Water Management for Wine Grapes
In a Drying Environment

The Water Recycling Efficiency branch of the Department of Water (DoW) and the Grape Wine Research Development Corporations (GWRDC) regional's program have funded the development and production of this information booklet.

Components of these two program have been linked together to ensure wine producers in WA have the appropriate information available to efficiently and effectively manage vineyard irrigation. In WA, the Wine Industry Association of Western Australia (WIAWA) are responsible for delivering the GWRDC regional's program, and Perth Region NRM are responsible for delivering on the DoW Water efficiency in wine and table grape production in the Swan Valley project.

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gwrdc GRAPE AND WINE RESEARCH AND DEVELOPMENT CORPORATION

WINE INDUSTRY ASSOCIATION WESTERN AUSTRALIA

AHA viticulture

Contents

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Climate change and water shortages close to urban areas are real threats and are concerns in communities across the country, including the Swan Valley and the wine producing regions in the South West of Western Australia. The greater demand for water through urban use and irrigators has necessitated increased management and regulation of water resources by the Western Australian Department of Water.

Model simulations indicate that climatic conditions are currently changing and will continue to change, resulting in higher average temperatures, reduced rainfall and runoff and greater seasonal variability. While climate change has 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.

1. WATER RESOURCE MANAGEMENT STRATEGIES

Irrigation is required to provide water to meet the crop growth and *evapotranspiration* (ET) requirements of the vine when there is insufficient water from rainfall or existing soil moisture. Water is also an important input during the winemaking process. A range of practices are used in the vineyard to conserve and manage water resources efficiently and sustainably. They can be grouped under the following topics:

- Improving the security of the water supply
- Reducing water loss from the source of water
- Maximising water use efficiency
- Improving management practices in the vineyard
- Improving site, variety and rootstock selection

This information booklet focuses mainly on ‘maximising water use efficiency’ through irrigation techniques, with an emphasis on drip irrigation as this is an efficient system and is widely used. However, many of the principles discussed also apply to undervine sprinkler systems. For information about the other topics listed above, a useful reference is Proffitt and Ward (2009) which provides references on each topic for further reading.

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2. Soil factors which influence irrigation management

An understanding of the soil and how it changes across the vineyard is critical in the management of irrigation water and for the type and design of irrigation system that should be operating.

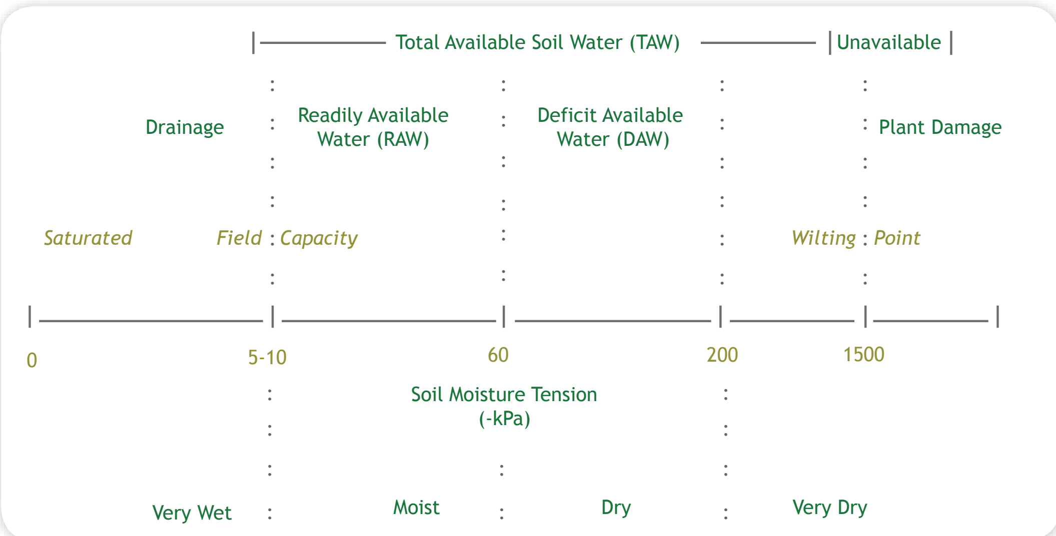
2.1 The concept of soil water holding capacity

The soil acts as a reservoir for water that will feed the vine during the growing season. Water is held in the soil as films around soil particles and within soil pores (spaces). When all the pores are full of water and air has been removed, the soil is *saturated*. Under the influence of gravity, some water then moves out of this reservoir. This can take place within a few hours or up to two days in a well-structured soil, at which point the soil has reached an equilibrium known as *field capacity* (or FC). The suction in the soil corresponding to FC is about 5-10 kPa (kilo Pascals).

The water content of the soil decreases as roots extract moisture, and if this moisture is not replenished through rain or irrigation, a point is reached when vine leaves start to wilt and suffer permanent tissue damage. This point is known as the *wilting point* (WP) and will vary with grapevine variety, rootstock and soil type. The suction of the soil corresponding to WP is about 1500 kPa.

The *total available water* (TAW) is the difference in soil water content between FC and WP. From experience, grape growers have found that the water held in the soil between about 5-10 and 60 kPa is easily extracted by the vine and is therefore known as the *readily available water* (RAW). Water that is held between 60 and about 200 kPa is less easily extracted by the vine and is known as the *deficit available water* (DAW). A diagram showing this concept is shown in Figure 1.

Figure 1: Relationships between available soil water and soil water tension (Goodwin 1995).



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If a vine is within the DAW range it is likely to experience some degree of water stress. Although vines can still extract some water within the DAW range, the rate of moisture supply is not fast enough for them to function optimally. The suction at which this stress is imposed changes with soil texture and is about 100 kPa for sandy soils, 200 kPa for loams/clay loams, and 400 kPa for clay soils.

Vines less than three years old should not be subjected to suctions greater than 60 kPa since they should be kept well-watered and not undergo any stress in order to maximise growth.

2.2 Soil type

In order to calculate the irrigation requirements for a vineyard, it is important to understand how much soil water is readily available to the vine. To estimate RAW values it is necessary to determine the depth and texture of each soil layer and the maximum depth that vine roots can explore. Figure 2 shows the amount of soil water (mm of water per cm depth of soil) stored between field capacity (-8 kPa) and a range of soil moisture tensions for different soil textures. Note that when the word *tension* is used the kPa units are negative. When the word *suction* is used, the kPa units are positive.

Texture	Soil moisture tension (kPa)				
	-8 to -40	-8 to -60	-8 to -200	-8 to -400	-8 to -1500[1]
Sand (S)	0.36	0.37	0.46	0.49	0.62
Loamy sand (LS)	0.52	0.55	0.65	0.70	0.86
Clayey sand[2] (CS)	0.55	0.60	0.74	0.80	1.01
Sandy loam (SL)	0.59	0.64	0.84	0.92	1.15
Light sandy clay loam (LSCL)	0.65	0.74	1.03	1.11	1.37
Loam (L)	0.69	0.84	1.00	1.11	2.34
Sandy clay loam (SCL)	0.61	0.71	1.01	1.13	1.43
Clay loam (CL)	0.53	0.65	1.03	1.16	1.48
Clay (C)	0.46	0.57	0.90	1.09	1.49
Heavy clay (HC)	0.25	0.41	0.49	0.59	1.20

Figure 2: Volumes of water that soils with different textures can hold between field capacity and other soil moisture tensions. (Nicholas and Wetherby 2004).

Figure 3 shows an example of how to calculate RAW values for a sandy loam over sandy clay loam soil. The RAW value for each soil layer is calculated by multiplying the thickness of the layer by the -8 and -60 kPa texture factor shown in Figure 2. RAW values for each layer within the rootzone are added together to give the total RAW.

Thickness of layer	mm/cm	Calculation	RAW (mm)
30cm	0.64	30 x 0.64	19.2
50cm	0.71	50 x 0.71	35.5
Total rootzone RAW			54.7

Figure 3: Readily available water (RAW) for a 30 cm deep sandy loam over a 50 cm deep sandy clay loam soil (Nicholas and Wetherby 2004).

Sandy soils have many large pores and very little clay resulting in small RAW values. Water applied by drip irrigation tends to move vertically rather than horizontally in these soil types due to gravity pulling the water through the large pores. In comparison, clay soils have many small pores and therefore have higher RAW values. In these soils there is a greater horizontal movement of water. Vines growing in soils with different physical characteristics (referred to as soil types) may therefore be using the same amount of water for growth but will have access to different amounts of water. The amount of water applied at each irrigation event and the frequency that they are applied will therefore depend on the soil type and the rooting depth of the vine.

2.3 Soil Variability

Variation in soil types and topography across the vineyard can have a large impact on how vines perform. For example, a variation in soil depth and/or texture will have a large effect on vine growth and how much irrigation water needs to be applied. It is therefore important to have a good knowledge about the distribution of soil types across the vineyard. This can be done by looking at changes in vine characteristics and digging holes/pits (e.g. as shown in Photo 1) where there are marked changes. In new vineyard developments it is recommended that a soil survey is done before vines are planted and irrigation systems designed so that accurate boundaries showing changes in soil types can be mapped.

Photo 1: Typical gravel soil profile

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3. Managing vine growth, yield and fruit quality with irrigation

The Department of Agriculture and Food, Western Australia have developed a calculator to help growers determine irrigation water requirements for different regions.
http://www.agric.wa.gov.au/PC_92510.html?s=550803914

3.1 Growth stages

In order to understand how to manage vines with irrigation water it is important to understand the annual growth cycle of the vine and its annual water requirements. The amount of water required at different stages of grapevine growth will depend on the variety, rootstock: scion interaction, climate, soil type and depth, and crop load. The main growth stages are:

- Stage 1: budburst to flowering
- Stage 2: flowering to fruit set
- Stage 3: fruit set to veraison
- Stage 4: veraison to harvest
- Stage 5: harvest to leaf-fall

Stage 1: Budburst to flowering

Photo 2: Vines between budburst and flowering

This growth stage (Photo 2) uses about 9% of the annual water requirements. Although this period of growth is critical for root growth and for establishing canopy size and potential yield, irrigations that are applied too soon will be wasted and not used by the vine. Soil moisture monitoring should commence two weeks before anticipated budburst as this will provide sufficient time to fill the soil profile if winter/spring rain has been insufficient. Vines will begin to flower once the leaf canopy is fully developed towards early to mid November. Water use at this time is moderate and water stress should be avoided as this can result in poor set and aborted fruit (i.e. loss of yield) and reduced shoot growth and leaf size. Generally water stress does not occur during this period in the Swan Valley and south west regions and irrigation is therefore not required.

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Stage 2: Flowering to fruit set

This growth stage (Photo 3) uses about 6% of the annual water requirements. Flowering and berry set are very sensitive to water stress as cell division is involved. It is a period when shoot growth is rapid and as a precaution, irrigation water should be applied prior to flowering if soil water levels are low.

Photo 3: Vines at flowering

Stage 3: Fruit set to veraison

This growth stage (Photo 4) uses about 35% of the annual water requirements. This is the time when irrigation techniques such as regulated deficit irrigation and partial rootzone drying (see section below) can be used to impose water stress to control shoot vigour and berry size, both of which can have positive effects on fruit quality.

Photo 4: Onset of verasion

Stage 4: Veraison to harvest

This growth stage (Photo 5) uses about 36% of the annual water requirements. Sugars accumulate in the berries during this period so it is important to maintain healthy leaf function. Severe water deficits should be avoided in order to maintain leaf health and function. If leaves begin to die then the rate of berry ripening can slow down with a potential loss of acid and fruit flavour intensity. Once berries have reached full maturity, water deficits are less harmful to production so irrigation volumes can be reduced. Excessive irrigation may increase lateral leaves to grow which is not desirable since this will increase berry shading and splitting.

Photo 5: Vines with fruit close to being harvested

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Stage 5: Harvest to leaf fall

Where water remains available, the post-harvest period uses about 14% of the annual water requirements. Irrigation is usually required to maximise root growth and to ensure that leaf function is maintained so that the vine is able to accumulate sufficient carbohydrate reserves for the next season before going into dormancy (Photo 6). Excessive amounts of water can lead to re-growth of shoots which is not desirable.

Note: The figures (%) used for annual water requirements are based on figures from the Riverland region of South Australia. While they may not be accurate for Western Australia, the relative difference in water use between each growth stage is relevant.

Photo 6: Vines after mechanical harvesting

4. Relationship between yield and water

The effect of irrigation on yield is not a linear relationship as shown in Figure 4. There is an irrigation threshold where the vine reaches its maximum productivity (i.e. the maximum yield is achieved). Any irrigation applied above this level is wasted water (lost to drainage and evaporation) and can lead to excessive canopy growth, nutrient leaching, pest and disease problems and poor fruit quality.

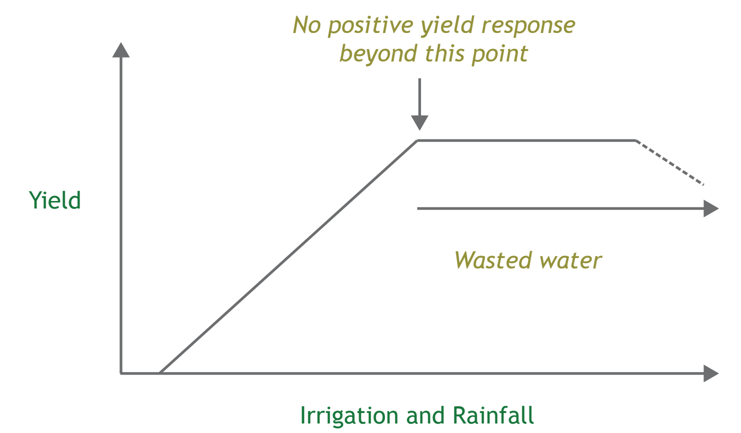

Figure 4: Theoretical relationship between irrigation and rainfall on yield (Chalmers 2009).

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4.1 Vine characteristics

When soil water is within the RAW range, vines are considered to be well-watered and have actively growing shoot tips and shoots with normal internode length. If there is too much water in the soil after stage 2, excess vigour may result. Vines in this condition are often 'out of balance' (ie. there is too much vegetative growth relative to the amount of crop being produced). Under moderate water stress conditions towards the bottom of the DAW range, shoot growth will slow down, and during the hottest part of the day, shoot tips may droop and leaves are likely to be warm to touch with the palm of the hand.

4.2 Maximising water use efficiency in vineyards

Conserving and utilising water as efficiently as possible is very important in irrigated vineyards. Water use efficiency (WUE) can be calculated either on a production or crop value basis. *Production water use efficiency* (PWUE) determines how efficiently water is used for the amount of fruit produced and is calculated using the following equation:

PWUE (tonnes/ML) = fruit yield (tonnes/ha) / (rainfall in mm/100 + irrigation water in ML/ha).

Value Water Use Efficiency (VWUE) determines how efficiently water is used for the monetary value of the fruit produced and is calculated using the following equation:

VWUE ($/ML) = fruit value ($/ha) / (rainfall in mm/100 + irrigation water in ML/ha).

4.3 Irrigation scheduling

Irrigation scheduling is one of the most common techniques for improving WUE. Several irrigation practices have been developed which form the basis of how much irrigation water to apply and when to apply it (i.e. irrigation interval). Such practices include *regulated deficit irrigation* (RDI) (Goodwin 1995) and *partial root zone drying* (PRD) (Dry and Loveys 1998).

4.4 Regulated Deficit Irrigation

The implementation of RDI involves restricting water supply to the vine for a period of time during the growing season. The most common period to implement RDI is during stage 3 (after fruit set). During this period, the vine utilises the RAW and some DAW, and gradually reduces the soil water content to a certain 'deficit' level (known as the *refill point*). Often a soil suction of more than 200 kPa is required to reduce berry size. When this refill point is reached, short irrigations are then required to maintain the soil

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water content at or near this level. After the RDI period has come to an end, irrigation should be applied to return the soil water content to within the RAW range (Figure 1).

RDI should be used for established vines only and for red varieties in particular. Five steps are required when implementing an RDI irrigation plan:

- Withhold irrigation as stage 3 approaches in order to dry out the soil profile.
- Apply short (shallow) irrigations after the refill point has been reached so that only part of the root zone is wet.
- Measure soil moisture regularly to ensure that the timing of irrigation is correct.
- Monitor vine performance visually during each growth stage and in particular during stage 3.
- Keep records including rainfall, irrigation, evaporation, and soil moisture data as well as vine measures such as canopy size and shoot length, and crop yield (including bunch weights and berry size).

4.5 Partial Rootzone Drying

PRD is a relatively new irrigation scheduling practice which relies on the alternate wetting and drying of different parts of the vine root zone during the growing season. The most common method of implementing PRD is by the installation of a second drip line adjacent to the existing line.

The biggest limitation to implementing RDI and PRD is the amount of water in the soil at the start of the season since this makes it difficult to apply a moisture stress at the correct time. This is more of a problem in regions further south than in the Swan Valley. However, under a drier climate with less rainfall such techniques may become better options for improving WUE. For further information on these irrigation scheduling techniques, refer to Campbell-Clause and Fisher (1999).

4.6 Evaporation losses

Evaporation losses from the soil and from storage dams are considerable. The following practices are recommended to reduce these losses:

- Irrigate at night (losses can be reduced by 10%).
- Apply mulch under vine (losses can be reduced by 10-30% when using above-ground drip irrigation systems).
- Apply protective films to storage dams and/or establish windbreaks close by (losses can be reduced by 20-30%).

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4.7 Sub-surface irrigation

Sub-surface drip irrigation systems can improve the WUE by reducing water loss through soil evaporation and run-off. However, there are issues with such systems including termites, root intrusion, reduced flow due to line compression as a result of compaction, salinity accumulation near the soil surface and soil degradation. Further work is therefore required before such systems can be promoted to grape growers.

4.8 Monitoring soil water content

In order to know how much water to apply and when, it is important to regularly measure how much water is stored in the soil. There are a range of commercially-available sensors that make this possible (Photo 7). Most of these measure changes in either soil moisture suction or volumetric soil water content, with data being collected either manually at set times or automatically at regular intervals.

Suction is measured using tensiometers and/or gypsum blocks. Tensiometers are generally the preferred sensing equipment to use for young vines where the soil suction should be maintained at or below 60 kPa.

Photo 7a: Gypsum block

Photo 7b: Tensiometer

The trigger to start irrigation for mature vines is generally set between 60 and 200-400 kPa depending on the soil texture and the degree of stress to be imposed. Gypsum blocks (or electrical resistance blocks) work more efficiently at this suction range and are therefore the preferred sensing equipment in established vineyards. Volumetric soil water content is measured using instruments such as capacitance probes, heat pulse probes and time domain reflectometers.

The positioning of such equipment is important (photo 8) and the following points should be considered:

- The values obtained depend on soil type, depth and distance from the vine and dripper.
- Measurements should be reliable and easily taken.
- There should be at least one measuring site per soil type with three or more measurement depths per site. One measurement depth should be close to the surface within the zone where the majority of roots occur (i.e. about 20-30 cm depth). The other measurement depths should be lower in the soil profile (e.g. 50-60 cm depth) and close to the base of the root zone.
- The measurement sites should be representative of the majority of the vineyard and not positioned in hollows or ridges.

Photo 8: Gypsum block positioned within the rootzone

5. Irrigation system design and maintenance

5.1 System design

The irrigation system itself can have a large effect on WUE and should be checked to ensure that pressures and flow variation across vineyard blocks are within industry standards. An under-designed system can be costly to correct and may not become apparent until the vines reach full cropping potential. A qualified designer should be used, preferably accredited by the Irrigation Association of Australia.

5.2 Drip irrigation systems compared to overhead sprinkler systems

- WUE is higher with drip systems than with overhead sprinkler systems due to the uniformity of application, reduced evaporation losses, minimal runoff and limited loss passing through the root zone.
- The grower has greater control over water application with drip systems.
- Fertilizers can be applied by fertigation more efficiently with less off-site pollution when using drip systems.

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- The effect of salinity is reduced under drip systems as salt accumulates at the edge of the wetted zone.
- Water quality has to be better for drip systems in order to prevent drippers from clogging.
- Drip systems generally have a lower capital and operating costs.

5.3 Dripper output and spacing

The choice of dripper and its position under a drip irrigation system will be influenced by soil type, topography and water quality (Photo 9).

- On sandy soils drippers may need to be as close as 0.5 m with an output of 4 L/hr to give sufficient horizontal spread to form a continuous wetted strip under vine.
- Loam and clay soils give a better horizontal spread so the distance between drippers can be larger (e.g. 1 m) and outputs can be reduced (e.g. 2 L/hr).
- In some situations with medium to heavy soil textures, 1.2 L/hr drippers spaced at 0.5 m intervals may work well if a continuous wetted strip is desired (e.g. for young vines).

Photo 9: Typical wetting pattern for a loamy soil

5.4 Distribution uniformity

Field evaluations of irrigation systems are often overlooked with many growers assuming that their system is working according to design specifications. Every irrigation system has various components which contribute to the overall *distribution uniformity* (DU). In drip irrigation systems, these components include:

- Pressure differences which cause flow rates to be different between drippers.
- Uneven spacing's between drippers caused by having a different number of drippers per unit area.
- Unequal drainage which relates to the loss of water from drippers once the water has been turned off.
- Dripper blockages caused by iron, algae and calcium.

Understanding the above components is important in determining where improvements and modifications can be made to improve the DU.

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5.5 Maintenance

Maintenance throughout the year is critical to prevent losses when moving water from its source to the vineyard and within the vineyard itself. Depending on the quality of water, the system should be flushed at the start and end of the growing season. Automatic flushing valves can be installed to flush laterals at the start of each irrigation cycle. Blockages can be removed by flushing with either chlorine or hydrochloric acid. Other cleansing products are commercially available.

6. Improving management practices in the vineyard

Vineyard design in terms of aspect, row orientation, vine spacing, soil preparation, trellis type and use of windbreaks all affect soil water availability and vineyard water use. How vineyard design affects subsequent vine water use is discussed in a number of viticulture text books.

Once the vineyard is established, management practices will affect the amount of water vines have access to and how much water the vines use. Mid-row and under-vine management have a significant effect on vineyard water status. For example, competing mid-row or under-vine plants will use water and limit water availability to the vines. Management and its effect on water use therefore needs to weighed against other factors such as soil health and erosion.

Trellis type and canopy management practices affect vine size, crop load and hence water requirements. Practices that cater for high levels of foliage and soil exposure to radiation, ambient air temperature and wind encourage high rates of evapotranspiration. Severe winter pruning will have the effect of limiting canopy size and crop load. Removing unproductive shoots should be removed before flowering and after fruit set the crop load should be adjusted by removing bunches. After bunch closure, shoot growth should be slowed down by removing the tips. At veraison, vine condition and balance between crop load and canopy size should be assessed and if water resources are limited, bunches may need to be removed in order to ensure that the remaining crop fully ripens.

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7. Improving variety and rootstock selection

The amount of water required to produce grapes for different wine styles can vary significantly. Generally red grape varieties require less water than white varieties. Grapes for aromatic and light style wines require more water to minimise water stress than grapes producing medium to full bodied wine styles.

Varieties differ in their response to water restrictions. For example Shiraz growth will slow down and show symptoms of water deficits more readily than some other varieties. Shiraz vines look limp while under a water deficit but have a remarkable capacity to recover when soil moisture conditions improve. Cabernet Sauvignon fruit generally shrivels before any basal leaf loss is observed. Water stress resulting in excessive leaf loss and bunch exposure increases the risk of sunburn which may reduce flavours and quality, particularly in white varieties.

Photo 10: Damaged fruit where overly exposed to the sun

Rootstocks are used for a number of reasons including drought tolerance. A number of so-called ‘drought tolerant’ rootstocks have been identified (Dry 2007) which may become attractive options when water resources become limiting. These include Ramsey, K51-32, Paulsen 1103, Richter 99 and 110. Schwarzmann and 34EM appear to perform to drought situations in a similar way to own rooted vines. However, more work on rootstock response to drying conditions is required before this becomes a recommended viticultural practice.

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8. Risk management

Reducing water use without increasing the risk requires more than a standard set of guidelines. Each vineyard block should be assessed at critical stages of vine growth to determine how much water to apply. The following assessments will aid decision-making:

- Weather forecast to preempt hot and dry periods
- Soil moisture content of the soil
- Water loss through evaporation
- Water availability and its quality
- Soil type and variability
- Growth stage of the vine
- Age of the vine
- Vine health and canopy size
- Crop load
- Fruit quality
- Irrigation system, design and operating efficiency

9. Summary

A range of vineyard management and irrigation practices are available which allow water resources to be conserved and used efficiently and sustainably. Issues such as soil type, growth stage, vine health, variety and rootstock, crop yield and quality, water quantity and quality, irrigation system, design and maintenance, and minimising soil evaporation need to be considered when managing water resources, particularly when water is in short supply and regulated.

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