despite the ostensible complex formation (polymerisation) of the tannin monomers. Similar trends to what were found with skin colour and phenolic contents were also evident in the wine colour and phenolic profiles (Table 10).

Non-irrigated wines increased in colour with ripening, but failed to result in exceptional colour at any stage. It is clear that water was needed under the conditions of the specific terroir (despite the rainfall a shown in Figs. 2a & 2b), but that 75% or 100% irrigation at all stages was too much. The 75% pea size, post-véraison irrigation and 75% pea size+post-véraison irrigation consistently resulted in highest colour at all stages. The 75% pea size+véraison irrigation also seemed reasonably successful in this regard. The group of treatments that performed best seems to be that which included post-véraison irrigation. It is reasonable to assume that vines would react similar under similar terroir conditions and with similar genetic material and ecophysiological sensitivity.

Table 8. Effect of level and stage of irrigation on must and berry skin composition of Shiraz/Richter 99.

Stage	Irrigation Treatment (stage+level)	Total soluble solids (^{0}B)	Titratable acid (g/l)	pH	^{0}B:TA ratio	Skin water (%)	A_{520}	A_{420}	A_{280}
V	**NI**	12.3	15.65	2.71	0.78	76.2	1.48	0.42	1.50
	75All stages	10.6	17.45	2.68	0.61	75.9	1.00	0.35	1.13
	100All stages	11.2	18.40	2.66	0.61	74.8	1.01	0.35	1.12
	75PS	11.2	16.00	2.72	0.70	75.2	1.17	0.38	1.26
	100PS	10.6	18.95	2.64	0.56	76.6	0.76	0.31	0.96
PV	**NI**	19.6	6.60	3.38	2.97	71.6	2.55	0.57	2.47
	75All stages	18.7	6.35	3.44	2.94	73.9	1.89	0.46	1.96
	100All stages	18.0	6.90	3.39	2.61	73.7	1.81	0.44	1.87
	75PS	20.9	6.30	3.45	3.32	71.0	2.36	0.54	2.23
	100PS	18.3	6.55	3.42	2.80	72.4	1.97	0.49	1.99
	75V	20.1	6.10	3.41	3.29	71.8	2.24	0.52	2.27
	100V	19.0	6.25	3.39	3.03	72.6	2.13	0.50	2.15
	75PS+V	20.0	6.08	3.45	3.29	70.9	2.45	0.57	2.38
	100PS+V	18.3	6.68	3.43	2.74	72.1	2.04	0.48	2.03
H1	**NI**	21.6	4.43	4.12	4.88	70.3	2.29	0.52	2.24
	75All stages	21.3	4.53	4.24	4.69	70.5	1.75	0.41	1.80
	100All stages	21.0	4.73	4.13	4.44	71.0	1.86	0.44	1.90
	75PS	23.3	4.75	4.15	4.90	67.8	2.68	0.59	2.53
	100PS	21.8	4.71	4.10	4.63	70.1	2.35	0.53	2.32
	75V	22.4	4.62	4.01	4.85	69.3	2.29	0.52	2.29
	100V	21.7	4.34	3.84	4.99	70.0	2.36	0.53	2.35
	75PV	23.0	4.34	4.02	5.30	69.6	2.42	0.54	2.32
	100PV	22.5	4.32	4.37	5.21	68.2	2.61	0.58	2.57
	75PS+V	22.0	4.50	4.07	4.89	68.3	2.61	0.58	2.54
	100PS+V	20.2	4.90	4.24	4.12	71.4	1.79	0.43	1.83
	75PS+PV	22.5	4.86	4.14	4.62	68.9	2.59	0.58	2.49
	100PS+PV	21.9	4.65	3.94	4.72	69.8	2.24	0.50	2.19
	75V+PV	22.5	4.44	3.85	5.06	68.8	2.44	0.55	2.41
	100V+PV	20.5	4.30	4.04	4.75	70.9	2.03	0.48	2.13
H2	**NI**	25.1	4.18	3.83	6.01	65.9	2.27	0.50	2.24
	75All stages	24.6	4.08	3.92	6.03	67.9	1.76	0.40	1.83
	100All stages	24.1	4.60	3.83	5.23	66.5	2.05	0.48	2.06
	75PS	25.8	4.28	3.85	6.04	64.9	2.33	0.52	2.06
	100PS	25.5	4.35	3.92	5.86	66.0	2.16	0.47	1.87
	75V	25.3	4.00	3.90	6.33	66.0	2.14	0.47	2.10
	100V	24.5	4.28	3.92	5.73	67.6	2.01	0.45	2.05
	75PV	26.3	4.28	3.81	6.14	65.2	2.37	0.52	2.31
	100PV	26.6	4.13	3.85	6.45	66.2	2.34	0.51	2.29
	75PS+V	26.5	4.35	3.93	6.08	66.0	2.01	0.45	1.99
	100PS+V	22.6	4.40	3.80	5.13	68.4	1.68	0.41	1.74
	75PS+PV	26.0	4.00	3.96	6.50	66.2	2.14	0.48	2.08
	100PS+PV	25.6	4.30	3.87	5.94	66.1	2.09	0.47	2.05
	75V+PV	25.5	4.13	3.93	6.18	67.2	1.91	0.43	1.91
	100V+PV	24.3	4.38	3.78	5.55	67.1	2.05	0.46	2.06
H3	**NI**	25.7	3.20	4.10	8.02	62.6	1.86	0.43	1.88
	75All stages	26.6	3.63	4.08	7.33	64.8	1.42	0.35	1.49
	100All stages	25.7	3.48	4.03	7.40	65.0	1.49	0.36	1.57
	75PS	28.6	3.50	4.02	8.18	61.4	1.98	0.44	2.02
	100PS	26.9	3.35	4.06	8.03	63.3	1.61	0.37	1.68
	75V	28.2	3.08	4.08	9.18	62.1	1.78	0.41	1.85
	100V	26.5	3.25	4.04	8.16	63.7	1.89	0.43	1.98
	75PV	28.0	3.28	4.03	8.54	62.9	1.97	0.43	1.97
	100PV	29.1	3.38	4.10	8.61	63.1	2.12	0.47	2.15
	75PS+V	26.9	3.25	4.08	8.27	63.4	1.78	0.41	1.82
	100PS+V	25.2	3.70	3.97	6.80	64.5	1.73	0.41	1.79
	75PS+PV	27.7	3.23	4.09	8.57	62.3	2.20	0.49	2.18
	100PS+PV	28.3	3.35	4.13	8.44	62.5	1.84	1.35	1.88
	75V+PV	28.4	3.08	4.14	9.23	62.2	1.88	0.43	1.94
	100V+PV	26.2	3.45	4.00	7.59	64.3	1.82	0.42	1.86

PS = Pea size; V = Véraison; PV = Post véraison PV = Post véraison; 75 = 75% field water capacity irrigation; 100 = 100% field water capacity irrigation; NI = No irrigation; Trm. av. = Treatment average; H1 = Harvest 1; H2 = Harvest 2; H3 = Harvest 3

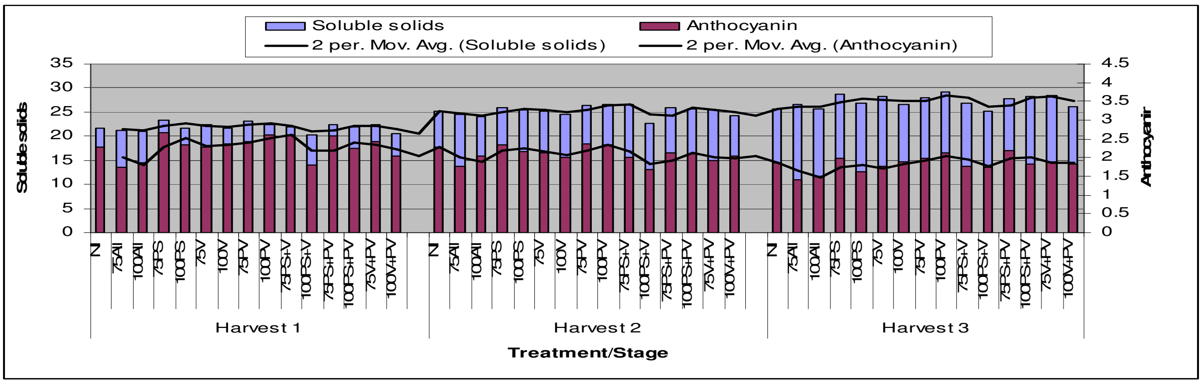

Fig. 10. Effect of level and stage of irrigation on the relationship between skin anthocyanin (A_{520}) and must soluble solids (^{0}B) of Shiraz/Richter 99.

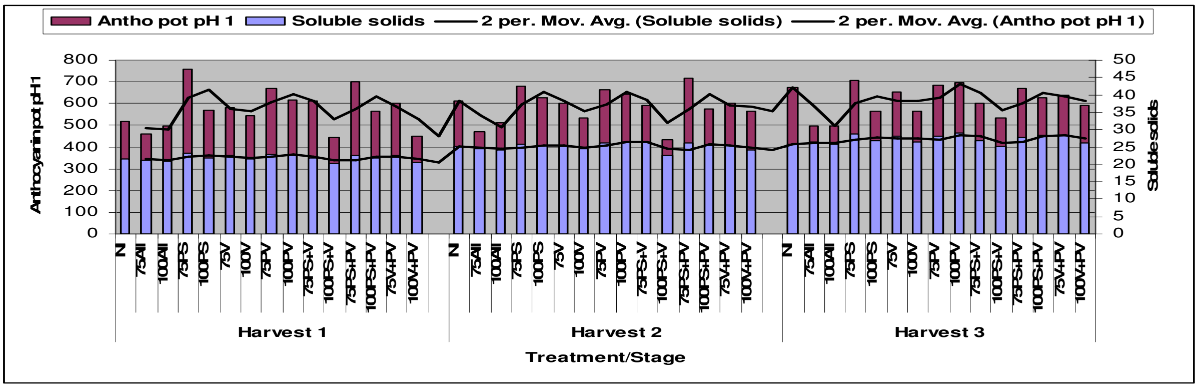

Fig. 11. Effect of level and stage of irrigation on the relationship between whole berry anthocyanin (A_{520}) extraction at pH 1.0 and must soluble solids (^{0}B) of Shiraz/Richter 99.

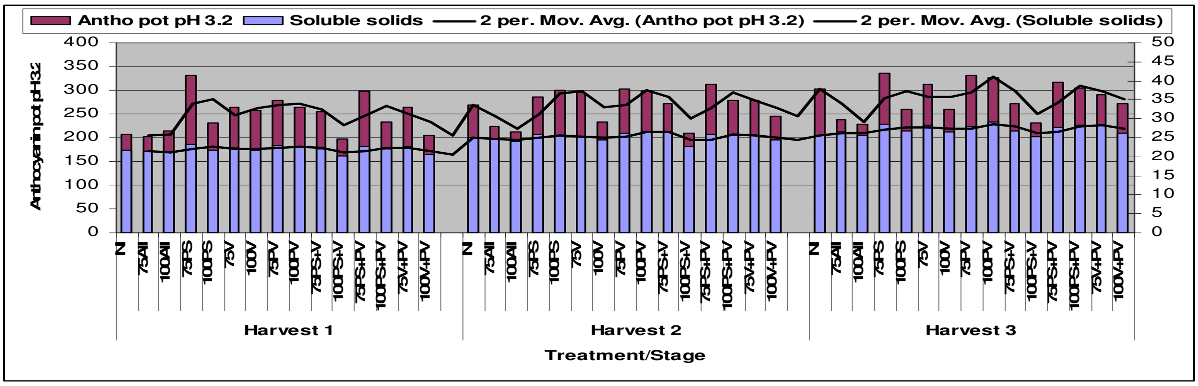

Fig. 12. Effect of level and stage of irrigation on the relationship between whole berry anthocyanin (A_{520}) extraction at pH 3.2 and must soluble solids (^{0}B) of Shiraz/Richter 99.

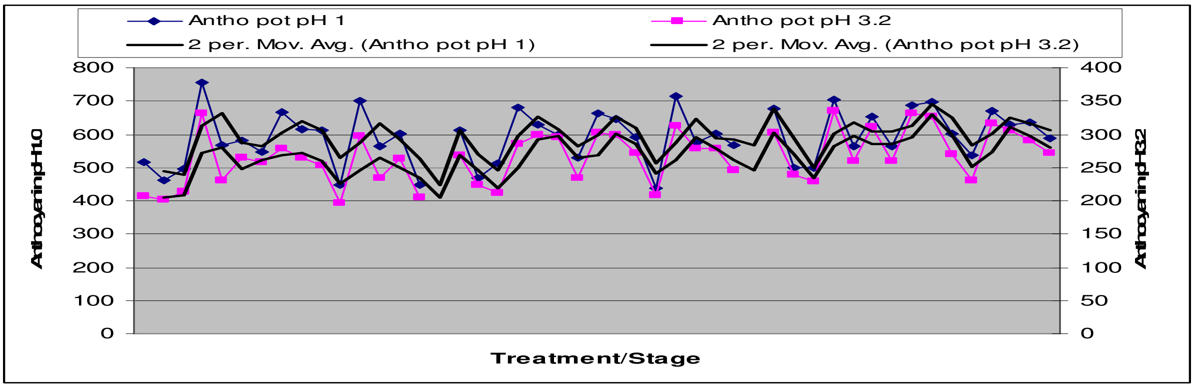

Fig. 13. Effect of level and stage of irrigation on the relationship between whole berry anthocyanin (A_{520}) extraction at pH 1.0 *vs* pH 3.2 of Shiraz/Richter 99.

Table 9. Effect of level and stage of irrigation on whole berry composition of Shiraz/Richter 99.

Stage	Irrigation Treatment (stage+level)	Antho pot pH 1.0	Antho Pot pH 3.2	Tannin g/l pH 1.0	MP % pH 3.2	I 280 pH 1.0	I 280 pH 3.2	DMAC mg Cat Eq/gFM pH 1.0	DMAC mg Cat Eq/gFM pH 3.2
PS	**NI**	5.7	6.1	1.52	23.4	33.8	30.5	0.46	0.43
	75All stages	3.9	6.1	1.37	20.1	33.0	28.2	0.47	0.37
	100All stages	3.1	4.4	1.48	25.6	35.1	35.1	0.48	0.44
V	**NI**	297.9	116.8	2.39	17.4	31.6	16.4	0.21	0.13
	75All stages	219.2	88.8	2.38	16.9	30.8	17.5	0.26	0.18
	100All stages	185.5	80.9	2.02	15.7	28.4	15.8	0.23	0.16
	75PS	223.6	108.9	2.28	16.5	29.7	16.5	0.22	0.14
	100PS	184.6	82.3	1.43	21.1	29.5	18.6	0.30	0.20
PV	**NI**	642.3	256.8	3.53	30.7	50.9	22.3	0.14	0.09
	75All stages	449.3	179.8	3.22	25.9	40.0	17.8	0.14	0.08
	100All stages	444.1	185.9	3.33	28.9	40.2	18.7	0.14	0.08
	75PS	715.3	296.2	3.80	32.6	55.7	24.2	0.15	0.08
	100PS	431.4	164.1	3.06	25.3	38.6	18.2	0.14	0.09
	75V	567.4	246.8	3.35	27.9	46.6	21.5	0.13	0.08
	100V	559.6	223.6	3.29	28.4	45.2	19.5	0.13	0.07
	75PS+V	621.3	244.6	3.43	30.6	49.6	22.0	0.13	0.08
	100PS+V	496.1	200.8	3.29	23.8	42.2	19.6	0.14	0.08
H1	**NI**	515.4	207.4	3.76	37.4	46.1	21.8	0.11	0.07
	75All stages	461.6	201.7	3.72	36.1	43.4	21.3	0.11	0.07
	100All stages	495.7	213.9	3.80	38.8	45.1	22.8	0.12	0.09
	75PS	756.0	330.8	4.15	40.9	58.9	28.7	0.13	0.09
	100PS	568.3	231.4	3.76	36.2	48.6	22.4	0.11	0.08
	75V	582.3	265.1	4.02	40.8	51.4	24.0	0.11	0.07
	100V	546.0	258.1	3.71	36.3	48.8	24.8	0.10	0.07
	75PV	667.2	278.7	3.72	40.6	55.6	24.8	0.11	0.08
	100PV	614.7	265.1	3.93	38.4	52.3	25.3	0.11	0.08
	75PS+V	610.8	253.8	3.98	38.7	51.6	24.7	0.11	0.07
	100PS+V	446.7	196.9	3.56	34.5	41.9	21.1	0.11	0.07
	75PS+PV	700.0	297.1	4.08	37.1	57.8	25.7	0.13	0.08
	100PS+PV	564.4	234.5	3.61	34.9	47.1	22.0	0.11	0.07
	75V+PV	602.0	263.4	4.09	40.2	51.9	24.9	0.12	0.08
	100V+PV	449.3	204.3	3.75	37.1	43.4	21.7	0.11	0.08
H2	**NI**	613.4	268.2	4.31	47.0	51.3	25.7	0.13	0.09
	75All stages	469.9	224.0	4.51	50.2	45.1	24.8	0.11	0.09
	100All stages	514.1	212.6	4.47	47.5	47.9	23.3	0.13	0.08
	75PS	679.0	286.1	4.71	50.6	58.9	29.5	0.14	0.10
	100PS	628.3	299.3	4.60	49.6	55.1	30.6	0.13	0.10
	75V	599.4	295.3	4.64	52.8	51.6	29.1	0.13	0.10
	100V	531.6	233.6	4.40	50.3	48.1	26.1	0.12	0.08
	75PV	664.1	303.2	4.67	50.0	53.3	27.9	0.12	0.08
	100PV	645.3	298.4	4.87	49.5	55.3	29.3	0.14	0.10
	75PS+V	591.1	271.3	4.64	51.9	52.6	27.9	0.11	0.08
	100PS+V	436.2	209.1	3.86	46.1	43.0	24.3	0.12	0.10
	75PS+PV	714.0	312.8	4.60	51.3	59.1	30.0	0.13	0.10
	100PS+PV	574.9	279.1	4.69	49.9	52.6	27.5	0.13	0.09
	75V+PV	602.9	278.7	4.76	53.0	52.5	27.8	0.12	0.09
	100V+PV	567.0	245.9	4.34	44.9	50.9	25.1	0.12	0.08
H3	**NI**	675.9	301.9	5.31	60.5	62.2	32.1	0.14	0.11
	75All stages	498.8	238.9	5.10	58.0	52.8	28.9	0.12	0.08
	100All stages	498.3	228.8	4.98	57.9	51.8	28.1	0.13	0.09
	75PS	704.4	335.6	5.22	61.4	63.7	33.5	0.13	0.10
	100PS	565.3	259.9	5.41	60.4	59.3	32.4	0.13	0.09
	75V	654.1	311.9	5.58	65.1	61.6	33.0	0.14	0.11
	100V	564.4	259.9	4.80	52.6	53.0	29.8	0.11	0.08
	75PV	686.4	332.1	4.72	57.8	63.9	32.3	0.13	0.09
	100PV	697.4	326.4	5.41	59.1	67.0	35.1	0.13	0.10
	75PS+V	600.3	270.8	5.20	59.3	54.9	30.2	0.11	0.08
	100PS+V	535.5	231.4	4.91	47.4	50.2	25.9	0.14	0.12
	75PS+PV	670.3	315.9	5.16	56.8	59.1	31.8	0.13	0.09
	100PS+PV	628.3	305.4	5.27	59.5	57.8	31.4	0.13	0.10
	75V+PV	637.0	290.5	5.37	60.0	60.9	30.6	0.14	0.09
	100V+PV	589.3	271.3	4.72	49.3	53.1	25.8	0.12	0.08

BS = Berry set; PS = Pea size; V = Véraison; PV = Post véraison; 75 = 75% field water capacity irrigation; 100 = 100% field water capacity irrigation; NI = No irrigation; Trm. av. = Treatment average; H1 = Harvest 1; H2 = Harvest 2; H3 = Harvest 3; Antho pot pH 1 = Total available anthocyanin; Antho pot pH 3.2 = Anthocyanin in average wine medium; MP % = Seed tannin contribution; I 280 = Phenol index; DMAC = Total tannin monomers

Table 10. Effect of level and stage of irrigation on wine colour and phenolic content of Shiraz/Richter 99.

Stage	Irrigation Treatment (stage+level)	Absorbance 520	Absorbance 420	Absorbance 280
H1	**NI**	0.14	0.10	1.43
	75All stages	0.09	0.06	1.09
	100All stages	0.10	0.08	1.18
	75PS	0.15	0.11	1.55
	100PS	0.11	0.08	1.24
	75V	0.15	0.10	1.44
	100V	0.13	0.09	1.39
	75PV	0.15	0.10	1.45
	100PV	0.15	0.10	1.52
	75PS+V	0.15	0.10	1.45
	100PS+V	0.11	0.07	1.09
	75PS+PV	0.14	0.10	1.44
	100PS+PV	0.13	0.09	1.33
	75V+PV	0.15	0.10	1.47
	100V+PV	0.11	0.07	1.20
H2	**NI**	0.17	0.13	1.72
	75All stages	0.13	0.09	1.55
	100All stages	0.15	0.11	1.64
	75PS	0.21	0.15	1.98
	100PS	0.17	0.13	1.71
	75V	0.19	0.14	1.91
	100V	0.17	0.12	1.78
	75PV	0.21	0.15	1.94
	100PV	0.20	0.15	1.93
	75PS+V	0.19	0.14	1.91
	100PS+V	0.12	0.09	1.50
	75PS+PV	0.18	0.13	1.82
	100PS+PV	0.15	0.11	1.63
	75V+PV	0.18	0.14	1.88
	100V+PV	0.13	0.10	1.56
H3	**NI**	0.22	0.17	2.03
	75All stages	0.17	0.14	1.88
	100All stages	0.17	0.14	1.90
	75PS	0.29	0.22	2.29
	100PS	0.24	0.18	2.08
	75V	0.22	0.17	2.04
	100V	0.21	0.16	2.05
	75PV	0.26	0.19	2.08
	100PV	0.24	0.18	2.11
	75PS+V	0.24	0.19	2.16
	100PS+V	0.19	0.14	1.90
	75PS+PV	0.27	0.21	2.23
	100PS+PV	0.23	0.18	2.05
	75V+PV	0.22	0.17	2.06
	100V+PV	0.19	0.14	1.92

BS = Berry set; PS = Pea size; V = Véraison; PV = Post véraison; 75 = 75% field water capacity irrigation; 100 = 100% field water capacity irrigation; NI = No irrigation; H1 = Harvest 1; H2 = Harvest 2; H3 = Harvest 3

The organoleptic wine quality and wine style data (Figs. 14, 15 & 16, Table 11) corresponded with the grape and wine composition data (Tables 8, 9 & 10). The total flavour intensity of the wine was highest at harvests two and three and seemed higher with lesser irrigation water. The spiciness increased up to harvest two and then decreased; it seems better stimulated by higher water levels. Berry fruit occurrence was highest at harvests two and three. At harvest two, where the best quality ratios were found (Table 8), berry fruit occurrence was increased by lower water levels. Acidity seemed reasonably well maintained at all harvest stages and was also better stimulated by lower irrigation levels at the second harvest stage. The body of the wine was clearly improved by lesser irrigation volumes at the first two harvests; at harvest three the effects were less evident. The wine colour was clearly also better perceived when the irrigation volume was reduced; this effect again faded to a large extent at the last harvest stage. The perceived astringency decreased from the first to the last harvest stage; at the first two harvest stages it was generally stimulated by less irrigation.

The total quality perceived during the tasting followed the trends observed for berry and wine composition. Non-irrigated wines failed to result in exceptional wine quality at any harvest stage. However, in comparison to the irrigation treatments applied at all stages, a better result on overall quality was obtained with no irrigation. Water was therefore needed under the conditions of the specific terroir of the experiment. Similar to the observations for berry and wine composition, the 75% pea size, post-véraison irrigation, and 75% pea size+post-véraison irrigation consistently resulted in high quality wines at all stages. **At the first harvest stage**, the 75% pea size, 75% post-véraison, 100% post-véraison, 75% pea size + véraison, 75% pea size + post-véraison and 75% véraison + post-véraison irrigations gave the better results; exceptional wines were obtained by irrigating to 75% FWC at post-véraison, to 100% FWC at post-véraison, to 75% FWC at pea size + at véraison combined, and to 75% FWC at pea size + at post-véraison combined. **At the second harvest stage**, the non-irrigated vines and vines irrigated 75% at pea size, 75% at véraison, 75% at post-véraison, 75% at pea size + at post-véraison combined, and 75% at véraison + at post-véraison combined, gave the better results; exceptional wines were obtained by irrigating to 75% FWC at pea size, and to 75% FWC at post-véraison. **At the third harvest stage**, 75% pea size, 75% post-véraison, 100% post-véraison, and 75% pea size + post-véraison resulted in the better wines; exceptional wines were obtained from irrigation to 75% FWC at post-véraison, and 100% FWC at post-véraison.

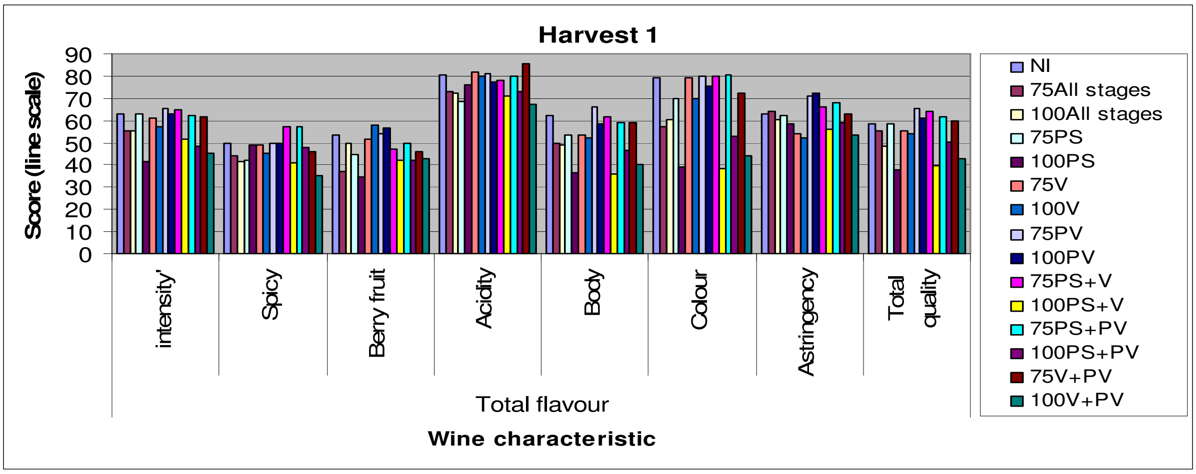

Fig. 14. Effect of level and stage of irrigation on organoleptic wine quality and wine style of Shiraz/Richter 99.

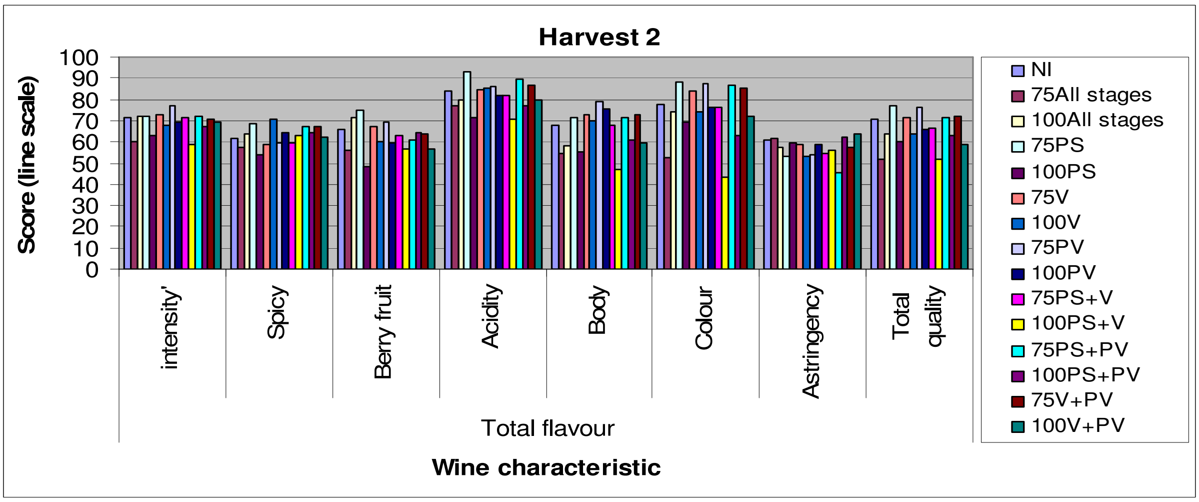

Fig. 15. Effect of level and stage of irrigation on organoleptic wine quality and wine style of Shiraz/Richter 99.

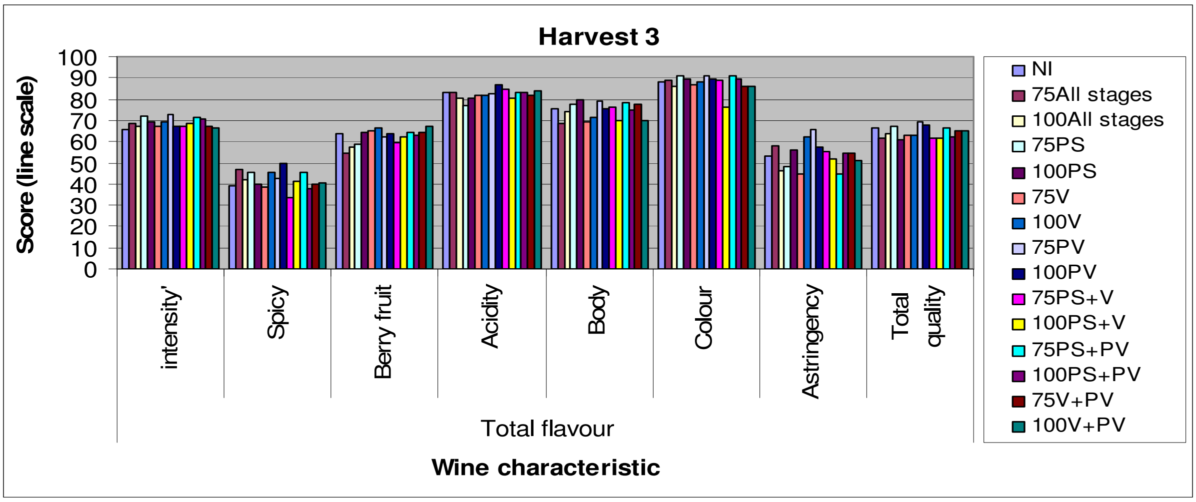

Fig. 16. Effect of level and stage of irrigation on organoleptic wine quality and wine style of Shiraz/Richter 99.

Table 11. Effect of level and stage of irrigation on wine colour and phenolic content of Shiraz/Richter 99.

Stage	Irrigation Treatment (stage+level)	Total flavour	Spicy	Berry fruit	Vege-tative	Acidity	Body	Colour	Astrin-gency	Total quality
H1	**NI**	63.1	49.5	53.8	30.0	80.3	62.2	79.1	62.9	58.4
	75All stages	55.3	44.2	37.1	40.0	73.1	50.0	57.5	64.2	55.6
	100All stages	55.6	41.6	49.5	39.4	72.1	49.0	60.7	60.4	48.3
	75PS	62.8	42.3	45.0	42.5	68.8	53.4	70.0	62.1	58.8
	100PS	41.4	49.4	34.6	28.1	76.1	36.7	38.9	58.3	37.9
	75V	61.3	49.2	51.3	47.5	81.9	53.6	79.4	54.2	55.3
	100V	57.2	45.4	58.1	34.4	79.7	52.0	69.6	52.5	54.4
	75PV	65.3	50.0	54.1	39.2	81.0	66.3	79.7	70.8	65.5
	100PV	62.8	50.0	56.4	47.5	77.7	58.4	75.3	72.5	60.9
	75PS+V	64.7	57.5	47.5	52.8	78.3	61.6	80.0	66.3	63.9
	100PS+V	51.9	41.0	42.1	30.0	71.2	36.0	38.6	56.1	39.4
	75PS+PV	62.5	57.2	50.0	44.4	80.0	59.4	80.3	68.2	61.6
	100PS+PV	48.8	47.7	42.4	34.2	72.9	46.7	53.0	59.2	50.3
	75V+PV	61.6	46.3	46.0	40.0	85.3	59.3	72.2	62.7	60.0
	100V+PV	45.6	35.0	42.9	29.3	67.5	40.0	44.3	53.6	42.5
H2	**NI**	71.1	61.4	65.8	53.8	83.8	67.5	77.5	60.6	70.8
	75All stages	60.4	57.3	55.7	50.4	76.7	54.4	52.5	61.4	51.5
	100All stages	72.3	63.6	71.7	64.1	80.0	57.7	74.0	57.1	63.6
	75PS	72.1	68.3	75.0	57.1	92.9	71.4	88.3	53.3	76.7
	100PS	62.9	54.2	48.6	61.7	71.5	55.0	68.9	59.4	60.0
	75V	72.9	58.8	66.8	54.6	84.6	72.7	83.9	59.0	71.1
	100V	67.9	70.8	60.4	61.8	85.0	70.0	74.3	53.3	63.6
	75PV	77.1	59.6	69.3	55.4	85.7	78.9	87.1	54.0	76.4
	100PV	69.3	64.2	59.6	61.0	81.7	75.4	76.2	58.8	65.7
	75PS+V	71.1	59.2	63.2	55.0	81.5	67.5	76.4	54.5	66.4
	100PS+V	58.6	62.7	56.5	60.8	70.8	46.7	43.6	56.3	51.8
	75PS+PV	71.8	67.1	60.7	58.1	89.6	71.2	86.8	45.5	71.1
	100PS+PV	67.1	64.2	64.6	61.7	76.8	61.2	63.1	62.2	63.2
	75V+PV	70.7	66.9	63.6	62.5	86.5	72.7	85.0	57.5	71.8
	100V+PV	69.3	61.9	56.9	62.7	80.0	59.6	72.1	63.3	58.9
H3	**NI**	65.7	38.8	63.8	59.5	83.2	75.4	87.9	52.9	66.4
	75All stages	68.2	46.8	54.6	61.9	83.2	68.2	88.9	58.1	61.8
	100All stages	67.3	41.9	57.5	52.7	80.4	73.9	85.7	46.4	63.6
	75PS	71.8	45.8	58.6	42.0	76.9	77.5	91.1	48.3	66.8
	100PS	69.3	39.6	64.2	50.0	80.4	80.0	89.3	55.8	61.1
	75V	66.8	38.5	65.0	41.1	81.8	68.9	86.8	45.0	62.7
	100V	68.9	45.5	66.4	54.5	82.1	71.5	87.9	62.1	62.9
	75PV	72.5	42.9	62.5	55.0	82.7	79.3	90.7	65.8	69.3
	100PV	67.1	50.0	63.5	46.0	86.8	75.4	89.3	57.1	67.5
	75PS+V	67.1	33.8	59.3	41.7	84.6	76.4	88.6	55.5	61.8
	100PS+V	68.2	41.3	62.5	39.0	80.4	69.6	76.1	51.7	61.4
	75PS+PV	71.5	45.5	64.2	45.7	83.1	78.5	91.2	44.4	66.7
	100PS+PV	70.8	37.9	62.9	50.5	82.9	74.6	89.3	54.6	62.1
	75V+PV	67.1	39.6	64.6	50.9	81.7	77.9	86.1	54.5	65.4
	100V+PV	66.4	40.8	66.8	44.1	83.8	70.0	86.1	51.3	65.0

BS = Berry set; PS = Pea size; V = Véraison; PV = Post véraison; 75 = 75% field water capacity irrigation; 100 = 100% field water capacity irrigation; NI = No irrigation; H1 = Harvest 1; H2 = Harvest 2; H3 = Harvest 3

Conclusions

The project was done over a period of four growth seasons. The water holding capacity of the soil and change in summer rainfall patterns from year to year within the Mediterranean climate impacted on the reaction of the vines to treatments, complicating the data set and deductions. Under the conditions of the terroir in which the project was done, additional water was certainly required in order to obtain the best grape and wine quality. Basic trends were in accordance to those found in other studies, whereas new information was obtained on the inter-relationships between the behaviour of the canopy and that of the grapes during ripening. The physical and compositional changes in the berry during late ripening were clarified further.

The 75% pea size, post-véraison irrigation, and 75% pea size+post-véraison irrigation consistently resulted in high quality wines at all stages. Different wine styles were, however, found at each stage and between stages. At the first harvest stage, exceptional wines were obtained by irrigating to 75% FWC at post-véraison, to 100% FWC at post-véraison, to 75% FWC at pea size + at véraison combined, and to 75% FWC at pea size + at post-véraison combined. At the second harvest stage, exceptional wines were obtained by irrigating to 75% FWC at pea size, and to 75% FWC at post-véraison. At the third harvest stage, exceptional wines were obtained by irrigating to 75% FWC at post-véraison, and to 100% FWC at post-véraison. The group of treatments that performed best seemed to be that which included post-véraison (three weeks to one month after véraison) irrigation. Although irrigation at such late stage to 100% FWC, especially when in combination with irrigation earlier during the season (up to véraison), may present a risk of too much re-growth under fertile soil conditions, slight re-growth, which may occur under different conditions, should nevertheless not be judged as detrimental to grape ripening and eventual wine quality.

It is clear that irrigation in terms of volume and stage may also under Mediterranean conditions, such as in the Western Cape, contribute largely to a required style of wine. Treatment effects were generally reduced at a late harvest stage. Overripe grapes seem to minimise the opportunity for the making of a unique or even terroir specific, wine. It would also to a large extent minimise the effect of any special cultivation practices followed during the season. Over-ripeness seems to have an equalising effect. Harvesting at optimal ripeness or within a window that allows the effects of terroir and vineyard-specific practices (including irrigation) to surface is critical.

Definitive guidelines regarding stage and volume of low intensity (supplementary) irrigation under Mediterranean climate (high winter rainfall and occasional, infrequent summer rainfall) and medium potential soil conditions on grape composition and wine quality and style were found. It certainly also has significance for other terroirs. It seems reasonable to assume that Shiraz/Richter 99 vines and other cultivar-rootstock combinations with similar environment requirements or abiotic resistance, specifically drought resistance, and ecophysiological reaction would react similar under similar terroir conditions.

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- the Winetech Viticulture Committee for their positive comments and support, also for sustaining active international collaboration, and
- various producers of the SA Wine Industry for stimulating discussions.

4. Accumulated outputs

Indicate the year actioned.

Technology developed

Technology improvement concerning analytical procedures

Human resources developed/trained

Post-doctorate students (2), PhD student (1), MSc student (1), Foreign Graduate student (1), Foreign researcher involvement (8)

International involvement: France, Italy, Spain, Germany

Patents

None

Publications (popular, press releases, semi-scientific, scientific)

Hunter, J.J. & Deloire, A., 2005. Relationship between sugar loading and berry size of ripening Syrah/R99 grapes as affected by grapevine water status. Proc. GESCO Conference, 23 – 27 August 2005, Geisenheim, Germany, pp. 127 - 133.

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Barbagallo M. G., Guidoni S., Hunter J.J. Effetto della dimensione degli acini e dell'orientamento dei filari sulle caratteristiche qualitative della cv Syrah. Proc.'s II Convegno Nazionale di Viticoltura, 14 – 19 luglio 2008, Complesso San Pietro, Marsala, Italy.

Presentations/papers delivered

Relationship between sugar loading and berry size of ripening Syrah/R99 grapes as affected by grapevine water status. Hunter, J.J. & Deloire, A. GESCO Symposium, Geisenheim, Germany. 23 – 27 August 2005.

Berry sugar loading and anthocyanin content as affected by bunch microclimate of Shyrah/R99. Deloire, A., Kraeva, E., Martin, M. & Hunter, J.J. GESCO Symposium, Geisenheim, Germany, 23 – 27 August 2005.

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The effect of ripeness levels on wine style and quality. Nadal, M. & Hunter, J.J. South African Society of Enology and Viticulture International Congress, November 2006, Somerset West.

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Grape ripening and wine style. Seminar, Winetech Industry meeting. March 2007.

Different wine styles as related to ripeness level of Syrah/R 99 grapes. Nadal, M. & Hunter, J.J., 2007. International Intervitis Interfructa Congress, Stuttgart, Germany.

Traslocazione dei metaboliti durante la maturazione dell'uva in *Vitis vinifera* L.: Effetti dell'anulazione del germoglio. Giacalone, C., 2008. University of Palermo, April 2008, Palermo, Italy.

Grapevine (Shiraz/Richter 99) water relations during berry ripening. Ellis, W., 2008. University of Stellenbosch, March 2008, Stellenbosch, South Africa.

Estrazione di antociani dalle bucce al mosto durante la fermentazione di uve Shiraz. Guidoni S., Barbagallo M.G., Hunter J.J. II Convegno Nazionale di Viticoltura, 14 – 19 luglio 2008, Complesso San Pietro, Marsala, Italy.

Effetto della dimensione degli acini e dell'orientamento dei filari sulle caratteristiche qualitative della cv Syrah. Barbagallo M. G., Guidoni S., Hunter J.J. II Convegno Nazionale di Viticoltura, 14 – 19 luglio 2008, Complesso San Pietro, Marsala, Italy.

EVALUATION BY INDUSTRY

This section is for office use only

Project number:	WW12/25

Project title:	Relationship between Shiraz/R99 water relations and physiological and developmental changes in the berry

Name of Subcommittee*:	

Comments on project:

Committee's recommendation:

- Accepted. ☐
- Accepted provisionally if the subcommittee's comments are also addressed. ☐
  Resubmit this progress report by ________________
- Unacceptable. Must resubmit progress report. ☐

Chairperson: ________________________ **Date:** ____________________

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*SUBCOMMITTEES:

Winetech

Viticulture: Organic Cultivation and Production; Cultivation; Soil Science; Plant Biotechnology; Vine Virus Committee; Plant Protection; Plant Improvement; Resource Poor Producers

Oenology: Production Technology; Bottling, Packaging & Distribution; By and Waste Production Handling; Brandy and Distilling; Microbiology

Deciduous Fruit

Producer Research Advisory Committees (RAC's): Pome fruit, Stone fruit, Table grapes

Peer Work Groups (PWG's): Biotechnology, Breeding & Evaluation (Pome Fruit), Breeding & Evaluation (Stone Fruit), Entomology, Horticulture, Pathology, Post Harvest, Soil Science, Table Grape Production