

DEPARTMENT OF  
PRIMARY INDUSTRIES



## Vineyard Soils of the Geelong Region

Improving water use efficiency through a better understanding of soil water-holding properties

Published by the Victorian Government Department of Primary Industries, July, 2009

© The State of Victoria, Department of Primary Industries, 2009.

This publication is copyright. No part may be reproduced by any process except in accordance with the provisions of the *Copyright Act 1968*.

**ISBN 978-1-74217-670-3 (print)**

**ISBN 978-1-74217-671-0 (CD-ROM)**

**Disclaimer**

This publication may be of assistance to you but the State of Victoria and its employees do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

***For further information, visit the DPI Website at [www.dpi.vic.gov.au](http://www.dpi.vic.gov.au) or contact the DPI Customer Service Centre on 136 186.***

# Vineyard Soils of the Geelong Region

Improving water use efficiency through a better understanding of soil water-holding properties



Sutherlands Creek. Photo: S. Engleitner, Oct.2007

## Soil Profile Report

### COMMISSIONED BY

Kieran Murphy  
Farm Services Victoria - Grapes Coordinator  
Victorian Department of Primary Industries  
Box Hill

### PREPARED BY:

Siegfried Engleitner  
Soil Scientist, Future Farming Systems Research  
Victorian Department of Primary Industries  
621 Sneydes Rd  
Werribee 3030

July 2009  
Department of Primary Industries

Summary .....	5
Introduction .....	7
The Geelong Wine Region – Some Statistics .....	8
Climate Change and Implications for Geelong Region Vineyards .....	10
Benchmarks for Vineyard Soils - Physical Parameters .....	12
Benchmark Criteria Explained .....	14
Total Available Water in Root Zone .....	14
Total Available Water Benchmark, applied to Soils of the Geelong Region.....	15
Deep Soil Water Reserves .....	15
Using Volumetric Water Data to calculate Irrigation Volumes .....	17
Waterlogging, Infiltration Rate and Air-filled Pore Space .....	18
Waterlogging .....	18
Infiltration Rate.....	20
Soil Strength (compaction).....	21
The Least-Limiting Water Range ( LLWR ) Concept.....	21
Chemical Benchmarks .....	22
Soil Profile Descriptions.....	23
Landscape.....	23
Main Soil Types.....	23
Location of Soil Pits and Visible Profile Features .....	24
Sutherlands Creek (Shiraz, planted 1998, i.e., 10 years old).....	25
Portarlington (Chardonnay, planted 2000, i.e., 8 years old; Plate 1, Photo 2).....	26
Mt.Moriac (Pinot Noir, planted 2000, i.e., about 8 years old) .....	27
Soil Amelioration Techniques for Increasing Vine Root Growth.....	29
Deep Ripping.....	29
Deep ripping to Increase Root Growth - Reducing Compaction.....	29
Deep Ripping to Decrease Root Growth - Root Pruning .....	30
Mulching .....	30
Organic Mulch.....	30
Vertical Gravel Mulch.....	30
Soil Moisture Sensors for Irrigation Scheduling.....	31
Types of Soil Moisture Sensors .....	31
Installation and Placement of Soil Moisture Sensors .....	31
Using Soil Moisture Sensors as an Early Warning System.....	31
Limitations of Field Measurements and the need for further work.....	32
Problems in Estimating Actual Grapevine Water Use .....	32
Improving Water Use Efficiency by Manipulating Irrigation Timing.....	32
Regulated Deficit Irrigation (RDI) .....	32
Soil Type and RDI .....	33
Record Keeping for RDI .....	34
Dewatering the Soil to Impose Water Stress .....	34
Rewatering Following the Deficit Period.....	34
Non-Soil Water Conservation Techniques .....	35
Canopy Management.....	35
Mothballing.....	35
Appendix: Geelong Vineyards.....	36
REFERENCES.....	38
Most Referenced Reading .....	40
Further Reading.....	40

## Summary

The purpose of this investigation was to improve vineyard water use efficiency in the Geelong Region, through better use of soil water in the top metre of the soil profile. The main findings and recommended priority actions are presented here in summary. They are based on field investigations, laboratory analyses, and interviews with vineyard managers, local farmers and agronomists in the Geelong Region and a literature review. Knowledge gaps (areas requiring more research or facilitation by DPI Farm Services Victoria - Grapes) are also identified. Specific data for soil types within the Region can be found in the body of the report. These can aid local vineyard managers and advisors to estimate soil water reserves as well as how to identify the most appropriate way to improve reserves for different soil types in the Region.

The report presents recommendations for improving vineyard water use efficiency in the context of climate change and the implications of a drier climate within the medium (5-15 years) and longer term (15+ years) to highlight the importance of immediate attention to improving water use efficiency within the Region.

The Geelong Region Plan predicts a *global* temperature rise of 2°C by 2050 will be associated with a *Regional* decline in annual rainfall of 20% ([www.g21geelongregionplan.net](http://www.g21geelongregionplan.net)). The Region's rainfall is already low (less than 550 mm). Hotter, drier conditions will increase plant water requirements and simultaneously reduce the volume of water available for irrigation.

Currently, vineyard managers within the Geelong Region supplement rainfall with irrigation, typically 1-2 ML/ha (equivalent to 100-200 mm), from which they produce low yields of 4-5 t/ha of grapes (for comparison, target yields in the Yarra Valley, where rainfall is approximately 1000 mm, are 10 t/ha). The Region's vineyards will need to adjust to what will amount to long term drought conditions and may struggle to produce economic yields. The severity and rapidity of predicted changes warrant immediate action to improve water use efficiency in the Region's vineyards. All vineyard managers in the Geelong Region should:

**Prepare water budgets.** These can help vineyard managers to allocate water to different blocks to maximise returns from irrigation water, particularly in years of drought. The approach used by DPI-SA links water use to yield (FactSheet No. 03/07, Water Budgeting Guidelines - Vines on the Lower Murray [www.pir.sa.gov.au/factsheets](http://www.pir.sa.gov.au/factsheets)). Vines are irrigated to achieve target yields of 100%, 90%, 50%, or 10% of potential yield (10% yield is the aim for survival of vines for future production). However, in order to utilise this approach within the Geelong Region, managers need district-based guidelines for target yields for different varieties, climates, stored soil water and the ability of vines to access this water in different soil types. Other factors include harvest index (above-ground biomass vs. harvestable yield), photosynthetically active radiation (PAR) and radiation use efficiency. Lack of such information highlights important knowledge gaps. However, a start can be made.

**Regulated Deficit Irrigation.** RDI offers irrigation savings of up to 30%, with minimal impact on yield while simultaneously improving quality (through smaller berry size). It is common practice in many vine growing areas within Australia, but perhaps under-utilised within the Geelong Region. It involves restricted irrigation at specific growth stages to reduce canopy size, hence, vine water requirements, In order to encourage trials by local vineyard managers,

it is recommended that specific Regional guidelines be developed for the application of RDI, for different varieties, climates and soil types within the Geelong Region.

Potential yield is governed by many factors, but adequate water is the overriding determinant. Grape quality must also be considered; Also, the timing of the ideal grape yield for ensuring best wine quality is determined by variety, climate and soil type. It follows therefore, that target yields will vary between vineyards, within a district, and from year to year.

**Install deep soil moisture sensors** to a depth of one metre that are capable of measuring soil moisture to a dryness of at least 400 kPa (or an equivalent, e.g., water as a percentage of soil volume), so that RDI can be implemented (tensiometers are inadequate as they do not work in soils drier than 80 kPa). Deep soil moisture sensors offer several benefits over shallow sensors. For example, they can identify low subsoil water recharge over winter, which allows managers to determine whether early-season irrigation is warranted. Conversely, deep-soil moisture data together with soil physical data (collected and presented in this report), can avoid creating temporary waterlogging through over-watering.

**Encourage a greater vine root depth** to make better use of deep soil (75+cm) water reserves. In general, better access to deep soil water can provide greater resilience to drought. However, the appropriateness of a more vigorous root system is vineyard-specific and deeper roots are not desirable in all situations. Root system vigour depends upon localised climate, topography, soil type, and rootstocks. Where vegetative vigour (canopy growth) is satisfactory, a stronger root system may lead to excessive canopy growth. The question of whether to rip or not (and to what depth) is also dependent upon the depth of subsoil water, and how deep roots need to be to access it. A lack of such localised information represents another knowledge gap, but this one can be easily addressed by on-farm inspections of soil pits and installation of deep soil moisture sensors.

**Maintain a surface mulch.** Mulching has been demonstrated in numerous trials to save water. It reduces surface evaporation and allows shallow roots (in the top 30 cm of soil) to utilise this conserved water.

**Conduct trials into vertical gravel mulching** as soon as practical. It is a cheap, easily installed, low-tech water-saving technique that improves water percolation.

**Investigate “mothballing”.** This is a vine survival technique, used to keep vines alive during prolonged drought. It involves severe pruning that takes parts of the vineyard out of production for a year, thus dramatically reducing their irrigation requirement. The saved water can then be applied to other areas so that at least some sections of the vineyard can produce a satisfactory yield of acceptable quality. Initial research is promising. The final report on a two-year DPI research trial in the Sunraysia is due in late 2008. Before this technique can be recommended for the Geelong Region, small-scale trials should be conducted. Lack of localised information represents another knowledge gap.

Because of the technical expertise required, it is recommended that implementation of priority actions and filling of knowledge gaps be facilitated by DPI Farm Services Victoria - Grapes. Facilitation should expedite adoption and minimise failures, which would only serve to discourage others from adopting worthwhile new practices.

## Introduction

The purpose of this report is to improve irrigation efficiency in vineyards within the Geelong Wine Region, through better use of soil water store, particularly in the top metre of the soil profile. The report also presents the implications of a drier climate in the medium (10-20 years) and longer term (20+ years). This will increase pressure on all vineyards to reduce irrigation volumes and improve water use efficiency, particularly those in low rainfall areas such as the Geelong Region, for which the long-term average is less than 550mm.

Benchmarks (targets) for good viticultural soils (physical features) are presented. These benchmarks are applied to the two main viticultural soils within the Geelong Region that were inspected (via soil pits) and analysed (chemical and physical parameters) for this report: duplex soils (Sodosols) and cracking clays (Vertosols). Two different cracking clay profiles are described to demonstrate that variations require specific irrigation management and amelioration to improve root growth.

The focus is on soil, particularly its physical properties and how we can modify these to increase vine's access to soil water. In brief, the explanation of soil physical properties describes management of conflicting requirements. For example, a higher water holding capacity may be a desirable aim, for protection against drought conditions, but it can make excessive vigour difficult to control through irrigation management. Another example: short irrigation run times are desirable to avoid temporary waterlogging, but longer run times may be necessary to leach salt or to wet up soil profiles that are dry before bud-burst. Temporary waterlogging can be a particular problem for cracking clays which swell on wetting, which dramatically reduces infiltration rates; irrigation run times of more than 12 hours should be avoided, particularly for cracking clays.

The report also discusses ways to increase root growth, which is an aspect of improving irrigation efficiency. However, again, the decision to increase root growth is one of conflicting needs: Deeper roots make better use of deep soil (75+cm) water reserves, potentially reducing the reliance on irrigation water. Deeper roots also provide better resilience to drought, which, in the face of global warming, should perhaps be the aim for all vineyards in lower rainfall areas, such as the Geelong Region (long-term average 550mm). However, deeper roots can also make it harder to control excess vegetative vigour, so deeper roots are not appropriate for all soils in Geelong vineyards.

Some of the questions that will be answered in this report include:

- What soil features determine the ability of roots to extract subsoil moisture?
- Should the soil be ripped, mulched, limed, gypsumed?
- Is the main root growth constraint physical (e.g., dense, poorly structured, subsoil clay)?
- Is the main root growth constraint chemical (e.g., is the soil highly alkaline, saline, sodic, or all three)?
- How should different physical and chemical constraints be rectified?
- How deep should vine roots be encouraged to grow (see the section on benchmarking vineyard soils)?
- Should deeper roots be the aim for all vineyards in the Geelong Region, which has a range of different soil types, local climatic conditions and of course different grape varieties of varying vigour.
- How should scarce water be utilised over the season in times of drought?
- How much water should be applied? How quickly? How frequently?
- Should irrigation water be used during the wetter months when more of it is available, in order to recharge the subsoil?
- During drought, and in the year leading up to drought, how can we use currently-available irrigation water strategically to maximise yield (profit) from a vineyard?

There are several questions which cannot be answered with certainty, but they will determine the long term viability of the Geelong Region's vineyards:

- Can Geelong Region Vineyard managers adjust to more frequent, more severe drought, combined with much lower average rainfall into the next 20 years, and continue sustainable, economic, production?
- What will average rainfall be over the next 10 years?
- How much recharge can be expected from rainfall in the medium term (the next 10-20 years)?
- What yields can Geelong vineyards expect into the future?

Maybe rainfall is *currently* providing sufficient recharge, and root growth is *currently* sufficiently deep enough to meet evapotranspiration demands. However, what will be the impact when rainfall is lower and subsoil water reserves within the root zone are exhausted?

The jury may still be out on whether lower rainfall is linked to global warming or a natural climatic cycle. Regardless of the driving forces, higher temperatures will increase water demand by vines. Higher temperatures mean greater evapotranspiration. To make matters worse for southern Australia, higher temperatures are predicted to coincide with lower rainfall, thus amplifying the need for more irrigation water. By 2050, rainfall in the Geelong Region is expected to decline by 20% and temperatures to increase by 2°C. The message for vineyard manager is: irrigation demands will increase in the long term. The prudent operator will plan to improve water use efficiency now.

## The Geelong Wine Region – Some Statistics

Wine Regions are a legally protected Register of Protected Names, which is maintained by the Australian Wine and Brandy Corporation ([www.wineaustralia.com](http://www.wineaustralia.com)). The AWBC is an Australian Government statutory authority established in 1981 to provide strategic support to the Australian wine sector.

The AWBC definitions are:

A **region** must be a single tract of land, comprising at least five independently owned wine grape vineyards of at least five hectares each and usually produce five hundred tonnes of wine grapes in a year. A region is required to be measurably discrete from adjoining regions and have measurable homogeneity in grape growing attributes over its area. There are 52 vineyards within the Geelong Region ([www.winegeelong.com.au](http://www.winegeelong.com.au), accessed May 2008). The Geelong Region lies within the Port Phillip Zone.

A **sub-region** also must be a single tract of land, comprising at least five independently owned wine grape vineyards of at least five hectares each and usually produce five hundred tonnes of wine grapes in a year. However, a sub-region is required to be substantially discrete within the region and have substantial homogeneity in grape growing attributes over the area. According to the AWBC the Geelong Region has no sub-regions, although other websites (e.g., <http://www.winegeelong.com.au/map.asp>) may break up the Geelong Region into the Bellarine, Moorabool (includes Anakie) and Surf Coast (includes Waurn Ponds).

**Figure 1. Map of the Geelong Region according to the Registrar of Protected Names**



Source: Australian Wine and Brandy Corporation ([www.wineaustralia.com](http://www.wineaustralia.com), accessed May 2008)

**Table 1. Grapevine Statistics for the Geelong Region (2008)**

Geelong SEC 1870-1970	
Map Coordinates	38° 07' S, 144 ° 22' E
Altitude	20 m - 350 m (66-1150 feet)
Heat degree days, Oct-Apr	1451 (cut off at 19°C (66.2 °F) but otherwise not adjusted)
Sunshine hours, Oct-Apr	1455 (Gladstones)
Annual rainfall	537 mm (21.1 inches)
Growing season rainfall	293 mm (11.1 inches)
Mean January temperature	19.1°C (66.2°F)
Relative humidity, Oct-Apr, 3 pm	Average 57%
Harvest	Early Mar-End Apr

Source: Australian Wine and Brandy Corporation ([www.wineaustralia.com](http://www.wineaustralia.com), accessed May 2008)

**Table 2. Additional Grapevine Statistics for the Geelong Region (2006)**

Area under vines*	600 ha (65% red, 35% white)
Number of vineyards *	100
Number of wineries *	60
Principal white grape varieties	Chardonnay, Sauvignon blanc, Riesling
Principal white wine styles	Chardonnay, Sauvignon blanc
Principal red grape varieties	Pinot noir, Shiraz, Cabernet sauvignon
Principal red wine styles	Pinot noir, Shiraz, Cabernet sauvignon
Percentages in descending order	Pinot noir, Shiraz, Chardonnay, Cabernet sauvignon
Harvest	Mid March (Pinot Noir) to late April (Riesling, Shiraz and Cabernet Sauvignon)

Source: Wine Atlas of Australia (Halliday 2006) and \*Shane Smith, Director, Williams & Jackson P/L, Geelong (Oct 2008)

## Climate Change and Implications for Geelong Region Vineyards

The Victorian Department of Primary Industries review report for 2007 on Dry Seasonal Conditions in Rural Victoria (DSC Report no. 74, Hollaway 2008) stated:

“2007 was Victoria’s warmest year on record, up 1.18°C on the long-term average, according to the Bureau of Meteorology’s 2007 Climate Statement (January 3). Australia-wide it was 0.67°C above average in 2007, making it the sixth warmest year since high quality Australia-wide records commenced in 1910 ... Despite promising rains during the first half of the year, July to October was particularly dry. South-eastern Australia has now missed out on the equivalent of an average year’s rainfall over the duration of this continuing 11 year drought. Australia has now recorded a warmer-than-average year for 16 of the past 18 years...However, it remains unclear how much of the current rainfall decline in the southeast can be attributed to human-induced climate change”.

“Climate change will dramatically alter the growing season for Australian grapes and affect wine styles produced here... This will cause a shift in budburst dates, shorter growing seasons and earlier harvest dates” (Webb et al 2006). These shifts in critical dates are probably the least of the worries for the Geelong Region. James Halliday identifies the chief viticultural hazard is drought (Wine Atlas of Australia, 2006, p. 103). Most Geelong viticulturalists would agree. Global warming will compound the drought problem, because higher temperatures mean greater evapotranspiration. To make matters worse, global warming is likely to coincide with lower rainfall (although it is not necessarily the cause of the lower rainfall). The Geelong Region, whose rainfall is already low, will need to adjust to permanent mild to severe drought.

The Geelong Region Plan predicts that a *global* temperature rise of 2°C by 2050 will be associated with a *Regional* decline in annual rainfall of 20% ([www.g21geelongregionplan.net](http://www.g21geelongregionplan.net)). It should be noted that 20% is an *average* figure, which means that in many years, rainfall will be much lower. Geelong’s long-term rainfall is 537 mm ([www.bom.gov.au/climate](http://www.bom.gov.au/climate)). Growing Season Rainfall (GSR, October-April) is 293 mm. A 20% reduction means the average would be 430mm and GSR 234 mm (assuming rainfall distribution remains the same – some predictions indicate more intense summer storms).

Geelong rainfall patterns show that dry years (below average rainfall) outnumber wet years, and two wet years in a row are unusual. In fact, dry years are the norm (Geelong Weather Services website, <http://users.pipeline.com.au/~gws>, accessed 2008). The last wet year was 2001: 714 mm at Mt. Duneed), 23% above average compared to the Cumulative Geelong total (since 1983) of 549 mm (Geelong Weather Services, accessed 2008). Between 2002-2007, the average was 467 mm, i.e., around 15% below average (this includes the record 2006 drought year: 285 mm). Victoria is currently (in 2008) supposed to be in a wet cycle. It remains to be seen how wet it will be and how long it will last. The important point is that there are few wet years between the many dry years, i.e., drought conditions are the norm and it is very likely that the wet years will not replenish deep soil moisture to the same extent as they did in the past.

It is also important to note that averages vary widely across the Geelong Region. Some viticultural areas such as Mt Moriac are closer to 700 mm. For better estimates of localised rainfall, visit the Geelong Weather Services website <http://users.pipeline.com.au/~gws> (note that the cumulative Geelong total - 549 mm - has been calculated by Geelong Weather Services based on localised weather data since 1983. The Bureau of Meteorology’s figure is 537 mm, which is based on the international standard 30 year period of 1961-1990)

Grape yields in the Geelong Region are generally described as low (Dry and Smart, 1988; Halliday, 2006) and are commensurate with the Region’s low rainfall and high aridity. Published data on Geelong grape yields are difficult to find. The Amietta Vineyard and Winery website ([www.amietta.com.au](http://www.amietta.com.au)) provides some useful yield data. They deliberately keep yields “low” (4.5-5.0 tonnes per ha, equivalent to 1.9-2.5 kg/vine). Personal communication with local growers and consultants suggest Amietta’s target yields are not unusual, although some growers report higher target yields for vigorous grape varieties and, average to above average rainfall. For more vigorous varieties, 7.5 t/ha is high and 6 t/ha moderate. For less

vigorous varieties, 5 t/ha is moderate. To achieve these yields, growers applying relatively little irrigation, around 100mm. For perspective, grapevine yields in southern Victoria (i.e., excluding Sunraysia) vary (approximately) from 5-7 t/ha (lower rainfall, 500-700 mm, e.g. ) up to 10 t/ha (>900 mm, e.g. Yarra Valley).

Dry and Smart (1988, p. 38) present an aridity index for estimating irrigation requirements. It is based on the assessment that well-watered, vigorous vineyards transpire about half of the (pan) evaporation rate over the growing season (October-March):

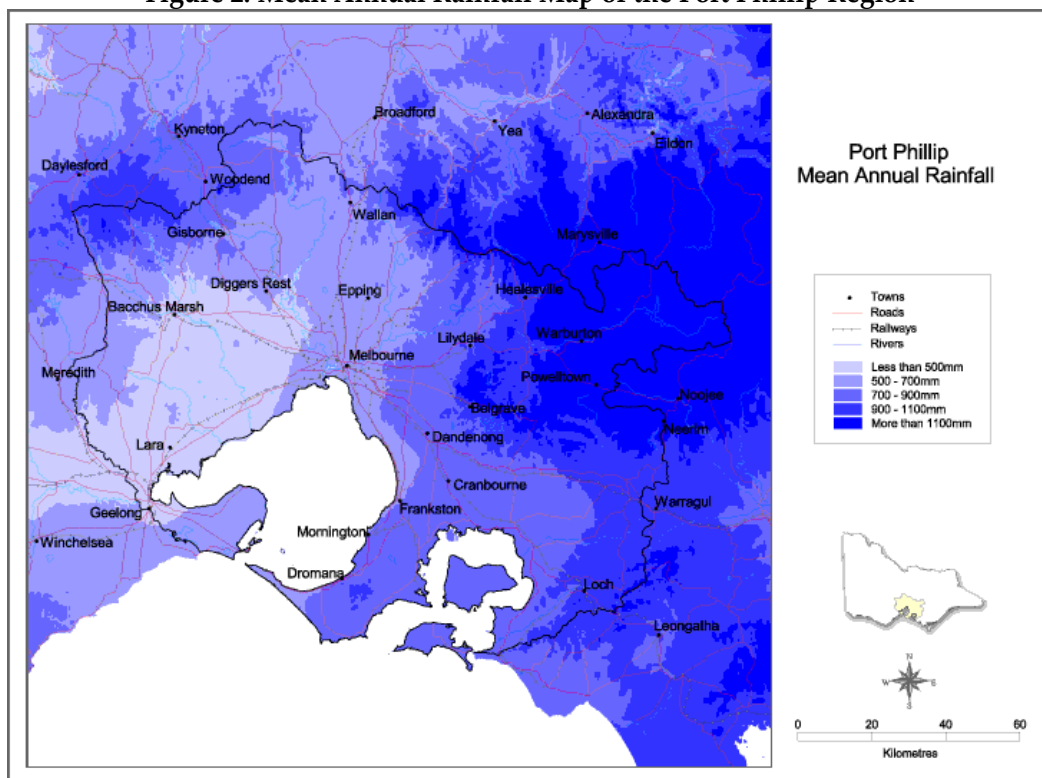
$$\text{Aridity Index (mm)} = \text{rainfall} - 0.5 \times \text{Epan, summed over the growing season (October-March)}$$

For Geelong, the aridity index is 266 mm (2.66 megalitres/ha). This is based on average annual rainfall (537 mm), which Geelong has not experienced for many years. Geelong vineyards typically supplement rainfall with around 100 mm of irrigation (Hugh Hull, local agronomist, pers.com. 2008). This discrepancy between the aridity index and typical irrigation rates, suggests a shortfall of 166 mm (266-100). So, either the aridity index overestimates water requirements, or growers are applying more than 100 mm of irrigation, or, vines extract more subsoil moisture in dry years to make up the shortfall.

Maybe rainfall is *currently* providing sufficient recharge, and root growth is *currently* sufficiently deep enough to meet evapo-transpiration demands? However, what will be the impact on grape yields when vines are continually under-irrigated, i.e., when the water requirement predicted by the aridity index is not met (assuming the aridity index is a reasonably accurate estimate of water requirements) and subsoil water reserves are exhausted within the root zone?

All agriculturalists should consider the impact of changing rainfall patterns, in terms of both annual and growing season rainfall. Non-growing season rainfall is important too, because it is largely winter rainfall that recharges a dry soil profile. A decline in winter rain means more irrigation may be required at the start of the growing season to avoid moisture stress at the critical period from bud-burst to fruit-set.

**Figure 2. Mean Annual Rainfall Map of the Port Phillip Region**



Source: [http://www.dpi.vic.gov.au/dpi/vro/map\\_documents.nsf/pages/vic\\_pp\\_rainfall](http://www.dpi.vic.gov.au/dpi/vro/map_documents.nsf/pages/vic_pp_rainfall)

## Benchmarks for Vineyard Soils - Physical Parameters

“The key to improving wine grape quality in irrigated vineyards is to achieve an appropriate balance between vegetative and reproductive development since an excess of shoot vigour may have undesirable consequences for fruit composition” (Dry 2005).

Benchmarks help to determine if intervention is justified to improve the soil. Table 3 presents soil *physical* benchmarks, put together by Australian experts (Lanyon et al 2004). However, many, successful, vineyards have soil characteristics that are unsatisfactory according to these benchmarks. Lanyon (ibid) recognise this and state: “...an ideal set of soil criteria will need to be aligned with different climatic conditions and access to irrigation. Hence there is no one set of criteria that is suitable for all climates. However, the ability of the soil to drain would have to be the one universal soil quality applicable to all climates. A criterion for the depth of the root zone and the nutritional status of the soil is needed for vineyard selection or selection of the most appropriate soil management method for a given vine performance target”.

Basically, this statement is saying that economical considerations should dictate intervention decisions for soil that is less than ideal. Will the cost of soil remediation justify the returns? Suppose a soil pit inspection identifies poor subsoil structure (compacted, poorly drained, sodic) that could be improved by deep-ripping to encourage roots to grow more deeply and gain greater access to deep stored soil moisture. But, what if we observe a few deep vine roots in the supposedly hostile subsoil, and vigour and production is satisfactory? In this situation, intervention to increase root depth doesn't seem warranted, unless perhaps as an insurance against future hotter, drier conditions associated with climate change.

The physical and chemical benchmarks in Tables 3, 4 and 5 are explained with reference to the Geelong soil profiles. In brief, the explanations describe management of conflicting requirements. For example, a higher water holding capacity may be a desirable aim, for protection against drought conditions, but it can make excessive vigour difficult to control through irrigation management. Short irrigation run times are desirable to avoid temporary waterlogging, but longer run times may be necessary to leach salinity or to wet up soil profiles that are dry before bud-burst. Temporary waterlogging can be a particular problem for cracking clays which swell on wetting, which dramatically reduces infiltration rates; irrigation run times of more than 12 hours should be avoided, particularly for cracking clays.

**Table 3a. Benchmarks for soil PHYSICAL quality for establishment and yield of irrigated vines**

Criterion	Benchmark	Relevance
Waterlogging	< 1 day of saturating irrigation or rainfall	Actively growing, waterlogged, vine roots can die off in 5 days. To minimise saturated conditions, poorly drained soils should be irrigated more often for shorter periods
Infiltration rate	500 mm/day (approx. 20 mm/h)	Slower infiltration rates can mean poor drainage and potential for waterlogging
Air-filled pore space	> 15% of soil volume	Vine roots need at least 10% air-filled pore space for adequate aeration. Rip soil if compacted. Maintain soil moisture at drier end of RAW (40-60kPa) if aeration is <10% at field capacity (10kPa)
Total available water in root zone (mm)	>200 (excessive)	Very difficult to control vigour
	150-200 (high)	Difficult to control vigour
	100-150 (optimal) (100 mm/m depth = 10% water v/v )	Good water storage capacity, that allows for control of vigour at the same time
	50-100 (sub-optimal)	Need frequent irrigation to avoid moisture stress
	<50 (insufficient)	Difficult to avoid moisture stress. May not support sufficient yield to be economically viable.
Penetration resistance	< 1 MPa at field capacity (10 kPa)  < 3 MPa at wilting point (1500 kPa)	While roots may penetrate soil with a resistance of up to 2MPa, soil that is harder than 1MPa when moist is likely to become impenetrable quickly as it dries. High resistance at wilting point means root penetration limit of 2 MPa will probably be reached within the deficit water range, i.e., roots won't grow. A 25-30 mm piece of moderately moist soil should be crushable between thumb & forefinger using moderate force. A piece that ruptures under slight force has a penetration resistance <1 MPa; 2 MPa is beyond strength of thumb and forefinger.

The suggested benchmark values are for moderately vigorous irrigated vines on wide spacing (3 x 2 m).

Source of first two columns: Lanyon et al (2004). Source of third column: author of this report

**Table 3b. Benchmarks for soil CHEMICAL quality for establishment and yield of irrigated vines**

Additional Parameters	Target Range	Management
pHc (1:5 soil : CaCl <sub>2</sub> , w/v)	5.0 – 5.8	Apply lime if pHc <5.0 (equivalent to pHw 5.8, in non-saline soil. If soil is saline, defer to pHc)
Salinity: EC (Electrical Conductivity, dS/m, 1:5 soil:water, w/v)	< 0.20 dS/m for sandy loams < 0.25 dS/m for clay loams <0.5 dS/m for clays	If source of salt is saline irrigation water, ensure sufficient leaching fraction is applied to avoid build-up of salt in the soil.
Sodicity (% of Ca, Mg, K, Na)	<6%	If ripping compacted & sodic soil, incorporate gypsum in rip lines at 5-10 t/ha.
Exchangeable Cations		Target ranges for cations percentages and ratios aim to provide satisfactory plant nutrition and, with respect to Ca and Mg, good soil structure
Calcium	60-80	
Magnesium	15-30	
Potassium	5-10	
Ca:Mg ratio	2-10	
K:Mg ratio	0.1-0.4	

Source: adapted from Lanyon et al (2004, Tables 2 and 5).

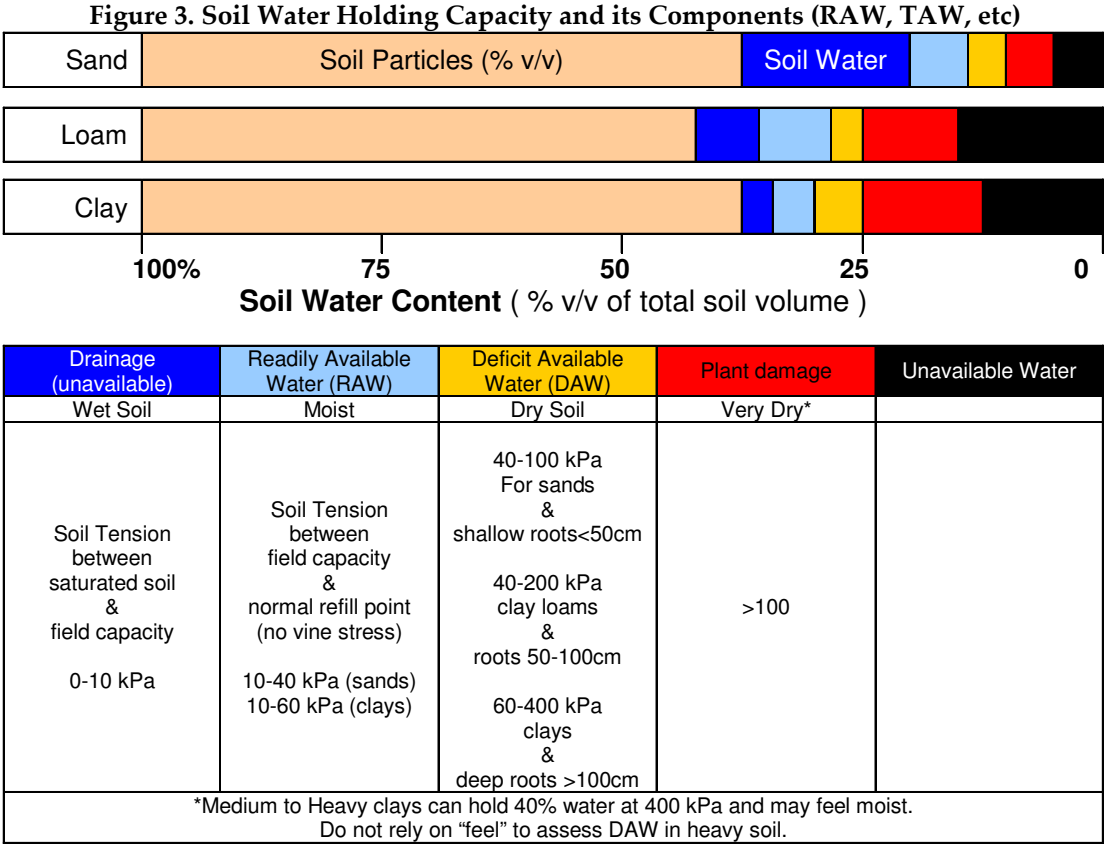
# Benchmark Criteria Explained

## Total Available Water in Root Zone

This benchmark (Table 3) is based on the *total* amount of Plant-Available Water (PAW or TAW, the amount of water held in soil between field capacity, which is the amount of water remaining in soil, 24 hours after a saturating rain or irrigation, and the permanent wilting point, 10-1500 kPa). TAW provides a guide to vine vigour and the ability to control it with irrigation management. TAW contents over 200mm (equivalent to 200 litres of water per cubic metre of soil) is rated excessive.

For irrigation-scheduling purposes, we are interested in only a small fraction of TAW: Readily Available Water (RAW) and, for the purposes of Regulated Deficit Irrigation, Deficit Available Water (DAW). The relationship between different components of soil water is presented in Figure 3. Note that although clays and sands may hold a similar *total* amount of water, in sands, about a third is lost to drainage and is therefore unavailable to plants. At the other extreme, in clays, very little is lost to drainage, but about a third is held by the soil so tightly that plants cannot extract it (i.e., water content at wilting point is high, which has a negative influence on soil aeration – see section on aeration). In practice, we would avoid drying (clay) soil out to beyond 400 kPa even when practising Regulated Deficit Irrigation, a technique that can reduce irrigation requirements by 20-30% (Kriedemann & Goodwin 2003).

Soil water components are described in terms of the increasing suction that must be applied to soil to remove more water as the soil becomes increasingly dry. The components of TAW can be manipulated by irrigation, to maximise water use efficiency and maximise grape quality (WUE is commonly measured in tonnes of grapes per megalitre of irrigation water, t/ML).



(source: Irrigation of Vineyards, Ian Goodwin 1995)

## Total Available Water Benchmark, applied to Soils of the Geelong Region

Table 4 presents calculations for TAW, based on field observations of root growth in soil pits dug in Geelong vineyards, and laboratory analyses of soil water (Table 5a). The bolded figures are based on the lateral spread of roots into soil pits. The TAW data are approximate, but sufficiently accurate to demonstrate why excessive vigour can be a problem for the Portarlington black cracking clays; TAW is excessive (much more than 200mm, see Benchmark Table 3). Sutherlands Creek also has a very high TAW in the main root zone, but excessive vigour was not reported to be a problem. How can this be explained? For both Sutherlands Creek and Portarlington, the activity of roots is probably restricted by very low air-filled porosity in the main root zone (less than 10%), so root activity will be restricted (see also next section). Perhaps this is just as well for Portarlington, or vigour may be an even greater problem. Aeration is discussed further in the next section.

The Sutherlands Creek profile is also compacted, which may restrict root activity, and, the soil is saline (EC 1 dS/m at 15-30 cm), which would almost certainly restrict vine growth.

The Mount Moriac profile, however, is neither compacted, poorly aerated nor saline. Soil pH is ideal too. There do not appear to be any physical or chemical constraints to root growth here and vigour is satisfactory. So, based on the benchmarks in Table 3, we may reasonably good growth and control of vine vigour through irrigation management. The subsoil clay is poorly drained, so waterlogging may be a problem in wet years.

## Deep Soil Water Reserves

It is also important to note the contribution of sparse root systems to the production of quality grapes, particularly during prolonged dry periods. While deep roots may cause problems of excessive vigour in years of normal rainfall, deep roots may be desirable during prolonged dry spells. Saayman and Kleynhans (1978) attributed good grape quality to stored water from subsoil clay in a duplex soil. Van Huyssteen (1988) concluded that occasional deep roots did not add much to vine vigour, but probably did add significantly to water supply during periods of prolonged water stress. In drought conditions, when irrigation water allocations are often low, access to deep soil water reserves by vine roots can make the difference between live or dead vines. Managers can use this information to determine whether intervention is warranted (e.g., deep ripping) to increase rooting depth.

**Table 4. Total Available Water ( 10-1500 kPa ) for three Geelong Region Vineyard Soil Profiles**

Location	Lateral Roots (m <sup>2</sup> )	Vertical Roots (Main Root Zone)* (metres)	Root Volume (Main Root Zone) (litres)	TAW* Main Root Zone (litres)
Sutherlands Creek	2.25	0.30	675	<b>200</b> (81+119)
Mount Moriac	2.25 (1.5 x 1.5)	0.35	790	<b>164</b> (100+64)
Portarlington	2.25	0.50	110	<b>437</b> (131+306)

Mount Moriac (duplex profile, 35 cm of sandy clay loam over medium-heavy, yellow sodic clay)

Sutherlands Creek (70 cm of grey cracking clay, compacted below 35cm, over calcareous clay)

Portarlington (60-90 cm of strongly-structured, deep, black cracking clay over sandy clay). NB: Portarlington TAW estimates may be misleading: although only a few roots extended beyond 200cm, they are probably contributing to the excessive vigour problems - see Tables 5a, b, c for laboratory data. Conversion factor: 1000 L = 1 m<sup>3</sup>

Table 5a can be used by Geelong Region vineyards to manipulate TAW, either by encouraging deeper root growth (by deep ripping) or restricting lateral root growth (by root pruning). Table 5b presents Readily Available, Deficit and total Plant-Available Water (% v/v), as well as actual water content (in litres), for each soil horizon. Table 5a demonstrates how an increase in root depth can dramatically increase the amount of water accessible to vines. This table can be used to calculate both RAW and DAW for various soil depths (using the % v/v data). The important point to note is how much the water content of different clay types can vary. This variation makes it difficult to use generic tables of Available Waterholding Capacity.

**Table 5a. TOTAL Available Water ( 10-1500 kPa ) for three Geelong Region Vineyard Soil Profiles for five different volumes of soil**

<b>Litres of TOTAL Available Water (TAW, 10-1500 kPa) to 1 metre depth for three Bellarine Peninsula Soils</b>									
Bolded data are based on current main root depth, based on soil pit inspections: the bolded figures are to be added together.									
The aim is to demonstrate the extra water available to vines as root growth increases vertically and laterally									
Aim for a root volume to provide max 200 litres of soil water - various combinations of vertical and lateral roots are possible.									
and achievable, either by encouraging deeper growth through ripping, or restricting lateral growth by root pruning									
If vigour is excessive, consider lateral root pruning, but trim only one side of vine row in any one year, then reassess									
<b>NOTE: A higher soil water target may provide greater drought tolerance</b>									
If irrigation water is plentiful, aim for a lower TAW of 100-150 litres (the benchmark optimal)									
<b>Extent of root growth (metres from vine trunk):</b>									
within rows (root growth along the vine bed)			<b>A</b>	1.0	1.0	1.5	1.5	1.5	
between rows (root growth into the inter-row area)			<b>B</b>	1.0	1.5	1.5	2	3	
A x B x 1.0 gives <b>volume of soil (m3) for one metre depth of soil</b>				<b>1.0</b>	<b>1.5</b>	<b>2.25</b>	<b>3.0</b>	<b>4.5</b>	
(soil water in last soil horizon has been calculated to 100cm depth, as indicated by 100cm figure)									
depth of soil metres			Litres/m3 at kPa		TOTAL available water, 10-1500 kPa				
			10	1500	litres				
Sutherlands Creek 0-15cm	0.15	Light clay	473	233	36	54	<b>81</b>	108	162
SutherlandsCk. 15-30cm	0.15	Light medium clay	695	342	53	79	<b>119</b>	159	238
SutherlandsCk. 30-70cm	0.40	Light medium clay	719	339	152	228	343	457	685
SutherlandsCk. 70+(100)cm	0.30	Light clay (sandy)	512	226	86	129	193	258	387
Litres of <b>TOTAL</b> available soil water (10-1500kPa) to depth of one metre for this profile					327	491	736	982	1472
Mount Moriac 0-20cm	0.20	Very fine sandy clay loam	286	63	45	67	<b>100</b>	134	201
Mt.Moriac 20-35cm	0.15	Coarse sandy clay loam	230	40	29	43	<b>64</b>	86	128
Mt.Moriac 35-55cm	0.20	Medium clay (sandy)	438	218	44	66	99	132	198
Mt.Moriac 55-75(100)cm	0.45	Medium clay	401	200	91	136	204	272	409
Litres of <b>TOTAL</b> available soil water (10-1500kPa) to depth of one metre for this profile					208	312	468	624	935
Portarlington 0-20cm	0.20	Light clay	632	342	58	87	<b>131</b>	174	261
Portarlington 20-60cm	0.40	Light clay	758	418	136	204	<b>306</b>	408	611
Portarlington 60-90cm	0.30	Light clay	856	450	122	183	274	365	548
Port. 90-200+(100)cm	0.10	Light clay	767	379	39	58	87	117	175
Litres of <b>TOTAL</b> available soil water (10-1500kPa) to depth of one metre for this profile					355	532	798	1064	1595

**Table 5b. Available Water and Actual Water Content for three Geelong Region Vineyard Soil Profiles**

Description	Depth cm	Texture	Available Water (% v/v)			Horizon thickness*	Water Content in Litres**		
			Readily	Deficit	Total		Readily	Deficit	Total
			30-100	30-300	30-1500		30-100	30-300	30-1500
			%	%	%	cm	%	%	%
Sutherlands Creek	0-15	Light clay	6	14	16	15	9	13	20
Sutherlands Creek	15-30	Light medium clay	8	19	23	15	13	24	55
Sutherlands Creek	30-70	Light medium clay	9	20	25	40	36	73	184
Sutherlands Creek	70-120	Light clay (sandy)	7	18	19	<b>30</b>	22	40	75
MountMoriac	0-20	Very fine sandy clay loam	7	20	22	20	14	27	61
MountMoriac	20-35	Coarse sandy clay loam	6	17	19	15	9	16	31
MountMoriac	35-55	Medium clay (sandy)	5	11	15	20	10	11	16
MountMoriac	55-120	Medium clay	4	11	13	<b>45</b>	17	19	25
Portarlington InValley	0-20	Light clay	7	17	19	20	14	25	48
Portarlington InValley	20-60	Light clay	7	16	22	40	29	47	106
Portarlington InValley	60-90	Light clay	10	30	37	30	30	88	320
Portarlington InValley	90-200+	Light clay	10	17	26	<b>10</b>	10	17	44
*thickness of last horizon is reduced to depth of 100cm to allow calculations to be made for a soil volume of one cubic metre)									
**Figures assume Lateral root growth of one square metre. However, established vines could easily cover 3 square metres, eg. 2.0 metre diameter along vine rows and 1.5 m between rows, thus tripling these volumes.									
Useful Conversion: one mm depth of water over 1 m2 = 1 litre. One cubic metre of soil occupies 1000L									

Table 5c shows the relationship between soil water content and available water. It shows how available water is calculated from volumetric water. For example, Sutherlands Creek (0-15 cm) has a Readily Available Water (RAW) content of 6% (31-25%).

**Table 5c. Available Water and Aeration Porosity for three Geelong Region Vineyard Soil Profiles**

Description	Depth	Texture	Volumetric Water (%v/v) at four tensions (kPa)				Available Water (% v/v)		
			30	100	300	1500	Readily 30-100	Deficit 30-300	Total 30-1500
	cm		%	%	%	%	%	%	%
Sutherlands Creek	0-15	Light clay	31	25	18	15	6	14	16
Sutherlands Creek	15-30	Light medium clay	46	37	27	23	8	19	23
Sutherlands Creek	30-70	Light medium clay	47	38	27	22	9	20	25
Sutherlands Creek	70-120	Light clay (sandy)	34	26	16	15	7	18	19
MountMoriac	0-20	Very fine sandy clay loam	29	22	9	6	7	20	22
MountMoriac	20-35	Coarse sandy clay loam	23	17	6	4	6	17	19
MountMoriac	35-55	Medium clay (sandy)	29	24	18	14	5	11	15
MountMoriac	55-120	Medium clay	26	23	15	13	4	11	13
Portarlington InValley	0-20	Light clay	42	35	24	23	7	17	19
Portarlington InValley	20-60	Light clay	50	43	34	28	7	16	22
Portarlington InValley	60-90	Light clay	57	47	27	30	10	30	37
Portarlington InValley	90-200+	Light clay	51	41	33	25	10	17	26

Note: Lab measurements are performed on soil that has been ground to pass a 2mm sieve, i.e., pore structure has been destroyed. Smaller pores hold onto water more tightly. To allow for this effect, tensions for lab-prepared soil are increased: field capacity is set at 30 kPa instead of 10 kPa, and 60 kPa=100kPa. Beyond 200 kPa, the differences between disturbed and intact soil are negligible. The deficit limit has been measured at 300 kPa, which is a conservative limit for clays, but an upper limit for clay loams. Large pores that may have existed in undisturbed soil are destroyed by grinding, leaving only smaller-sized pores. Large pores are more easily emptied of water, i.e., to empty small pores of water, more suction (tension) must be applied. This effect is much greater in clay soil and minor in i.e. (structureless) sandy soil. This is the principle behind tensiometers: as the tensiometer reading increases, we know that roots must work harder, to extract water from increasingly smaller pores; which requires more energy.

## Using Volumetric Water Data to calculate Irrigation Volumes

Soil water monitoring equipment tells us when the soil is dry enough to require irrigation, but they generally don't tell us how much water to apply. For efficient irrigation, we need to know about both timing and volume. We also want to know the soil's water-holding capacity, so that we can work out how much irrigation water to apply to bring soil moisture back up from the re-fill point to field capacity.

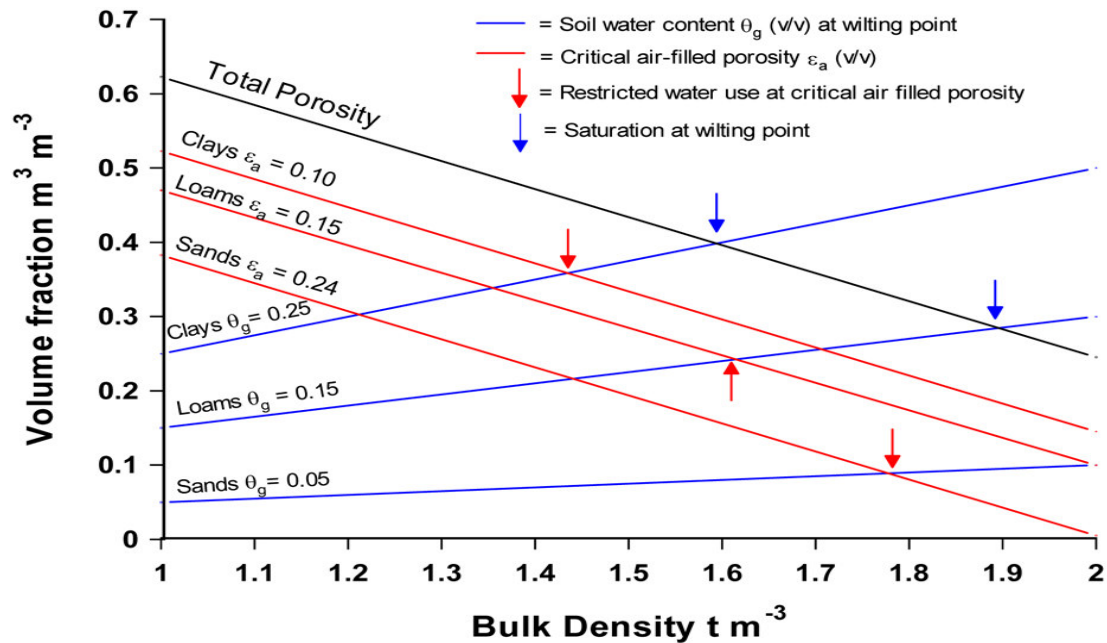
We can approximate soil water-holding capacity from RAW tables, which are commonly based on soil texture. A clay soil generally holds more water than a sandy soil. As a general rule, RAW (% water as a % of soil volume) are: coarse sand, 3%; fine sandy loam, 6%; loam, 8% clay-loam, 6 to 8%; and (heavy) clay soils, 6%. However, approximations based on texture can be misleading. A well-structured clay soil is likely to have a much higher RAW than a poorly structured clay. The poorly structured clay may well hold a lot of water and may feel moist to the touch, but may hold onto the water too tightly for plant roots to extract it. Laboratory analyses that actually measure the moisture held at a given suction value provide a more accurate guide (see site-specific volumetric water data in Appendix). Although a clay soil has theoretically a greater range of plant-available moisture (see Figure 6, page 11), root growth can be slower. Total length of roots per unit volume of soil is thus reduced and a smaller fraction of plant-available soil water is actually extracted. Consequently, there is a much greater discrepancy between plant-available, as opposed to plant-extractable soil water in a clay soil compared to a sandy soil.

RAW data is usually presented in units of mm of water per cm of soil depth. This data can then be converted into a more for practical unit, such as litres per cubic metre of soil, so we can work out how much water to apply. Where the irrigation water and plant roots are evenly distributed over the whole planting area, water storage and plant water use are commonly measured in mm. However, where drip irrigation is used, the irrigation water and roots are only distributed over a small area of the field. In these cases, it is often easier to use litres to describe both the water use and water storage in the plant root zone. This also has the advantage of enabling the simple calculation of irrigation time as the discharge from drip systems is also commonly reported in litres/hour (1 mm depth of water = 1 L over 1 m<sup>2</sup>).

## Waterlogging, Infiltration Rate and Air-filled Pore Space

These three criteria are discussed together because they are related (see also the Least Limiting Water Range concept, below). The relationship between soil moisture and porosity is an inverse one: as the soil dries, air-filled pore space (also called air-filled porosity or aeration porosity) increases (Fig. 4). The diagram shows that the critical air-filled porosity is related to compaction: more compaction (higher bulk density) means less aeration. Also, sands can be compacted to a greater degree and can still have better aeration than clays, i.e. compaction of clays should be avoided.

Figure 4. Relationship between soil water content and porosity



Source: (MacEwan et al 2009). Conversion : Volume fraction m<sup>3</sup>/m<sup>3</sup> x 100 = % v/v

## Waterlogging

Waterlogged soils have inadequate aeration for vine roots; they need at least 10% air-filled pore space, preferably 15%. Early waterlogging affects new root growth and can delay initial shoot growth by up to 10 weeks after bud break (Freeman and Smart 1976). Van Zyl (1988) found root growth was adversely affected when soil water content remained close to saturation for long periods and improved if the soil was allowed to dry out appreciably. Irrigating when 25 and 50 % of the *total* plant available water had been used, resulted in were 190 and 300 actively growing root tips per m<sup>2</sup>. However, excessive drying had a negative effect. Irrigation when 75% of the total plant available water had been used, a peak of approximately 40 tips/m<sup>2</sup> at flowering occurred and new root growth was less than this for the rest of the season. Freeman and Smart (ibid) also found that irrigation below saturation was preferable: when irrigation was applied at a rate of 100 % of evaporation, root growth was stimulated compared with irrigation at 300 % of evaporation.

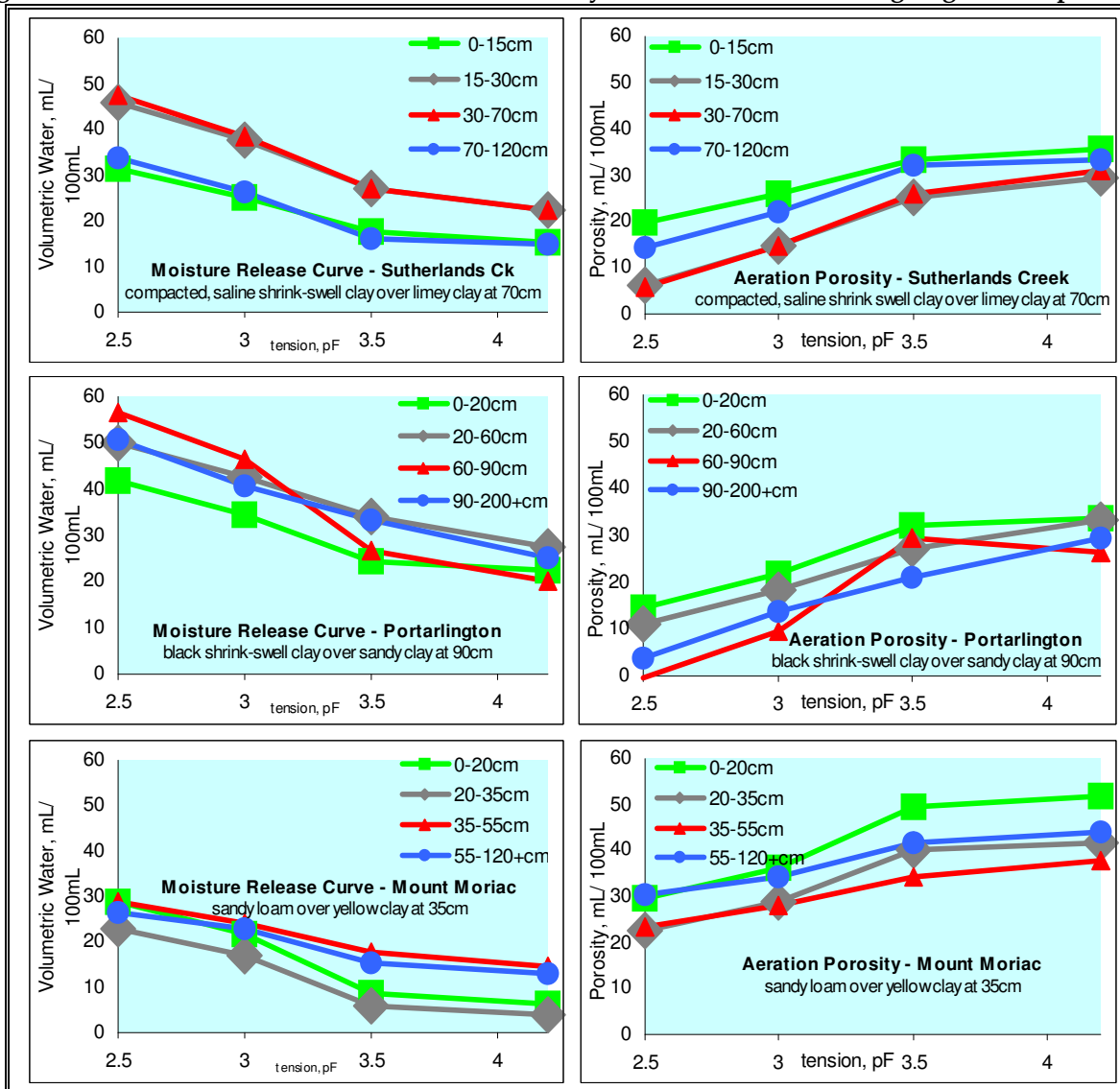
Dormant vines can withstand several weeks of waterlogging, but active roots may die after only five days. So the begging question is: are the subsoils likely to remain waterlogged for more than five days during the growing season? The answer is that it will depend on the amount of heavy winter rain and the timing of later spring rains, and, whether the subsoil was already close to saturation. The most likely time for growing season waterlogging is early spring. Following the 2006 drought, for example, where rainfall was generally half the average, subsoil moisture reserves were most likely very low. It would have taken an extraordinarily wet winter and spring to saturate the subsoil and hence become waterlogged. Low-lying areas would of course be at greater risk.

Table 5d shows the relationship between soil water, aeration and total porosity for the three Geelong profiles at four important levels of soil water: field capacity, no stress and deficit limits, and wilting point (10, 60, 300, 1500 kPa). Roots in the Sutherlands Creek profile were restricted to 30 cm. This could be explained by the very low air-filled porosity from 15 cm onwards (6% at field capacity and still only 15% at the no stress limit (no stress refill point), indicating compaction. So despite a high water holding capacity (46% at field capacity), roots are effectively waterlogged until the soil dries beyond the normal refill point. The situation for the Portarlington profile is similar: water holding capacity is very high (57% at 60-90 cm), and, although not compacted, air-filled porosity is very low (0 and 10% at field capacity and the no stress limit respectively), i.e., the soil is close to saturation and roots are effectively waterlogged. Conversely, the Mt Moriac subsoil clay has a relatively low water holding capacity (29% at field capacity for the top 20 cm of clay, 35-55 cm), but air-filled porosity is a healthy 23% and so roots can make use of water in this subsoil. The differences show that, like waterholding capacity, aeration porosity can also vary dramatically between clays.

**Table 5d. Available Water and Aeration Porosity for three Geelong Region Vineyard Soil Profiles**

Physical Analyses	Depth		Volumetric Water (%v/v)				Porosity at each tension				
			at four tensions (kPa)				( aeration & total, % v/v )				
Description	cm	Texture	30 %	100 %	300 %	1500 %	30 %	100 %	300 %	1500 %	Total %
			2.5	3.0	3.5	4.2	2.5	3.0	3.5	4.2	
Sutherlands Creek	0-15cm	Light clay	31	25	18	15	20	26	33	36	51
Sutherlands Creek	15-30cm	Light medium clay	46	37	27	23	6	15	25	30	52
Sutherlands Creek	30-70cm	Light medium clay	47	38	27	22	6	15	26	31	53
Sutherlands Creek	70-120cm	Light clay (sandy)	34	26	16	15	14	22	32	33	48
MountMoriac	0-20cm	V. fine sandy clay loam	29	22	9	6	29	36	50	52	58
MountMoriac	20-35cm	Coarse sandy clay loam	23	17	6	4	23	29	40	42	46
MountMoriac	35-55cm	Medium clay (sandy)	29	24	18	14	23	28	34	38	52
MountMoriac	55-120+cm	Medium clay	26	23	15	13	31	34	42	44	57
Portarlington InValley	0-20cm	Light clay	42	35	24	23	14	22	32	34	56
Portarlington InValley	20-60cm	Light clay	50	43	34	28	11	18	27	33	61
Portarlington InValley	60-90cm	Light clay	57	47	27	20	0	10	29	26	56
Portarlington InValley	90-200+cm	Light clay	51	41	33	25	4	14	21	29	54

**Fig. 4. Moisture Release Curves and Aeration Porosity Curves for three Geelong Region soil profiles\***



\*The x-axis is presented as a logarithmic (pF) scale: pF 2.5, 3.0, 3.5 and 4.2 correspond to soil tensions of 30, 100, 300 and 1500 kPa. See note for Table 5c for further explanation of why these tension values are used in a laboratory.

### Infiltration Rate

A well-structured soil has a (saturated) infiltration rate faster than 25 mm/hour. Slow infiltration rates (less than 20 mm/h, equivalent to 500 mm/day) can mean poor drainage and a greater potential for waterlogging. Poorly drained, saturated subsoil is likely to take days, weeks or months to drain. Infiltration rate was not measured for the profiles described in this report. Based on soil texture, the sandy loam topsoil of the Mt. Moriac profile probably has a satisfactory infiltration rate. However, the profile as a whole is not well-drained. What we really want to know is the infiltration rate of the least permeable horizon in the soil. The topsoil may be highly permeable, but in most duplex profiles, the main restriction to drainage is subsoil clay. The infiltration rate of the subsoil is probably less than 10 mm/h, which is typical of poorly structured subsoil clay, and explains why subsoils often become waterlogged. For cracking clays with strong shrink-well properties (Sutherlands Creek, Portarlington), the infiltration rate can fall from around 25 mm/h to as little as 1–2 mm/h as the cracks close up. In contrast, in permeable soils, water from 2 L/hr drippers commonly reaches 60cm after 6 hours (i.e., a rate of 100 mm/h)

So, how should slow-draining soils be irrigated to manage the conflict between sufficient irrigation and adequate aeration? Cracks in soil initially allow the soil to accept high rainfall rates, but as the soil wets from the bottom up, the cracks close, the initial infiltration rate falls from 25 to 1-2 mm/hour, and air-filled porosity reduces dramatically. So, to maintain air-filled porosity above the 10% minimum – in the

main root zone, it is suggested by this author that cracking clays should be kept drier than field capacity: wet them back up to where shallow-placed tensiometers (in the middle of the main root zone, i.e., around 30 cm) read no more than 30 kPa rather than 10 kPa. Vine growth may thereby be improved.

Slow-draining soils require slow irrigation rates to avoid runoff. To avoid (temporarily) waterlogging the soil, short run times are required, e.g., 6 hours using one 4L/h dripper per vine. This is a general guide for efficient drip irrigation. For cracking clays, avoid irrigation run times of more than 12 hours. Scheduling is fine-tuned from tensiometer readings (placed within the middle of the main fibrous root zone).

**Table 6. Soil structural assessment with respect to infiltration rate**

Rate of water entry (mm/h)	structure quality
0-10	Very poor
30-70	Moderate
10-30	Poor
> 70	Good

### Soil Strength (compaction)

The effective root zone of own-rooted vines is limited to soil a penetration resistance of 2 MPa (using a standard penetrometer), measured when the soil is at field capacity (Myburgh et al. 1996; Van Huyssteen 1983). Penetrometer readings may not be very useful guide for cracking clays, because roots will take advantage of the cracks common in swelling clay soils.

### The Least-Limiting Water Range ( LLWR ) Concept

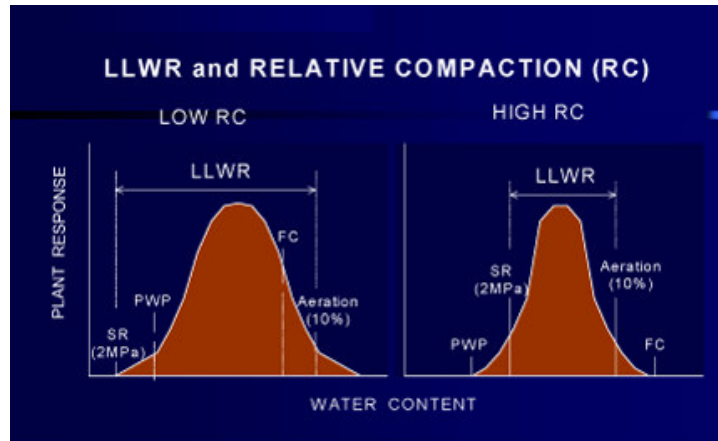
The concept of non-limiting water range (LLWR) integrates three physical factors that affect plant (root) growth: soil water, aeration and compaction (Letey 1985; refined by da Silva et al. 1994). Since it is conceptually well based, it should be used as a simple procedure to be used by farmers and field technicians to evaluate soil quality and propose mitigation management techniques to overcome the soil physical constraints factors.

The LLWR is defined as the soil water range over which plant growth is least limited. The upper end (high soil water content) is controlled by soil porosity and sufficient air-filled soil pores (usually 10% v/v). The lower end of the range (low soil water content) is determined by the water content at which either soil strength (max. for vine roots is usually 2 MPa) or available water limits plant growth (soil that is drier than 60 kPa can cause moisture stress in vines)

The LLWR concept can also help managers to recognise when soil amelioration is warranted, such as deep-ripping (to reduce soil compaction for improved root growth and better water permeability of soil to water. An understanding of the link between these components can aid irrigators to manage specific soil types, to determine appropriate irrigation rates and volumes that will meet vine requirements while ensuring sufficient soil aeration for good root growth.

The three components are inversely related: as soil water content increases, the soil's pores become field with water, and the volume of air-filled pores decreases. A compacted soil has fewer air-filled pores to begin with, so it becomes effectively waterlogged more quickly. Soil aeration may restrict gas diffusion and thus root growth at moisture lower than field capacity, and mechanical impedance may restrict root growth at moisture greater than the value correspondent to permanent wilting point.

As all physical soil factors are affected by soil structure, there is a dynamic variation of LLWR for each soil as soil bulk density changes over time, implying variation of root growth and function with temporal variation and variations related to soil management. The LLWR becomes narrower as the bulk density increases and poor structure occurs (Figure 4). For instance, soil aeration may restrict gas diffusion and thus root growth at moisture lower than field capacity, and mechanical impedance may restrict root growth at moisture greater than the value correspondent to permanent wilting point.



Source: Reichert et al (2008). Soil Moisture and Structure as Key Factors for Crop Production

### Chemical Benchmarks

Table 7 presents chemical data from the three soil profiles. According to these benchmarks (Table 3b), all three profiles have a low potassium: magnesium K:Mg ratio, indicating a need for potassium (K) fertiliser. However, K-fertiliser is not recommended unless petiole analysis indicates a need. Excess potassium can reduce grape juice quality.

The most significant issue, chemical or physical is very high salinity (Electrical Conductivity, EC) in the Sutherlands Creek profile. Because the level is very high, it is currently the single most important soil issue and demands immediate attention. Because chloride (Cl) is also high, we know that the high EC is not due to a recent application of fertiliser (all fertilisers are salts), and is more likely to be associated with use of saline irrigation water. The high chloride (Cl) will also have a direct toxic effect on vines. At the current level of EC, the expected decline in yield due to salinity is close to 50%. High EC also makes it harder for plants to extract water from soil (the osmotic effect of high EC). In extreme cases, a soil may feel moist, but plants may still be suffering from moisture stress.

The Sutherlands Creek soil requires leaching. This can be achieved using saline water, but leaching fractions will need to be high. Based on the current soil EC, the leaching fraction is likely to be in the order of 30%.

**Table 7. Benchmark Chemical Characteristics for three Geelong Region Vineyard Soil Profiles**

Laboratory Analyses - Chemical																
		pH and Salinity Parameters					Exchangeable cations (ammonium acetate, with prewash)									
Description		pHc	pHw	EC	Cl	Ca	Mg	K	Na	CEC	Ca%	Mg%	K%	Na%	Ca:Mg	K:Mg
	cm	-	-	dS/m	mg/kg	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	%	%	%	%	-	
Sutherlands Creek	0-15	7.5	8	0.29		14	7.4	1.1	1.4	23	58	32	5	6	1.8	0.15
Sutherlands Creek	15-30	7.4	7.9	1	710	12	14	1.1	4.9	32	38	43	3	16	0.9	0.08
Sutherlands Creek	30-70	7.7	8.1	1.4		9.8	15	0.95	5.4	31	31	49	3	17	0.6	0.06
Sutherlands Creek	70-120	8.7	9.3	0.95		20	12	0.34	5.6	38	52	32	<1	15	1.6	0.03
MountMoriac	0-20	7	7.3	0.16		6.9	1.1	0.13	0.09	8.3	84	14	2	1	6.2	0.12
MountMoriac	20-35	5.4	6	0.07		1.3	0.58	<0.05	0.12	2	64	28	1	6	2.3	0.09
MountMoriac	35-55	5.5	6.7	0.21		1.1	4.9	0.1	2	8.1	13	61	1	25	0.2	0.02
MountMoriac	55-120	6	7.1	0.26		0.97	5.9	0.13	2.6	9.6	10	62	1	27	0.2	0.02
Portarlinton InValley	0-20	5.6	6.2	0.12		24	10	2.8	0.75	38	64	27	7	2	2.4	0.28
Portarlinton InValley	20-60	5.7	6.3	0.23		24	15	1.9	2.3	44	56	35	4	5	1.6	0.13
Portarlinton InValley	60-90	5.9	6.3	0.52		23	19	0.98	2.8	47	50	42	2	6	1.2	0.05
Portarlinton InValley	90-200+	6.6	7.2	0.25		23	29	1.7	5.5	59	39	49	3	9	0.8	0.06

## Soil Profile Descriptions

This section presents analyses of local soil profiles. Descriptions begin with obvious, visible, features and their relevance to vine (root) growth. Laboratory analyses (physical and chemical) provide extra information about (invisible) root zone constraints. The relevance of landscape (elevation, slope) and climate (change) are also incorporated into the discussion. All of these factors, physical, chemical, landscape and climate, help to inform whether amelioration (liming, ripping, leaching, mulching) is warranted, based on ideal benchmarks for viticultural soils.

## Landscape

Landscape is an important management consideration. For example, vines on flat country in these poorly drained soils are more likely to suffer waterlogging, making sloping country more desirable. Sloping land also has better air drainage (less frost risk). The photo below shows that most of the Region is still used for grazing and cropping, for good reason. Most of the vines on the Geelong Region are either on sloping land, or on land that is higher in the landscape.

A discussion of landscapes and how they formed (geomorphology) is beyond the scope of this report. For more information, refer to: A Land Resource Assessment of the Corangamite Region (Robinson et al. 2003). The website [http://www.dpi.vic.gov.au/dpi/vro/coranreg.nsf/pages/soil\\_landform\\_map](http://www.dpi.vic.gov.au/dpi/vro/coranreg.nsf/pages/soil_landform_map) contains a detailed geomorphic and landform map of Geelong, and pdfs for each soil-landform unit, which provide detail on climate, geology, topography, soil type and depth, and soil pit data.

**Plate 1. Aerial view of the gently undulating basalt plains near Bannockburn**



(photo: Robinson et al. (2003): Corangamite Land Resource Assessment; soil-landform unit 119)

## Main Soil Types

“The Bellarine Peninsula is a gently to moderately undulating plain with the majority of soils consisting of grey-brown sedimentary sandy loams overlying mottled, medium to heavy textured clay. The Bellarine Hills are a significant variation, being heavy black self mulching clay loams” (Geelong City State of the Environment Report, 2001; [www.geelongcity.vic.gov.au/soe](http://www.geelongcity.vic.gov.au/soe)). Most local farmers are familiar with these two main soil types and their occurrence on the plains and hills of the Geelong Region and may describe them as either duplex soils or cracking clays. Soil scientists describe them as Sodosols or Vertosols. However, farmers also know that variations occur within these two main soil types. A couple of variations - differences in the depth and structure of cracking clay profiles - are described in this report, in order to demonstrate that variations require specific management.

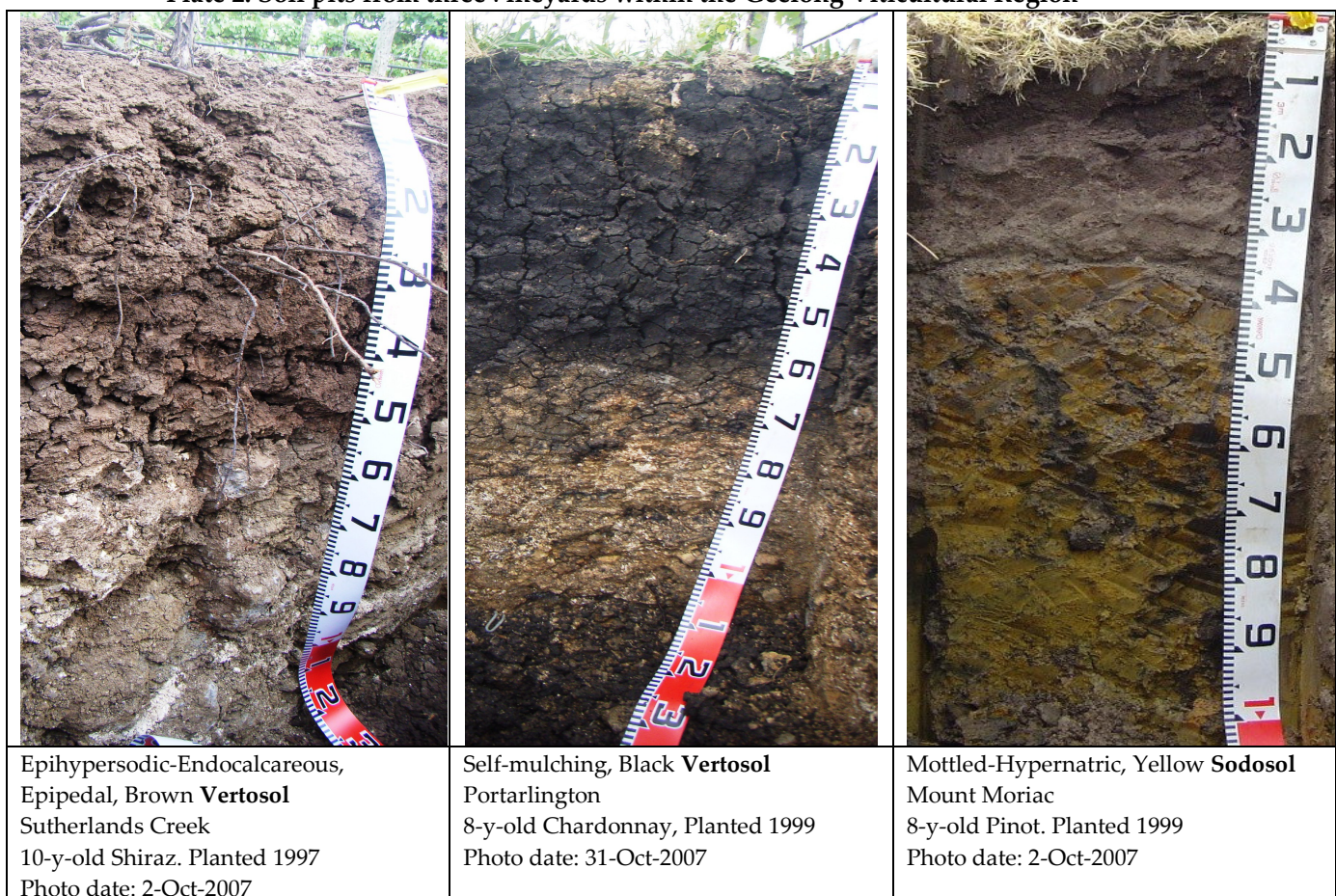
## Location of Soil Pits and Visible Profile Features

In October 2007, soil pits were inspected on three established vineyards within the Geelong viticultural Region, representing the main soil types of the Bellarine Peninsula and Barabool Hills:

- Sutherlands Creek (*Strathmore* Vineyard,), in compacted, shrink-swell soil (Brown Vertosol)
- Portarlinton (*Scotchmans Hill* Vineyard), in strongly structured, Black Vertosol. Two pits were dug here to investigate differences in vigour due to deeper root depth in a depression compared to a rise.
- Mount Moriac (*Kurabana* Vineyard), texture contrast soil profile (Yellow Sodosol)

Based on colour differences and degree of cracking, it is easy to distinguish topsoil from subsoil in each profile. Photos of air-dry soil are also presented, arranged in boxes according to horizons. Soil structure is often easier to see in dry soil. The blocky structure of the Mt. Moriac subsoil is clearly evident in the boxed soil, but not so obvious in the moist profile photo (around field capacity at the time of inspection).

Plate 2. Soil pits from three Vineyards within the Geelong Viticultural Region



Note: Photo 3 is of a profile on a hill crest, whereas the photo in Plate 5 is of a pit in a depression, 20 m downslope.

Deep topsoils are desirable, because they generally have better structure and lighter texture (less clayey), so root growth is better. The main root zone was restricted to the relatively shallow topsoil (30-40 cm). Unless roots grow into the subsoil, these shallow-rooted vines will be prone to moisture stress during dry conditions and will need frequent irrigation. Where irrigation water is plentiful, shallow roots are actually desirable for effective practice of Regulated Deficit Irrigation (see relevant section), because it's easy to control vigour just by turning off the tap. However, where water is scarce, deep roots may be essential just to keep the vines alive, particularly in low rainfall areas (less than 500 mm). Vineyards in the Geelong Region District typically receive 1-2 ML/ha (equivalent to 100-200 mm) of irrigation water (Hugh, pers.com. 2008). An exception are the black cracking clay profiles in which significant root growth was evident to almost the entire depth of the black horizon (see discussion for Portarlinton profile).

**Sutherlands Creek (Shiraz, planted 1998, i.e., 10 years old)**

The photo of this soil pit profile shows most of the vine roots in this block are restricted to a (shallow) depth of about 30 cm, even though this clay horizon (above the calcareous clay/ limestone boulder layer) is around 70 cm. Although subsoil structure is less than ideal, given the age of these vines, we would expect to find several roots growing to the full depth of the clay subsoil, and one or two in the softer parts or cracks of the carbonate layer. The centre row shows photos of air-dried soil in trays. Soil structure is sometimes easier to see in dry soil, compared to a moist soil pit profile. The boxed soil shows clearly that the upper subsoil is compacted; structure is cloddy (massive) and there is little evidence of smaller aggregates (soil fragments) that we can see in the topsoil (0-15 cm).

We also need to check whether the roots are also restricted due to some chemical problem. Is the subsoil highly alkaline or highly saline? Chemical tests show the soil is high in exchangeable sodium (i.e. sodic), so gypsum should be incorporated in the rip lines to displace the sodium and help keep the rip lines permeable to water movement (roots can also follow the rip lines). The soil is also saline throughout the profile, which is further justification for ripping to improve drainage, hence leaching of excess salt. High soil salinity (especially salt in the form of sodium chloride) is directly toxic to vines. High salinity regardless of its source makes it harder for vines to suck water from soil.

**Plate 4. Compacted (to 30 cm depth), shrink-swell clay soil overlying limestone**

Epihypersodic-Endocalcareous , Epipedal, Brown Vertosol

(Strathmore Vineyard, Sutherlands Creek, near Bannockburn. 10-y-old Shiraz. Planted 1997)

Showing profile and air-dry soil in trays (pit photo date: 2-Oct-1997)

		<p>A1: 0-15 cm. light clay (very fine sandy)                  pHw 7.5 EC 0.29dS/m, ESP 6%.                  Volumetric Water &amp; Aeration (% v/v):                  - at Field capacity: 31% &amp; 20%                  - at Stress Limit for RAW: 25%, 26%                  - at Stress Limit for DAW: 18%, 33%                  - RAW+DAW: 6+7 = 13% (high)                  Soil strength at field capacity: weak</p>
		<p>B21: 15-30 cm. light-medium clay                  pHw 7.4, EC 1.0dS/m, ESP 16%.                  Volumetric Water &amp; Aeration (% v/v) at:                  - at Field capacity: 46%, 6%                  - at Stress Limit for RAW: 37%, 15%                  - at Stress Limit for DAW: 27%, 25%                  - RAW+DAW: 9+10 = 19% (high)                  Soil strength at field capacity: weak</p>
		<p>B22: 30-70 cm. light-medium clay                  pHw 7.7, EC 1.4dS/m, ESP 17%.                  Volumetric Water &amp; Aeration (% v/v) at:                  - at Field capacity: 47%, 6%                  - at Stress Limit for RAW: 38%, 15%                  - at Stress Limit for DAW: 27%, 26%                  - RAW+DAW: 9+11 = 20% (high)                  strength at field capacity: firm</p>
		<p>B3 lower 70-120 cm+. medium clay                  pHw 8.1, EC 0.95 dS/m, ESP 15%.                  Volumetric Water &amp; Aeration (% v/v) at:                  - at Field capacity: 34%, 14%                  - at Stress Limit for RAW: 26%, 22%                  - at Stress Limit for DAW: 16%, 32%                  - RAW+DAW: 8+10 = 18% (high)                  strength at field capacity: firm</p>

So, for this Sutherlands Creek block, radical intervention is justified to break up the impenetrable soil. Deep-ripping to 70 cm will double effective root depth, offering greater resilience to drought conditions. Gypsum in the rip lines will help to keep the rip lines permeable to water, which will aid in excess salt

out of the main root zone and further down the soil profile. Permeable rip lines can also improve recharge into the subsoil during heavy rainfall events, minimising runoff and waterlogging). Ripping will inevitably cause some root damage, so only one side of the vine row should be ripped in a single year. There are a few other issues associated with deep-ripping (see relevant section later on in the report).

### Portarlington (Chardonnay, planted 2000, i.e., 8 years old; Plate 1, Photo 2)






The profiles of Sutherlands Creek and Portarlington (Scotchmans Hill) are both cracking clays. However, vigour in the Portarlington soil is stronger, even excessive in low-lying sections where the soil is deeper. Root growth at Sutherlands Creek is restricted to the top 30-35 cm of the 70 cm thick (grey) clay horizon. Roots in the Portarlington profile were concentrated within the top 40 cm. However, they were also common throughout the 60-70 cm thick (black) clay horizon (“common” is defined as 2-5 medium-sized roots, 2-5 mm diameter and/or coarse roots >5 mm, per 100x100 mm of pit face; McDonald et al 1984). A few (1or 2) medium-sized, roots extended to 2 metres, into the yellow (sandy, calcareous) clay.

#### Plate 5. Strongly-structured, shrink-swell clay soil overlying limestone

Self-Mulching Haplic Black Vertosol

(Scotchmans Hill Vineyard, Portarlington, 8-y-old Chardonnay. Planted 1997)

Showing profile and air-dry soil in trays (pit photo date: 2-Oct-1997)

		<p>A1: 0-20cm. light clay (very fine sandy) pHw 6.2 EC 0.12dS/m, ESP 2%. Volumetric Water &amp; Aeration (% v/v): - at Field capacity: 42% &amp; 14% - at Stress Limit for RAW: 35%, 22% - at Stress Limit for DAW: 24%, 32% - RAW+DAW: 7+9 = 16% (high) Soil strength at field capacity: weak</p>
		<p>B21: 20-60cm. light-medium clay pHw 6.3, EC 0.23dS/m, ESP 5%. Volumetric Water &amp; Aeration (% v/v) at: - at Field capacity: 50%, 11% - at Stress Limit for RAW: 43%, 18% - at Stress Limit for DAW: 34%, 27% - RAW+DAW: 7+9 = 16% (high) Soil strength at field capacity: weak</p>
		<p>B22: 60-90cm. light clay pHw 6.3, EC 0.52dS/m, ESP 6%. Volumetric Water &amp; Aeration (% v/v) at: - at Field capacity: 57%, 0% - at Stress Limit for RAW: 47%, 10% - at Stress Limit for DAW: 27%, 29% - RAW+DAW: 10+20= 30% (v. high) strength at field capacity: weak</p>
		<p>B3 lower 90-200+cm. light clay pHw 7.2, EC 0.25dS/m, ESP 9%. Volumetric Water &amp; Aeration (% v/v) at: - at Field capacity: 51%, 4% - at Stress Limit for RAW: 41%, 14% - at Stress Limit for DAW: 33%, 21% - RAW+DAW: 10+8 = 18% (high) strength at field capacity: firm</p>

On the crest, vigour is satisfactory because the black clay is only 60 cm deep and soil water supply is more easily controlled. However, in the depression of the block, black clay extends to 90 cm and vigour is excessive. Although only relatively few rows are affected, the difference in vigour is sufficiently problematic that managers intend to modify to the irrigation system to restrict irrigation water to lower-lying sections. In contrast to the Sutherlands Creek profile, the reduction in roots below 40 cm did not appear to be due to compaction; the soil remains relatively friable as it dries. Rather, the reduction appears to be due to low aeration porosity in the deeper part of the black clay horizon. At a soil water

tension of 60 kPa (the lower limit for no vine water stress in clay soil), aeration porosity at 60cm is only 10% (v/v). The underlying sandy clay (90-200+ cm) is well-aerated at a relatively high water content (aeration porosity is 14% at a water tension of 60 kPa), which suggests that roots at this depth may have sufficient air to be active. Armed with this knowledge, irrigation management and placement of soil water sensors can be improved. A deep-placed tensiometer (at the bottom of the black clay horizon) can determine whether vine roots are utilising significant amounts of soil water beyond the main root zone. If so, irrigation water can be delayed until this part of the profile dries to at least 60 kPa, providing visible indicators of drought stress (pruning weights, berry size, soluble solids) indicate satisfactory vigour. Low aeration porosity means active root growth beyond about 60cm may be delayed until later in the season, when the deeper soil is drier.






### Mt.Moriac (Pinot Noir, planted 2000, i.e., about 8 years old)

The photo shows a classic duplex profile of a lighter-textured (sandy loam) grey topsoil, overlying dense, yellow, clay subsoil (in fact this profile is similar to the 'people's choice' for Victorian State Soil ([www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil\\_vic](http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_vic))).

#### Plate 5. Mount Moriac texture-contrast soil profile (Mottled-Hypernatric, Yellow Sodosol)

(Kurabana Vineyard: 8-y-old Pinot. Planted 1999)

Showing profile and air-dry soil in trays (pit photo date: 2-Oct-1997)

		<p>A1: 0-20cm. clay loam (very fine sandy) pHw 7.3, EC 0.16dS/m, ESP 1%. Volumetric Water &amp; Aeration (% v/v): - at Field capacity: 29% &amp; 29% - at Stress Limit for RAW: 22%, 36% - at Stress Limit for DAW: 9%, 50% - RAW+DAW: 7+13 = 20% (high) Soil strength at field capacity: weak</p>
		<p>A2: 20-35cm. clay loam (coarse sandy) pHw 6.0, EC 0.07dS/m, ESP 6%. Volumetric Water &amp; Aeration (% v/v) at: - at Field capacity: 23%, 23% - at Stress Limit for RAW: 17%, 29% - at Stress Limit for DAW: 6%, 40% - RAW+DAW: 6+11 = 17% (high) Soil strength at field capacity: weak</p>
		<p>B21: 35-55cm. medium clay pHw 6.7, EC 0.21dS/m, ESP 25%. Volumetric Water &amp; Aeration (% v/v) at: - at Field capacity: 29%, 23% - at Stress Limit for RAW: 24%, 28% - at Stress Limit for DAW: 18%, 34% - RAW+DAW: 6+11 = 17% (high) strength at field capacity: firm</p>
		<p>B22: 55-100+ cm. medium clay pHw 7.1, EC 0.26dS/m, ESP 27%. Volumetric Water &amp; Aeration (% v/v) at: - at Field capacity: 26%, 31% - at Stress Limit for RAW: 23%, 34% - at Stress Limit for DAW: 15%, 42% - RAW+DAW: 6+11 = 17% (high) strength at field capacity: firm</p>

Two features indicate this soil probably suffers from periodic waterlogging: mottled subsoil clay, and a slightly lighter (bleached) topsoil immediately above the clay, compared to topsoil colour near the surface. Bleaching indicates the minerals which give the soil colour have been leached out through regular exposure to prolonged waterlogging. Bleaching is more clearly seen in dry soil. A few roots (two or three), could be seen growing up to 40cm into the subsoil, although no roots were obvious beyond that depth. It is likely that roots move into the B horizon only when moisture conditions are favourable (not

waterlogged). Roots probably show greater growth into this horizon during drier rather than wetter years, which is handy, because it is in drier years when we want to encourage deeper root growth.

So, even in the absence of a chemical analysis we know that the subsoil clay is dense and poorly structured, which means it is only slowly permeable to water (movement of water through the subsoil, i.e., hydraulic conductivity is probably less than 0.5 cm/hour). The chemical analysis confirms that the poor structure is mainly due to a very high (hypernatric) sodium content. Sodic soil can be improved by gypsum (calcium sulphate). Gypsum works by displacing sodium with calcium.

Despite the negative physical and chemical features of the subsoil, the vineyard manager reported satisfactory vine vigour. So, should there be any intervention? The short answer is no.

Deeper root growth may encourage an increase in vigour, which is not wanted. Also, vigour is harder to control with irrigation management, in deeper-rooted plants. If rainfall annual were to decline permanently (over the life of the vines), then perhaps there would be a greater imperative to increase root depth to take advantage of subsoil moisture. Predictions are that rainfall in the Geelong Region will decline by 20% and temperatures will increase by 2° C by 2050. While this is a long way down the track, between now and then, there will almost certainly be more (severe) droughts.

Mt. Moriac enjoys a higher rainfall than the Regional average. Annual rainfall at Mt. Moriac is around 700mm (based on local reports), compared to around 537mm for the Greater Geelong district (Bureau of Meteorology website: [www.bom.gov.au](http://www.bom.gov.au)). Further, elevation is over 200m, so temperatures are lower, hence evapo-transpiration is lower.

For every 100 m increase in elevation, (moist) air temperature declines by 0.6 °C (1.0 °C for dry air; known as the adiabatic lapse rate (see website: [www.physics.usyd.edu.au/Ag/climatology\\_lecture06](http://www.physics.usyd.edu.au/Ag/climatology_lecture06)). So, drought conditions will have a more severe impact in localities that already have a lower rainfall. However, let's assume that rainfall is permanently reduced from 700 to 600 mm from now on, in which case we want to see deeper root growth. If conditions are drier, can we expect greater root growth into the subsoil even if there is no intervention? The answer is probably yes.

At the time of inspection (early October 2007), the subsoil was very moist, approximately at field capacity (pF2.5, equivalent to 10 kPa in the field). The vineyard manager reported last winter's rainfall had been relatively normal, so we can assume that soil moisture that we saw in the pit is typical for this time of the year, i.e., subsoil moisture is close to field capacity or slightly waterlogged and is probably still moving slowly downwards.

We can also see that the vines have started to shoot, i.e., they have come out of winter dormancy and could therefore suffer from waterlogging if wet conditions were to persist, i.e., if heavy spring rains. Dormant vines can cope with water logged conditions for weeks at a time, but it only takes 3 days of waterlogging to affect non-dormant vines.

Complete waterlogging is not necessary to affect vine growth. If air-filled porosity (the percentage of pores in the soil that are filled with air) remains at less than 10%, gaseous exchange is inadequate and root growth will suffer. Physical analyses determined that air-filled porosity at field capacity was 8% in the top part of the subsoil (at 35-55 cm; see appendix for physical analyses), which is below the required 10% minimum for adequate root aeration. However, AFP actually increases with depth (AFP is 17% at 55-75 cm), which is well above our required 10% minimum. Therefore, it can reasonably be expected that under moist conditions, when this subsoil is soft and therefore offers little resistance to root penetration, it remains sufficiently well-aerated to allow roots to survive and seek out subsoil moisture to depths of at least 75 cm probably well beyond one metre (assuming that the soil remains relatively uniform).

In summary, no intervention is recommended for this block at this time, based on:

- The manager's feedback that vine vigour (of well-established vines that are over five years old) is currently satisfactory, and
- Soil pit inspection data, which shows roots are actually growing into the dense clay subsoil, and
- Soil chemistry and physics data, which found satisfactory aeration within the available soil moisture range (i.e., at field capacity and therefore also in progressively drier soil), which suggests vine roots can access subsoil moisture regardless of any intervention.
- Current Climatic conditions at Mt Moriac (rainfall and temperature) means the possible impact of more frequent drought are likely to be less damaging here than in hotter, drier parts of the Region.

## Soil Amelioration Techniques for Increasing Vine Root Growth

In districts with low rainfall (less than 700 mm) and high evapotranspiration (more than 1400 mm/year), deep-rooted vines will fare better than shallow rooted vines in a prolonged drought (i.e. no irrigation) because they can access a greater volume of soil moisture. In view of long-term (more than 20 years) predictions for a drier climate, all vineyards in the Geelong Region should investigate the economics of increasing root depth. Money should be the bottom line for deciding which or whether any new management technique, including the ones described in the following sections (ripping, mulching, mothballing, RDI) are implemented. The situation for each vineyard will be unique and all options should be carefully considered and evaluated by trialling techniques on a small part of the vineyard, before broad scale implementation.

Deep ripping and mulching are two common soil amelioration techniques for improving root growth, but, they are not appropriate for all soil types, grape varieties, topographies and local rainfall patterns. Excess vegetative vigour is harder to control in deep-rooted vines. However, in a drier climate, excess vegetative vigour may be less of a problem and vine roots may need to be deeper to access deeper soil moisture. Deeper roots can make the difference between adequate yield and the need for drastic action just to keep the vines alive (see mothballing below). Therefore, vineyard managers should be investigating the benefits of ripping and mulching *now*, in anticipation of inevitably drier conditions, before the situation becomes grim.

## Deep Ripping

### Deep ripping to Increase Root Growth - Reducing Compaction

Ripping (tillage) of the inter-row can ameliorate compaction caused by traffic (particularly when the soil is wet, hence weak and prone to compaction), thus allowing greater (shallow) root growth into the inter-row. Deep-ripping, close to the planting row (within 50 cm), can break up restrictive layers and thereby increase root depth, thus increasing the amount of water available to vines. This can provide greater drought tolerance. Ripping is also used to improve drainage. In sodic soil, gypsum is sometimes placed in the rip lines to help prevent the rip lines from closing-up.

Although there are general guidelines for the practice of ripping (timing, depth, frequency), they are not established well enough to determine ripping-best-practice. Best practice may well vary with soil type, root distribution, location, and variety. In general, the guidelines are:

- Rip after harvest, to coincide with the second period of active root growth (although spring-ripping, to a depth of 300-400 mm, using a winged ripper has also given positive results (Cass 2003).
- Rip only one side of the vine row in a single year to avoid excessive root pruning.
- Don't repeat the operation within 5 years; although there is little data to support this assertion and some will rip alternate sides over two years.

Deep-ripping along the vine row has already been recommended for the Sutherlands Creek profile, where ripping could potentially double rooting depth from 35cm to 70cm.

## **Deep Ripping to Decrease Root Growth - Root Pruning**

Ripping has been used to reduce vegetative vigour, through root pruning, to limit the availability of water to the vines and thereby reduce canopy size. Root pruning improved grape composition in the Coonawarra, in black cracking clays (Proffitt 2000). However, in other situations, it was ineffective, possibly because root distribution data was not used to guide the operation (Dry et al. 1998; Ferree et al. 2000).

Within the Geelong Region, excessive vegetative vigour is a problem for vines in black cracking clays, especially deeper soil profiles associated with lower (valley) sections of vineyard blocks. Root pruning may be an effective way of evening out growth within an undulating block. However, results have been variable in other parts of Australia, so, as with any new practice, it should be trialled first on a small area. Also, the economics of ripping should be compared to the cost of modifying the irrigation system to restrict water to deeper profiles; which would also offer water savings.

## **Mulching**

### **Organic Mulch**

The main benefits attributed to mulching are water savings and weed control (DPI Victoria 2004). Conservatively, mulch can reduce irrigation water requirements by 10%. The size of the benefit depends on the irrigation-wetted area and its exposure to direct radiation. Herbicide use can be more than halved over the life of the mulch. In most cases only small yield increases are needed to cover the cost of mulch application. Mulch is applied as a 7.5 cm-thick layer, in a 50 cm band under the vine and is expected to last about 3 years.

For cracking clays, the use of mulches requires more investigation into whether it offers water savings overall. Soil water storage in cracking clays is maximised if the cracks are undisturbed and left open. Mulches may have the effect of closing cracks. Evaporation losses from cracks are negligible.

Composts can also be used for mulching, if they are low in nutrients, particularly nitrogen, (e.g., total N-P-K 0.6 - 0.3 - 0.4 %), otherwise vegetative vigour may be excessive. High-nutrient composts can be applied, but the rate must be restricted. As a guide, where compost is applied as a fertiliser, apply up to 5 cm thick in a 10-20 cm band under the irrigation dripper.

### **Vertical Gravel Mulch**

In her travel report to the Grape and Wine Research & Development Corporation, Pudney (2004) identified three areas requiring further investigation:

- The relationship between vine nutrition and berry colour
- The relationship between wetted soil volume and plant nutrient status
- The use of vertical gravel mulching

Vertical gravel mulching can conserve water by improving infiltration and reducing evaporative losses from puddles that may form around drippers. The greatest potential benefit is in clay soil with low infiltration rates. The gravel mulch equipment is very simple; consisting of a cylindrical tube made of iron-mesh, 5cm in diameter and 15cm in length (filled with gravel). Gravel mulch has advantages over organic mulch: it doesn't need to be replaced over time and root intrusion of drip lines is not a problem.

Given its simplicity and potential water-saving benefits, vertical gravel mulching should be trialled as a priority within the Geelong Region.

## Soil Moisture Sensors for Irrigation Scheduling

Efficient Irrigation Scheduling depends upon accurate and properly installed soil moisture monitoring equipment. There are various types of monitoring equipment, each with benefits and drawbacks.

### Types of Soil Moisture Sensors

Tensiometers are cheap and relatively easy to install. However they require almost daily maintenance in hot weather and are unsuitable for RDI because they don't work in soil that is drier than 80 kPa. They are designed to work in relatively moist soil over the RAW range.

Gypsum Blocks are cheap and, they work in soil as dry as 500 kPa, which means they are suitable for RDI. However, they may overestimate soil moisture in saline soil because they rely on measuring an electric current (the wetter the soil, the greater the current; the saltier the soil, the greater the current). They need to be replaced every 3-4 years because the gypsum breaks down.

Neutron Probes are very accurate. Rather than measuring a suction, they measure soil water content (%volume of water/volume of soil) directly. They providing readings at 10 cm intervals down to 90 cm, so it is possible to check the depth from which vines are drawing upon soil moisture reserves and data is quick to download. Their drawback is that they are expensive and use radioactive material, which requires a skilled licensed operator.

Capacitance-type Sensors (e.g., EnviroScan) measure soil water content (% v/v). They are very accurate and data is quick to download, and they can be linked to a datalogger. As for neutron probes, they providing readings at 10 cm intervals down to 90 cm. and, they are expensive. However, they don't use radioactive material and don't require a licensed operator.

### Installation and Placement of Soil Moisture Sensors

Correct placement of sensors and good soil contact is essential. Sensors should ideally be placed both in the middle of the main root zone (typically 30 cm) and at depth (60 cm). Deep-placed soil moisture-monitoring equipment (to one metre) is also valuable because it provides information about deep soil water storage and extraction by deep roots. Neutron and capacitance probes are ideal because they measure soil moisture at 10 cm increments to one metre.

### Using Soil Moisture Sensors as an Early Warning System

Installation of deep soil moisture probes (to at least 90 cm) can provide advance warning of impending moisture stress for the next season(s) and should be strongly considered for all vineyards in the Geelong Region. For example, if the soil profile is dry at the end of winter and moisture probes indicate that there has been no recharge, it may be wise to irrigate early, rather than rely on recharge from spring rains. Recharging subsoil that is dry at winter's end is also a part of Regulated Deficit Irrigation (RDI) strategy.

Deep soil moisture probes can help to avoid under-irrigation, which encourages shallow roots and also means that the soil must be irrigated more frequently.

With very low water allocations (i.e., severe drought) it may be necessary to deliberately restrict yield to reduce vine stress, which is best done by further reducing irrigation post-flowering to reduce berry set and potential size in addition to cuts in water application across the entire season.

If water supply is limited, the best strategy to avoid yield loss and maintain soluble solids is:-

- If the soil is dry prior to bud burst, irrigate the majority of root zone (ie. Deep)
- Irrigate regularly to minimise stress during flowering and fruit set

- Irrigate (if there is no summer rainfall) at veraison to reduce stress but maintain a moderate stress. i.e., do not fully irrigate) for the following four weeks.
- Irrigate the shallow fibrous root zone after harvest to avoid severe water stress

(from DPI agnote by Goodwin 2002: Managing water stress in grape vines in Greater Victoria)

## Limitations of Field Measurements and the need for further work

### Problems in Estimating Actual Grapevine Water Use

In 2002, a workshop was held by the Cooperative Research Centre for Viticulture on Vine and Vineyard Water Requirements. The workshop identified a need to more accurately measure factors influencing actual vine water use and other components of evapotranspiration; cover crop water use and soil evaporation. They stated... "There remains conjecture as to the range of actual values for grapevine water use. There is also a clear and necessary distinction to be made between actual vine water use and vineyard water requirements. There is increasing evidence to suggest that soil (water) evaporation can be a significant component of vineyard evapotranspiration or ET" (CRCV 2002)..."

Research papers presented at the workshop stated *actual* water use by 'typical' grapevines in Australia was often in the range 5-15 litres/vine/day (equivalent to approximately 0.6-1.8 mm/vine/day for standard 2.3 m x 3.3 m spaced vines with a canopy cover of approximately 40%), equating to 1-2 megalitres per hectare. In contrast, overseas research showed water use for well-watered vines (with 40 %ground cover) was more like 7 mm/d or 42 l/vine/d (Stevens 2002).

Clearly, such a large range in estimates is unacceptably inaccurate for the purpose of irrigation scheduling and makes it difficult to impose techniques such as Regulated Deficit Irrigation. Nevertheless, RDI is standard practice in many grapevine regions, so success with RDI may simply be a question of intimate knowledge of vine water use within the vineyard. A better knowledge of how soil influences water supply is a critical part of this question.

## Improving Water Use Efficiency by Manipulating Irrigation Timing

Deficit irrigation is now established practice for at least half of the area planted to red wine varieties in Australia (Kriedemann & Goodwin 2003). There are three well-known deficit irrigation techniques for viticulture: Regulated Deficit Irrigation (RDI), Partial Rootzone Drying (PRD) and Sustained Deficit Irrigation (SDI). The techniques are similar in that they limit vegetative growth and enhance water use efficiency for crop production. With RDI, water application is manipulated over time whereas, with partial rootzone drying irrigation, water is manipulated over space (part of the root zone while another part is wetted). SDI, as the name suggests, is a continuous under-watering throughout the entire irrigation season. The main message is that RDI is best suited to the Geelong Region because it is easier to apply to clayey soil, and only this technique is described below. Watering during drought is also described.

### Regulated Deficit Irrigation (RDI)

RDI involves restricting irrigation, at particular growth stages, to reduce canopy growth and decrease berry size. RDI offers water savings of 20-30% over full irrigation but yield is reduced by only around 10%. Even if RDI is not strictly practiced, water budgets should utilise the principles of RDI, i.e., when to avoid water stress (from flowering to fruit set), and when to allow it (pre-veraison).

RDI is mainly a technique for red varieties. Red grape returns are driven by colour, Brix (grape sugar content, expressed as dissolved sugar-to-water mass ratio, °Bx) and yield. Smaller berries promote more highly coloured and flavoursome red wine, by increasing berry skin anthocyanins and tannins.

Mild water stress may also enhance sugar accumulation. Time to maturity is also reduced. As a general rule, the sooner a red variety reaches maturity and is harvested, the better the wine. For white varieties (with the exception of Chardonnay, which can benefit from more tannin), returns are mainly driven by yield, so there is less incentive to adopt deficit irrigation.

Vegetative growth is generally more sensitive to water stress than fruit growth, so RDI is generally imposed from early November to early January. Application at the correct growth stage is critical, otherwise large yield losses can be incurred. The RDI strategy (as described by (Kriedemann & Goodwin 2003) are summarised below:

- From Budburst to flowering: Keep the soil moist (no drier than 30 kPa). Winter and spring rain usually predominates and dry conditions are not generally a problem. Avoid waterlogging.
- During flowering & fruit set: Keep the soil *very* moist (around 10 kPa) throughout the rootzone
- From fruit set to veraison: Apply RDI: Allow rootzone soil to dry out to a maximum of 80 kPa (the limit of a tensiometer's range). If irrigation is necessary, wet no more than 25 % of the rootzone to 10 kPa (this works out to 25 cm depth, assuming a max depth of 1 metre)
- From Veraison to harvest: If irrigation water is readily available, maintain rootzone soil water at 80 kPa. If water is scarce, allow rootzone soil to dry out to maximum of 200 kPa in clay loams (100 kPa for sands, up to 400 kPa for clays) (note: tensiometers are only good to 80 kPa. For drier soil, gypsum blocks, neutron probes or capacitance meters are needed).
- From Harvest – leaf fall: Autumn rain usually predominates. Avoid rootzone soil water tensions greater than 200 kPa.
- During Dormancy: Winter rain is usually predominant. Avoid soil water tension greater than 200 kPa. If rootzone soil water tension is greater than 30 kPa shortly before budburst, thoroughly wet the rootzone to 10 kPa. Avoid waterlogging.
- Irrigate after harvest to avoid severe water stress.

These guidelines on their own should not be used to embark upon broadscale RDI. It is a complicated strategy and over-stressing can result in severe yield reductions, so until managers are experienced, they should practice RDI on small areas, ideally on less valuable blocks.

Understanding phenological changes for different varieties is critical for timing of RDI. Water stress should be applied only during the vegetative growth period when fruit is growing slowly. Water stress must be avoided or minimised (if water is limited) during rapid fruit growth.

The interested reader is referred to the publication by Ian Goodwin (1995) "Irrigation of Vineyards: a winegrape grower's guide to irrigation scheduling and regulated deficit irrigation", published by the Institute of Sustainable Irrigated Agriculture, Victorian Department of Primary Industries. For a great summary of the annual water requirement at different growth stages, see the GWRDC Fact Sheet no.5: Insights into the relationships between yield and water in wine grapes (Chalmers, in <http://waterandvine.gwrdc.com.au>).

Note that RDI should not be viewed in isolation; correct nutrition and canopy management are also important for maximising quality.

## Soil Type and RDI

For RDI to work well, it must be possible to impose moisture stress at strategic growth stages. This generally means that roots need to be restricted to a depth of one metre. However, for the low-rainfall Geelong Region, encouraging *deeper* root growth may be more important, in order to give vines greater drought tolerance in future years of lower rainfall. Nevertheless, the water-saving strategies that RDI offers can be employed, regardless of root depth. Although it may not be appropriate or practical for all soil types or situations, Geelong Region winegrape growers should investigate the potential for RDI.

Most difficulties in practising RDI occur where soil is difficult to dry out either because it is a type which retains moisture or it is in a region where late spring rainfall keeps it moist. Soil must dry out enough to induce a deficit response at the required growth stage and take in moisture at an adequate rate to relieve the deficit when irrigation is resumed.

The degree of moisture stress that must be applied (in the main root zone) varies with soil type. The soil needs to be dried out to 150-200 kPa for sands, 250 kPa for loams and 300-400 kPa for clays. RDI may not be suitable for very light sands because of their low water holding capacity (DPI-WA-2004. Farmnote 67), which makes it difficult to apply moderate stress without risking severe moisture stress.

### **Record Keeping for RDI**

A variety of important records should be collected every year, covering irrigation (volume, timing), soil moisture and plant performance (flowering, fruit set, harvest date, nutrient analyses, Brix), and of course climate (rainfall, temperature, evaporation). Fruit weight is especially useful for adjusting irrigations. Measure shoot length and berry size weekly, by tagging several bunches and shoots.

### **Dewatering the Soil to Impose Water Stress**

At budburst in most temperate-climate orchards and vineyards, soil profiles are usually fully charged with water after rain in winter or spring. To impose RDI-level water stress, the rootzone must first be dewatered. Soil water content is decreased to a point where canopy transpiration cannot match atmospheric demand. The time required for de-watering will depend on evaporative conditions, rootzone depth and lateral root distribution, soil water holding capacity, and further rainfall (ideally nil).

### **Rewatering Following the Deficit Period**

A secure water supply is crucial because substantial and sustained irrigation is needed to rewet the soil following the deficit period back to full irrigation (from 400 kPa back to field capacity, 10 kPa; 20 kPa for cracking clays). Application rates after RDI are likely be 100 to 150% of potential crop evapotranspiration, in order to fully restore rootzone moisture in time for rapid fruit growth.

Most soil types will be hard to wet after RDI, and about double the volume of a regular irrigation will be necessary to fully restore profile moisture. A quick succession of close irrigation cycles (to the point of run off) is often required.

In clay soils (especially cracking clays, once the cracks close up), poor permeability slows the downward permeation of irrigation water, so that rootzones re-wet much more slowly compared with sandy loam soils. Increasing delivery rate from a point source is not a solution to this slower re-wetting because low permeability quickly results in wasteful runoff. Maintain a slow, continuous irrigation rate up to the point of runoff, for as long as it takes to rewater.

Best practice calls for closely spaced emitters (from 50 to 60 cm apart) to ensure that all vines receive some water during deficit phases.

A key condition in implementing regulated deficit irrigation: Soil water must be measured at least twice a week to ensure precise timing of irrigation water application.

## Non-Soil Water Conservation Techniques

The main aim of this report has been to illustrate that “soils ain’t soils”, in order to improve irrigation efficiency. An understanding of the differences in physical and chemical properties informs us to take the most appropriate action (deep-ripping, mulching, gypsum) to improve root growth. We must also consider appropriate amelioration within the environmental context of those soils (climate and geography). Inspection and analysis of soil profiles from the Geelong Region has demonstrated the value of understanding soils within different environments, to help improve the vine’s access to soil water and thus improve water use efficiency.

### Canopy Management

We have focused on soil management to improve water use efficiency, but water conservation in a drought situation can be tackled from many angles. A discussion of canopy management is beyond the scope of this report, but canopy size is a major determinant of vine water use and should therefore be a part of drought management.

### Mothballing

During a drought, it may not be possible to properly irrigate the vineyard to get any useful yield. In a severe drought year, the aim may be to simply keep the vines alive.

Recently a 2-year trial (2006-2008) into “mothballing” was completed at Dareton (in NSW, 25 km north-west of Mildura), by Gregory Moulds, ([greg.moulds@dpi.nsw.gov.au](mailto:greg.moulds@dpi.nsw.gov.au)) and Liz McGuire, Industry Development Officer, Murray Valley Winegrowers ([liz.mcguire@murrayvalleywinegrapes.com.au](mailto:liz.mcguire@murrayvalleywinegrapes.com.au)).

Mothballing takes vines out of production for one season. Three techniques were investigated:

1. Harsh Pruning – the most successful technique, resulting in only 1-2 bunches per season.
2. Calcium Nitrate to burn out bunches on the top cordon
3. Ethrel®, a plant growth regulator, to reduce the number of bunches .

After one season of mothballing, vines recovered well enough to allow mothballing to be recommended by the researchers as effective. Work is continuing on the effect of mothballing for two seasons in a row.

Mothballing is an emerging technique, so its use should be approached with caution until more is known about its effects. It is mentioned here, because initial research is promising. However, the reader should seek further advice. Inappropriate use of mothballing may cause vine death.

## Appendix: Geelong Vineyards

(source: <http://www.winegeelong.com.au/locations>)

Business Name	Address	Region	Phone	Opening Hours
Bellarine Estate Winery	2270 Portarlington Road, Bellarine	Bellarine	03 52593310	11am - 4pm
Kilgour Estate Winery	85 McAdams Lane, Bellarine	Bellarine	03 52512223	10.30am - 5pm
Scotchmans Hill Vineyard & Winery	190 Scotchmans Road, Drysdale	Bellarine	03 52513176	10.30am - 4.30pm
Adventure Estate	1251 Bellarine Highway, Wallington	Bellarine	03 52502756	Weekends 10am - 5pm September - April or by appointment
Banks Road Vineyard	600 Banks Road, Marcus Hill	Bellarine	03 98222954	Weekends 10am - 4pm
Leura Park Estate	1400 Portarlington Road, Curlewis	Bellarine	03 52533180	Weekends and public holidays 11am - 5pm
Mermerus	60 Soho Road, Drysdale	Bellarine	03 52532718	First Sunday of every month and every Sunday in January 11am - 4pm or by appointment
Oakdene Vineyards, Restaurant & Cellar Door	255 Grubb Road, Wallington	Bellarine	03 52551255	Wednesday - Sunday 12pm - 5pm or by appointment
Ponda Estate	150 Rhinds Road, Wallington	Bellarine	03 52505300	Weekends 11am - 5pm
Bargowan Vineyard	30 Pax Parade, Curlewis	Bellarine	03 52503861	
Curlewis Winery	55 Navarre Road, Curlewis	Bellarine	03 52504567	
Fenwick Wines	180 Lings Road, Wallington	Bellarine	03 52501943	
Grassy Point Wines	145 Coatsworth Road, Portarlington	Bellarine	0409 429 608	
Hat Rock Vineyard	2330 Portarlington Road, Bellarine	Bellarine	03 52591386	
McGlashans Wallington Estate	225 Swan Bay Road, Wallington	Bellarine	03 52505760	
Nalbra Estate Wines	225 Whitcombes Road, Drysdale	Bellarine	03 52532654	
Baie Wines	120 McDermott Road, Curlewis	Bellarine	03 52513587	
Spray Farm	2275 Portarlington Road, Portarlington	Bellarine	03 52513176	
Terindah Estate	90 McAdams Lane, Bellarine	Bellarine	1300 651 485	
Wayawu Estate	1070 Bellarine Highway, Wallington	Bellarine	03 52504457	
Wyuna Park Vineyard and Garden	105 Soho Road, Drysdale	Bellarine	03 52531348	
Clyde Park Vineyard & Bistro	2490 Midland Highway, Bannockburn	Moorabool	03 52817274	11am - 5pm. Bistro open weekends and public holidays.
Jindalee Estate	256 Ballan Road, Moorabool	Moorabool	03 52761280	10am - 5pm
Lethbridge Wines	74 Burrows Road, Lethbridge	Moorabool	03 52817279	Monday to Friday 12pm - 3pm. Weekends & public holidays 11am - 5.30pm or by appointment
Shadowfax Vineyard and Winery	K Road, Werribee	Moorabool	03 97314420	11am - 5pm

Ceres Bridge Estate	84 Merrawarp Road, Stonehaven	Moorabool	03 52711212	Sunday 10am - 5pm
del Rios of Mt. Anakie	2320 Ballan Road, Anakie	Moorabool	03 52841221	Friday - Sunday 11am - 5pm or by appointment
Eagles Rise (Wild Wine)	310 Russells Bridge Road, Russells Bridge	Moorabool	03 52812040	Thursday to Sunday 11am - 5pm or by appointment
Moorabool Ridge	37 Spiller Road, Lethbridge	Moorabool	03 52819240	Weekends and public holidays 11am - 5pm
Mount Anakie Winery	130 Staughton Vale Road, Anakie	Moorabool	03 52841256	Tuesday - Sunday, 11am - 5pm
Amietta Vineyard & Winery	30 Steddy Road, Lethbridge	Moorabool	03 52817407	
Austins Wines	870 Steiglitz Road, Sutherlands Creek	Moorabool	03 52811799	
Bannockburn Vineyards	Kelly Lane (off Midland Highway), Bannockburn	Moorabool	03 52811363	
Barwon Ridge	50 McMullans Road, Barrabool	Moorabool	0418 324 632	
Moorabool Estate	45 Dog Rocks Road, Batesford	Moorabool	03 52761536	
Provenance Wines	870 Steiglitz Road, Sutherlands Creek	Moorabool	03 52812230	
Spence	760 Burnside Road, Murgheboluc	Moorabool	03 52651181	
Brown Magpie Wines	125 Larcombes Road, Moriac	Surf Coast	03 52613875	
Otway Estate Winery & Brewery	Colac - Lavers Hill Road (C155), Barongarook	Surf Coast	03 52338400	10am - 5pm
Pettavel Winery & Restaurant	65 Pettavel Road, Waurm Ponds	Surf Coast	03 52661120	10am - 5.30pm
St. Regis Vineyard & Winery	35 Princes Highway, Waurm Ponds	Surf Coast	03 52418406	10am - 5pm
Bellbrae Estate (Longboard)	520 Great Ocean Road, Bellbrae	Surf Coast	03 52648480	Weekends and public holidays 11am - 5pm. 7 days a week in January
Blakes Estate	80 Bambra Cemetary Road, Deans Marsh	Surf Coast	03 52363246	Weekends & school holidays 11am - 5pm. November - April
Dinny Goonan Family Estate	880 Winchelsea - Deans Marsh Road, Bambra	Surf Coast	03 52887100	11am - 5pm weekends and public holidays November - April. 7 days during January or by appointment
Feehans Road Vineyard	50 Feehans Road, Mount Duneed	Surf Coast	03 52641706	Weekends and public holidays 10am - 5pm
Kinsella's Bridge Winery (Gosling Creek)	495 Murroon Road, Murroon	Surf Coast	03 52363229	Weekends, public holidays and January 11am - 4pm or by appointment. Closed July - August
Newtons Ridge Vineyard	1170 Cooriemungle Road, Cooriemungle	Surf Coast	03 55987394	September - Easter, 10am - 5pm or by appointment
The Minya Vineyard & Winery	Minya Lane, Connewarre	Surf Coast	03 52641397	Weekends from Christmas to Easter 10.30am - 5pm
Waurm Ponds Estate	Nicol Drive North, Deakin University, Waurm Ponds	Surf Coast	03 52272143	Weekdays 10am - 4pm or by appointment
Waybourne Winery	60 Lemins Road, Waurm Ponds	Surf Coast	03 52418477	Weekends and school holidays 11am - 5pm
Wolseley Wines	1790 Hendy Main Road, Paraparap	Surf Coast	0412 990638	Weekends and school holidays 11am - 5pm
Prince Albert Vineyard	100 Lemins Road, Waurm Ponds	Surf Coast	03 52418091	

## REFERENCES

- Chalmers Y (2005) Insights into the relationships between yield and water in wine grapes. Factsheet: Water and vine, Module 5. Grape and Wine Research & Development Corporation.  
<http://waterandvine.gwrdc.com.au/content/documents.pdf>
- Chalmers Y (2005) Understanding Varietal Responses to Water Deficit And Travel To The ISHS International Grapevine Conference. Final Report by the Victorian Department Of Primary Industries to the Grape And Wine Research & Development Corporation. Project Number: Dpi 04/03.  
[www.gwrdc.com.au/downloads/ResearchTopics/DPI%2004-03.pdf](http://www.gwrdc.com.au/downloads/ResearchTopics/DPI%2004-03.pdf)
- CRCV (2002) Vine and Vineyard Water Requirements. Report by the Cooperative Research Centre for Viticulture on the workshop held at the Waite Campus, Adelaide University, 3 September 2002, to review and scope needs on efficient water use in viticulture. Final Report to THE Grape and Wine Research and Development Corporation, GWRDC Project No GWR 02/02d.EDS. Rob Walker and Mark Gibberd CRC for Viticulture and CSIRO Plant Industry PMB Merbein
- CRCV (2007) Viticare on Farm Trials. Manual 2.1 - Improving Soils 1. Report by the Cooperative Research Centre for Viticulture
- da Silva AP, Kay BD and Perfect E (1994) Characterization of least limiting ranges of soils. *Soil Science Society of American Journal* 58:1775-1781. As cited in Reichert et al (2008).
- Dry PR (2005) Irrigation deficit strategies for maximising water use and wine quality in Australia. Website: [www.inia.cl/platina/descarga/docs/seminarios/s0001/18\\_vides2005\\_pdry.pdf](http://www.inia.cl/platina/descarga/docs/seminarios/s0001/18_vides2005_pdry.pdf), accessed May 2008
- Dry PR (2005) Irrigation Deficit Strategies for Maximising Water Use and Wine Quality in Australia. Presentation by Dr Peter Dry, Associate Professor, Faculty of Sciences, School of Agriculture and Wine, University of Adelaide. Website, accessed May 2008. [www.Inia.Cl/Platina/Descarga/Docs/Seminarios/S0001/18\\_Vides2005\\_Pdry.Pdf](http://www.Inia.Cl/Platina/Descarga/Docs/Seminarios/S0001/18_Vides2005_Pdry.Pdf)
- Dry PR and Smart RE (1988) Grapegrowing Regions of Australia, and, Vineyard Site Selection. In: *Viticulture, Resources Vol.1, Chapters 2 & 10.* Eds. BG Coombe & PR Dry. Australian Industrial Publishers
- Dry PR, Loveys B, Johnstone A and Saddler L (1998) Grapevine response to root pruning. *The Australian Grapegrower and Winemaker Annual Technical Issue* 414a, 73-78. As cited in: Lanyon *et. al.* (2004), p.20
- Ferree DC, Mcartney SJ, Scurlock D and Riesen RR (2000) Root pruning to control growth and fruiting of grapevines. 5th International Symposium on Cool Climate Viticulture and Oenology, Melbourne, Australia. As cited in: Lanyon *et. al.* (2004), p.20
- Freeman BM and Smart RE (1976) A root observation laboratory for studies with grapevines. *American Journal of Enology and Viticulture* 27, 36-39. As cited in: Lanyon *et. al.* (2004), p.6
- Geelong Weather Services website <http://users.pipeline.com.au>
- Goodwin I (1995) Irrigation of Vineyards: a winegrape grower's guide to irrigation scheduling and regulated deficit irrigation. Published by the Institute of Sustainable Irrigated Agriculture, Victorian Department of Primary Industries.
- Goodwin I (2002) Managing water stress in grape vines in Greater Victoria. Department of Primary Industries Victoria Agnote AG1074. Author: Ian Goodwin. [www.dpi.vic.gov.au/dpi/nreninf.nsf](http://www.dpi.vic.gov.au/dpi/nreninf.nsf)
- Grant C (2002) Scoping Study: Identify Research Priorities to Improve The Ability of Horticulturalists to Manage Rootzones for Desired Outcomes. Final Report by the University of Adelaide to the Grape and Wine Research & Development Corporation. Project Number: UA 02/01.[www.gwrdc.com.au/downloads/Researchtopics/Ua%2002-01.pdf](http://www.gwrdc.com.au/downloads/Researchtopics/Ua%2002-01.pdf)
- Groenevelt PH, Grant CD, Semetsa S (2001) A new procedure to determine soil water availability. *Australian Journal of Soil Research* 39, 577-598.
- GWRDC (2004) Weblink to list of irrigation-related project reports as at 2004.  
<http://www.gwrdc.com.au/rtopics.asp?ID=14>
- Hollaway K (2008) Dry Seasonal Conditions in Rural Victoria. Report no. 74, Department of Primary Industries Victoria, February 2008
- Kriedemann PE. and Goodwin I (2003) Regulated Deficit Irrigation and Partial Rootzone Drying. NPSI 4. Irrigation Insights: National Program for Sustainable Irrigation, Land and Water Australia. 102 pp.  
[http://www.lwa.gov.au/downloads/publications\\_pdf/PR020382c.pdf](http://www.lwa.gov.au/downloads/publications_pdf/PR020382c.pdf)  
[www.gwrdc.com.au/downloads/ResearchTopics/NPI%2001-01%20PRD%20irrigation%20insights.pdf](http://www.gwrdc.com.au/downloads/ResearchTopics/NPI%2001-01%20PRD%20irrigation%20insights.pdf)
- Lanyon DM, Cass A and Hansen D (2004) The effect of soil properties on vine performance. CSIRO Land and Water Technical Report No. 34/04.
- Lety J (1985) Relationship between soil physical properties and crop production. *Advances in Soil Science*, 1:277-294.

<p>Lovey B, Grant J, Stoll M, Dry P, McCarthy M (1997) The Influence of Partial Rootzone Drying on Grape Quality. SA Viticulture Technical Conference, 1997  <a href="http://www.sardi.sa.gov.au/pages/hort/viticulture/influence_of_partial_rootzone_dr.htm">www.sardi.sa.gov.au/pages/hort/viticulture/influence_of_partial_rootzone_dr.htm</a></p>
<p>MacEwan RJ, Crawford DM, Newton PJ, Clune TS (2009 draft). Subsoil Constraints in the High Rainfall Cropping Zone of South East Australia. Australian Journal of Soil Research, special issue on subsoil constraints, pending.</p>
<p>Maschmedt D, Fitzpatrick R, Cass A (2002) Key for identifying categories of vineyard soils in Australia. CSIRO Land and Water Technical Report 30/02.</p>
<p>McDonald RC, Isbell RF, Speight JG, Walker J, and Hopkins MS (1984) Australian Soil and Land Survey Handbook. 2<sup>nd</sup> ed. Inkata Press.</p>
<p>PIRSA-Primary Industries and Resources, South Australia (2007). <b>Drought strategy checklist for horticulture</b>. PIRSA Factsheet No: <b>19/06</b>. <a href="http://www.pir.sa.gov.au/pirsa/drought/irrigation">www.pir.sa.gov.au/pirsa/drought/irrigation</a></p>
<p>PIRSA-Primary Industries and Resources, South Australia (2006) Irrigating horticulture crops with reduced water supplies. PIRSA Factsheet No. 18/06. Author: <b>Irrigated Crop Management Service (ICMS) – Rural Solutions SA</b> <a href="http://www.pir.sa.gov.au/factsheets">www.pir.sa.gov.au/factsheets</a>. <a href="http://www.pir.sa.gov.au/pirsa/drought/irrigation">www.pir.sa.gov.au/pirsa/drought/irrigation</a></p>
<p>PIRSA-Primary Industries and Resources, South Australia (2006). Water budgeting guidelines - Vines on the Upper Murray. (PIRSA Fact Sheet 15/06). <a href="http://www.pir.sa.gov.au/pirsa/drought/irrigation">www.pir.sa.gov.au/pirsa/drought/irrigation</a></p>
<p>PIRSA-Primary Industries and Resources, South Australia (2007). Water Budgeting Guidelines - Vines on the Lower Murray (PIRSA Fact Sheet 03/07 ). <a href="http://www.pir.sa.gov.au/pirsa/drought/irrigation">www.pir.sa.gov.au/pirsa/drought/irrigation</a></p>
<p>PIRSA-Primary Industries and Resources, South Australia (2002). <b>Regulated deficit irrigation strategies in winegrapes</b>. PIRSA Factsheet No. <b>No: FS 106/97/02</b>. Author: <b>Irrigated Crop Management Service (ICMS) – Rural Solutions SA</b>. <a href="http://www.pir.sa.gov.au/pirsa/drought/irrigation">www.pir.sa.gov.au/pirsa/drought/irrigation</a></p>
<p>Proffitt T (2000) Using cover crops and root pruning to affect water uptake. Australian Viticulture 4, 45-51. As cited in: Lanyon <i>et. al.</i> (2004).</p>
<p>Pudney S. (2004) Irrigation strategies for improving Water Use Efficiency. SARDI travel report to Grape and Wine Research &amp; Development Corporation. Project Number: SAR 03/10.</p>
<p>Queensland Natural Resources and Water. Irrigation Fact Sheets. <a href="http://www.nrw.qld.gov.au/rwue/factsheets.html">http://www.nrw.qld.gov.au/rwue/factsheets.html</a></p>
<p>Reichert JM, Da Silva VR and Reinert DJ (2004) Soil Moisture, Penetration Resistance, and Least Limiting Water Range for Three Soil Management Systems and Black Beans Yield. 13th International Soil Conservation Organisation Conference – Brisbane, July 2004. Conserving Soil and Water For Society: Sharing Solutions. Paper No. 721</p>
<p>Reichert JM, José R. Benites JR, and Reinert DJ (2008) Soil Moisture and Structure as Key Factors for Crop Production. Working Draft for Food and Agriculture Organization of the United Nations (FAO). <a href="ftp://ftp.fao.org/agl/emailconf/soilmoisture/t3_Reichard_1.pdf">ftp://ftp.fao.org/agl/emailconf/soilmoisture/t3_Reichard_1.pdf</a>. Accessed April 2008.</p>
<p>Retallack M, Scholefield P (2004) Grapevine management in times of drought and water restrictions. Newsletter by Scholefield Robinson Horticultural Services for the South Australian Wine Industry Association. <a href="http://www.winesa.asn.au">www.winesa.asn.au</a></p>
<p>Robinson N, Rees D, Reynard K, MacEwan R, Dahlhaus P, Imhof M, Boyle G and Baxter N (2003) A land resource assessment of the Corangamite region. Department of Primary Industries, Victoria. <a href="http://www.dpi.vic.gov.au/dpi/vro/coranregn.nsf/pages/soil_landform_map">http://www.dpi.vic.gov.au/dpi/vro/coranregn.nsf/pages/soil_landform_map</a>  <a href="http://www.dse.vic.gov.au/DSE/dsencor.nsf">http://www.dse.vic.gov.au/DSE/dsencor.nsf</a></p>
<p>Saayman D and Kleynhans PH (1978) The effect of soil type on wine quality. Proceedings of the South African Society of Enology and Viticulture, 21st Annual meeting, Cape Town, pp.105-119. As cited in: Lanyon DM, Cass A, and D Hansen (2004) The effect of soil properties on vine performance. CSIRO Land &amp; Water Technical Report No. 34/04, p.7</p>
<p><b>Stewart D (2005).The effect of soil and irrigation management on grapevine performance.</b>  <a href="http://www.gwrdc.com.au/downloads/ResearchTopics/NPI%2001-01%20PRD%20irrigation%20insights.pdf">www.gwrdc.com.au/downloads/ResearchTopics/NPI%2001-01%20PRD%20irrigation%20insights.pdf</a></p>
<p>Van Huyssteen L (1988) Soil preparation and grapevine root distribution – a qualitative and quantitative assessment. In: ‘The grapevine root and its environment’ Ed. J.L Van Zyl (Technical communication No. 215, Dept. Agric. Wat. Supply, Pretoria) pp. 1-15. As cited in: Lanyon DM, Cass A, and D Hansen (2004) The effect of soil properties on vine performance. CSIRO Land &amp; Water Technical Report No. 34/04, p.7</p>
<p>Van Zyl JL (1988) Response of grapevine roots to soil water regimes and irrigation systems. In: ‘The grapevine root and its environment’ Ed. J.L. Van Zyl (Technical communication No. 215, Dept. Agric. Water Supply, Pretoria) pp. 30-43. As cited in: Lanyon <i>et. al.</i> (2004), p.3</p>
<p>Viticare on Farm Trials Manual 2.2 - Improving Soils 2 - mulches, cover crops (Cooperative Research Centre for Viticulture, 2005).</p>
<p>Webb, LB, Whetton, PH., Barlow, EWR (2006) Potential impacts of projected greenhouse gas induced climate change on Australian Viticulture, pp 16-20, vol 21, no 4, Wine Industry Journal, July/August 2006. As cited in: The Australian Wine Grape Industry: Taking Stock and Setting Directions Project, 2006. Kiri-Ganai Research Pty Ltd</p>
<p>Wilkinson K (2004) Compost for Wine-Grape Growers. Fact Sheets (series of five). State of Victoria, Department of Primary Industries.</p>

## Most Referenced Reading

In writing this report, heavy reliance was placed on these references...

CRCV (2002). Vine and Vineyard Water Requirements. Report by the Cooperative Research Centre for Viticulture on the workshop held at the Waite Campus, Adelaide University, 3 September 2002, to review and scope needs on efficient water use in viticulture. Final Report to THE Grape and Wine Research and Development Corporation, GWRDC Project No GWR 02/02d.EDS. Rob Walker and Mark Gibberd CRC for Viticulture and CSIRO Plant Industry PMB Merbein

Dry PR and Smart RE (1988). Grape growing Regions of Australia, and, Vineyard Site Selection. In: Viticulture, Resources Vol.1, Chapters 2 & 10.. Eds. BG Coombe & PR Dry. Australian Industrial Publishers

Goodwin I (1995). Irrigation of Vineyards: a winegrape grower's guide to irrigation scheduling and regulated deficit irrigation. Published by the Institute of Sustainable Irrigated Agriculture, Victorian Department of Primary Industries.

Lanyon DM, Cass A, and D Hansen (2004). The effect of soil properties on vine performance. CSIRO Land and Water Technical Report No. 34/04.

Maschmedt D, Fitzpatrick R, Cass A (2002). Key for identifying categories of vineyard soils in Australia. CSIRO Land and Water Technical Report 30/02.

Primary Industries and Resources, South Australia (2007). Irrigating horticulture crops with reduced water supplies. Fact sheet no. 15/06. Author: [Irrigated Crop Management Service \(ICMS\) – Rural Solutions SA. www.pir.sa.gov.au/factsheets/pdf](http://www.pir.sa.gov.au/factsheets/pdf).

Viticare on Farm Trials Manual 2.2 - Improving Soils 2 - mulches, cover crops and Viticare on Farm Trials Manual 3.2 - Soil Profiling. [www.crcv.com.au/viticare/trials](http://www.crcv.com.au/viticare/trials) and [www.crcv.com.au/viticare/vitinotes](http://www.crcv.com.au/viticare/vitinotes)

## Further Reading

The references section provides a list of publications for further reading on managing with limited water and efficient irrigation techniques such as Regulated Deficit Irrigation, which are introduced briefly, but are outside the scope of this report. Many of these publications can be downloaded free from the internet.

Geelong City State of the Environment Report, 2001; [www.geelongcity.vic.gov.au/soe](http://www.geelongcity.vic.gov.au/soe))

Gladstones JS (1992) Viticulture and Environment. Winetitles, Adelaide.

The Research Practice series of publications, "Viticare on Farm Trials" (Cooperative Research Centre for Viticulture; there are nine in the series) are particularly good. They provide guidelines on how to conduct on-farm trials (design and measurements). Freely downloadable from: [www.crcv.com.au/viticare/vitinotes](http://www.crcv.com.au/viticare/vitinotes).

DPI Victoria (2004). Compost for Wine-Grape Growers. Fact Sheets (series of five). State of Victoria, Department of Primary Industries. [www.dpi.vic.gov.au](http://www.dpi.vic.gov.au)

National Wine and Grape Industry Centre Alliance. The Three partners in the NWGIC alliance are Charles Sturt University (CSU), NSW Department of Primary Industries (NSW DPI), NSW Wine Industry Association (NSW WIA). <http://www.csu.edu.au/research/nwgic/research/sustainable.htm>

Numerous articles about Regulated Deficit Irrigation and other water management techniques have been published in various issues of The Australian and New Zealand Grapegrower and Winemaker. Visit [www.grapeandwine.com.au/](http://www.grapeandwine.com.au/) for details.

Also see: [www.pir.sa.gov.au/factsheets...](http://www.pir.sa.gov.au/factsheets...)

Water Budgeting Guidelines - Vines on the Upper Murray (PIRSA Fact Sheet 15/06)

Water Budgeting Guidelines - Vines on the Lower Murray (PIRSA Fact Sheet 03/07)

Drought Strategy Checklist (PIRSA Fact Sheet 19/06)

Irrigating Horticulture Crops with Reduced Water Supplies (PIRSA Fact Sheet 18/06)

Regulated Deficit Irrigation Strategies in Winegrapes (PIRSA Fact Sheet 106/97/02/06)

Business Decision Making Tool (PIRSA Spreadsheet)

Irrigators Toolkit, Latest River Murray Information, Government Assistance and Support

[http://www.pir.sa.gov.au/pirsa/drought/irrigation\\_\\_and\\_\\_water\\_management](http://www.pir.sa.gov.au/pirsa/drought/irrigation__and__water_management)

-end