CUT 1001: AO8 – Optimising the utilisation and acquisition of water resources in irrigated vineyards under water-limiting conditions

This is an excerpt from the final report CUT 1001: **Optimising industry returns from existing soil and water research.**

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Adoptable Outcome 8. Optimising the utilisation and acquisition of water resources in irrigated vineyards under water-limiting conditions

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1. Introduction

Water resources

Approximately 87% of the Australian wine grape production comes from regions that rely wholly or partly on irrigation water. Full allocations or reserves of water allow grape growers to apply sufficient irrigation to replace the water lost by crop evapotranspiration and to leach salts from the soil. However, in recent years, wine grape producers in south east Australia have started their growing seasons with anywhere between 0 and 70% water allocations (Stevens et al. 2008). Similarly, in southern parts of the south west of Western Australia, irrigation resources have been limited and irrigation allocations have been based on risk minimisation strategies.

During the past decade, the security of water supply has been challenged through industry expansion, drought and increased competition from other water users. In the case of the Murray Darling Basin where approximately 60% of Australia's wine grapes are produced (White 2010), a further constraint on water resources has been imposed by the management authority which recommends a reduction in irrigation entitlements for environmental reasons.

In the south west of Western Australia, greater demand for water by irrigators has necessitated increased management and regulation of water resources by the Department of Water. In areas where demand for water is particularly great, ground water and surface water resources have been proclaimed and irrigators now require a licence. In some viticultural regions (eg. the Great Southern) water supplies are also limited by salinity and many grape growers have difficulty in securing sufficient irrigation water for their annual requirements.

Climate change

Climate change, and the associated increased variability in rainfall, temperature and evaporative demand, has become a real threat for Australia (Jones et al. 2005, Webb et al. 2007, Anderson et al. 2008). Anthropogenic climate change is thought to have exacerbated the drought conditions experienced in southern parts of Australia in recent years and according to the Department of Climate Change and Energy Efficiency (2010), this is shown through the following effects:

- a reduction in the total amount of rain
- a change in its distribution
- an increase in evaporative demand
- an increase in the frequency of periods of high temperature

While these threats have the potential to impact on most forms of agriculture, wine grape production is particularly sensitive because wine is strongly associated with regional and varietal characters which, in turn, are dependent on seasonal climatic conditions. These changes put further pressure on water resources and its utilisation both now and in the future.

Water stress effects on the vine

Limiting the amount of irrigation applied to grapevines during the season often compromises crop yield through its effect on bunch number, berry number and berry weight (Van Zyl 1984, Grimes and Williams 1990, Girona et al. 2006). Similarly it can impact on fruit quality, either positively or

negatively depending on the timing (ie. phenological stage) and severity of water stress imposed on the grapevine.

Severe and prolonged water stress can adversely affect vine physiological processes such as stomatal conductance, transpiration and photosynthesis (Naor et al. 1994, Williams and Araujo 2002), which may, in turn, delay the accumulation of sugar in berries and adversely affect the balance of flavour components.

Soils and rooting distribution

Wine grape production generally requires significantly less irrigation than many other horticultural crops (Australian Bureau of Statistics 2008). There are a number of reasons for this:

- the grapevine has a potentially deep and extensive root system that is able to efficiently extract soil water
- the method of water delivery in approximately 70% of irrigated vineyards uses drip and/or micro-jet systems which are efficient in relation to evaporation losses (McCarthy et al. 2010).

However, many Australian soils have characteristics which potentially restrict both the volume and distribution of vine roots. Where this occurs, vines may not be able to access and hence utilise water and nutrients efficiently from either the mid-row area or within the vine row below restricted root zones. This is likely to have a negative impact on vine water use efficiency (WUE) and hence the long-term sustainability of the vineyard.

Water use efficiency

Maximising both the returns (ie. crop yield and fruit quality) and WUE are not only compatible objectives, but are also necessary and achievable objectives, particularly in environments with limited (and potentially diminishing) water resources. In such environments, irrigation is likely to move from being a yield/growth strategy to a risk management strategy.

This document provides guidelines on how to optimise the utilisation and acquisition of water resources in irrigated vineyards under water-limiting conditions.

2. Optimising the utilisation of water

2.1 Water use efficiency

Production water use efficiency (WUEp)

Production water use efficiency (WUEp) is generally the way in which water utilisation is measured and compared. WUEp is defined as the amount of crop produced per unit of water applied as irrigation and effective rainfall, and for any viticultural production system, is therefore an outcome of the efficiency by which water reaches vines and the efficiency by which those vines access and transpire the water in fixing carbon.

Gibberd et al. (2001, 2002) and Tyerman et al. (2011) propose that there are various sources of variation associated with WUEp.

- Irrigation efficiency: described as the proportion of applied water (the resource) that is transpired by the vine. For this efficiency to be close to optimal, water loss through runoff, drainage, leakage, evaporation and cover crop transpiration has to be minimal. Irrigation efficiency is mainly influenced by water management practices since it is dependent on both the water delivery infrastructure and the way in which the water is then applied to optimise crop production and/or fruit quality.

- Transpiration efficiency: described as the amount of carbon fixed during photosynthesis per unit of water transpired by the vine. Gibberd et al. (2001) found that a large proportion of the variation in transpiration efficiency can be attributed to variation in vine genotype through differences in stomatal conductance and photosynthetic capacity.
- Harvest index: described as the proportion of total dry matter removed as harvested product (ie. crop yield). It is dependent on the supply of sugar from both photosynthesis and reserves and is an important parameter as it determines yield from the product of transpiration efficiency and the volume of water transpired. As for transpiration efficiency, it is strongly influenced by scion and rootstock genotypes (Gibberd et al. 2002).

For any given established vineyard, practical solutions to optimise WUEp therefore need to focus on improving irrigation efficiency since this is mainly influenced by management practices.

Value water use efficiency (WUEv)
Water utilisation can also be considered on a value basis. Value water use efficiency (WUEv) is defined as the monetary value of the fruit or wine per unit of water applied as irrigation and effective rainfall. Whereas WUEp relates to the vineyard, WUEv relates to the vineyard-winery-market place continuum. This form of WUE also needs to be considered in the decision-making process since a reduction in productivity as a consequence of deliberate or otherwise under-irrigation practices could be offset by a potential improvement in fruit and wine quality and hence monetary value.

When comparing irrigation strategies and water use across a single vineyard or vineyards in close proximity to each other for any given season, the effective rainfall component can be excluded. WUEp and WUEv can then be expressed as t/ML and $/ML respectively.

2.2 Vine water requirements

Minimising the risk of crop loss when insufficient water is available requires an understanding of the vine's water requirements during the season. Under these circumstances it is critical that grape growers examine their irrigation scheduling practices with a view to optimising WUE. There are two key questions that need to be considered to achieve this.

When does the vine require water?
Temporal improvements in WUE can be achieved by avoiding wastage (ie. over-irrigation) and by ensuring sufficient water is applied during key growth periods (ie. avoid under-irrigation when the risk of yield reduction is high). The amount of water required during different stages of the growing season will depend on:

- climatic conditions
- variety:rootstock combinations
- soil type and depth
- crop load

Table 1 provides guidelines on vine water requirements to ensure that productivity and fruit quality are not compromised for the current and subsequent growing seasons.

Table 1. A guide to vine water requirements for the key phenological growth periods.

Growth period	Vine water requirements
Budburst to flowering	Although this period is critical for root growth and establishing canopy size and potential yield, irrigations that are applied too soon will be wasted and not used by the vine. In many warm/cool regions, winter/spring rainfall ensures an adequate supply of water for all or most of this period and irrigation is not required. Under water-limiting/drought conditions, irrigation may need to be applied. Water stress during this period is likely to result in reduced shoot growth and leaf size.
Flowering to fruit set	Flowering and fruit set are particularly sensitive to water stress as cell division is a critical developmental stage. It is a period when shoot growth is rapid. Irrigation should be applied prior to flowering if soil water levels are low.
Fruit set to veraison	The amount of water required depends on soil water content and the desired fruit quality. This is the period when irrigation techniques such as regulated deficit irrigation (RDI) and partial rootzone drying (PRD) can be implemented to impose water stress to control shoot growth and berry size, both of which can have positive effects on fruit quality.
Veraison to harvest	Poor leaf function is likely to delay the accumulation of sugar and adversely affect the development and balance of flavour components in berries. Once berries have reached full maturity, water deficits are less harmful so irrigation volumes can be reduced. Severe water deficits should be avoided in order to maintain leaf health and function.
Post-harvest	Ideally, vines need to accumulate sufficient carbohydrate reserves for the next season before going into dormancy. If water is available, irrigation is likely to benefit vines by ensuring that conditions are suitable for root growth and leaf function.

The effect of water stress on vine growth and berry development differs depending on the timing and degree of stress during the season.

- Severe water stress prior to flowering and fruit set should be avoided because of its negative impact on crop potential for both the current and subsequent seasons.
- The timing of irrigations is critical and a block by block assessment at key phenological growth stages is therefore imperative.
- This assessment should take into consideration vine vigour, root distribution, target crop yield and wine style and environmental conditions.
- Environmental factors include current and forecast temperature and evaporation rates, water quality, soil moisture status, and the water holding capacity of the soil. Each factor needs to be assessed progressively throughout the growing season and is likely to carry a different degree of importance at various times.

Under extreme cases of water shortage, minimising the risk of a loss in crop and/or wine value may be more important than a loss in productivity. In this case water should be allocated to those blocks from which the greatest monetary value will be gained.

Visual indicators of vine water stress

In situations where there are no water stress symptoms, it is possible that irrigation water is being wasted, thereby resulting in WUE being sub-optimal. Where there are signs of mild water stress, it is likely that WUE is close to being optimal. Where there are signs of either severe or extreme water stress, it is likely that yield and fruit quality are being compromised, thereby reducing WUE. Table 2 provides guidelines for assessing shoot, berry and soil in relation to the degree of vine water stress and should be used in combination with quantitative measures of vine and/or soil water status to determine when and how much water to apply.

Table 2. Shoot, berry and soil indicators of vine water status. There is a gradual progression of conditions through the different stages of water status ranging from luxury conditions and no signs of water stress (dark blue), to optimal conditions with possible signs of mild water stress (light blue), and sub-optimal conditions with signs of severe (light red) and extreme (dark red) water stress (adapted from Iland et al. 2011).

NO WATER STRESS	MILD WATER STRESS
Shoots • Shoot growth is active. • Growing tip is not enclosed when the last formed leaves are pushed towards the growing tip. • Tendrils are turgid. • Top tendrils reach past the growing tip. • All leaves are green and healthy. • Leaf blades are orientated to the sun. • Exposed and shaded leaves feel cool to touch with palm of the hand. **Berries** • Berries are turgid. **Soil** • Soil water content is within the Readily Available Water range. • Soil can be easily moulded into a ball; moisture can be seen and felt in the hand.	**Shoots** • Shoot growth is slowing or has ceased. • Growing tip is not enclosed when the last formed leave are pushed towards the growing tip. • Tendrils are turgid. • All or majority of leaves are green and healthy. • Leaf blades are orientated to the sun. • Exposed and shaded leaves feel cool / warm to touch with palm of the hand. **Berries** • Berries are turgid. **Soil** • Soil water content is at or approaching bottom of Readily Available Water range. • Soil is difficult to bind together and mould into a ball without adding some water.
SEVERE WATER STRESS	**EXTREME WATER STRESS**
Shoots • Shoot growth has ceased. • Growing tip is enclosed when the last formed leaves are pushed towards the growing tip. • Shoot tips are dull-grey and may be dry. • Shoot tips may be missing. • Middle to upper leaves are green. • Basal leaves are yellow or pale green. • Leaves are wilting and leaf blades have altered their position to reduce direct radiation interception. • Leaves are folded with their backs orientated to the sun. • Exposed and shaded leaves feel warm to touch with palm of the hand. • Basal tendrils are drooping. • Late in the season, exposed basal leaves are yellow and may have necrotic edges. • Basal leaves may have senesced and fallen. **Berries** • Berries start to become flaccid and begin to shrivel. **Soil** • Soil water content is approaching the middle or bottom of the Deficit Available Water range. • Soil is either hard or loose; water is required before it can be moulded into a ball.	**Shoots** • Shoot growth has ceased. • Growing tip is enclosed when the last formed leaves are pushed towards the growing tip. • Shoot tips are dull-grey and may be dry. • Shoot tips may be missing. • Most leaves are yellow or pale green. • Leaves are wilting and leaf blades have altered their position to reduce direct radiation interception. • Leaves are folded with their backs orientated to the sun. • Exposed and shaded leaves feel warm / hot to touch with palm of the hand. • Basal tendrils are drooping or dead. • Late in the season, exposed basal leaves are yellow with necrotic edges. • Some leaves are scorched. • Basal leaves have senesced and fallen. **Berries** • Berries are flaccid; some are shriveled and/or raisined. **Soil** • Soil water content is below the Deficit Available Water range. • Soil is either hard or loose; difficult to wet up and/or mould into a ball when water is added.

How much and when should water be applied?

To make informed decisions about how much water to apply and the timing of those applications, a measure of vine water status is required. This is generally done either directly using plant-based measures or indirectly using soil-based and/or climate-based measures.

Plant-based measures

A range of instruments are available that generate information that can be used to indicate irrigation requirements. These include measures of:

- water potential (eg. a pressure chamber for leaves and stems or a psychrometer for leaves)
- stomatal conductance (eg. a porometer)
- sap flow
- leaf temperature
- trunk diameter

Schultz and Stoll (2010) and Tyerman et al. (2011) discuss current and emerging technologies for measuring vine physiological parameters. Currently, these devices are being used for research rather than commercial purposes. However, this is likely to change as some have the potential to be developed into user-friendly irrigation scheduling tools.

Soil-based measures

Since relationships can be established between vine physiological parameters and changes in soil water measurements, in practice it is easier to assess vine water status using devices that measure either soil water suction or volumetric soil water content. The measurements should preferably be collected automatically using loggers programmed to acquire data at regular intervals. Simple observations of soil moisture status can also be made by assessing samples collected using a spade, auger or dig-stick.

There is a wide range of commercially available devices and associated software with a number of factors that will influence instrument choice:

- output measures (ie. water content or suction)
- data presentation (ie. absolute or relative data, continuous or periodic data)
- purchase and operating costs
- ease of use and data interpretation
- reliability and accuracy
- site characteristics (ie. vineyard area, soil type/depth, water quality, spatial variability)

Table 3 provides a guide to a range of commonly-used devices. Refer to Pudney et al. (2000, 2001) for information on their performance over two growing seasons.

Table 3. Description of a range of commercially available soil moisture monitoring devices.

Sensor / relative purchase cost	Measure	Mode of operation	Comments
Gypsum Block Heavy Low purchase cost	Tension Direct soil contact	Resistance AC resistance is measured between two electrodes inserted in a block of gypsum. As water content of block increases, the resistance of the block decreases. A calibration curve relates resistance to soil water tension.	Continuous data. Cable/ Radio link. Dissolve over a number of years. Suited for use in heavier clay soils. 60-600 kPa.
Gypsum Block Lite Low purchase cost	Tension Direct soil contact	Resistance Same operating principle as gypsum block heavy. Consists of granular matrix supported in a metal screen. A wafer of gypsum is impregnated into the granular matrix.	Continuous data. Cable/ Radio link. Suited for use in sandier soils. 10-200 kPa.
Theta Probe® Intermediate purchase cost	Volumetric Direct soil contact	Capacitance Measures soil properties using a standing wave measurement technique. The dielectric property of the soil is related to soil water content.	Continuous data. Cable/ Radio link.
EnviroSCAN® and C-Probe® High purchase cost	Volumetric Indirect soil contact. Measurement through wall of PVC tube.	Capacitance Oscillator used to generate an AC field that is applied to the soil to detect changes in soil dielectric properties. Changes in dielectric properties are linked via a calibration equation to soil water content.	Continuous data. Cable/ Radio link. Requires computer.
Diviner2000® Intermediate purchase cost	Volumetric Indirect soil contact. Measurement through wall of PVC tube.	Capacitance. Same as EnviroSCAN®. Manually inserted down a PVC access tube.	Periodic data. Manually operated. Auto-Depth sensing.
Reflectometer Intermediate purchase cost	Volumetric Direct soil contact.	Time Domain Reflectometry (TDR) Measures the travel time of an electro-magnetic pulse through the sensor electrodes.	Continuous data. Cable/ Radio link.

The correct installation and positioning of such equipment is important if the data is to be representative of the vineyard conditions.

- There should be at least one measuring site per soil type, with 3 or more measurement depths per site.
- The greater the spatial variation in soil characteristics and vine performance, the greater the number of measuring sites required.
- Ensure that the measuring sites are not positioned in hollows or ridges.
- One measurement depth should be close to the soil surface within the zone where the majority of roots occur (ie. about 20-30 cm depth).
- The other measurement depths should be lower in the soil profile (eg. 50-60 cm depth) and close to the base of the root zone.

Climate-based measures
Water use by a vineyard is closely related to evaporation from an exposed water surface. The standard meteorological device to measure evaporation is the Class A pan evaporimeter. Crop factors (CF) are then used to convert pan evaporation (Epan) to vineyard water use. However, this is not the preferred method when the canopy cover is incomplete.

An alternative and more commonly used method is the use of evapotranspiration figures derived from a reference crop (ETo) in conjunction with crop coefficients (Kc) to convert ETo to vineyard water use (ETc). Kc values are defined in reference to particular calculations of evaporative demand. Long-term ETo can be used to plan an approximate irrigation frequency based on average climatic conditions and forecast ETo can be used to predict when the next irrigation is due.

The Bureau of Meteorology provides recent ETo values on its website (www.bom.gov.au/watl/eto/) and registered users can access forecast ETo via the meteogram service. CSIRO provide recent and forecast ETo values for selected locations via the irriGATEWAY website (http://weather.irrigateway.net/).

Recent research has shown that by adjusting Kc for grapevine canopy cover, it is now possible to improve ETc calculations (Williams and Ayars 2005). This approach is being trialled by CSIRO for the Irrisat-SMS irrigation scheduling service (www.irrigateway.net/tools/sms/) (Hornbuckle et al. 2008).

Other options include remote sensing to provide figures of actual evapotranspiration to aid irrigation scheduling (Glenn et al. 2007, Allen et al. 2011).

2.3 Spatial variability and the effect on water use efficiency

A further question to consider in relation to irrigation scheduling practices with the objective of optimising WUE is where to apply the water.

Crop yield and fruit quality
Land is variable and because of this, vine performance (eg. crop yield and berry composition) within vineyards has been shown to have a distinct spatial structure (Bramley and Hamilton 2004, Bramley 2005, Cortell et al. 2005, Reynolds et al. 2007, and Trought et al. 2008). The range of variation in crop yield obtained from blocks under uniform management is typically 10-fold (Bramley and Hamilton 2004). In the absence of intervention, within-vineyard patterns of yield variation appear to be temporally stable (Bramley and Hamilton 2004, 2007). Similarly, indices of fruit quality measured at vintage (eg. total soluble solids, titratable acidity, pH, and anthocyanins), and sensory attributes of finished wine have also been shown to be spatially variable (Bramley 2005, Cortell et al. 2005, Trought and Bramley 2011), but not necessarily temporally stable as they are more susceptible to climatic conditions.

This heterogeneity, regardless of the cause, is undesirable from both a grape and wine production point of view.

Canopy characteristics and the identification of management zones
Numerous studies (Hall et al. 2002, 2011, Lamb et al. 2004, Proffitt et al. 2006) have used airborne remote sensing to acquire digital multi-spectral imagery (DMSI) at 0.5 m spatial resolution to identify relative differences in canopy characteristics at veraison. This data, in the form of Plant Cell Density (PCD) or Normalised Difference Vegetation Index (NDVI) values, have been used to identify zones for differential management.

Differential management of irrigation water

Spatial variability has generally been accepted as 'normal' and the majority of vineyards have been managed on the assumption that they are homogenous. When a variable block is managed in this way, inputs (or resources) such as irrigation water are uniformly applied. A number of studies (Tisseyre et al. 2005, Acvedo-Opazo et al. 2008) have shown that there is significant within-vineyard variability in grapevine water status. Taylor et al. (2010) found that canopy size, which is associated with vine vigour, and soil type are the dominant drivers of this variation, particularly as water becomes restricted. They concluded that canopy architecture is an effective parameter for creating zones of similar vine performance within which to measure vine water status and to differentially apply irrigation water.

Case study 1 (Goodwin et al. 2009, McClymont et al. submitted)

This study demonstrates how the differential application of limited water supplies increased the productivity of a low yielding section (zone) and reduced the volume of irrigation water applied in a high vigour section (zone) of a 6.4 ha Shiraz block located in the Sunraysia region of Victoria. This practice therefore improved WUEp within these sections (zones).

The vineyard was planted in 1994 and was irrigated using a drip system. Figure 1 shows how three irrigation zones (west, east and south) were identified and delineated using DMSI and canopy temperature. A sub-main within the block allowed differential irrigation. Additional irrigations were applied to the west zone in certain seasons. In 2009, in-line taps were installed to create the south zone.

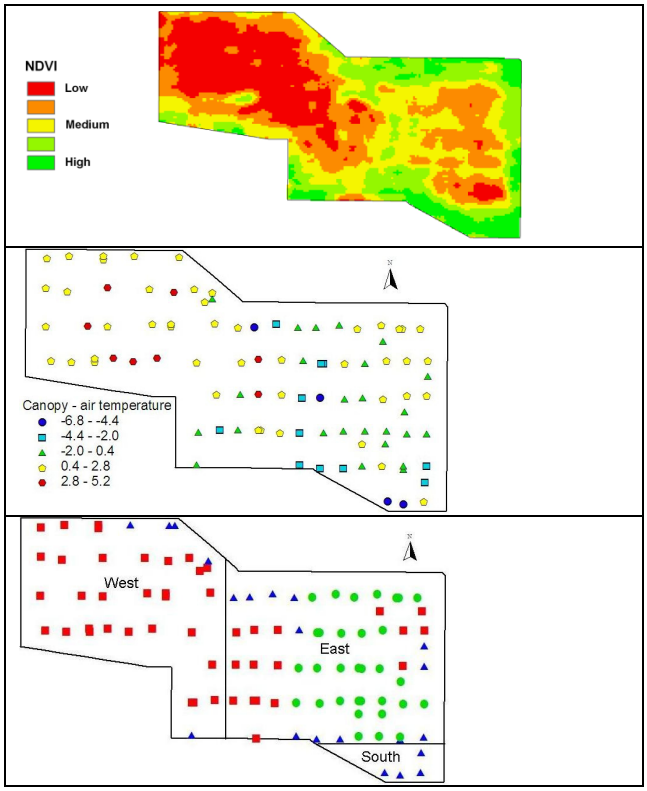


Figure 1. (a) Spatial variation in vine vigour expressed as the Normalised Difference Vegetation Index (NDVI) which relates to relative differences in canopy surface area and leaf health. The digital multi-spectral imagery (DMSI) data was acquired at 0.5 m spatial resolution at veraison in the 2005/06 season, (b) Spatial variation in canopy air temperature acquired at veraison in the 2007/08 season. Measurements were recorded directly above the canopy using infrared sensors mounted on a 4-wheel bike, (c) Irrigation management zones (east, west and south) identified within the block. Points indicate the target vines for the measurement of yield and berry composition. The different colours refer to the multivariate cluster analysis used to derive the three zones (McClymont et al. submitted).

A range of vine and berry composition parameters were measured for 5 consecutive seasons. Prior to the implementation of differential irrigation practices in the last season (2009/10), low vine vigour and yield, together with symptoms of water stress, were typical of the west zone. In the south zone, vines were generally too vigorous, producing large crop yields with poor fruit quality parameters. The east zone produced moderate yields with intermediate fruit quality parameters. In 2009/10, the frequency of irrigation was reduced in the south zone while in the west zone the frequency was increased to improve the availability of soil water supplies. Towards the end of the season the whole block was irrigated uniformly. At the end of the season, the east and west zones received similar irrigation volumes (4.5 ML/ha), while the south zone received less water (3.7 ML/ha).

Table 4 shows that the outcome was an increase in productivity and WUE in the west zone relative to the east zone and a slight improvement in WUE in the south zone. The differential application of water also resulted in more uniform fruit quality parameters such as berry pH and titratable acidity but not in ^{o}Brix and anthocyanins.

Table 4. Mean crop yields and production water use efficiencies for three irrigation zones (west, east and south) over four seasons (2005/06, 2006/07, 2007/08, 2008/09) where water was applied uniformly across the whole vineyard block and one season (2009/10) where water was applied differentially. Values followed by a different letter within a row are significantly different from the east (control) zone at the 0.05 probability level (adapted from McClymont et al. submitted).

Parameter	Season	West	East	South
Crop yield (kg/m^2)	2005/06	2.43b	3.60a	4.44a
	2006/07	0.86b	3.07a	4.09a
	2007/08	2.33b	4.32a	4.61a
	2008/09	2.62b	3.77a	4.5a
	2009/10	2.80a	2.96a	3.98a
Production water use efficiency (t/ML)	2005/06	4.40b	6.58a	8.11a
	2006/07	2.04b	7.57a	10.09a
	2007/08	4.04b	7.91a	8.44a
	2008/09	4.51b	6.95a	8.29a
	2009/10	4.75b	5.08b	7.81a

Case study 2 (Goodwin et al. 2009, Zerihun et al. 2010)
Until recently, it was not clear whether the utilisation of irrigation water varied spatially in accordance with vine performance or whether it was uniform throughout a block. This study demonstrates how vine vigour in a 6.8 ha drip-irrigated Shiraz block located in the Great Southern region of Western Australia, has a considerable influence on vine physiological processes and water use.

Figure 2 illustrates the relationship between vine vigour (expressed as PCD) and leaf photosynthesis and stomatal conductance. Stomatal conductance provides an integrated measure of the level of water stress experienced by a vine (Flexas et al. 2002). On average, leaf photosynthetic rates and stomatal conductance for the least vigorous vines were about 40% lower than those of the most vigorous vines. As expected, it was found that stomatal conductance increased after irrigation was applied. However, this was not accompanied by a corresponding increase in photosynthesis. This resulted in a lowering in WUE which was more apparent in low vigour vines than in high vigour vines.

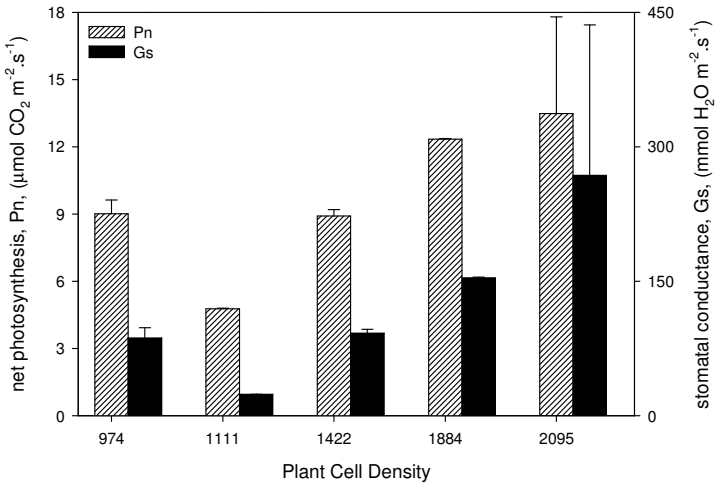


Figure 2. Relationship between vine vigour (expressed as plant cell density values determined from airborne imagery at 0.5 m resolution) and leaf photosynthesis (Pn) and stomatal conductance (Gs). Data shown are mean values with standard error bars (Zerihun et al. 2010).

Figure 3 shows the average daily soil moisture tension recorded at 0.25 m depth during the growing season for vines with contrasting vigour. The data shows that water use also varied with vine vigour, with the more vigorous vines fully utilising the applied irrigation water compared to the less vigorous vines where uptake was incomplete.

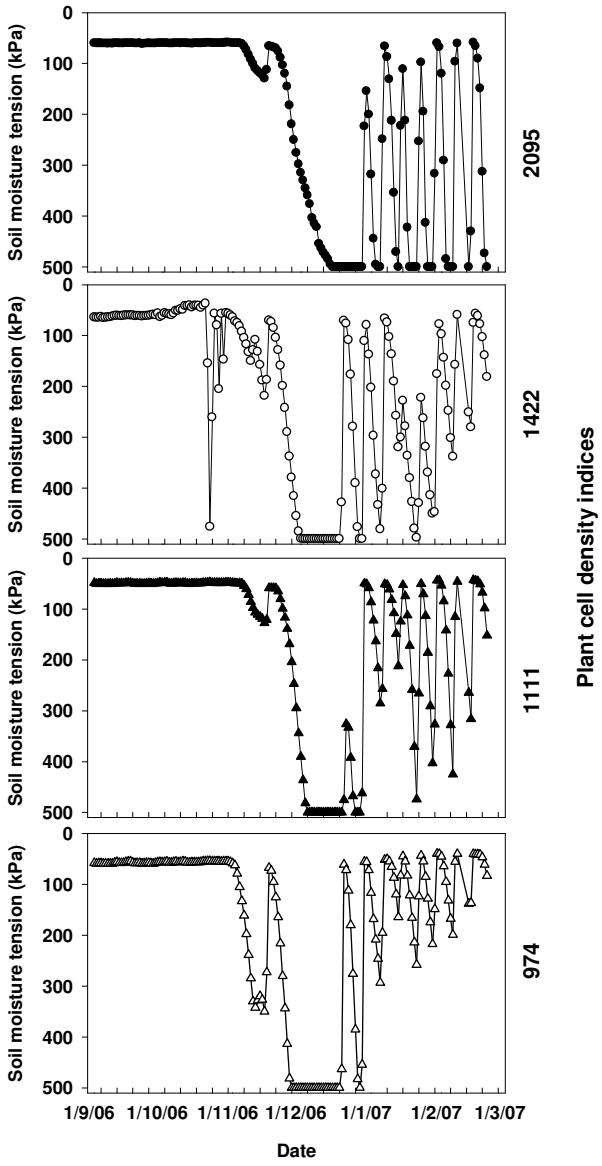


Figure 3. Average daily soil moisture tension recorded at 0.25 m depth from September 2006 to March 2007 at four locations within the vineyard corresponding to different values of plant cell density which is an index of vine vigour (Zerihun et al. 2010).

Crop yield was also found to be linearly correlated to the vine's capacity to utilise the applied water ($r = 0.995$, $p = 0.002$, $n = 4$). The dependence of crop yield on water availability and use indicates that to increase yield, a vine must be able to utilise all the available water. The fact that low vigour vines did not use all the irrigation water indicates that other factors must limit a vine's response.

One hypothesis is that this may be related to the death of fine roots in spring when the weaker vines were under severe water stress prior to the commencement of weekly irrigations. This suggests that severe water stress early in the season for weaker sections of a vineyard block must be avoided.

The outcome of these two case studies shows the importance of either applying irrigation differentially to minimise the under-utilisation of the limited water resource, or removing constraints to water utilisation in low vigour vines in order to improve the uniformity in WUEp. The uniform application of irrigation to a vineyard block with spatially variable vine vigour results in spatially variable vegetative growth and crop yield, as well as an inefficient use of water resulting in spatially variable WUEp. This is shown in Figure 4.

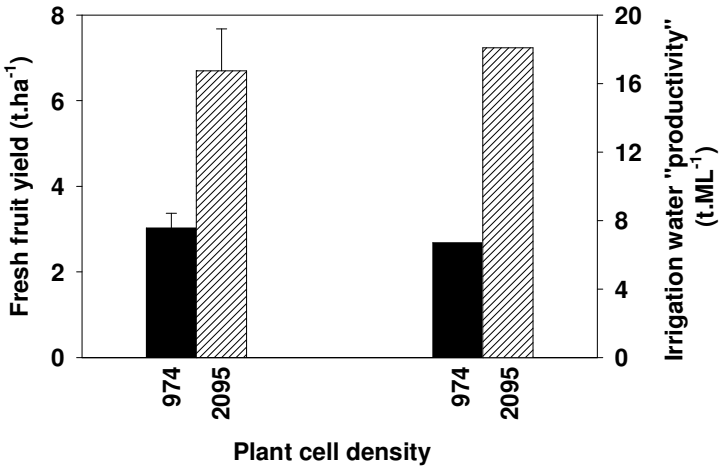


Figure 4. Mean crop yields and production water use efficiencies for low and high vigour vines as determined by plant cell density values (Zerihun et al. 2010).

Differential irrigation management seems to be a promising technique to improve WUEp through increased crop yield and/or lower irrigation volumes. However, it should be noted that these results are based on only one year of data and need to be followed up to see whether there are long-term gains. In addition, any management change will need to take into consideration the costs associated with modifying the irrigation system.

3. Optimising the acquisition of water

Vine performance and soil water uptake is dependent on the health and activity of the root system since roots must be able to reach reserves of water, air and nutrients both horizontally and vertically. McClymont et al. (2006) showed that under non-limiting water and nutrient conditions, vine growth and crop yield decreased as the available soil volume was reduced. This implies that root volume and/or distribution have a direct effect on vine performance.

Table 5 illustrates how soil type and root distribution influences the amount of readily available water (RAW) that is potentially accessible to a grapevine.

Table 5. Hypothetical combinations of soil type and root distributions showing their influence on the amount of stored soil water that is potentially available to the vines (assume 2 x 3 m vine x row spacing).

Soil type	Readily Available Water (mm/m) (-8 to -60 kPa)	Rooting dimensions (vine row x width x depth)	Readily Available Water (L/vine)	Readily Available Water (ML/ha)
Sand	37	Whole vineyard area (2m x 3m x 1.2m)	266	0.44
Sand	37	Restricted to vine row (2m x 1m x 1.2m)	89	0.15
Sandy Loam	64	Whole vineyard area (2m x 3m x 1m)	384	0.64
Sandy Loam	64	Restricted to vine row (2m x 1m x 1m)	128	0.21
Clay	57	Whole vineyard area (2m x 3m x 0.75m)	256	0.43
Clay	57	Restricted to vine row and limited depth (2m x 1m x 0.5m)	57	0.09

By restricting roots to the vine row in the sand and sandy loam examples, the volume of RAW, expressed on either per vine or per area basis, is reduced by about 33%. This situation occurs in many vineyards where soil compaction within the mid-row area prevents roots from growing laterally (Myburgh et al. 1996). In the clay soil example where root growth is restricted both horizontally and vertically, the volume of RAW is reduced by about 80%. Limited vertical root growth is again commonly found in vineyards (Myburgh et al. 1996).

A number of soil modification techniques are available to overcome restrictive root zones and reduce vine dependence on irrigation by improving water acquisition. Options include:

- ripping to overcome physical restrictions such as compaction layers and rock
- drainage to overcome anaerobic environments due to waterlogging
- mounding to increase the volume of soil for root development
- application of surface and sub-surface amendments such as lime to correct pH imbalances and gypsum to ameliorate soil structure by exchanging calcium for sodium
- application of surface mulches and composts to improve soil organic matter levels and reduce evaporative losses

Modifying the subsoil through ripping and the topsoil through mulching are techniques which have great potential in manipulating rooting depth and distribution. However, the responses to these techniques do not appear to be universal and nor are they predictable since seasonal weather conditions and soil properties have a significant role in determining soil water storage and vine performance. Goodwin et al. (2009) and Lanyon et al. (2010) found that vine response to ripping was more variable than mulching, with the response to mulch being greater and more immediate for lighter-textured soils than for heavier-textured soils.

4. Further management options to improve water use efficiency

The information provided above is aimed at maximising crop production and/or value through the strategic application of irrigation water. Further improvements in WUE can potentially be gained through other management practices which recognise the spatial heterogeneity of vineyards.

Production water use efficiency

Lanyon and Bramley (2006), Lanyon et al. (2010), and Panten and Bramley (2011) recognise that soil modification techniques have generally been applied across a range of soil types and recommend that such practices should be aligned to variations in soil characteristics to optimise their effect. Therefore, there is a need to know how responses to different modification techniques vary in relation to the spatial variability of the vineyard. The use of high resolution spatial data and geostatistical techniques provides a solution to this problem by enabling highly replicated designs in experiments to be conducted over whole vineyard blocks.

Using this approach, the effects of different management practices can be linked to soil properties over much larger areas than is possible using traditional experimental approaches.

Figure 5 provides an example of such an approach where the growing of ryegrass or a cereal/legume mix within the midrow is evaluated with either an application of mulch or compost under the vine rows (Panten and Bramley 2011). The results show how the implementation of a particular soil management practice may deliver yield (and potentially WUEp) benefits in some parts of the block while another practice may be more effective in other areas. In this case replacement of the existing ryegrass midrow sward with the cereal/legume-based alternative is only justified in terms of increasing productivity (number of bunches) in about half of the block. For each soil management treatment the amount of irrigation water applied via the drip irrigation system was the same, so differences in WUEp are likely to mirror the productivity benefits.

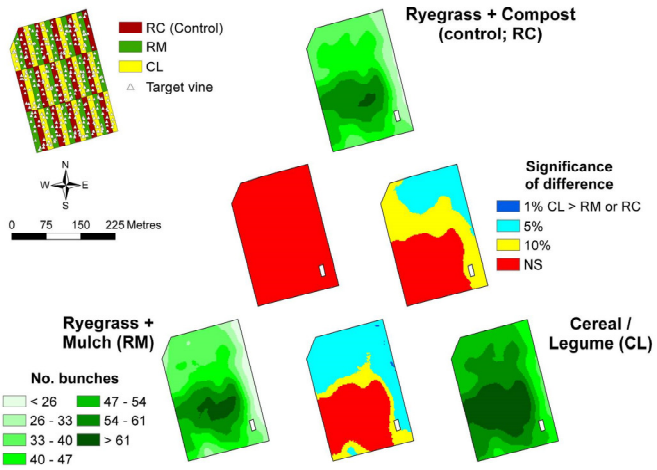


Figure 5. A whole-of-block experiment in which a replicated trial (top left) was applied over a 4.8 ha Merlot block in the Clare Valley (South Australia) to assess the merits or otherwise of various soil management practices (ryegrass and compost, ryegrass and mulch, and cereal/legume mix without mulch or compost undervine) on crop productivity. Vine responses are shown in terms of bunch number per metre of row. Significance of difference between each practice is shown in maps positioned between each soil management response map (Panten and Bramley 2011).

Value water use efficiency

Selective harvesting provides an opportunity to potentially increase the WUEv of vineyards through an increase in the price of fruit and/or wine as a consequence of providing separate parcels of fruit of uniform quality to the winery. Where the lack of water is limiting production, this strategy may be particularly beneficial in the context of risk management.

Several commercial examples exist that demonstrate an increased profitability using this differential harvesting approach (Bramley et al. 2005, Proffitt et al. 2006). Table 6 show the economic benefits for two case studies. The volume of irrigation water applied during the season is

unknown and hence values of WUEv cannot be calculated. However, given that irrigation management is known to have been uniform across the respective vineyard blocks, and assuming that the emitter output is also relatively uniform across each vineyard block, WUEv is likely to mirror the economic benefits.

Table 6. Examples of the economic benefits gained by separately harvesting parcels of fruit of uniform quality as opposed to harvesting the whole vineyard of mixed fruit quality. The benefits shown are gross values based on the harvesting of fruit from different zones of the vineyard on the same day. Increased economic benefits are sometimes realised by harvesting zones on different days (Bramley et al. 2005).

Region	**Variety**	**Estimated increase in gross retail value of grape production ($)**	**Estimated increase in gross retail value of wine production ($)**
Padthaway, SA	Shiraz	4,657 (+3.2%)	272,971 (+20.5%)
Margaret River, WA	Cabernet Sauvignon	2,508 (+5.5%)	139,480 (+19.2%)

5. Summary points

- With enhanced pressure on water resources, particularly in water-limited environments, the increasing demand for supplementary irrigation will only be met if the utilisation and acquisition of water by the vines is optimised. A key part of any production/risk management strategy revolves around the question of how best to use the available water resources.
- Improvements in the utilisation of water can be made through temporal changes in irrigation management. This can be achieved by avoiding both the over-irrigation of vines which results in water loss through drainage and evaporation, and the under-irrigation of vines at key phenological periods where severe water deficits can result in reduced crop yield and fruit quality.
- An understanding of vine water requirements on a spatial context is also essential to ensure that the correct amount of water is delivered to vines at the appropriate time. This can be achieved by tailoring irrigation to match vine water requirements since this will potentially increase WUEp and reduce the variability in fruit quality across a block of vines. In most cases, spatial improvements in irrigation management will require vineyard blocks to be divided into a number of irrigation zones so that areas with different water requirements can be managed separately. High resolution airborne imagery or intensive on-ground measurements can provide the spatial information that is required to enable the irrigation zones to be identified.
- Recent work has shown that vine vigour has a considerable influence of water utilisation. Weaker (ie. less vigorous and productive) vines must have access to sufficient water early in the season in order to effectively utilise soil water reserves. Monitoring vine and/or soil water status is therefore required throughout the whole growing season. However, applying the full allocation of water to weaker sections of a vineyard later in the season should be avoided since there is unlikely to be a response with respect to increased productivity. While such an action is likely to decrease WUEp, the lower yields could potentially be offset by an improvement in fruit quality and hence WUEv.
- The scheduling of irrigation water to ensure that the right amount is applied at the correct time needs to be supported using soil-based and/or climate-based tools. Soil-based devices must be

installed correctly and positioned in representative areas of the vineyard, which again requires knowledge of the spatial variability in soil characteristics and/or vine performance. Knowledge of the visual indicators of water stress provides an opportunity to quickly assess the water status of vines across a vineyard.

- The utilisation of water resources, and ultimately vine performance, relies on the vine's ability to access soil moisture via its root system. A number of soil modification techniques are available to overcome restrictive root zones in order to optimise the acquisition of water. Before remedial action is taken, it is critical that the cause of the problem is correctly identified. Subsoil ripping and/or mulching the topsoil are management practices that have proved beneficial in overcoming physical impediments to root growth and distribution. However, ripping has proved to be more variable in vine response than mulching, and the response to mulching has been greater and more immediate for lighter-textured soils than for heavier-textured soils.
- The differential harvesting of vines (ie. selective harvesting) provides a further opportunity to increase the WUEv of vineyard blocks provided that there is an increase in the price of fruit and/or wine as a consequence of providing separate parcels of fruit to the winery.
- In water-limited conditions, the production/risk management strategy should consider the option of sacrificing yield with a view to improving fruit quality, provided that the opportunity exists to receive a greater price per tonne of fruit or to produce a wine that commands a greater retail price.

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Adoptable Outcome 8. Optimising the utilisation and acquisition of water resources in irrigated vineyards under water-limiting conditions

Authors: Tony Proffitt and Mark Gibberd

Optimising Industry Returns for Existing Soil and Water Research

Optimising the utilisation and acquisition of water resources in irrigated vineyards under water-limiting conditions

Presenter(s)

1. Introduction

Water resources

- About 87% of Australian wine production comes from regions which rely wholly or partly on irrigation water
- Full allocations / reserves allows growers to apply sufficient water to replace water lost by crop (ET) and to leach salts from soil

Water has been limited (0-70% allocations / reserves) in recent years
- Irrigation has had to based on risk minimisation strategies

1. Introduction

Water resources

- Security of water supply has been challenged during the past decade
  - Industry expansion
  - Drought
  - Increased competition from other users
  - Regulation (eg. licensing, reduction in entitlements in MDB)

1. Introduction

Climate change

- Wine grape production is sensitive to changes in seasonal climatic conditions and increased variability
- Changes are already occurring
  - Reduction in total amount of rain and its distribution
  - Increase in evaporative demand
  - Increase in frequency of periods of high temperature

Such changes put further pressure on water resources and its utilisation both now and in the future

1. Introduction

Water stress effects on the vine

- Limiting the amount of water applied compromises crop yield and may impact of fruit quality (positively or negatively)
  - Depends on time and severity of stress
- Severe and prolonged water stress can adversely affect physiological processes (eg. stomatal conductance, transpiration, photosynthesis)

1. Introduction

Soils and rooting distribution

- Wine grape production generally requires less irrigation than many other horticultural crops
  - Deep / extensive root systems that efficiently extract water
  - Method of water delivery is generally efficient in relation to evaporation losses
- Many soils have characteristics which potentially restrict both volume and distribution of vine roots
  - Results in inefficient utilisation of water and nutrients from mid-row and / or vine row
  - Negative impact on water use efficiency (WUE) and long-term sustainability of vineyard

2. Optimising the utilisation of water

Water use efficiency (WUE)

- In environments with limited (and diminishing) water resources, maximising returns (crop yield and fruit quality) and WUE is critical
  - Irrigation moves from a yield / growth strategy to a risk management strategy

2. Optimising the utilisation of water

Water use efficiency (WUE)

- Production WUEp
  - Amount of crop produced per unit of water applied (irrigation / rainfall)
  - Efficiency by which water reaches vines and how vines access / transpire water in fixing carbon
  - Various sources of variation in WUEp – this material focuses on solutions to optimise WUEp by focusing on ways water is managed and applied to vines
- Value WUEv
  - Monetary value of fruit / wine per unit of water applied
  - Reduction in productivity due to under-irrigation could be offset by a potential improvement in fruit / wine quality

2. Optimising the utilisation of water

Vine water requirements

- When does the vine require water?
  - Avoid over-irrigation (wastage)
  - Avoid under-irrigation (compromised crop yield)
    Amount required depends on:
    - climatic conditions
    - variety / rootstock combinations
    - soil type and depth
    - crop load

2. Optimising the utilisation of water

Guide to vine water requirements for key phenological growth periods

Growth period	Vine water requirements
Budburst to flowering	Critical for root growth and establishing canopy size and potential yield. Irrigation applied too early will be wasted and not used. In many regions, winter / spring rainfall ensures an adequate supply of water for all or most of this period. Under drought conditions, irrigation may need to be applied. Water stress is likely to result in reduced shoot growth and leaf size.
Flowering to fruit set	Flowering and fruit set are sensitive to water stress as cell division is a critical development stage. It is a period when shoot growth is rapid. Apply irrigation prior to flowering if soil water content is low.
Fruit set to veraison	Amount of irrigation required depends on soil water content and desired fruit quality. Consider implementing irrigation techniques such as RDI and PRD to impose water stress to control shoot growth and berry size (can have positive effects on fruit quality). Generally not imposed on white varieties.

2. Optimising the utilisation of water

Guide to vine water requirements for key phenological growth periods

Growth period	Vine water requirements
Veraison to harvest	Poor leaf function could delay accumulation of sugar and adversely affect development / balance of flavour components in berries. Once berries have reached full maturity, water deficits are less harmful so irrigation volumes can be reduced. Severe water deficits should be avoided.
Post-harvest	Ideally, vines need to accumulate sufficient carbohydrate reserves for the next season before going into dormancy. If water is available, irrigation will benefit vines by ensuring that conditions are suitable for root growth and leaf function.

2. Optimising the utilisation of water

- Visual indicators of vine water stress

NO WATER STRESS

Shoots

- Shoot growth is active.
- Growing tip is not enclosed when last formed leaves are pushed towards the growing tip.
- Tendrils are turgid.
- Top tendrils reach past the growing tip.
- All leaves are green and healthy.
- Leaf blades are orientated to the sun.
- Exposed and shaded leaves feel cool to touch with palm of the hand.

Berries

- Berries are turgid.

Soil

- Soil water content is within the Readily Available Water range.
- Soil can be easily moulded into a ball; moisture can be seen and felt in the hand.

2. Optimising the utilisation of water

MILD WATER STRESS

Shoots

- Shoot growth is slowing or has ceased.
- Growing tip is not enclosed when last formed leave are pushed towards the growing tip.
- Tendrils are turgid.
- All or majority of leaves are green and healthy.
- Leaf blades are orientated to the sun.
- Exposed and shaded leaves feel cool / warm to touch with palm of the hand.

Berries

- Berries are turgid.

Soil

- Soil water content is at or approaching bottom of Readily Available Water range.
- Soil is difficult to bind together and mould into a ball without adding some water.

2. Optimising the utilisation of water

SEVERE WATER STRESS

Shoots

- Shoot growth has ceased.
- Growing tip is enclosed when last formed leaves are pushed towards the growing tip.
- Shoot tips are dull-grey and may be dry and / or missing
- Middle to upper leaves are green and basal leaves are yellow/pale green
- Leaves wilting and leaf blades have altered position to reduce direct radiation interception.
- Leaves are folded with their backs orientated to the sun.
- Exposed and shaded leaves feel warm to touch with palm of the hand.
- Basal tendrils are drooping.
- Late in the season, exposed basal leaves are yellow and may have necrotic edges.
- Basal leaves may have senesced and fallen.

Berries

- Berries start to become flaccid and begin to shrivel.

Soil

- Soil water content is approaching middle or bottom of the Deficit Available Water range.
- Soil is either hard or loose; water is required before it can be moulded into a ball.

2. Optimising the utilisation of water

EXTREME WATER STRESS

Shoots

- Shoot growth has ceased.
- Growing tip is enclosed when last formed leaves are pushed towards the growing tip.
- Shoot tips are dull-grey and may be dry and / or missing.
- Most leaves are yellow or pale green.
- Leaves wilting and leaf blades have altered position to reduce direct radiation interception.
- Leaves are folded with their backs orientated to the sun.
- Exposed and shaded leaves feel warm / hot to touch with palm of the hand.
- Basal tendrils are drooping or dead.
- Late in the season, exposed basal leaves are yellow with necrotic edges.
- Some leaves are scorched and / or basal leaves have senesced and fallen.

Berries

- Berries are flaccid; some are shriveled and/or raisined.

Soil

- Soil water content is below the Deficit Available Water range.
- Soil is either hard or loose; difficult to wet up and/or mould into a ball when water is added.

2. Optimising the utilisation of water

Vine water requirements

- How much and when should water be applied?
  A measure of vine water status is required
  - Plant-based measures
  - Soil-based measures
  - Climate-based measures

2. Optimising the utilisation of water

Vine water requirements

- Plant-based measures
  (generally not used commercially at present)
  - Water potential (eg. pressure chamber)
  - Stomatal conductance (eg. porometer)
  - Sap flow
  - Leaf temperature
  - Trunk diameter

2. Optimising the utilisation of water

Vine water requirements

- Soil-based measures
  - Soil water suction
  - Volumetric soil water content

Range of commercially available devices / software

- Gypsum blocks (suction)
- Theta probe (volumetric)
- Enviroscan / C-Probe (volumetric)
- Diviner (volumetric)
- Reflectometer (volumetric)

2. Optimising the utilisation of water

Installation / positioning of soil-based instruments is critical

- 1 site / soil type (minimum)
- Greater the soil variability, greater the number of sites required
- 3 or more measuring depths / site
- 1 measurement depth close to surface within rootzone (eg. 20-30 cm)
- Other measurement depths should be deeper (eg. 50-60 cm and at base of rootzone)

2. Optimising the utilisation of water

Vine water requirements

- Climate-based measures
  - Pan evaporation (Epan) and crop factors (CF)
    Vineyard water use (mm) = Epan x CF
    (not the preferred method when canopy cover is incomplete)
  - Evapotranspiration (ETo) and crop coefficients (Kc)
    Vineyard water use (ETc) (mm) = ETo x Kc

    BOM provides recent ETo values on its website
    CSIRO provides recent and forecast ETo values via irriGATEWAY website

2. Optimising the utilisation of water

Spatial variability and the effect of WUE

- Where should the water be applied?
  - Land is variable and vine performance (canopy growth, crop yield, berry composition) has been shown to have a spatial structure (eg. 10-fold variation in yield under uniform management)
  - Digital multi-spectral imagery (DMSI) used to identify 'zones' of relative difference in canopy characteristics / vine performance
  - This provides an opportunity to move from a 'uniform' approach to irrigation scheduling to a 'differential' approach of applying water

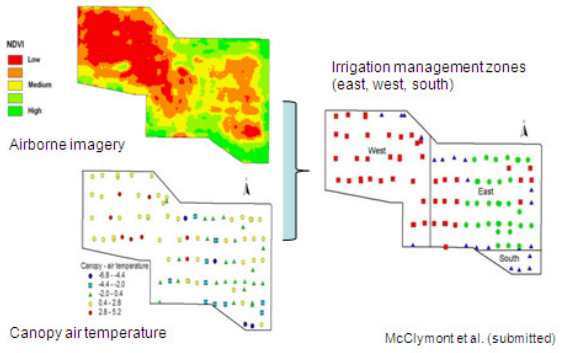
2. Optimising the utilisation of water

Case study 1 (Goodwin et al. 2009, McClymont et al, submitted)

Differential application of limited water supplies:
- Increased productivity and WUEp of low yielding areas
- Reduced variability in yield and fruit composition

- 6.4 ha Shiraz block
- Sunraysia, Victoria
- Irrigated uniformly (drip) from 1994
- Airborne imagery (measured as NDVI), canopy temperature and irrigation system used to delineate 'zones' of contrasting vine performance
- Sub-main within block allowed differential irrigation. In 2009, in-line taps were installed to create the south zone.

2. Optimising the utilisation of water



McClymont et al. (submitted)

2. Optimising the utilisation of water

Under uniform irrigation:

- West zone – low vigour, low yield, water stress symptoms
- East zone – moderate vigour, moderate crop and fruit quality
- South zone – high vigour, high crop yield, poor fruit quality

Under differential irrigation:
(changes relative to East zone, 2009/10 season)
- West zone – increase in productivity and WUE
- South zone – increase in WUE
- Greater uniformity in berry pH and TA but not in °Brix and anthocyanins

2. Optimising the utilisation of water

Parameter	Season	West	East	South
Crop yield (kg/m²)	2005/06	2.43b	3.60a	4.44a
	2006/07	0.86b	3.07a	4.09a
	2007/08	2.33b	4.32a	4.61a
	2008/09	2.62b	3.77a	4.5a
	2009/10	2.80a	2.96a	3.98a
Production water use efficiency (t/ML)	2005/06	4.40b	6.58a	8.11a
	2006/07	2.04b	7.57a	10.09a
	2007/08	4.04b	7.91a	8.44a
	2008/09	4.51b	6.95a	8.29a
	2009/10	4.75b	5.08b	7.81a

Values with same letter within row = significant difference at $p = 0.05$

McClymont et al. (submitted)

Seasons 2005/06 and 2006/07: Water applied uniformly

Season 2009/10: Water applied differentially

2. Optimising the utilisation of water

Case study 2 (Zerihun et al. 2010)

Vine vigour had a considerable influence on vine physiological processes and water use

- 6.8 ha Shiraz block,
- Great Southern, Western Australia
- Airborne imagery used to identify vines with different canopy size and health (measured as PCD)



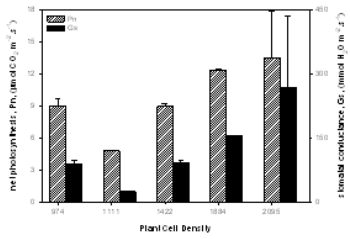
High vigour vine (high PCD)



Low vigour vine (low PCD)

2. Optimising the utilisation of water

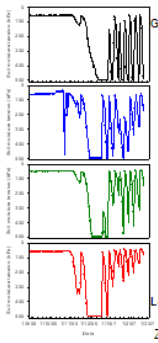
Leaf photosynthesis and stomatal conductance in relation to vine vigour (PCD)



Leaf photosynthetic rate and stomatal conductance for the least vigorous vines were 40% lower than those of more vigorous vines

Zerihun et al. (2010)

2. Optimising the utilisation of water



Average daily soil moisture tension at 25 cm depth

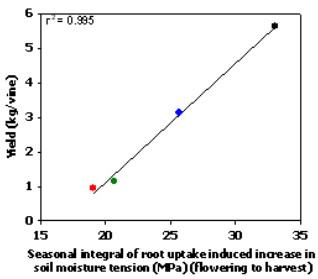
- Water use varied with vine vigour
- Applied water was fully utilised by the vigorous vines
- Water uptake was incomplete for less vigorous vines – Why?

  Could be related to death of fine roots in spring when weaker vines were water stressed before irrigation commenced

Zerihun et al. (2010)

2. Optimising the utilisation of water

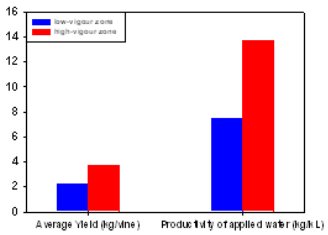
Crop yield was linearly correlated to vine's capacity to utilise the applied water



To increase yield, vines must be able to utilise all the available water

Zerihun et al. (2010)

2. Optimising the utilisation of water



The uniform application of irrigation to a spatially variable vineyard results in spatially variable vegetative growth and crop yield and inefficient use of water → spatially variable WUEp

Zerihun et al. (2010)

3. Optimising the acquisition of water

Soil type and root distribution influence the amount of readily available water (RAW) that is potentially accessible to vines

Soil type	Readily Available Water (mm/m) (-8 to -80 kPa)	Rooting dimensions (vine row x width x depth)	Readily Available Water (L/vine)	Readily Available Water (ML/ha)
Sand	37	Whole vineyard area (2m x 3m x 1.2m)	266	0.44
Sand	37	Restricted to vine row (2m x 1m x 1.2m)	89	0.15
Sandy Loam	64	Whole vineyard area (2m x 3m x 1m)	384	0.64
Sandy Loam	64	Restricted to vine row (2m x 1m x 1m)	128	0.21
Clay	57	Whole vineyard area (2m x 3m x 0.75m)	256	0.43
Clay	57	Restricted to vine row and limited depth (2m x 1m x 0.5m)	57	0.09

3. Optimising the acquisition of water

Soil modification techniques

Used to overcome restrictive root zones – reduces vine dependence on irrigation by improving water acquisition

- Ripping to overcome physical restrictions
- Drainage to overcome anaerobic environments
- Mounding to increase soil volume
- Use of surface / sub-surface amendments to correct pH and improve structure
- Use of mulches / composts to improve organic matter levels and reduce evaporative losses

4. Further management options to improve WUE

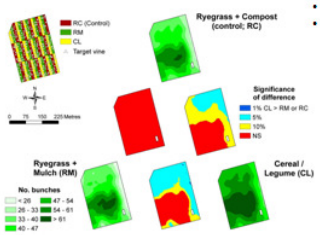
Improvements in WUE can be achieved through other management practices which recognise vineyard heterogeneity

Example 1: Soil management and WUEp

- Applying a single soil modification technique across a range of soil types with varying characteristics is unlikely to deliver optimal benefits
- Matching soil modification technique to the soil limiting factor increases chance of delivering maximum yield (and potentially WUEp) benefits

4. Further management options to improve WUE

4.8 ha Merlot block, Clare Valley, South Australia (Panten and Bramley 2011)



Soil management practice:

- Ryegrass + compost undervine
- Ryegrass + mulch undervine
- Cereal / legume + bare undervine

Outcome:

Replacement of midrow ryegrass with cereal / legume alternative increased productivity (bunch no.) in only half the block

4. Further management options to improve WUE

Improvements in WUE can be achieved through other management practices which recognise vineyard heterogeneity

Example 2: Harvesting and WUEv

- Differential harvesting is an opportunity to provide wineries with separate parcels of fruit of uniform quality
- Potential increase in WUEv through an increase in price of fruit and / or wine

4. Further management options to improve WUE

Economic benefits of differential harvesting for two case studies:

Gross values: harvesting fruit from different zones of vineyard on same day (Bramley et al. 2005)

Region	Variety	Estimated increase in gross retail value of grape production ($)	Estimated increase in gross retail value of wine production ($)
Padthaway, SA	Shiraz	4,657 (+3.2%)	272,971 (+20.5%)
Margaret River, WA	Cabernet Sauvignon	2,508 (+5.5%)	139,480 (+19.2%)

WUEv can be assumed to be similar to economic benefits as irrigation management was the same across the vineyards and emitter outputs were relatively uniform

5. Summary points

- A key part of the production / risk management strategy concerns the question of how best to use the available water
  - Avoid over-irrigating (water loss through drainage and evaporation)
  - Avoid under-irrigating at key phenological periods (reduced crop yield and fruit quality)
- Understand vine water requirements on a spatial context
  - Tailor irrigation to match vine water requirements by dividing blocks into management zones based on airborne imagery or on-ground measurements
  - Capital expenditure required to modify irrigation system to support this change
- Vine vigour has a considerable influence on water utilisation
  - Early season - weaker vines must have access to sufficient water
  - Late season – weaker vines do not require full water allocation (wastage)
  - Monitoring vine and / or soil water status is required throughout the season

5. Summary points

- To ensure that the right amount of water is applied at the correct time, use soil-based or climate-based tools as well as visual indicators
  - Locate / install soil monitoring devices accurately
  - Use visual indicators of water stress to quickly assess vine water status
- A range of soil modification techniques are available to improve vine access to water in order to increase WUEp
  - Nature of root zone restrictions needs to be identified before action is taken
  - Due to spatial variation in soil properties, it is unlikely that a single remedial action will be appropriate across the whole vineyard
- The differential harvesting of vines provides a further opportunity to increase WUEv
  - Implement only if there is an opportunity to increase value of fruit and / or wine

5. Summary points

- The production / risk management strategy should consider the option of sacrificing yield in order to improve fruit quality providing that a greater grape and / or wine price can be achieved
- Under extreme cases of water shortage, minimising the risk of loss in crop and / or wine value could be more important than a loss in productivity
  - Allocate water to blocks from which greatest monetary value will be gained

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