IMPACT OF VINEYARD SOIL MANAGEMENT ON SOIL PHYSICAL PROPERTIES AND VINE RESPONSE

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1 SUMMARY

Due to the rapid expansion of the wine-grape industry in Australia, vineyards have been developed on a wide range of soil types and this has caused performance of vines to be variable. Some soils have natural limitations such as poor aeration and high strength in the grey, gleyed clays, the black cracking clays and the red-brown earths. Other soils have anthropogenic limitations such as degraded soil structure (crusting and hard-setting) and sub-soil compaction. Soil management techniques to counter these natural and man-made limitations have yet to be developed in Australia for the soil types used in wine-grape production.

The majority of research on the effects of management on soil physical fertility and grapevine performance has, until recently, been conducted in South Africa (e.g. van Zyl 1988; Saayman and van Huyssteen 1980, 1983a,b and van Huyssteen and Weber 1980a,b,c). For example, the benefits of deep-ripping and minimal tillage on soil structure, root development and performance of grape vines were demonstrated by van Huyssteen and Weber (1980a,b,c). Myburgh and Moolman (1991), and more recently Eastham et al. (1996), demonstrated the positive impact that mounding the mid-row soil onto the vine row has on soil structure and grapevine performance. However, the potential benefits of combining such mounding treatments with various soil amendments (eg. gypsum and polymers, etc) and surface covers (eg. composts) to improve soil structure and increase water use efficiency in vineyards had not been investigated in Australia. Furthermore, our understanding of potential interactions between soil management and irrigation management was rudimentary, particularly in relation to recent advances in irrigation technology such as partial rootzone drying.

The balance between irrigation management and soil management to maximize available water for certain berry qualities is a site-specific exercise requiring great skill and understanding for different soil types in different viticulture regions. The aims of this thesis were therefore to:

- Evaluate the effects of soil profile management (soil mounding and deep-ripping) and surface-cover management (straw mulch, herbicide, polymer, ryegrass) on soil structure, plant available water and vine performance in some South Australian vineyards on different soils.
- Evaluate the effects of irrigating by Partial Rootzone Drying (PRD) on plant available water and vine performance in combination with various strategies for managing the soil profile and surface covers in some South Australian soils with varying limitations.

The impacts of deep-ripping, mounding, polymers, grape marc, straw mulch, ryegrass, calcium amendments and PRD irrigation on soil structure, grapevine root development, plant available water and grapevine performance were determined in various combinations depending on the limitations at each of three vineyards within South Australia.

The results for the various soil and water management treatments were site-specific and depended on the magnitude of soil limitations present before the treatments were imposed. For example at the Padthaway Plain where the depth of root growth was limited by shallow limestone, mounding increased the amount of available water and increased grape yield. Where soil was relatively deep (eg. Lyndoch), mounding was shown to produce no

benefit. Similarly, deep-ripping greatly reduced soil resistance at the Padthaway Range site and this increased root development, vine performance and yield. The effects, however, lasted for only 2 to 3 years.

Mulches and other soil amendments had varying impacts on soil structure and soil water availability depending on soil texture. For example, mulches had a deleterious effect on soil structure soon after application on the heavier textured soils (Lyndoch and Padthaway Plain) but had a beneficial effect on the soil structure of a sandy soil (Padthaway Range). The impact of mulches on soil salinity was also variable and site specific. At Lyndoch, for example, salinity was reduced under mulch but at both Padthaway sites salinity varied with time and was related to other factors.

As expected yields were greater in those treatments that provided the greatest amount of available water (which across all sites included the mulch treatment). Yields alone, however, did not define total grapevine performance, and the treatments with mulches tended to produce berry juices with reduced colour (quality).

Due to the shallow soil profile the PRD irrigation treatment was difficult to manage so that a water stress was induced. As a result the expected improvement in water use efficiency and the positive impact on root development in the subsoil was not observed.

STATEMENT

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person except where due reference has been made in the text.

I give consent for this copy of my thesis, when deposited in the University Library, to be available for loan and photocopying.

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2 INTRODUCTION

Since 1996 the area of land used for wine-grape production in Australia has more than doubled from 64,845 ha in 1996 to 166,006 ha in 2004. Much of this recent expansion has occurred in South Australia (SA), which accounts for the largest proportion of Australia's wine-grape production (44% of total fresh weight) and the greatest area of land dedicated to wine-grapes (43% of Australia's 166,006 ha) (ABS 2004).

In such an important industry, it would be expected that vine establishment and health would be high priorities, and that the soil quality and management would be taken into serious consideration during planting and subsequent management. However, the rapid expansion of vineyards in South Australia during the 1990s occurred indiscriminately on a wide range of highly variable soils, including the grey, gleyed clays, black cracking clays and the duplex red-brown earths with heavy-textured B-horizons. Many of the soils were not ideally suited to grape production and so vineyard establishment was often difficult and productivity was less than expected (Myburgh et al., 1996). The more difficult soils exhibited degraded soil structure with crusted and hard-setting surfaces, plus subsoil compaction due to either tillage and traffic or high subsoil pH and strength, plus poor drainage and aeration (Myburgh et al., 1996).

These problems are all known to limit the size of the root system for perennial plants, and thus their ability to extract water and nutrients from the soil and maintain plant vigour (Southey 1992, Smart 1995). To produce high quality wine-grapes (i.e. with intensive flavour), a moderate root volume is required and this depends on climate, soil characteristics, quality of irrigation water, grape variety and canopy management. Of particular importance to vine root growth is the magnitude of soil strength experienced during growth. It has been well documented in South African and South Australian vineyards that soil resistance > 2 MPa seriously reduces root growth (van Huyssteen 1983; Myburgh et al. 1996).

In response to the gradual decline in yield and vine-vigour in various South Australian vineyards over the last ten years, soil managers focussed their attention on improving soil structure using various new techniques. Some techniques appeared to succeed on some soils while others appeared to fail. A rigorous evaluation of the new techniques, however, was never conducted and so the full benefits of any advances have not generally been appreciated by viticulturists. With the rapidly increasing cost of irrigation water over the last decade, the wine-grape industry became interested in the evaluation of the soil management techniques in vineyards across South Australia, with particular interest in determining whether water savings could be made without jeopardizing grape and wine quality.

As part of the broad-scale evaluation between 1996 and 2000, the Cooperative Research Centre for Soil & Land Management (CRCSLM), with support from the wine-grape industry established field experiments at three sites on different soils in vineyards (one at Lyndoch, SA, and two at Padthaway, SA). At the Lyndoch site, soil management had not changed since the vines were planted, and grape yield had declined for 5 consecutive years. Preliminary investigations suggested that low water-holding capacity in the surface soil plus high subsoil strength had seriously limited the ability of vine roots to access water and nutrients. At 1 of the 2 Padthaway sites, relatively saline irrigation water (2 dS m^{-1})

and wheel-traffic compaction were thought to be the main factors limiting vine performance. At the other site (Padthaway Plain) the presence of limestone at 0.5 m depth was thought to be limiting the vertical development of vine roots.

These three sites were set up to determine the extent to which good soil management could overcome the problems with soil structure, and thus increase the amount of plant-available water in the soil and improve grapevine performance. Because soil structure, soil salinity, root growth and soil water content were considered to be the main problems at the three sites, these factors were (variously) monitored as part of the evaluation.

Because the soil restrictions and vine responses varied at each site, the approach taken to soil management also varied, and thus the experimental treatments applied to the soil at each site differed. Nevertheless, all treatments addressed at least one of the following two hypotheses:

1) Mounding, deep ripping, or the application of various soil surface covers can improve vine performance by increasing the amount of plant available water in the soil.
2) Irrigation by partial root-zone drying (PRD) can reduce the amount of water required by vines without reducing grape yield.

The field experiments evaluated the effects of vineyard soil management on the following attributes:

1) soil structure and soil strength,
2) vine root growth,
3) amount of plant-available water in the soil,
4) soil salinity and
5) grapevine performance.

The results of these field experiments form the chapters of this thesis, which examine the effects of soil physical limitations on vine root development, and the effects of soil management on vine performance. A final section of the thesis is devoted to an evaluation of soil management practices to overcome the limiting soil factors at the three field sites.

3 LITERATURE REVIEW

3.1 Introduction

Soil and water management effect grapevine performance through their impact on soil physical factors (eg. soil structure), as well as soil biological and chemical factors. Soil structure effects grapevine performance directly through the supply of water and nutrients and indirectly by impacting grapevine root development. This literature review evaluates the relationship between soil physical fertility and grapevine performance with particular emphasis on the link between root growth and vine performance and the role of physical fertility in controlling root development. This is followed by a review of the effect of various soil management operations on soil physical fertility, hence root growth and grapevine performance.

3.1.1 Link between root development and grapevine performance

Roots transfer virtually all water and nutrients from the soil to the aboveground parts of the plant under the influence of various hormones synthesised in different parts of the root system (Richards, 1983). The size and health of the grapevine root system therefore govern vine vigour (Smart, 1995; Southey, 1992). This is not to say that vine vigour is the ultimate goal of good soil management – in fact, optimum berry quality is seldom achieved if vines are excessively vigorous (e.g. McCarthy et al., 1983). Consequently it is necessary to aim for the 'optimum' rather than simply the 'maximum' root growth and shoot development.

In vineyards where soil is physically fertile, the quantity and quality of berries may not be limited by soil conditions. However, where berry quantity and/or quality do not meet specifications, soil physical fertility may need to be examined and adjusted. While targeted grapevine water stresses are often used to improve grape quality, it is almost never the case that severely restricted root systems produce berries of high quality (ie. with intense flavour and colour). Van Huyssteen and Weber (1980c) found that where soil physical fertility was improved through minimum tillage, the volume and density of roots generally increased by comparison with other treatments. Furthermore, pruning-mass, grape yield, and grape quality in the final two years of their experiment were also superior.

Irrigation- and canopy-management are generally known to affect grape quality (Hardie and Martin, 1989), but little is known about the effects of soil management on root-shoot relationships in grapevines. This is because estimates of root density and volume are extremely difficult to obtain in vineyards and are thus not measured routinely. However, in the few studies that have attempted root measurements in southeastern Australia and Western Australia, Myburgh et al. (1996) found that soil limitations restricted root development in most vineyards. Importantly, in many of these vineyards, irrigation water was of poor quality and increasingly expensive, which was a significant incentive to minimise irrigation and to use stored soil water from rainfall more efficiently. Soil physical fertility is one of the main variables that can be managed to improve root development and shoot response.

The assertion of McCarthy et al. (1983) that increasing the root volume may lead to poor berry quality needs to be considered in light of the fact that canopy management, irrigation management, as well as soil management all affect grape quality in an interrelated way –

thus no single factor should be evaluated independently. An increased root-volume through improved soil management may best be capitalised upon (to improve grape quality) by reducing the amount of irrigation. The optimum root volume should thus be considered in relation to many factors, including soil and water management, water quality, climate, canopy management, varietal vigour and growth-habit, and the end-use intended for the grapes.

3.2 Soil physical fertility and root development

The quality of soil structure is determined by the arrangement of the soil particles to form a system of interconnected pores. The presence and arrangement of soil pores affects root volume and thus the storage and flux of water, air, and nutrients in the soil (Hamblin, 1985). Important attributes of soil structure that influence grapevine root growth include pore size distribution, soil structural stability, and mechanical impedance. How a soil maintains its pore size distribution and its structural stability controls the longevity and function of the pores (Cass et al. 1993). Each of these attributes of soil structure will be considered below.

3.2.1 Soil structure

3.2.1.1 Pore size distribution

The pore size distribution within the soil matrix is the most important feature associated with soil structure. All the essential belowground physical requirements for plant growth and development are provided via classes of different sized soil pores.

For example, small (micro-)pores as well as larger (bio-)pores are necessary for optimum functioning of soil processes and so they influence root growth and development. Some pore-size limits, pore groups and their associated functions are listed in Table 3.1. The maximum sizes of water-filled pores at significant matric suctions are also listed. A change in the pore size distribution as a result of, for example, excessive trafficking, may reduce infiltration, water storage and drainage and will invariably increase soil strength. Consequently, developing and maintaining a balanced pore size distribution is an integral part of good soil management.

3.2.1.2 Soil structural stability

Once an optimal pore size distribution is established, soil management practices must maintain the integrity or stability of this soil structure (Oades, 1993). Structurally stable soils retain the physical integrity of their pores and solids upon wetting and drying, even if the total volume changes (Hamblin, 1985).

Oades (1993) discussed the importance of biological activity in the stabilisation of soil structure. Plant roots and fungal hyphae enmesh soil particles to form a "sticky string bag", (while at a micro scale mucilage from roots, hyphae, bacteria, and fauna such as earthworms are involved in stabilising smaller aggregates and linings of biopores. When microflora and fauna are lost from soil, structural decline takes place)

Soil types vary enormously in the areas used for viticulture in Australia, and thus the soil structure and structural stability also vary greatly. Myburgh et al. (1996) found that one of the very important soils of the Coonawarra, the Terra Rossa, is structurally quite stable and also highly resilient, in-as-much-as it recovers its structural form through natural processes when applied stresses are reduced or removed (Kay 1990).

Table 3.1 Soil pores and their functions (after Hamblin 1985 and Cass et al. 1993).

Pore diameter, μm	Pore description	Pore function	Corresponding matric suction, kPa
5000 to 500	Biopores	gas exchange, water infiltration	
500 to 75	Macropores	drainage, structural friability	
75 to 30	Mesopores	water transmission to micropores	
30			Field capacity (-10 kPa)
5	Micropores	plant water storage	Readily available water (-60 kPa)
0.2			Permanent wilting point (-1500 kPa)

3.2.1.3 Soil structural limitations to root growth

Structural instability to wetting and trafficking leads to surface crusting, hardsetting, and aggregate coalescence. Surface crusts are typically <10 mm deep, while hardsetting may extend to a depth of ≥ 300 mm (Gusli et al., 1994a). Aggregate coalescence can cause aggregates to weld together and become strong with little or no increase in bulk density (Cockroft & Olsson 2000; Grant et al. 2001). Sodic subsoils and dense sands also occur in vineyards of south-eastern Australia and Western Australia (Myburgh et al. 1996).

3.2.1.3.1 Hardsetting and crusting

Gusli et al. (1994a) found that the mechanism causing collapse of soil structure leading to hardsetting involved two steps: (i) slaking of aggregates on wetting, and (ii) collapse of the aggregate bed on draining. The outcome of these events is loss of large pores, increased bulk density and rapid development of high strength as the soil dries. Braunack et al. (1979), Mullins (1990) and Gusli et al. (1994b) all found that the larger pores (>75 μm) are lost in the hardsetting process. These pores include biopores and macropores, which promote water infiltration, drainage and structural friability (Table 3.1). Consequently hardsetting results in soils with poor drainage, poor infiltration, and high strength.

Crusting involves slaking, dispersion and aggregate collapse on draining, but only in the top 10 mm of soil. Gusli et al. (1995) found that crusting generally occurred when the soil was rapidly wetted from a very dry state. This caused extensive surface slaking, dispersion, and a moderate volume change, which caused a thin surface layer to become sealed. By contrast, they found that hardsetting occurred even when the soil was wet slowly. Only limited slaking occurred but this was followed by extensive dispersion and volume change, which caused sealing of a thick layer that extended well into the root zone.

3.2.1.3.2 Wheel and tillage compaction

Compacted layers in the region 50 to 300 mm below the surface may be due to regular tillage at the same depth (the so-called *tillage pan*). In established vineyards, the tillage pan predominates in the mid-row where regular tillage takes place (van Huyssteen, 1988b).

Compaction by trafficking occurs in the mid-row of vineyards close to the vine-row depending on row-width and the tractor-wheel spacing. (Soil texture influences the severity of wheel compaction. Light textured soils such as sands and sandy loams tend to compact more readily than heavier textured soils such as loams and clays. Myburgh et al. 1996 found that wheel compaction occurred in most of the vineyards they studied and that this caused shallower root systems in the coarser-textured soils than in the finer textured soils.)

3.2.1.3.3 Restrictions due to naturally sodic subsoils and dense sands

Restrictive soil layers may occur at varying depths under the vine-row and in the mid-row. These layers may be very dense due either to high sodicity or to particle size distributions that allow close inter-particle packing.

(Sodicity, which often occurs naturally particularly in subsoils exposed to sodium over long periods of time (Sumner 1995) causes aggregated clay particles to disperse. (Soil pores become blocked with dispersed clay, which cause poor infiltration and drainage, high soil strength, and hence poor root growth.) Examples of vineyard soils that contain naturally dense layers include some of the grey-gleyed clays, some of the black-cracking clays, soils with carbonate layers, all of the red gravelly laterites and most of the red-brown earths (Myburgh et al. 1996).

Compacted sandy duplex (i.e. texture-contrast) soils with bleached A_2-or E-horizons (at 200-400 mm depth) are common in vineyards of the Padthaway and Coonawarra regions of South Australia (Myburgh et al. 1996). These soils slake upon wetting and the saturated sand particles pack densely to generate very high soil strength (A. Cass, *pers. comm.* 1996).

Vine root responses to some of these restrictions are shown in Figure 3.1. Section "**A**" illustrates the small and restricted root system resulting from wheel and tillage compaction, hardsetting and crusting, and naturally restrictive compacted zones. Section "**B**" illustrates that grapevine root systems can grow under compacted zones caused by traffic, and then grow into the mid-row so long as they do not encounter further restrictions. However, where subsoil compaction also occurs within the top 450 mm, traffic compaction confines roots to the area immediately under the vine (Van Huyssteen 1988a). Section "**C**" illustrates that with no compaction the potential root volume is shown to be larger, thus increasing access to water and nutrients.

Limitations to vertical growth of grapevine roots may arise from factors other than structural degradation, compaction or natural soil mechanical limitations. For example, grapevine root growth may be reduced in soils of high salinity, as water from saline soils is less available than from non-saline soils (Groenevelt et al. 2004). Consequently salinity limits the potential effective root volume of grapevines. The effect of soil management on soil salinity and sodicity is discussed later in this literature review.

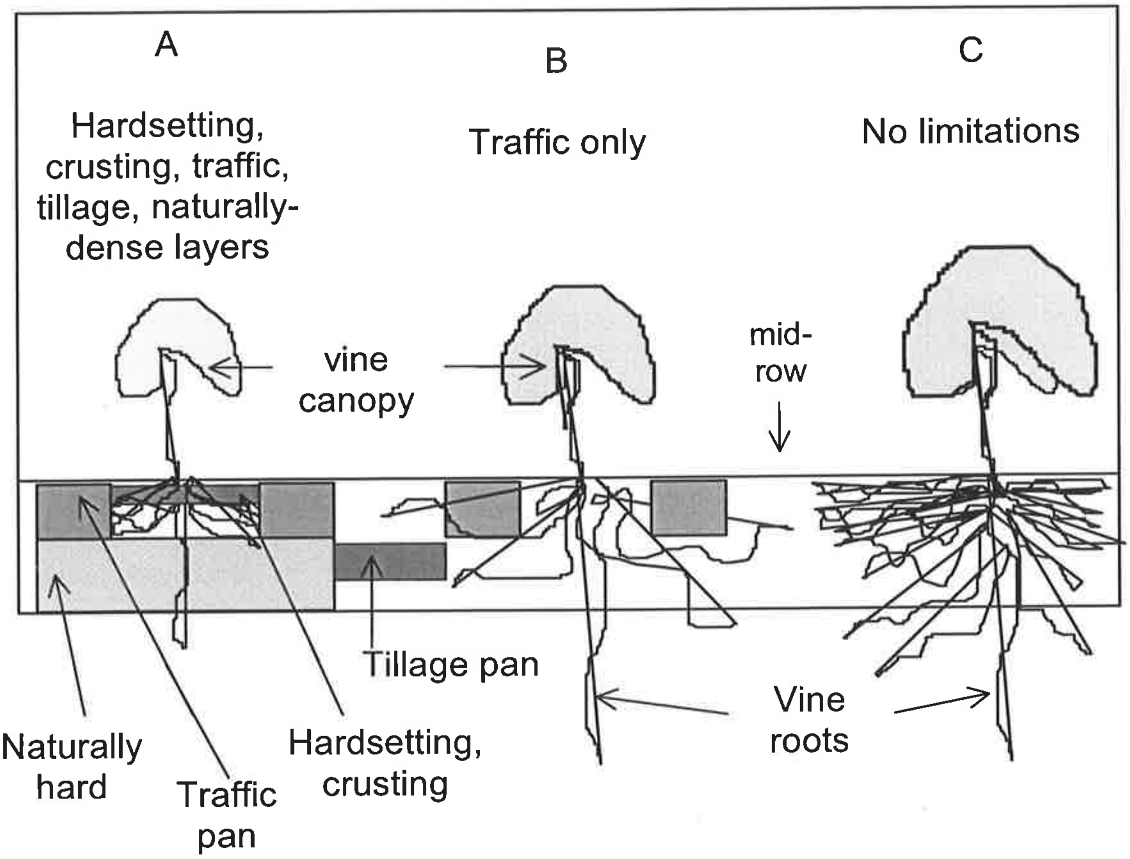

Figure 3.1 Soil structural limitations and subsequent grapevine root growth.

3.2.2 Soil strength

One of the major limitations to root growth in compacted soils is high soil strength. Roots can penetrate soil if the pressure they can exert exceeds the resistance they meet (Richards, 1983). Consequently if soil strength is high and the soil is not deformable, root tips are unable to enter pores smaller than the diameter of the root tip (Dexter, 1988). Compression of elongating root tips or underground shoots by the resistance of the soil reduces their rate of elongation (Barley 1976). Mechanical compression of elongating root tips causes the enlarging cells to become shorter and wider than usual.

The physiological mechanisms that determine whether roots penetrate soil of high strength are not well understood.(There is no doubt, however, that as soil strength increases beyond a critical limit, root growth becomes restricted and eventually ceases altogether beyond that limit.)This has serious implications for water and nutrient availability in vineyards (Groenevelt et al. 2001).

3.2.2.1 Bulk density

Van Huyssteen (1988a) grew vines of Chenin Blanc/99 Richter in pots of different soils with subsoil bulk densities in the range from 1.3 to 1.7 Mg m^{-3}. Root penetration into the subsoil decreased with increasing bulk density but they concluded no critical value of bulk density or penetration resistance could be found at which root penetration was fully impeded. This was possibly due to the ability of roots to grow in directions to exploit cracks and pathways of lower resistance – that is, they do not respond solely to the density and strength of the bulk soil. Van Huyssteen (1988a) concluded the experiment demonstrated the beneficial effects of loose subsoils on vine performance.

3.2.2.2 Penetration resistance

Penetration resistance (often referred to as 'soil resistance') estimates the bulk soil strength using the force required to insert a metal cone attached to a rod into moist soil. It provides only a general indication of the strength-environment that roots encounter – not an exact measure of the pressure experienced by growing root tips. In coarse textured soils and in mechanically heterogeneous soils, roots penetrate more easily than do metal probes because they follow paths of less-than-average soil resistance (Barley 1976). Despite the limitations of a cone-penetrometer, it remains one of the more useful tools for identifying zones in the soil that restrict root growth (van Huyssteen 1983).

Penetration resistance varies inversely with soil water content, so it must be measured at the same water content in the field every time – usually the 'field capacity'. The field capacity describes the moisture status of the soil water after it has been saturated and allowed to drain for 24 - 48 hours. This is a rather imprecise concept that depends to some extent on soil texture (e.g. clays take longer than sands to reach 'field capacity'), but for most practical purposes, it does not vary for a given soil and is considered to be the point of maximum soil water availability for most plant roots (Groenevelt et al 2001).

Root growth is typically inhibited by penetration resistances ranging from <1 MPa up to >4 MPa and depends on factors such as the texture of the soil, the pore water pressure, and the plant species (Hamblin 1985). Van Huyssteen (1983) concluded that a soil resistance of <2 MPa is adequate for root growth of vines. Myburgh et al. (1996) concluded from a study of root growth in a large number of soil pits in vineyards of southern Australia, that 2 MPa (at field capacity) was the threshold (maximum) penetration resistance for grapevine root growth. Dexter (1987) related root development to soil strength (penetration resistance) and soil water suction. He described the relative rate of elongation of the root tip, R/R_{max}, as follows:

$$\frac{R}{R_{max}} = \frac{-\varphi_o}{\varphi_w} + e^{-0.6931\,(Q_p/Q_{0.5})}$$

where ψ_o is the soil water suction at the permanent wilting point for a particular plant species (approximately -1500 kPa), Q_p is the soil resistance to penetration (MPa) at a given soil water suction, ψ_w, and $Q_{0.5}$ is the value of the penetrometer resistance that reduces the relative root elongation rate to 50% for a given plant species. Values of $Q_{0.5}$ for different species range from 0.72 to 2.03 MPa (Dexter 1987).

3.2.3 Soil water deficit

Freeman and Smart (1976) found when irrigation was applied at a rate of 100% of evaporation root growth was stimulated compared with irrigation at 300% of evaporation. Van Zyl (1988) found that if irrigation was applied to grapevines when 50% of the total plant available water had been used, this maximized the rate of root growth at critical periods. After flowering, for example, there were 190 actively growing root tips/m^2, and at harvest there were 300 actively growing root tips/m^2. If irrigation was applied only when 75% of the total plant available water had been used, the number of actively growing root tips after flowering peaked at only ~40 tips/m^2 and new root growth was consistently less than this for the remainder of the season. It therefore appears that the ideal water status at which vines need to be kept for maximum root development lies somewhere around 50% of the total available water capacity. This allows sufficient aeration in the root zone, while at the same time not exposing the roots to significant water deficits.

3.2.4 Soil aeration

The effect of soil aeration on grapevine root development is not well understood because there is little quantitative information on the response of grapevine roots to aeration status. Furthermore, plant response to aeration is complex and the most visible symptoms are shown in the above-ground parts of the vine. Nevertheless, overall plant performance can be diminished by poor soil aeration, and this gives the vineyard manager an opportunity to monitor the soil.

While it is relatively easy to measure simple estimates of soil aeration, it is very difficult to quantify soil aeration in a manner that can be linked directly to plant response (e.g. redox potential, oxygen diffusion etc). Most of the work on soil aeration and root growth has therefore used rather crude estimates of soil aeration. For example, air-filled pore space depends on both soil structure and soil moisture content, so one can compare air-filled porosity at a consistent soil moisture status. It is thought that plants require at least 10% of the bulk soil volume to be filled with air at 'field capacity' so that root respiration is not limited by oxygen (Dexter 1988).

Stevens and Douglas (1994) found ~73% of irrigated grapevine roots grew within the top 800 mm of soil, while only ~27% of the roots grew in the zone below 800 mm. This coincided with a volumetric air content of 13 % in the top 800 mm and only 6 % below 800 mm. While other soil variables may have confounded the effects of aeration, the importance of aeration in the subsoil cannot be overstated.

Myburgh and Moolman (1991) analysed soil air and found that under waterlogged conditions, oxygen in the soil air is largely replaced by carbon dioxide. They also concluded that soil oxygen concentrations <16% by volume may increase leaf water suction and increase stomatal resistance in grapevines. Accumulation of toxic gases such as ethylene may also occur during periods of prolonged water-logging.

3.2.4.1 Soil water availability described by NLWR, LLWR, and IWC

Northcote (1992) concluded (indirectly) that the (non-limiting) available water was the most important characteristic of a soil for growing grapevines in Australia, particularly as a function of soil depth (Letey 1985). The non-limiting water range (NLWR) describes the amount of water available to plants between the wet end (where macropores remove much of the water between saturation and 'field capacity', and where poor aeration may limit the availability of the remaining water) and the dry end (where micropores hold water against plant uptake beyond 'permanent wilting point', and where high soil resistance may limit access to water by roots). The non-limiting water range thus defines a 'window of opportunity' of soil water contents for maximum root growth and development. When soil water contents fall outside this range, root restriction is likely to occur and plant performance will suffer. DaSilva et al. (1994) and daSilva and Kay (1996) described this range for maize plants in the field and called it the Least Limiting Water Range (LLWR). They found that the frequency with which soil water contents fell outside the LLWR was directly related to plant response, particularly at critical periods during the growth season.

They used critical water contents corresponding with the volumetric air content (10%), field capacity (matric suction = 10 kPa), soil penetration resistance (2 MPa) and the wilting point (matric suction = 1500 kPa).

More recently, Groenevelt et al. (2001, 2004) described the availability of soil water in terms of various limiting factors such as soil resistance, soil aeration, hydraulic conductivity, and soil salinity. These factors were taken into account in a gradual way (rather than as critical, cut-off water contents) by weighting the differential water capacity for each limiting factor and then integrating all factors to produce an integral water capacity (IWC). Considerable work is required still to link the IWC to plant response, and is therefore outside the scope of the present thesis.

3.2.5 Soil salinity

Grapevines are considered to be 'moderately sensitive' to soil salinity (Maas and Hoffman 1977) on a 5-class scale of crop-tolerance: 'sensitive', 'moderately sensitive', 'moderately tolerant', 'tolerant' and 'unsuitable for (commercial) crops'. Soil salinity as measured in a saturated paste extract, EC_{se}, must exceed 1.5 dS m^{-1} before a decrease in yield occurs, above which a 10% yield reduction is experienced for every 1 dS m^{-1} above that value.

Prior et al. (1992a) found that the effect of irrigation water salinity was most severe on grapevines growing in heavy-textured soils, primarily due to poor aeration and the build-up of soluble salts due to reduced leaching. Stevens and Harvey (1995) highlighted the combined effect of soil salinity and water-logging on grapevine performance. They found that increasing the sodium chloride concentration in irrigation water from 1 to 60 mM caused growth to decline by 47% in vines with free-draining root zones and by 61% in vines with waterlogged root zones. Water-logging even reduced the ability of a chloride-excluding rootstock to reduce chloride concentrations in the leaf (18% compared to 60% in free-draining root zones). Southey (1992) also found that grapevine root development was restricted in a sandy clay loam with high salinity. The Ramsey rootstock used by Southey (1992) was affected by salinity even though it was capable of restricting salt uptake – the top growth was balanced by the restricted root growth, and so canopy development was also reduced. Prior et al. (1992c) found that the type of salt had an affect on root-zone depth and root density – these were lower in heavier-textured soils in the presence of sodium and magnesium salts (rather than calcium salts).

Sumner (1995) highlighted the effect of salinity-fluctuations on soil structure. Clay dispersion is promoted by lower electrical conductivity of the soil solution in the presence of high exchangeable sodium. This situation occurs when natural rainfall (or irrigation-water of high quality) follows irrigation water of low quality. The dispersion of colloids that occurs in these situations causes the soil to become unstable. This leads to hardsetting, poor infiltration and drainage, and reduced water storage, all of which limit root growth (Figure 2 of Cass et al., 1996). Consequently soil management that reduces sodium build-up within the root zone invariably benefits soil structure and root growth.

3.2.6 Soil temperature

Roots of many woody plants grow within temperature limits of 5 to 35°C with an optimum range between 15 and 30°C (Richards 1983). Proebsting (1943) grew peach and pear seedlings in containers of loam-textured soil held at a series of six constant temperatures between 7 and 35°C and found that root growth was greatest at 24°C and least at 7°C.

Woodham and Alexander (1966) found that the growth of Sultana grapevine roots, shoots as well as inflorescences increased with increasing root temperature from 11°C to 30°C. This suggests grapevine roots are well-suited to Mediterranean climates, where air temperatures in summer exceed 40°C, and where temperatures in the root zone can approach 30°C.

3.3 Effect of soil and water management on grapevine performance

It is widely thought that some restriction of the root system leads to higher-quality grapes for wine production. However, excessive restriction can reduce grapevine performance to the extent that grape quality is reduced. Where vineyard performance is poor, management has focussed on trellis management, irrigation management, and soil nutrition. Until recently, however, the soil physical requirements of grapevine roots have been neglected, particularly outside South Africa, where scientists have been more progressive in many ways (e.g. van Zyl 1988; Saayman and van Huyssteen 1980, 1983a,b; van Huyssteen and Weber 1980a,b,c; van Huyssteen 1983, 1988a,b; Myburgh 1994; Myburgh and Moolman 1991, 1993).

Very little work has been undertaken in Australia to evaluate effects of soil management on physical fertility and grapevine performance. The works of Cockroft and Wallbrink (1966a,b), Cockroft, (1966), Cockroft and Tisdall (1978), and Adem and Tisdall (1983) in orchards and other horticultural operations, however, have been seminal in formulating an approach to similar studies in vineyards (e.g. Cass, Cockroft and Tisdall 1993).

Soil management practices can be described in two groups, which will be discussed separately:
(1) profile-scale soil management, which includes deep-tillage (or deep-ripping) or mounding the topsoil from the alley onto the vine-strip, and
(2) surface-cover soil management, which deals with only the topsoil, and includes cultivation, cover crops, permanent swards, mulches and use of herbicides.

3.3.1 Deep-tillage (deep-ripping)

Deep-ripping is an important tool for ameliorating soils that have natural or management-induced compacted zones. If performed correctly, deep-ripping can reduce soil strength and create a series of continuous cracks and pores from the soil surface to a depth of at least 0.7 m. These cracks and pores significantly increase infiltration and aeration, and enhance the drainage of salts below the root zone.

Deep-ripping is the most common form of deep-tillage in viticulture in Australia, but Myburgh et al. (1996) reported varying degrees of its success in reducing soil strength and enhancing root development in vineyards. He found that ripping was sometimes unsuccessful because ripping tools were poorly designed or they were used improperly. For example, in some cases, wings were attached to the ripper and caused no loosening/shattering, which made the ripper effective in only a narrow band under the vine-row. For the ripper to be effective to say 1 m depth, the ripper needed to be longer (e.g. 1.5 m), which was often not the case. Furthermore, very little cross-ripping and ripping-in-the-mid-row were practiced, and so roots developed in only a narrow band in the vine-row. Ripping the soil when it was too wet also resulted in a lack of shattering and therefore limited root-development under the vine-row.

Mixing of subsurface layers is also not common practice in Australian viticulture and implements are not generally available to carry out this task (Myburgh et al. 1996). Van Huyssteen (1983, 1988a) reported on the success 'delving' (resulting in lifting and turning the soil, causing greater mixing than with other implements) to reduce soil strength and enhance grapevine performance. Comparing different methods of soil preparation, van Huyssteen (1983) found that penetration resistance indicated shallow ploughing was totally ineffective in creating a favourable subsoil root environment. The most favourable loosening effect was obtained by double-delving. Single-direction delving showed significantly greater soil strengths at all depths than double-delving. The wing-plough yielded only slightly less favourable soil strength than double-delving.

Van Huyssteen (1988a) reported on the root distribution and grapevine performance under different soil preparation methods in a sandy clay loam soil at Stellenbosch, South Africa. As the depth of soil preparation increased, the total number of roots increased and shoot mass and yield increased (Table 3.2). Shallow ploughing (220 mm) resulted in the lowest total number of roots, the lowest percentage of roots <2 mm diameter, the lowest grapevine shoot mass, and the lowest yield. Ripping to a depth of 700 mm improved all of these characteristics, but delve-ploughing to 700 mm depth resulted in the greatest total number of roots, the greatest percentage of roots <2 mm in diameter and the greatest shoot mass and grape yield. Saayman and van Huyssteen (1980) found similar results on a sandy clay loam soil at Robertson, South Africa. They obtained root data by dividing 3m-long profile-walls into rectangular grids and then plotting the root positions and size classes. Shallow ploughing to a depth of 600 mm resulted in a total of 331 roots within the grid from 0 to 1000 mm, a shoot mass of 1.46 kg/vine, and a yield of 10.4 kg/vine. Delve-ploughing to a depth of 900 mm plus 28 t/ha of straw resulted in a total of 482 roots within the grid from 0 to 1000 mm depth, a shoot mass of 1.81 kg/vine, and a yield of 11.9 kg/vine.

Table 3.2 Root distribution and grapevine performance under different soil preparation methods (after van Huyssteen, 1988a).

Tillage treatment	Total number of roots	% Roots < 2 mm diameter	Shoot mass (kg/vine)	Grape yield (kg/vine)
Shallow (220 mm)	271	90.0	0.704	5.52
Ripper (700 mm)	356	90.5	0.844	6.59
Delver (700 mm)	527	93.8	1.027	8.13

The relation between cumulative yield and depth of tillage had a correlation coefficient of $r = 0.72$ for the Stellenbosch site and $r = 0.68$ for the Robertson site. The relation between cumulative shoot mass and the depth of tillage gave an r-value of 0.81 for the Stellenbosch site and 0.67 for the Robertson site.

The authors suggested that deep tillage to, say 700 mm, may be essential for optimum grapevine root and shoot development. The researchers also emphasise that the 'quality' of the tillage operation is important and quality control ought to be in place to assess the outcomes of the tillage, because different tillage implements and their operation have different effects on the soil physical fertility, root development and grapevine performance[1].

3.3.2 Mounding topsoil to create raised soil beds

Mounding topsoil from the mid-row onto the vine-row is done to increase the total volume of well-structured soil available for root development. This is generally done where shallow surface soils occur over hostile subsoils or bedrock, which can cause waterlogging and can limit the volume of the rootzone.

Myburgh and Moolman (1991) found that mounding of a marginal, waterlogged soil improved soil aeration by increasing topsoil depth and internal drainage. The ratio of O_2 : CO_2 in the mound-soil air was increased through unrestricted gas exchange between the atmosphere and the soil. Mounding also improved drainage of sodium and other salts within the soil profile, which improved soil structure and root growth.

In a similar experiment conducted in the Barossa Valley, South Australia, Eastham et al. (1996) found that the bulk density of soil in mounded soil beds (1.25 Mg m^{-3}) was significantly lower than in flat beds (1.5 Mg m^{-3}) at comparable soil depths. This allowed more rapid root development and significantly greater root-lengths in the mounds, which allowed greater extraction of water and nutrients and thus better performance of the vines.

The shape of the mound has an impact on soil moisture and soil temperature. Smaller mounds (e.g. 400 mm high, 1 m wide) have been found by Myburgh and Moolman (1993) to reach greater temperatures at 150 mm depth than larger mounds (e.g. 600 mm high, 1.5 m wide). With more radiation absorbed per unit volume of soil the maximum temperature in the mounded soil may (rarely) exceed 30°C, although this would not likely cause permanent damage to shallow vine roots. Myburgh and Moolman (1993) also concluded that where temperature is too low at the beginning of the growing season in waterlogged soils, mounding can increase soil temperatures and provide a more favourable environment to root development.

Myburgh (1994) found that mounding of non-irrigated soil improved the structure above a compacted and waterlogged soil horizon, and that this increased root development. Root development in the top 200 mm of soil was greater for non-mounded treatments due to excessive drying of the topsoil. In a separate experiment, irrigated mounds produced significantly greater yields than non-irrigated mounds, and non-mounded treatments. The benefits of greater drainage and aeration of excess water in mounds must therefore be balanced against the risk of mounds becoming too dry in non-irrigated conditions.

Myburgh (1994) found that during fruit-ripening, the ratio of the surface-area of soil mounds (m^2) to the bulk-volume of soil mounds (m^3) was important. For mounds containing double rows, adverse conditions caused yield losses when this ratio was <0.6 m^2/m^3. For single vine-row mounds, yield losses occurred when ratios were <1.0 m^2/m^3. Consequently, the ideal dimensions for double vine-row mounds were found to be < 400 mm high and ≥ 1.5 m wide at the crest. Similarly, for single row mounds, the ideal

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[1] South African recommendations on deep-ripping would not be recommended in Australia for situations where subsoils are highly sodic, unless this were done in conjunction with other treatments (e.g. gypsum).

dimensions were found to be < 400 mm high and ≥1.0 m at the base, with flat crests approximately 500 mm wide.

3.3.3 Conventional tillage, mulching, swards and cover crops

The errant practice of cultivating the soil in the vineyard mid-row 'to conserve soil moisture' is still common in some regions of Australia, despite the availability of other better moisture-conserving practices, such as mulching, cover-cropping, or permanent swards.

Van Huyssteen and Weber (1980b,c), for example, found that a combination of herbicides and straw-mulches conserved far more soil water for longer periods of time than cultivation. Furthermore, this produced better growth and yielded grapes of superior quality. Without irrigation, they found that permanent swards, of course, competed for water and nutrients. Enz et al. (1988) found, in line with general expectation, that evaporation was always greater from a bare surface than from a stubble-covered surface until the water content dropped to a critical value. Evaporation from the stubble-covered soil thereafter remained very small due to reduced wind speed and lower surface temperatures in the stubble.

Van Huyssteen and Weber (1980a) found that 2 to 4 clean cultivations per year using a disc-harrow had deleterious effects on soil physical and biological properties in the surface and subsoil of a South African vineyard. By contrast, herbicide, straw-mulch, and permanent swards, which excluded cultivation, produced mainly favourable effects on soil physical and biological fertility. Clean cultivation generated high bulk density and a tillage pan between 200 and 300 mm depth, as shown in Table 3.3. Low bulk densities are shown in the top-soils of the permanent sward and herbicide-treated soils. The soil treated with straw mulch had slightly higher bulk density and lower porosity in the topsoil than the other treatments (Table 3.3).

Table 3.3 Bulk density and total porosity as affected by different soil surface-management (after van Huyssteen and Weber 1980a).

	Bulk Density, Mg m^{-3} and (Total porosity, %)			
Soil depth (mm)	**Soil surface management**			
	Straw mulch	**Herbicide**	**Clean cultivation**	**Permanent sward**
0-100	1.57 (40.4)	1.53 (42.4)	1.33 (49.9)	1.53 (42.4)
100-200	1.69 (36.6)	1.54 (42.6)	1.64 (38.7)	1.66 (37.9)
200-300	1.59 (40.1)	1.37 (48.9)	1.70 (36.3)	1.54 (43.3)
300-500	1.54 (42.2)	1.42 (47.0)	1.56 (41.6)	1.41 (47.4)
500-700	1.75 (35.1)	1.81 (32.9)	1.64 (39.1)	1.54 (39.1)
700-900	1.83 (32.2)	1.86 (31.2)	1.77 (34.5)	1.77 (34.3)

Aggregates and corresponding pores may be destroyed by cultivation, particularly if the soil is too wet or too dry (van Huyssteen and Weber 1980a). This makes the soil vulnerable to compaction and erosion. Cultivation also disturbs the habitat of larger organisms, such as worms, and may decrease their numbers (Oades 1993). Plant roots create biopores and enmesh soil particles, which stabilise aggregates. Monocotyledons have larger numbers of fine roots than dicotyledons, and so monocotyledonous plants stabilize soil aggregates better than dicotyledons. Dicotyledonous plants generally grow longer and have the ability to exert greater radial pressure on surrounding soil as they expand their diameters. It is possible that the major function of monocotyledonous plants is to stabilise aggregates, while the major function of dicotyledonous plants is to create biopores, although roots tend to grow preferentially through existing pores rather than create new pores by growing through soil aggregates (Dexter, 1988).

Microfauna and microflora proliferate in undisturbed environments, particularly under straw mulches. Tillage kills these fauna and flora and disturbs their habitat. Earthworms, for example, create cylindrical biopores as they ingest soil and excrete waste in the form of spherical casts (McKenzie and Dexter, 1988). Fungal hyphae and bacteria also create and stabilise soil structure (Oades, 1993). Like plant roots, these microorganisms create pores during growth, and they enmesh soil aggregates with filamentous structures and stabilise them with biopolymers and polysaccharides (known collectively as mucilage).

Tisdall (1978) found fewer earthworms in cultivated orchards (150 worms/m^2) compared with orchards to which straw and sheep manure were added (2000 worms/m^2). Van Huyssteen and Weber (1980a) found significantly greater quantities of fungi in the topsoil under straw mulch compared with clean-cultivated treatments. While cultivation seemed to have no effect on bacterial numbers, the application of herbicides reduced both fungi and bacteria, which was thought to have been due, in part, to poor aeration generated by a thick surface crust on the herbicide-treated soil. While cultivation may have negative impacts on some beneficial organisms, the lack of soil disturbance may enhance the proliferation of various disadvantageous microfauna, such as nematodes. Van Huyssteen and Weber (1980a) found nematodes proliferated most successfully under a permanent sward, and progressively less well under a straw mulch treatment, a clean cultivation treatment and a herbicide treatment, respectively.

Van Huyssteen and Weber (1980c) found the total number of grapevine roots was greatest in an uncultivated soil treated with herbicide (Table 3.4). The number of vine roots was less under clean-cultivated soil (due to soil disturbance) and the permanent sward soil (due to competition for soil water) throughout the growing season (Van Huyssteen and Weber, 1980c).

Table 3.4 Total number of vine roots under different soil surface cover treatments (after van Huyssteen and Weber 1980c).

Soil surface management	No. of roots > 5 mm diameter	No. of roots < 5 mm diameter	Total no. of roots	Relative abundance of roots (%)
Herbicide	4	325	329	100.0
Straw mulch	9	247	256	77.8
Clean cultivation	4	170	174	52.9
Permanent Sward	2	162	164	49.8

The effects on vine top growth and yield are shown in Tables 3.5 and 3.6. Overall, the pruning-mass from the straw mulch treatment was significantly greater than for the cultivated and permanent sward treatments. Pruning mass was significantly less for the permanent sward treatment than for all other treatments, and this was primarily due to competition for water and nutrients that the sward presented.

Table 3.5 Pruning mass as a function of soil surface management over 7 growing seasons (after van Huyssteen & Weber, 1980c).

	Total pruning mass (t ha^{-1})			
	Surface soil management			
Season	**Straw mulch**	**Herbicide**	**Clean cultivation**	**Permanent sward**
1971/72	0.460^{a}	0.288^{a}	0.301^{a}	0.070^{b}
1972/73	1.152^{a}	0.553^{b}	0.490^{b}	0.171^{bc}
1973/74	1.08^{a}	0.903^{a}	0.683^{a}	0.159^{b}
1974/75	1.11^{a}	1.22^{a}	1.14^{a}	0.312^{b}
1975/76	2.64^{a}	1.75^{a}	1.65^{b}	0.420^{c}
1976/77	3.70^{a}	3.10^{a}	2.49^{a}	0.640^{b}
1977/78	2.78^{a}	2.44^{a}	1.96^{a}	1.08^{b}
Mean	1.84^{a}	1.46^{ab}	1.24^{b}	0.400^{c}

Within same growing season, pruning masses with different superscripts were significantly different at $P = 0.05$.

The grape yields followed a similar pattern to the pruning mass, although the mean yield from the cultivated treatment was not significantly less than that for the straw mulch treatment (Table 3.6). The mean yield from the permanent sward treatment was significantly less than for all other treatments, due once again to competition for water and nutrients.

Due to the higher pruning mass and yield under the straw mulch one might expect the straw mulch vines to produce the lowest quality grapes (and wines) and the permanent sward vines to produce the best grapes (and wines), but this did not occur. The straw mulch vines produced the best quality wine in 2 out of the 3 years measured and the vines under permanent sward produced the poorest quality wine (van Huyssteen and Weber 1980c). The difference in wine quality was likely due to incomplete fermentation caused by low N content of the musts. The low N content occurred because of competition for water and N between the grapevines and the permanent swards.

Table 3.6 Grape yield as a function of soil surface management over 7 growing seasons (after van Huyssteen & Weber, 1980c).

	Grape yields (t ha^{-1})			
	Surface soil management			
Season	**Straw mulch**	**Herbicide**	**Clean cultivation**	**Permanent sward**
1971/72	7.64^{a}	4.35^{a}	4.11^{b}	1.60^{b}
1972/73	8.07^{a}	3.73^{b}	4.74^{b}	1.23^{c}
1973/74	9.93^{a}	7.87^{ab}	6.00^{b}	1.81^{c}
1974/75	9.53^{a}	9.81^{a}	7.72^{a}	1.47^{b}
1975/76	12.29^{a}	10.84^{a}	10.29^{a}	3.39^{b}
1976/77	13.63^{a}	10.94^{ab}	9.38^{b}	3.40^{c}
1977/78	25.13^{a}	20.84^{a}	19.28^{a}	8.85^{b}
Mean	12.32^{a}	9.77^{a}	8.79^{a}	3.11^{b}

Within same growing season, pruning masses with different superscripts were significantly different at $P = 0.05$.

In summary, the work by van Huyssteen and Weber (1980a,b,c) clearly demonstrated that conservation of limited soil water by straw mulch and herbicide treatments resulted in several important favourable attributes such as improved soil physical fertility, greater vine-root development, greater pruning masses, greater grape yields and better quality of wine.

While mulch may be beneficial in the vineyard for conserving soil moisture and managing weeds, it also decreases soil temperature. In a comparison between bare and stubble covered soil surfaces, Enz et al. (1988) found soil surface temperature of bare soil surfaces was almost always greater than that for stubble-covered surfaces. An exception occurred when weather conditions were overcast and soil surfaces were wet, where the soil temperatures were approximately equal. Early in the growing season and in cool climates this may not be beneficial (Ludvigsen, 1995). Later in the growing season when soil temperatures can rise significantly, particularly in raised soil beds, mulches can maintain beneficially lower temperatures (Myburgh and Moolman, 1993; Proebsting, 1943).

The issue of frost risk with straw mulches must also be considered in relation to soil-surface management (McCarthy et al., 1992). They stated that the most effective practice to reduce frost damage was bare (cultivated or herbicide-treated), compacted, wet soil, and barring this treatment, the most effective soil management practice was a closely-mown sward with a clean vine strip. Thick mulches and high swards provided the highest frost risk because they prevented the upward movement of heat during sub-zero evenings.

3.3.4 Gypsum and lime

Gypsum, which increases soil-solution electrolyte concentrations (promoting flocculation of dispersed clay) and replaces exchangeable sodium with exchangeable calcium, has been the most widely used practice to ameliorate poor (sodic) soil structure (Shanmuganathan and Oades, 1983). Lime can also be used for a similar purpose on acidic sodic soils, but gypsum is usually the preferred calcium source for neutral to alkaline sodic soils because it is more soluble and does not increase soil pH.

One of the most widely distributed viticultural soils in South Australia is the red-brown earth. Adding gypsum to these can significantly improve aggregate stability and reduce shear strength of soil crusts where the exchangeable sodium percentage (ESP) is >10 (Grierson 1978). The addition of between 5 and 12 t/ha gypsum decreased runoff at 4 out of 5 sites in the first year and 3 out of 5 sites the second year. The decrease in run-off was attributed to improved water infiltration caused by greater aggregate stability and greater resistance to breakdown by rainfall impact. Improvements in infiltration can also occur with lower application rates of gypsum, depending upon soil type. For example, incorporation of 1.25 t/ha gypsum to a sandy loam in California increased infiltration rates from 0.63 cm/h to 0.89 cm/h (Aljibury and Christensen 1972).

Improved soil structure can increase root development and improve vine performance. For example, Kirchhof et al. (1997) found that slotting lime to ~15cm in an acidic soil and mounding the amended soil onto the vine-strip increased root-length density by more than an order of magnitude and nearly doubled grape yields from 4.8 t/ha to 8.2 t/ha.

3.3.5 Organic polymers

There is little published about the effect of polymers on grapevine performance. I will therefore briefly discuss the role of polymers in improving soil physical properties in general, and then relate this to potential vineyard application.

Organic polymers are manufactured with different functional groups of varying charge, and their effects on soil physical fertility vary significantly (Ben-Hur et al., 1989; Helalia and Letey, 1989; and Laird, 1996). Ben-Hur and Letey (1989), for example, found differences in performance of polymers in their ability to aggregate soil particles and to maintain infiltration, according to their charge and ionic status, in the order: high-charge, cationic polymers > low-charge, cationic polymer >> nonionic polymers > anionic polymers (no effect). Similarly, Laird (1996) found that anionic polyacrylamide (PAM) flocculated colloids in relation to the properties of the colloids, in the order: kaolinite > illite > quartz.

Electrostatic adsorption of polymers onto negative clay surfaces appears to be one of the dominant mechanisms providing stability to aggregates (Ben-Hur and Letey 1989). For cationic polymers, the attraction is strictly electrostatic between the clay surfaces and the polymer (Saleh and Letey 1988). Attraction for anionic polymers is achieved through cation-bridging (Laird, 1996) and the presence of calcium which is required for maximum flocculation (Laird 1996; Wallace and Wallace 1996).

Polymers can be applied in granular form to the soil, or in irrigation water. Ben-Hur et al. (1989) found that spraying PAMs directly onto the soil surface did not maintain infiltration rates during subsequent irrigations nearly so effectively as when PAM was mixed into the irrigation water. The optimum concentration of polymer in the irrigation water appears to be about 10 g m^{-3} or 10 ppm (Ben-Hur and Letey, 1989; Helalia and Letey, 1988).

Terry and Nelson (1986) found that bulk density and penetration resistance of flood-irrigated plots were significantly lower, and infiltration rates significantly higher when granulated PAM was applied to the soil at 650 kg ha^{-1}. Helalia and Letey (1989) found that a mixture of a cationic-guar and an anionic-PAM significantly increased cotton seedling emergence by reducing penetration resistance and increasing aggregate stability of the aggregates at the soil surface.

Cover-crops and other surface covers prolong the beneficial effects of polymers. Ben-Hur et al. (1989) found that infiltration rates of soils to which cationic polysaccharide-guar-derivatives and a PAM-polymer were added declined with successive irrigations when the soil was not covered. This implies that where cover-crops are used in vineyards, less polymer may be needed during the irrigation season. Within vineyards of Australia where infiltration rates are low and soil strength is high near the soil surface, polymers may improve grapevine performance. The use of polymers in conjunction with a cover crop would promote the sustained effect of polymers on soil structure.

3.3.6 Organic matter

Reports on the effect of organic matter on grapevine performance vary. Many different materials can be used including straw, winery waste (grape marc), synthetic polymers, wood-chips, synthetic humates (with nutrients added), and compost derived from municipal waste.

There is little benefit expected, for instance, from adding large quantities of organic matter to a soil that already has a high organic matter content. Placement of the organic matter may also be important. For example, Saayman and Van Huyssteen (1980) found that addition of compost at rates of 19 or 28 t ha^{-1} (in narrow bands) had no effect on grapevine performance over 9 years. The placement of compost as a thin isolated band of organic matter may have isolated the effects to a narrow range of soil, and thus had little effect on bulk soil properties.

Natural by-products, such as grape marc (dried remains of crushed grapes) may be more economical to use, simply because they cost less than commercially produced synthetic materials. However it is important to consider the chemical as well as the physical impacts of composts, particularly where potassium may leach from grape marc and have deleterious effects on soil structure and/or vine performance in the long-term.

Aljibury and Christensen (1972) found that incorporation of wood chips into the top 10 cm of an irrigated sandy loam in California at 500 m^3/ha significantly increased infiltration rate (0.51 cm/h) compared with no wood chips (0.28 cm/h). The vineyard, which was irrigated with 2 broad furrows, achieved the greatest infiltration rate, 0.76 cm/h, when wood chips (500 m^3/ha) as well as gypsum (2.5 t/ha) were incorporated into the top 10 cm of soil.

Reynolds et al. (1995) found that the commercial humate called "Gro-Mate" increased nutrients as well as the soil organic matter content – these led to improved top growth of the grapevines, which made it difficult to distinguish between the effects of the humate on the physical versus chemical properties. Pinamonti et al. (1995) applied municipal waste as a compost and found that it maintained higher soil water contents, reduced variation in soil temperatures, and increased soil porosity. Under these conditions, growth and yield of grapevines was enhanced. Buckerfield and Webster (2000) reported improved vine performance with surface application of compost six months after planting. They concluded that organic materials applied as surface mulches improved earthworm activity, increased water infiltration, reduced soil strength. Furthermore, root growth increased in the upper part of the soil profile.

3.3.7 Limitations on water supply

In South Australia, where most of Australia's wine-grapes are produced, there are many water resource issues. Where water is available it is highly regulated and increasingly expensive. Heavy fines may be imposed in some regions (e.g. McLaren Vale) if water is seen to be applied excessively. Groundwater salinity is also an issue in many areas of South Australia – in the Padthaway region, for example, rising salinity of irrigation water means that using this water resource is unsustainable at current rates. Finally, the irrigation licensing system in the southeast part of South Australia is presently being converted from an area-based allocation to a volume-based allocation. Given the pressures on supply, quality and cost of irrigation water, it is essential that good practices in soil and water management be used to optimise the available water to grapevines.

3.3.7.1 Irrigation systems

Many different types of irrigation systems are used in Australian viticulture, but the accepted industry standard is drip irrigation, and properties using other methods are rapidly adopting their systems to use drippers. While drippers may be more efficient in terms of water use, their influence on grapevine performance is less clear, particularly in the long term. In this section I will focus on the effect of different irrigation systems on grapevine performance.

Grapevine productivity, as defined by shoot growth and berry development, is reduced when soil matric suction exceeds ~100 to 200 kPa (Hardie and Martin, 1989). On the other hand, allowing a water deficit of this magnitude or greater to develop at various periods during the growing season (a method known as 'regulated deficit irrigation', RDI) is thought to enhance fruit quality (Hardie and Martin, 1989; Dry et. al. 1998; McCarthy, 1997). Irrigation systems that allow small, precise quantities of water to be applied (e.g. 2 L/h) are best suited to deficit irrigation (Hardie and Martin 1989).

The method of irrigation affects the wetted volume of soil and therefore where most of the vine roots grow. For example, closely spaced emitters (e.g. 75 cm) allow a continuous 'wetted sausage' of soil under the vine-row, and this maximises grapevine root development over a larger area (compared with emitters spaced further apart). In the low-rainfall Riverland region of Australia, Stevens and Douglas (1994) found that drip irrigation systems caused roots to concentrate under the vine-row, whereas with microjet irrigation systems, roots were evenly spread across the planting area. In South Africa, van Zyl (1988) also found with trickle irrigation that most roots were concentrated under the vine strip in the wetted soil volume, while with microjet systems, roots grew in the mid-row.

In addition to variations in aerial wetting patterns between different irrigation systems, uniformity of wetting with depth can also be quite variable, and this influences the efficiency with which root systems access or use the water applied. Low uniformity of wetting may create confined areas of water-logging as well as dry zones in the soil, and neither of these are suitable for root development. Smart et al. (1974) found that trickle irrigation applied at 0.4 times the rate of Class-A pan-evaporation produced yields of similar magnitude to furrow-irrigated vines with a crop factor of 0.5. That is, trickle irrigation systems were more efficient at providing grapevines than were furrow irrigated systems, and this was due partly to excessive water losses to deep drainage and partly due to evaporation of free water from the furrow.

For optimum root performance the irrigation system should be matched to the soil type so that horizontal and vertical wetting is uniform, minimizing dry and waterlogged zones. Minimising water loss (evaporation, run-off and drainage) is essential.

3.3.7.2 Irrigation management

As indicated above, *regulated deficit irrigation* can have a direct effect on grapevine performance by limiting grapevine vigour at critical periods and improving berry quality. Freeman and Smart (1976) showed that grapevine root growth is also affected by water supply. Root growth was stimulated when irrigation was applied at a rate equal to the evaporation rate compared with irrigation applied at 300% of the evaporation rate. Van Zyl (1988) found that grapevine root development was the greatest where irrigation was applied only after 50% of the total plant available water was used. More recently, the practice of irrigation by 'partial root-zone drying', PRD (Loveys et al 1998), is being used to manipulate root growth and grapevine performance, and this will be discussed below.

3.3.7.3 Regulated deficit irrigation (RDI) and available water

To obtain high-quality wine, grapes are thought to require an optimum ratio of certain compounds in their juice, and while the precise details of this are not well understood, we know that various stresses influence grape qualities and that irrigation management influences these stresses in terms of both root and shoot growth. For example, controlled water stresses applied to grapevines at certain periods in the growing season can reduce shoot growth and thus reduce protective shading of grapes later in the season. Additionally water stresses may increase the surface area-to-volume ratio of the berries (i.e. smaller grapes) which in turn may improve the quality of the berry juice through increased colour and flavour (Smart et al., 1974; Hardie and Considine, 1976; Neja et al., 1977; Freeman et al, 1980; Hepner et al., 1985; Hardie and Martin, 1989; Matthews et al., 1987; Poni et al., 1993; and McCarthy, 1997). The technology behind timing of water stresses and prediction of their subsequent effects on grapevine physiology are still being sorted out, but indications are that water stresses applied three weeks after flowering and following can improve berry juice quality while minimising yield loss (McCarthy, 1997; Hardie and Martin, 1989).

Regulated deficit irrigation, RDI, focuses on allowing the soil matric suction to increase to particular values after irrigation, but this may differ for different soil types in different regions and at different stages of vine growth. Such details have not been widely investigated in terms of how irrigation and management of soil structure can be varied to achieve optimum berry quality and quantity.

Water availability depends not only on the amount of water stored in the soil but also on the volume of soil accessible to plant roots. Optimal use of available soil water generally occurs when a dense system of fine roots (<1 mm diameter) penetrates the soil under the vine to a depth of 0.8 to 1.0 m, as well as penetrates soil in the mid-row (Myburgh et al. 1996).

3.3.7.4 Partial root-zone drying (PRD)

Loveys et. al. (1998) described the development and practice of irrigation by *partial rootzone drying* (PRD) in vineyards. Withholding irrigation from half the vine-root system triggers a hormonal response in the roots, which produce abscisic acid (ABA). The ABA is transported to the leaves, which causes the stomata to reduce their aperture, lose less water and reduce photosynthesis. If stomatal closure is not too great, water use efficiency increases. While half the root system is allowed to dry the other half is kept moist, providing water to the grapevine. So long as water is maintained on the moist half of the grapevine root system, shoot growth is limited in such a way that neither fruit yield nor quality are restricted.

Irrigation by PRD affects the growth habit of vine-root systems. For example, Stoll et al. (2000) found that PRD caused roots to grow more extensively into deeper soil layers and less in shallow layers. The change in root distribution may inadvertently increase tolerance of grapevines to drought. This is consistent with van Zyl's (1988) finding that grapevine root development was greatest when 50% of the total plant available water was used.

3.4 Summary

The qualitative assessment of the physical fertility of Australian vineyards by Myburgh et al. (1996) gives some insight into the types of soil physical problems that challenge water use efficiency in viticultural regions of Australia.

The mechanisms by which some soil physical limitations restrict grapevine root growth are not well understood, and so the best soil management techniques to promote optimum root growth have not yet been developed or are still rather crude. While general principles have been established, the more complex relations (e.g. the optimum rooting volumes on different soil types in different climates for different grapevine cultivars under different trellis and irrigation management for optimum grape yield and quality) continue to evade our understanding.

Specific management targets, such as keeping the penetrometer resistance in a vineyard below 2 MPa (Myburgh et al. 1996) have great value to the viticulture industry in the long term. The work of McCarthy (1997) on RDI is also valuable to the industry, but it needs to be extended to create sustainable management systems for different regions and soil types outside the Barossa Valley.

Soil management systems for viticulture have been assessed in other parts of the world, particularly in South Africa, and these need to be considered for application in Australia. In particular, the work of van Huyssteen and Weber (1980a,b,c), has demonstrated significant water conservation using straw mulches and herbicides plus improved soil physical fertility, grapevine root development, pruning masses, grape yields and wine quality.

The sustainable use of the limited water resources is an issue worldwide in viticulture. The relation between irrigation management practices, soil management and available water for berries of specific qualities requires considerable development for different soil types in different viticulture regions.

The aims of this thesis were therefore to:

1) Determine the effect of soil profile management (soil mounding and deep-ripping) on soil structure, plant-available water and vine performance in South Australian vineyards with soil and water limitations.

2) Determine the effect of soil surface cover management (straw mulch, herbicide, polymer, ryegrass) on soil structure, plant-available water and vine performance in South Australian vineyards with soil and water limitations.

3) Determine the effect of the PRD irrigation strategy on plant-available water and vine performance in combination with various soil profile management and soil surface cover management strategies in a South Australian vineyard with soil and water limitations.

4 EXPERIMENTAL SITE DETAILS

4.1 Location and site descriptions

4.1.1 Lyndoch site

In 1995 the Lyndoch site was selected on the basis of poor vine performance. Yields had declined from 23 t/ha in 1990 to 5.5 t/ha in 1995. The vineyard had been established without deep-ripping and no improved soil management practices were implemented after planting in 1946 on own-roots of cv. Semillon. The topsoil had a low water holding capacity due to its sandy texture and poor soil structure, and the subsoil had very high soil resistance as measured by a penetrometer.

The vineyard was located between Lyndoch and Williamstown in the Barossa Valley, South Australia (34.7° S, 138.9° E) with an elevation of approximately 395 m, and an average annual rainfall of 650 mm. Monthly rainfall and potential evapotranspiration for the 1996 growing-season are shown in the Appendix Figure 11.2. The Barossa Valley climate is considered to be moderate, with winter-dominated rainfall, high summer evaporation and low relative humidity. Vines typically suffer water stress in most parts of the region in most seasons (Dry and Smart, 1998).

Typical pruning management for this vineyard consisted of a machine trim followed by hand pruning to 2-bud spurs, approximately 60 buds per vine. Under-vine herbicides were generally applied and the permanent sward in the mid-row was slashed. The vine row orientation was east-west. The inter-row distance was 3.3 m, the inter-vine distance within a row was 2.1 m. Dripper application rate was 4 L/h and the distance between drippers was 2 m.

A schematic of the mounded soil profile at the Lyndoch site is shown in Appendix Figure 11.1. The soil profile consisted of 20 cm of sandy loam (A_1-horizon) over 15 cm of bleached loamy sand (A_2-horizon) over medium-to-heavy clay (Bt-horizon) containing a large amount of carbonate rubble. It was described by Maschmedt et al. (2002) as a restrictive duplex soil with thin, well structured topsoil, and was classified as a Yellow Solodic in Stace et al.'s (1968) classification, or a Yellow Chromosol in Isbell's (1996) Australian Soil Classification.

4.1.2 Padthaway Range site

The Padthaway Range site was 1 km north of Padthaway on the western slope of the Padthaway Range (36.6° S, 140.5° E) at an elevation of ~52 m above sea level. The climate of this region is similar to the Coonawarra region (located 150km to the south). With winter dominated rainfall, high summer evaporation and low relative humidity, (Dry and Smart, 1998). Monthly rainfall and potential evapotranspiration for the 1998-99 and for the 1999-00 seasons are shown in Appendix Figures 11.4 & 11.5. Average annual rainfall was 508 mm.

The Padthaway Range experiment was conducted in a block of cv. Shiraz vines known as Shiraz 17. This block was originally planted in 1971 with cv. Riesling. It was grafted in 1996 with cv. Shiraz clone 1654, and established on a two-wire vertical trellis. The row width was 3.5m, the distance between the vines within rows was 1.83m, and the dripper spacing was 0.6m. Typical pruning management for this vineyard consisted of a machine trim followed by hand pruning to 2-bud spur leaving approximately 140 buds per vine. Under-vine herbicides were generally applied and the permanent sward in the mid-row was slashed. The vine row orientation was north-south.

This site was chosen because salinity was becoming a problem due to the use of saline irrigation water, and compaction had developed due to a history of extensive wheel traffic. A schematic of the mounded soil profile at the Lyndoch site is shown in Appendix Figure 11.3. The soil profile consisted of 95 cm of sand over medium clay. A denser, bleached A_2-horizon was found at approximately 15 cm depth. It was described by Maschmedt et al. (2002) as a deep, sandy, uniform soil, and was classified as a Siliceous Sand in Stace et al.'s (1968) classification, or an Arenic Tenosol in Isbell's (1996) Australian Soil Classification.

4.1.3 Padthaway Plain site

The Padthaway Plain site was approximately 1 km west of the Padthaway Range and 1 km northwest of Padthaway Township on the flat inter-dunal plain at an elevation of ~37 m above sea level. This site was chosen because compaction due to wheel traffic was a problem and there was a hard, limestone layer at ~0.5 m depth.

The Padthaway Plain experiment was conducted in a block of cv. Shiraz vines known as Shiraz 11. This block was originally planted in 1977 with cv. Sylvaner. It was grafted in 1991 with cv. Shiraz clone 1654 and established on a two-wire vertical trellis. The row width was 3.5m, the distance between vines within rows was 1.83m, and the dripper spacing was 0.6cm. Typical pruning management for this vineyard consisted of a machine trim, machine sawn and then a hand clean up leaving approximately 120 buds per vine. Similarly to the Padthaway Range site herbicides were generally applied to the under vine strip and the mid-row permanent sward was slashed. The vine row orientation was east-west.

A schematic of the mounded soil profile, which consisted of a shallow loam (0-350 mm) over clay (350-500 mm) over limestone (>500 mm) is shown in Appendix Figure 11.6. It was described by Maschmedt et al. (2002) as a restrictive duplex with thin, well structured topsoil,, and was classified as a Yellow Solodic in Stace et al.'s (1968) classification, or a Calcic Yellow Chromosol in Isbell's (1996) Australian Soil Classification.

4.2 Experiment Details

4.2.1 Lyndoch

Two main soil management treatments were applied at this site (Table 4.1):
(1) *Flat* – no soil was mounded onto the vine-row, and
(2) *Mound* – formed by mounding mid-row soil (A_1- and A_2-horizons) onto the vine-row using a "V-delver", which made the mid-rows V-shaped. Mounds were ~0.35 m high from the original surface to top of the raised bed, 0.5 m across the top and a ~1 m wide base.

Table 4.1 Description of soil management treatments at **Lyndoch**.

	Lyndoch Treatments	
Mounding	**Deep-ripping**	**Soil surface-cover**
Not mounded: *Flat*	No-ripping: *No-rip*	Bare: *Flat+NR+Bare*
		Mulched: *Flat+NR+Mulch*
		Bare+Limed: *Flat+NR+Lime*
		Mulched+Limed: *Flat+NR+Mulch+Lime*
	Ripped once: *Flat+SR (single-rip)*	Bare: *Flat+SR+Bare*
		Mulched: *Flat+SR+Mulch*
		Bare+Limed: *Flat+SR+Lime*
		Mulched+Limed: *Flat+SR+Mulch+Lime*
	Ripped twice: *Flat+DR (double-rip)*	Bare: *Flat+DR+Bare*
		Mulched: *Flat+DR+Mulch*
		Bare+Limed: *Flat+DR+Lime*
		Mulched+Limed: *Flat+DR+Mulch+Lime*
Mounded: *Mound*	Ripped once: *Mound+SR (single-rip)*	Bare: *Mound+Bare*
		Mulched: *Mound+Mulch*
		Limed: *Mound+Lime*
		Ryegrass: *Mound+Ryegrass*
		Grape marc: *Mound+Grape marc*
		Polymer: *Mound+Polymer*
		Mulched+Limed: *Mound+Mulch+Lime*
		Ryegrass+Limed: *Mound+Ryegrass+Lime*

Three *deep-ripping* treatments were applied to the *Flat* soil using a small bulldozer pulling a single ripping-tine, approximately 0.5 m deep located 0.8 m away from grapevine trunks, which was approximately the centre of the wheel track (Table 4.1):
(1) No ripping
(2) Single rip on one side of the vine-row, and
(3) Ripping on both sides of the vine-row.

Four surface-cover treatments were applied to each *deep-ripping* treatments (Table 4.1):
(1) No surface cover (bare),
(2) Straw mulch of Phalaris applied to the vine-row at 50 t/ha,
(3) Lime applied at 1% of the soil mass in the A_1- and A_2-horizons under the vine, and
(4) Straw mulch and lime applied at same rates as in (2) and (3).

The *Mound* soil treatment had a single deep-rip on one side of the vine-row only, and 7 soil surface-cover treatments were applied (Table 4.1):
(1) no surface cover,
(2) Straw mulch of Phalaris applied to the vine-row at 50 t/ha,
(3) Lime applied at 1% of the soil mass in the A_1- and A_2-horizons under the vine,
(4) Victorian perennial ryegrass sown at 25 kg/ha,
(5) Grape marc applied at 40 t/ha,
(6) Mixture of two synthetic organic polymers applied at 400 mg/kg soil.[2]
(7) Straw mulch and lime applied at same rates as for *Flat* treatments (see above),
(8) Lime (1% of total soil mass), plus Victorian perennial ryegrass sown at 25 kg/ha.

The experiment consisted of 17, 100 m-long vine rows, with one buffer row between the soil management treatments. Each 100 m row consisted of four 25m plots with 16 vines per plot. One vine on either end of the plot was left as a buffer. There were 3 complete blocks consisting of the different soil preparation methods and a half block consisting of a single- and a double-ripped row. The soil surface treatments were applied based on 4 replicates using a 4 x 4 Latin square design. Analysis of variance was used to determine significant difference between treatments.

4.2.2 Padthaway Range

Six replicates of 2 main treatments were applied (Table 4.2):
(1) No deep-ripping, and
(2) Single deep-ripping on one side of the vine-row. Deep ripping was undertaken to a depth of 0.9m using two Howard® 'Paraplough' ripping tines pulled behind an 80-horsepower, four-wheel drive tractor. The tines were located on a frame directly in line with the tractor wheels, 0.8 m from the vine-row.

Two soil surface-cover sub-treatments were applied to the main treatments (Table 4.2):
(1) Bare (not mulched), and
(2) Phalaris straw mulch applied at 50 t/ha.

Table 4.2 Description of soil management treatments at Padthaway Range.

Padthaway Treatments	
Deep-ripping in vine-row	**Soil surface-cover**
No-rip: *No-rip*	Bare: *No-rip+Bare*
	Mulch: *No-rip+Mulch*
Single-rip: *Rip*	Bare: *Rip+Bare*
	Mulch: *Rip+Mulch*

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[2] The polymers were mixed due to their differing properties. The polymer, AP173, consisted of acrylamide and sodium acrylate – an anionic polymer with a molecular weight of 10-15 x 10^6 and a moderate-to-low flocculation power plus a high ability to stabilise soil aggregates. The other polymer, PV 200, consisted of polyvinyl acetate and polyvinyl alcohol – a cationic polymer with a molecular weight of 0.2 to 2 x 10^6 and a high flocculation power plus a low ability to stabilise soil aggregates. The combination of the two polymers was expected to induce high flocculation of colloids and high aggregate stabilisation.

Six replicates of each treatment were randomly applied over six rows, 40m in length. Each treatment was 10m long consisting of 5 vines per treatment, 3 measurement-vines and 1 buffer-vine at the end of each treatment. Analysis of variance was used to determine significant difference between treatments.

4.2.3 Padthaway Plain

Three replicates of 2 soil management treatments, 2 irrigation treatments and 2 soil surface-cover treatments were applied at this site, as follows.

Two soil management treatments (Table 4.3):
(1) *Flat* treatment – no soil was mounded onto the vine-row, and
(2) *Mounded* treatment – A_1-horizon from mid-row was mounded onto the vine-row.

Two irrigation treatments (Table 4.3):
(1) control irrigation using the traditional irrigation method (one drip-line with one emitter/vine delivering 2 L/h), and
(2) vine irrigated by partial root-zone drying (alternately on either side of vine), when soil matric pressures dropped to ca. 400 kPa.

Two soil surface-cover treatments (Table 4.3):
(1) *Bare* - no soil surface cover, and
(2) *Mulch* - 50 t/ha Phalaris straw mulch.

Table 4.3 Description of soil management treatments at Padthaway Plain.

Padthaway Plain Treatments		
Mounding	**Irrigation method**	**Soil surface-cover**
Not mounded *(Flat)*	Control Irrigation: *Flat+Control*	Bare: *Flat+Control+Bare*
		Mulched: *Flat+Control+Mulch*
	PRD Irrigation: *Flat+PRD*	Bare: *Flat+PRD+Bare*
		Mulched: *Flat+PRD+Mulch*
Mounded: *(Mound)*	Control Irrigation: *Mound+Control*	Bare: *Mound+Control+Bare*
		Mulched: *Mound+Control+Mulch*
	PRD Irrigation: *Mound+PRD*	Bare: *Mound+PRD+Bare*
		Mulched: *Mound+PRD+Mulch*

Three replicates of each treatment were applied over 12 rows, 400m in length. Each treatment was 100m long with 50 vines in each treatment. Six complete rows were mounded and the irrigation treatments were applied to each half row. Mulch was then applied randomly to these treatments. Analysis of variance was used to determine significant difference between treatments.

5 EFFECTS OF MANAGEMENT ON SOIL STRUCTURE AND VINE ROOT GROWTH

5.1 Introduction

As indicated in the Literature Review, deep-ripping and topsoil-mounding can improve soil structure and reduce soil strength resulting in increased root development. The combination of mulching, herbicide applications, and use of permanent swards can also improve and maintain soil surface structure, as can the use of organic materials applied as surface mulches or synthetic polymers and gypsum. Furthermore, irrigation management has also been shown to affect grapevine root development. There is little published information, however, on the effects of soil management on soil structure and grapevine root growth for Australian soils and environmental conditions, and this was particularly the case at the three experimental sites examined in this thesis.

5.1.1 Hypotheses

For these experiments, three hypotheses were tested with minor variations at each of the three sites to accommodate the different treatments applied:

Hypothesis 1. Mounding increases the soil volume with improved structure (reduced soil strength) such that vine roots proliferate by comparison to traditional (*Flat*) practice.

Hypothesis 2. Deep-ripping increases the subsoil volume with improved structure (reduced soil resistance) such that vine roots proliferate to a greater depth by comparison with traditional (*No-rip*) practice.

Hypothesis 3. Organic materials such as polymers, grape marc, mulches, or ryegrass swards, and the use of calcium amendments, improve the structure of mounded soil, such that root development and soil water retention increases near the soil surface in comparison to mounded (but otherwise untreated) soil.

5.2 Materials and methods

5.2.1 Water retention and soil resistance

Soil cores were collected at all sites at various times (eg. beginning or end of the experiment):

- Lyndoch (1995, beginning, 1995, 3 months later): 1 core/treatment from the top 10 cm x 3-4 blocks + 3 cores/treatment from each soil horizon.
- Padthaway Range (1998, beginning; 2000, end): 3 cores/treatment x 3 blocks.
- Padthaway Plain (1998, beginning; 2000, end): 3 cores/treatment, excluding irrigation treatments, for each soil horizon x 3 blocks).

McIntyre Sampler (McIntyre and Barrow 1972). Brass rings (50 mm high, 70 mm diameter) were pressed into the soil to obtain undisturbed samples, which were taken to the laboratory, saturated and then placed on ceramic pressure plates at suctions between 10 and 60 kPa. Disturbed soil samples were also collected simultaneously, saturated and placed on ceramic pressure plates at suctions of 300 and then 1500 kPa. Samples were weighed after reaching equilibrium at each suction, then oven dried. The amount of water held between the suctions 10 kPa (*field capacity*) and 60 kPa (*refill point*) was calculated as the *readily available water* (RAW) in mm water per m soil. The amount of water held between the suctions 10 kPa (*field capacity*) and 1500 kPa (*wilting point*) was calculated as the *total available water* (TAW) in mm water per m soil. Finally, at both Padthaway sites, RAW- and TAW-values were normalized[3] to account for differences in soil volume occupied by plant roots under different treatments; this produced values of RAW_v and TAW_v (m^3 water per vine).

Measurements of soil penetrometer resistance were taken in the field two days after a saturating irrigation or rain event. This was done using a portable Microscan penetrometer, which consisted of a stainless steel cone having a 12.5 mm basal-diameter and 30° included angle, mounted on an 800 mm-long recessed stainless steel shaft. The shaft was attached to a 450-N dual-guided cantilever and shear-beam load-cell, ('S type'), which sensed the force on the cone as it pushed through the soil. The output-force from the strain gauge was converted to a penetrometer pressure (MPa) by dividing the force by the surface area at the base of the penetrometer cone. All measurements were compared to the maximum soil resistance suggested by van Huyssteen and colleagues, and it was assumed root growth was limited at values above 2 MPa. At each site, three penetrometer readings were taken to 0.8 m in every block (Lyndoch, 3-4 blocks; Padthaway Range, 6 blocks; Padthaway Plain, 3 blocks). Values were averaged across 0.2 m increments and standard errors were calculated and shown in each Figure as one standard error either side of the mean.

5.2.2 Root-length density

Two seasonal flushes of grapevine root growth occur each year: one (more extensive) flush from October to December and another (less vigorous) flush from March to April, (Freeman and Smart, 1976). Whenever possible, soil samples were therefore collected during these periods to increase the chance that root-responses to the treatments would be observed.

5.2.3 Lyndoch

5.2.3.1 Water retention and soil resistance

Water retention curves were measured on the undisturbed soil cores described in Section 5.2.2.1 when the field experiment was established in August 1995, and then again after three months (December 1995) to evaluate the extent of change upon settling of the mounds. These cores were taken 0.3 m from a vine, representing the different soil horizons, A_{new}, A_1, A_2 and B. Penetration resistance was measured once per soil core to a depth of 40 mm after equilibrating each core on a porous ceramic plate at 10 kPa suction. This was achieved using a Lloyd Instruments laboratory-penetrometer, and all penetrometer readings were averaged to obtain a single mean penetration resistance for each core.

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[3] Volume of soil occupied by vine roots was determined from soil pit observations, data on soil penetration resistance, and data on root-length density; it was assumed that the growth habit of vine root system was cone-like in morphology, which enabled a volume to be calculated. The required information to calculate rootzone volume was not available at Lyndoch, so this calculation was not made there.

5.2.3.2 Root-length density

Because soil management treatments had been established for only 2 months prior to the first sampling, large differences in root-length density between treatments were not expected. Soil core samples were therefore collected from only the *Flat+SR+Bare* and *Mound+Bare* treatments in December 1995. Soil samples were collected from all treatments for root analysis after the first complete season in July 1996.

In December 1995 soil pits were dug along the vine-strip extending 0.8 m into the mid-row in *Flat+SR+Bare* and *Mound+Bare* treatments for preliminary assessment of soil structure, soil chemistry and root distribution. Soil cores were taken in the vine-row and in the mid-row space using brass rings (70 mm diameter by 50 mm high). The mid-row cores were collected 0.8 m from the vine-row, adjacent to the dripper, while cores in the vine-row were collected at three locations relative to the position of the dripper:
1) directly under the dripper,
2) 0.4 m along the row from the dripper, and
3) 0.9 m along the row from the dripper.

In July 1996, samples were taken again, but this time I used a 100 mm diameter auger to collect 150 mm-deep samples to a depth of 900 mm. This method was used because it was less intrusive than soil pits and allowed a greater number of samples to be collected. Samples were collected at 0.8 m from the vine-row into the mid-row (directly under the wheel track) and 1.2 m into the mid-row. They were also collected at three locations in the vine-row:
1) directly under the dripper,
2) 0.4 m along the row from the dripper, and
3) 0.8 m along the row from the dripper.

The soil samples were washed through a 2 mm sieve, which retained most of the grapevine roots. The root samples were placed (without overlapping) on a translucent plastic dish and viewed under a microscope, which was connected to a video camera and display unit. The image analysis software package, *Front Edge*, (pers. comm. Cliff Hignett) was used to interpret the length of roots displayed as an image on the video screen. This estimation was calibrated with the Newman (1966) line intersection technique.

5.2.4 Padthaway Range and Padthaway Plain

5.2.4.1 Water retention and soil resistance

Undisturbed soil cores were collected from the Padthaway Range site in August 1998, January 2000 and August 2000, and for the Padthaway Plain site in March 1998 and August 2000. Soil water retention curves were determined on each core as described above.

In August 1998 and 1999 a Microscan penetrometer was used to measure penetration resistance as a function of depth (to 0.8 m at Padthaway Range; to 0.4 m at Padthaway Plain) within the vine-row, as well as at 4 points out from the vines into the mid-row space (at 0.3m intervals at Padthaway Range; at 0.4m intervals at Padthaway Plain). These measurements were conducted when the soil was nominally at 'field capacity'.

5.2.4.2 Root-length density

Soil samples were collected for root-length density at the beginning of the experiment in September 1998 as well as at the completion of the experiment in April 2000 (Table 5.1). An auger (100 mm diameter) was used to collect soil samples at 15 cm intervals to a depth of 1.05 m at Padthaway Range and to a depth of 0.30 m at Padthaway Plain.

At the beginning of the experiment soil samples at Padthaway Range were collected from only the *No-rip+Bare* treatment because the treatments had not been established for long enough to expect any differences between the treatments.

The soil samples were washed through a nest of sieves: 1 mm over 0.295mm over 0.210 mm to catch as many roots as possible. Vine roots were collected and the total length of roots was measured using the techniques described above.

Table 5.1 Sampling strategies to measure root-length-density at the 2 Padthaway sites.

Site	Date	Position	Treatment	Location of soil sample
Padthaway Range	Sept 1998	Vine row	*No-rip+Bare*	0.3 m intervals to 1.05 m depth
		Mid row	*No-rip+Bare*	Every 0.3 m in single line straight out from vine-row to depth of 1.05m.
	April 2000	Vine row	*All treatments*	0.3 m from vine and 0.3 m from dripper to depth of 0.9m.
		Mid row	*No-rip+Bare* and *Rip+Bare*	Single line every 0.4 m from vine-row to 0.9m depth.
Padthaway Plain	Sept 1998	Vine row	*All treatments*	0.3 m from vine & 0.3 m from dripper. For *Flat* and *Mound* treatments every 0.3 m along vine-row to 0.3m depth.
		Mid row	*Flat+Control+Bare* and *Mound+Control+Bare*	Every 0.3 m into mid-row in single line from vine-row to 0.3m depth.
	April 2000	Vine row	*All treatments*	0.3 m from vine & 0.3 m from dripper to 0.3m depth.
		Mid row	*Flat+Control+Bare* and *Mound+Control+Bare*	0.75 m & 1.5 m from mid-row adjacent to 0.3 m sample in vine-row to 0.3m depth.

5.3 Results and Discussion

5.3.1 Water retention (RAW and TAW)

Examples of the water retention curves prepared for all sites are shown in Appendix Figures 11.17 to 11.19. The following analysis of the data deals strictly with the water held between 10 and 60 kPa (RAW) and that held between 10 and 1500 kPa (TAW).

5.3.1.1 Lyndoch

It was expected that the water retention characteristics of the A_2- and B-horizons within the vine-row would not change (because they were simply buried under soil from the A_1-horizon during mounding), so the water-retention data for the A_2- and B-horizons of the *flat* and *mound* treatments were grouped. The water-retention data for the A_1-horizon within mounds was evaluated separately from that in the mid-row-A_1-horizon.

Readily available water, RAW, and total available water, TAW, for the different treatments are shown in Table 5.2. The *Mound*-A_1 and *Flat*-A_1 soils had similar RAWs, which indicated the mounding process had no impact on the pore-size distribution for these two horizons, and confirmed the decision to group the data for the deeper horizons under these two treatments.

The RAW data in Table 5.2 show a clear distinction among the treatments in the decreasing order: *Mound*-A_1 ≈ *Flat* A_1 > A_2 > *Mound*-A_{new} >> B. The relatively lower RAW for the *Mound*-A_{new} soil resulted from the large macro-porosities caused during mounding – thus a large quantity of water drained from them before *field capacity* (matric suction = 10 kPa), leaving less water held between 10 and 60 kPa. With natural settling over time, the macropores would be expected to collapse to some extent and contribute more pores in the RAW-range for the A_{new}.

Table 5.2 Readily available water (RAW) and total available water (TAW) for different soil horizons in *Mound & Flat* treatments, Lyndoch, August, 1995 (see Appendix Fig.11.1 for horizon thicknesses).

Mound-treatment and soil horizon	**RAW**		**TAW**	
	mm m^{-1}	**mm**	**mm m^{-1}**	**mm**
Mound-A_1	108_b	27.0	163	40.8
Flat-A_1	$100_{a,b}$	25.0	189	47.3
A_2	$86_{a,b}$	12.9	185	27.8
Mound-A_{new}	79_a	15.8	174	34.8
B	9_c	9 +	147	147 +

Figures with different subscripts are significantly different ($\alpha = 0.05$ significance level).

Table 5.2 also illustrates the very low RAW for the B-horizon (mm m^{-1}). The water retention data showed little water between 10 and 60 kPa and most of it between 60 to 1500 kPa, indicating a dominance of fine pores in the B-horizon. Furthermore, the TAW (mm m^{-1}) for the B-horizon was not significantly different from that for the other horizons and mounding treatments. The total TAW (mm) for the B-horizon was significantly greater than all other treatments and horizons only because of its much greater thickness.

The RAW and TAW (mm m^{-1}) for each of the soil surface-cover treatments at Lyndoch are shown in Table 5.3. The RAW was significantly greater for the *Mound+Bare* treatment than for all other surface-cover and mounding treatments. The reason for this is not entirely clear, but settling in the absence of any other treatments may have contributed to a more rapid settling of the mound and thus a greater proportion of pores holding water in the 10 to 60 kPa range.

Table 5.3 Readily available water (RAW) and total available water (TAW) as affected by the soil surface cover treatments on mounded soil at Lyndoch, August, 1995.

Treatment	**RAW (mm m^{-1})**	**TAW (mm m^{-1})**

Mound+Bare	109.3_{a}	179.8
Mound+Ryegrass	89.5_{b}	178.6
Mound+Lime	88.2_{b}	167.6
Mound+Polymer	84.3_{b1}	179.3
Mound+Mulch+Lime	82.0_{b1}	167.3
Mound+Grape marc	76.6_{b1c}	188.6
Mound+Mulch	65.3_{cd}	161.3
Mound+Ryegrass+Lime	56.8_{d}	137.3

Figures with different subscripts are significantly different at $\alpha = 0.025$; in the case of subscript 'a' compared with 'b1', and 'a' compared with 'c', and 'a' compared with 'd', the significance level is $\alpha = 0.01$.

The *Ryegrass* mounds had the next largest RAW but this was only significantly larger than two of the other treatments: *Mound+Mulch* and *Mound+Ryegrass+Lime*, both of which had lower RAWs because they had larger macro-porosities. The conditions in these treatments probably enhanced biological activity, which stabilized larger pores and allowed greater drainage of water through biopores (draining at suctions < 10 kPa) and thus produced smaller water contents at a matric suctions between 10 and 60 kPa. This effect also translated to smaller TAWs for these treatments.

5.3.1.2 Padthaway Range

Penetration resistance under the wheel tracks was significantly reduced after deep-ripping, and this effect extended to at least 1.2 m from the vine-row (Figure 5.1).

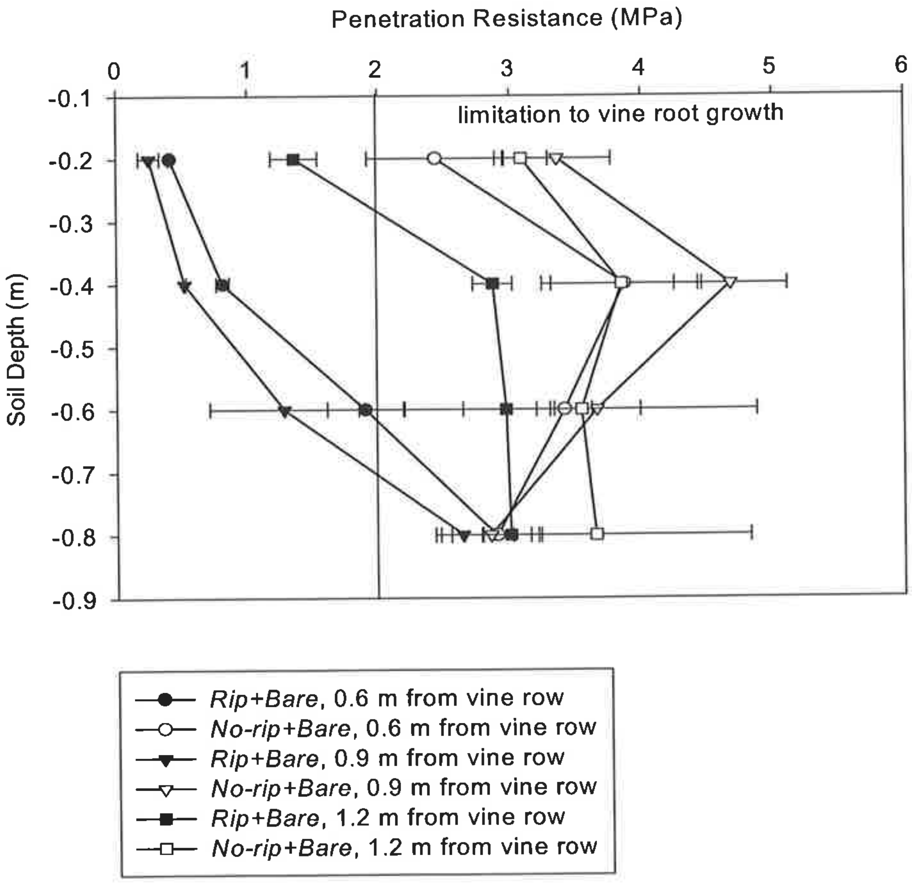

Figure 5.1 Soil penetration resistance as a function of depth in the mid-row as affected by deep-ripping at Padthaway Range, September 1998.

The bulk density in the A_1-horizon increased somewhat, from 1.18 g cm^{-3} in August 1998 to 1.34 g cm^{-3} in August 2000 (significant at $\alpha = 0.05$; Appendix Table 11.1). The wetter state allowed under the mulches may have been responsible for this.

Directly under the vine-row, RAW and TAW were not affected by the ripping treatments either in 1998, nor by the ripping and mulching treatments in 2000 (Table 5.4). The massive structure of this deep sandy soil meant that all horizons contained little RAW and that the effects of ripping ~0.8 m into the mid-row were not experienced under the vine.

Table 5.4 Readily available water (RAW) & total available water (TAW), Padthaway Range

Year	Soil management	Horizon	RAW (mm m^{-1})	RAW (mm)	TAW (mm m^{-1})	TAW (mm)
1998	*No-rip*	A_1	37	5.6_a	66	9.9_a
1998	*No-rip*	A_2	55	$11.1_{a,b}$	82	16.3_a
1998	*No-rip*	A_3	37	22.0_b	61	36.4_b
1998	*No-rip*	B	15	*	89	*
1998	*Rip*	A_1	37	5.6_a	66	9.9_a
1998	*Rip*	A_2	55	$11.1_{a,b}$	82	16.3_a
1998	*Rip*	A_3	37	22.0_b	61	36.4_b
2000	*No-rip+Mulch*	A_1	51	7.6	123	18.5
2000	*Rip+Mulch*	A_1	51	7.6	123	18.5

Figures with different subscripts are significantly different at the $\alpha = 0.05$ significance level

* Calculation of RAW & TAW was not always possible due to the unknown depth of the B-horizon at this site. Few vine roots were present at this depth (~1000 mm), so these figures were not calculated.

The following trends, while consistent with expectations, were not statistically significant at $P = 0.05$. Firstly, the more compacted A_2-horizon had the greatest RAW (55 mm m^{-1}) and the B-horizon contained the least (15 mm m^{-1}). However, because of the greater clay content of the B-horizon, it contained the greatest TAW (89 mm m^{-1}) while the (thinner) A_3-horizon contained the least TAW (61 mm m^{-1}). Application of mulch increased RAW in the A_1-horizon from 37 mm m^{-1} in 1998 to 51 mm m^{-1} in 2000. Similarly the TAW in the A_1-horizon increased from 66 mm m^{-1} to 123 mm m^{-1} between 1998 and 2000. Again, however, these trends were not statistically significant, so will not be discussed further.

The greatest (significant) differences in RAW (mm) and TAW (mm) were found between the different soil horizons and were independent of the ripping- and mulching-treatments. For example, because of the greater thickness of the A_3-horizon, its RAW (22.0 mm) and TAW (36.4 mm) were greater than all the other (thinner) horizons.

While there was no apparent effect on water retention due to either ripping or mulching, the ripping treatments allowed significantly larger bulk volumes of the soil to be explored by the vine roots (see 'Bulk root volume', Table 5.5). This was determined as the volume of soil having penetrometer resistances < 2 MPa and visible roots in the soil pits – and confirmed using root-length-density data: see Figures 5.6, 5.7 and 5.24, 5.25 later in this thesis). The effective root volume for vines in the ripped soil (*Rip*) was 1.269 m^3, while the effective root volume for vines in the un-ripped soil (*No-rip*) was less than half that of the ripped soil (0.612 m^3).

When expressed on a 'per vine' basis (RAW_v and TAW_v) it was found that deep-ripping doubled the RAW_v: 0.026 m^3 in the unripped soil (*No-rip*) versus 0.056 m^3 in the ripped soil (*Rip*). The *Mulch* treatments had a less dramatic (but significant) effect on both RAW_v and TAW_v.

Table 5.5 Total volume of soil containing roots per vine (Bulk root volume, m^3), volume of readily available water per vine (RAW_v, m^3) and volume of total available water per vine (TAW_v, m^3) at Padthaway Range, as affected by ripping and mulching.

Soil Management	Bulk root volume[4] (m^3 per vine)	RAW_v (m^3 per vine)	TAW_v (m^3 per vine)
No-rip	0.612	0.026	0.042
No-rip+Mulch	0.612	0.026 (in 1998) to 0.029 (in 2000)(5)	0.042 (in 1998) to 0.055(in 2000)(5)
Rip	1.269	0.056	0.090
Rip+Mulch	1.269	0.056 (in 1998) to 0.064(in 2000)(5)	0.090 (in 1998) to 0.123(in 2000)(5)

* The volume of water available to vines in the *Mulch* and *Rip+Mulch* treatments increased from 1998 to 2000 due to the effect of the mulch on soil water retention.

5.3.1.3 Padthaway Plain

As expected the A_{new}-horizon in 1998 had the lowest bulk density (0.99 g cm^{-3}) followed by 1.23 g cm^{-3} for the B-horizon, and 1.32 g cm^{-3} for the A_1-horizon (Appendix Table 11.2). By August 2000, however, settlement of the mound caused the bulk density of the A_{new}-horizon to increase significantly from 0.99 to 1.35 g cm^{-3} ($\alpha = 0.01$ significance level). The addition of mulch dampened the settling effects such that the bulk density increased from 0.99 g cm^{-3} in 1999 to only 1.09 g cm^{-3} in August 2000. It is likely that the increased activity of micro-flora and micro-fauna under *Mound+Control+Mulch* helped maintain macropores and biopores in the A_{new}-horizon. The bulk density of the A_1-horizon did not change from 1.31 g cm^{-3} between 1998 and 2000.

The RAW and TAW (expressed in both mm m^{-1}, and mm) are shown in Table 5.6. The properties of the A_1- and B-horizons were considered to be the same in both the *Mound* and *Flat* treatments at the beginning of the experiment in 1998. Changes were not expected in the B-horizon with time, so B-horizon measurements were not taken in 2000.

Differences in RAW between horizons were statistically significant at P=0.05 (compare A_1- and B-horizon in Table 5.6) but none of the TAWs were significantly different. Furthermore, none of the mounding and mulching treatments had any significant effect on either RAW or TAW between 1998 and 2000.

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[4] Bulk root-volume was estimated from the dimensions of the cone-shaped root-system exposed in a soil pit, which corresponded well with the region of soil penetrometer resistance < 2 MPa.

(5) The volume of water available to vines in the *Mulch* and *Rip+Mulch* treatments increased from 1998 to 2000 presumably due to the effect of the mulch on soil water retention.

The volume of bulk soil for roots per vine, plus the RAW_v and TAW_v values (all determined in same manner as for Padthaway Range) are shown in Table 5.7. The root volume per vine in the *Mound* treatments was virtually the same as that in the *Flat* treatments. There was a small, but insignificant, increase in both RAW_v and TAW_v between 1998 and 2000 in the mounded soil, but this was not influenced by either the presence or absence of mulch.

Table 5.6 Readily available & total available water (RAW & TAW), Padthaway Plain.

Year	**Treatments**	**Soil Horizon**	**RAW ($mm\ m^{-1}$)**	**RAW (mm)**	**TAW ($mm\ m^{-1}$)**	**TAW (mm)**
1998	*Mound+Control*	A_{new}	$30_{a,b}$	$6.0_{a,b}$	90	18.0
1998	*Mound+Control*	A_l	63_b	$9.5_{a,b}$	205	30.8
1998	*Mound+Control*	B	23_a	3.5_a	70	10.5
1998	*Flat+Control*	A_l	63_b	$9.5_{a,b}$	205	30.8
1998	*Flat+Control*	B	23_a	3.5_a	70	10.5
2000	*Mound+Control+Bare*	A_{new}	$52_{a,b}$	10.4_b	123	24.6
2000	*Mound+Control+Mulch*	A_{new}	$45_{a,b}$	$8.9_{a,b}$	124	24.8
2000	*Flat+Control+Mulch*	A_l	$50_{a,b}$	$7.5_{a,b}$	138	20.7

RAW figures with different subscripts are significantly different at $\alpha = 0.05$ significance level.

Table 5.7 Grapevine root volume and volume of readily available water per vine (RAW_v) and total available water per vine (TAW_v) at Padthaway Plain.

Soil management	**Bulk root volume (m^3 per vine)**	**RAW_v (m^3 per vine)**	**TAW_v (m^3 per vine)**
Flat+Control	1.296	0.045	0.141
Flat+Control+Mulch		0.045 (in 1998) to 0.040 (in 2000)	0.141 (in 1998) to 0.116 (in 2000)
Mound+Control	1.332	0.048 (in 1998) to 0.053 (in 2000)	0.149 (in 1998) to 0.157 (in 2000)
Mound+Control+Mulch		0.048 (in 1998) to 0.051 (in 2000)	0.149 (in 1998) to 0.157 (in 2000)

5.3.2 Soil resistance

5.3.2.1 Lyndoch

The profiles of soil penetration resistance for the *Flat+SR+Bare*, *Flat+SR+Mulch*, *Mound+Bare*, and *Mound+Mulch* treatments are shown in Figure 5.2. The original 'reference' elevation for the soil surface was set at zero, such that the *Mound* treatments are shown to be 0.1m above the reference height. While soil resistance was somewhat lower in the *Mounds* than in the *Flat* treatments at 0.3m depth, these differences were not statistically significant at the $\alpha = 0.05$ significance level. Furthermore, the soil resistance from a depth of 0.1m downward did not differ significantly as a result of the either *Mulch* or *Mound* treatments at equivalent depths. Penetration resistance for all treatments increased significantly with depth, reaching values approaching 2 MPa at a depth of 0.3 m ($\alpha = 0.05$ significance level). Thus, the *Mound* treatment increased the thickness of surface soil having low penetration resistance by 0.2 m, while the mulch did little or nothing to reduce soil resistance below the original soil surface.

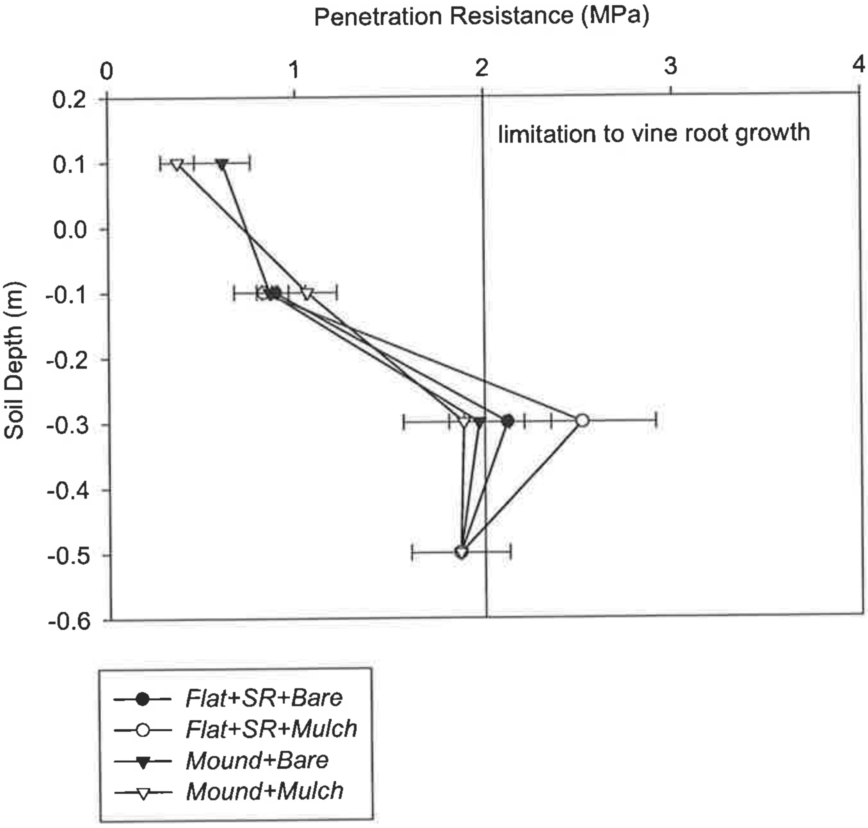

Figure 5.2 Soil penetration resistance as a function of depth with and without ripping and mulching at Lyndoch, December 1995.

The soil penetration resistance for the *No-rip*, *Flat+SR* and *DR* treatments are shown in Figure 5.3. There were no significant differences in soil resistance below the zone of ripping and within 0.1m of the soil surface, but at a depth of 0.3m (A_2-horizon) soil resistance increased with the number of deep rips, from 1.8 MPa (*No-rip*), to 2.4 MPa (*Flat+SR*), to 2.6 MPa (*DR*). The (apparently) negative effect of deep-ripping on soil resistance at 0.3 m was unexpected and may have resulted from compaction due to poor timing of the ripping operations (ripping was performed during mid-winter when soil was near field capacity – too wet!), or may simply have resulted from the soil-core samples being collected at points in the row too far from the line of ripping. The line of ripping was approximately 0.8 m from the vine-row, whereas soil-core samples were taken for penetration resistance approximately only 0.3 m from the vine-row. Under these conditions, one might expect a tendency for penetration resistance to increase with the number of ripping operations. If deep-ripping had been conducted when soil was slightly drier than the "plastic limit", or if the correct tine specifications had been used (see Cass et al., 1993), a decrease in soil strength with ripping would be expected. In either case, it must be concluded that ripping, as performed, had either a negative effect or certainly no positive effect on soil resistance.

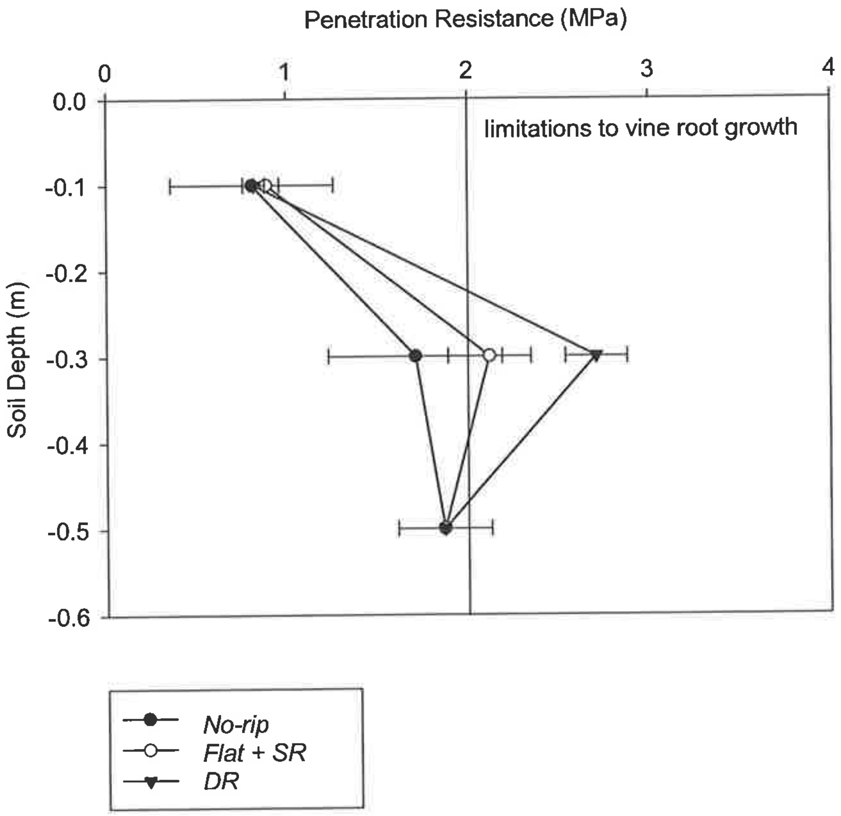

Figure 5.3 Soil penetration resistance as a function of depth for *deep-rip* treatments at Lyndoch, December 1995.

5.3.2.2 Padthaway Range

Penetration resistance increased significantly with depth for all treatments ($\alpha = 0.01$ significance level). Deep-ripping, which disturbed the soil between the rows, had no effect on penetration resistance within the rows in 1998, 1999 or 2000. In contrast to the effects on RAW and TAW at this site, mulching had no effect on penetration resistance. Within the vine-row, penetration resistance did not exceed 2 MPa in the top 0.8 m.

Penetration resistance, measured in September 1998 at three positions: 0.6, 0.9 and 1.2 m from the vines in the mid-row space is shown in Figure 5.1 for the *Rip+Bare* treatment. Immediately after ripping (0.8 m from the vine-row to a depth of 0.9 m), penetration resistance in the mid-row space was significantly less for the *Rip+Bare* treatment compared with the *No-rip+Bare* treatment, particularly near the soil surface ($\alpha = 0.01$ significance level). It was also significantly less in the positions bordering the ripping operation at 0.6 and 0.9 m from the vine-row compared with that further out at 1.2 m from the vine-row, ($\alpha = 0.01$ significance level). Penetration resistance did not exceed 2 MPa to a depth of approximately 0.6 m in the two positions bordering the ripping operation.

Measurements of soil resistance taken at 1.2 m away from the vine-row exceeded 2 MPa at a depth of approximately 0.3 m. The *No-rip* treatment had penetrometer resistances > 2 MPa throughout the entire soil profile.

By August 1999 re-compaction of the soil started to occur (compare Figures 5.1 and 5.4). However, penetration resistance remained < 2 MPa to depths of ~0.4 m at distances of 0.6 m and 0.9 m from the vine-row. By August 2000, significant re-compaction had occurred and the effect of ripping was virtually gone (Figure 5.5). Virtually all positions in the mid-row space had penetrometer resistances > 2 MPa throughout the soil profile.

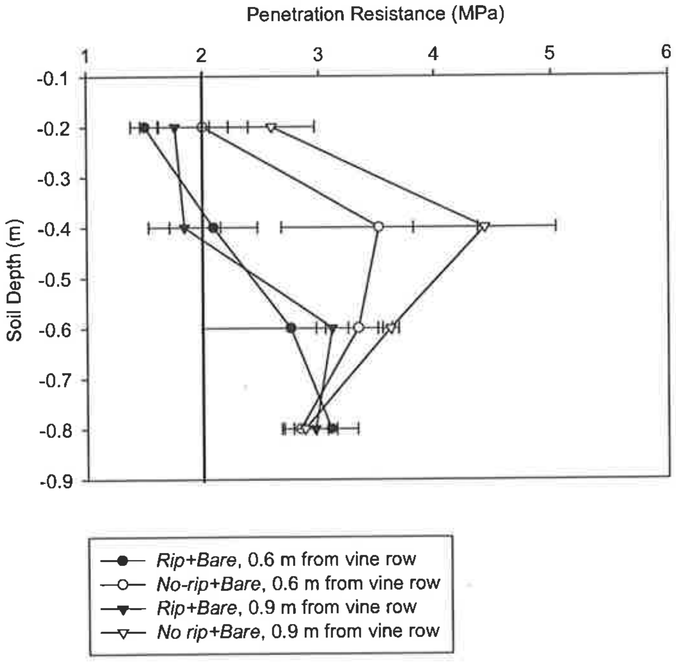

Figure 5.4 Soil penetration resistance as a function of depth at different positions in the mid-row for *ripped* and *no-rip*, bare soil surfaces at Padthaway Range, August 1999.

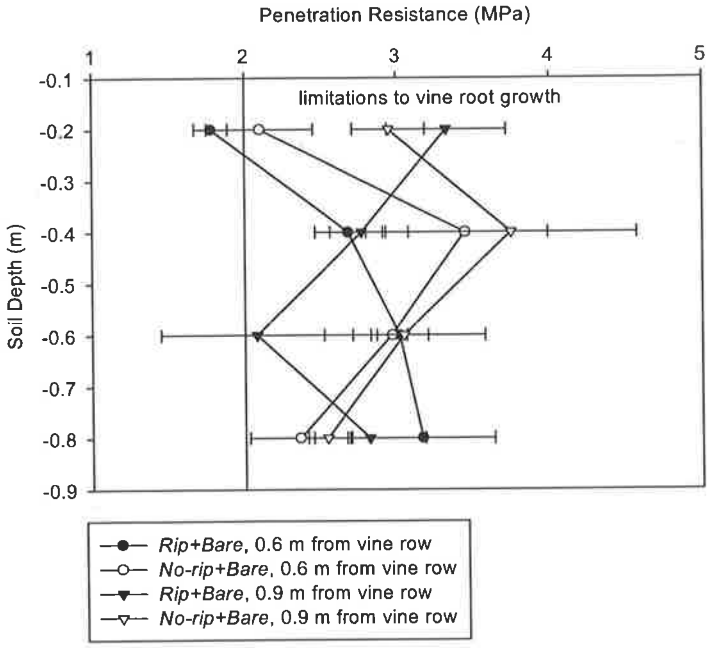

Figure 5.5 Soil penetration resistance as a function of depth at different positions in the mid-row for *ripped* and *no-rip*, bare soil surfaces at Padthaway Range, August 2000.

The gradual, but persistent increase in penetration resistance with depth in the mid-row over time after deep-ripping is illustrated in the iso-penetration resistance profiles produced each year from 1998 to 2000 (Figures 5.6 to 5.9). In September 1998 penetration resistance was greatest at approximately 0.8 m from the vine-row at a depth of 0.4 m (Figure 5.6). This location of maximum penetration resistance coincided with the concentration of wheel traffic and the location of the naturally very dense A_2-horizon. This combination produced penetration resistances exceeding 5.5 MPa. The only region of soil having a penetration resistance < 2 MPa occurred within 0.5 m of the vine-row to a depth of only 0.8 m.

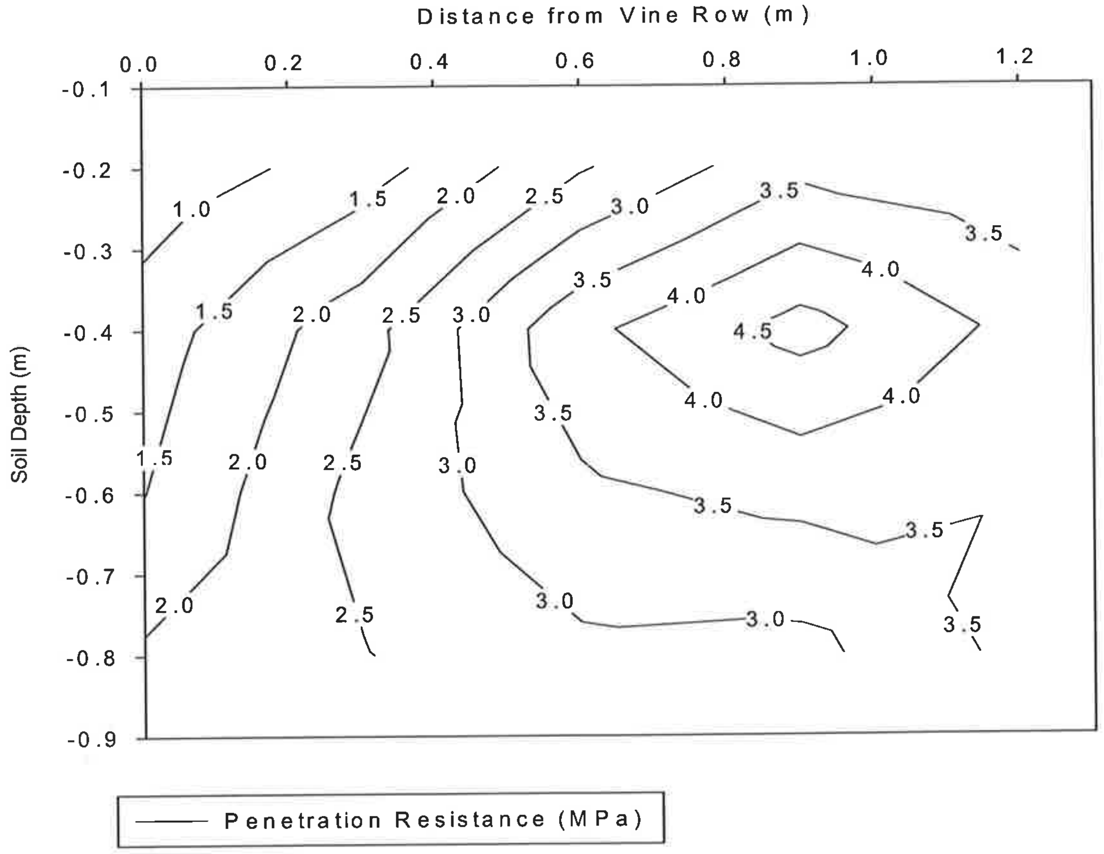

Figure 5.6 Iso-penetrometer resistance as a function of depth (and distance from the vine) for the *No-rip* treatment at Padthaway Range, September 1998.

Deep-ripping increased the region of soil with a penetration resistance < 2 MPa (Figure 5.7). The soil affected by the deep-ripping extended 0.4 to 1.0 m further into the mid-row to a depth of 0.8 m. However, after only one year, penetration resistance increased to the point where 2 MPa was exceeded at a depth of only 0.5 m (Figure 5.8). By August 2000 (after only 2 years) a zone of high penetration resistance formed at a depth of only 0.6m at 0.8 m from the vine-row (Figure 5.9), which was very similar to the original, un-ripped (*No-rip*) soil.

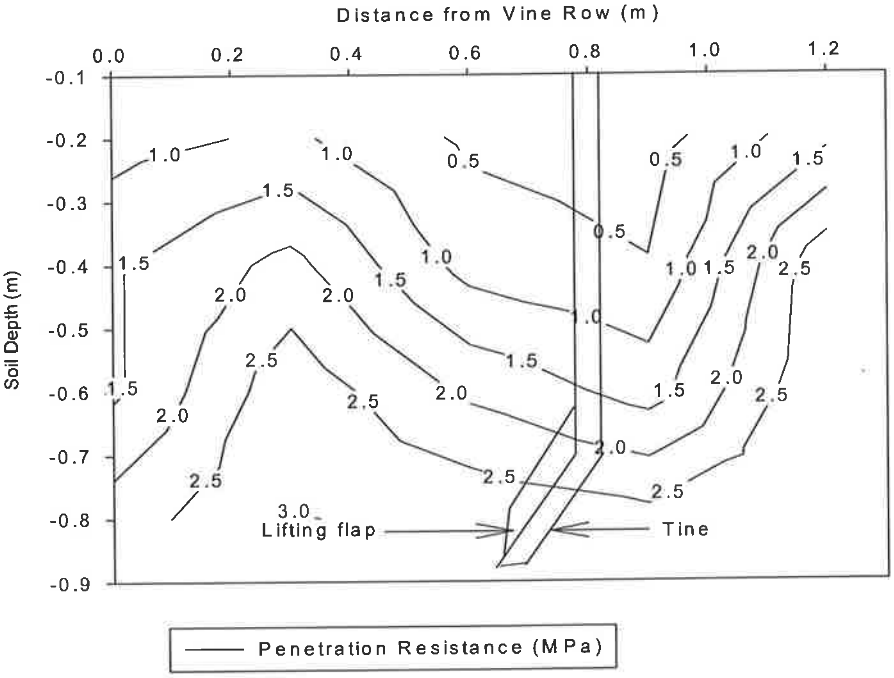

Figure 5.7 Iso-penetrometer resistance as a function of depth (and distance from the vine) for the *Rip* treatment at Padthaway Range, September 1998.

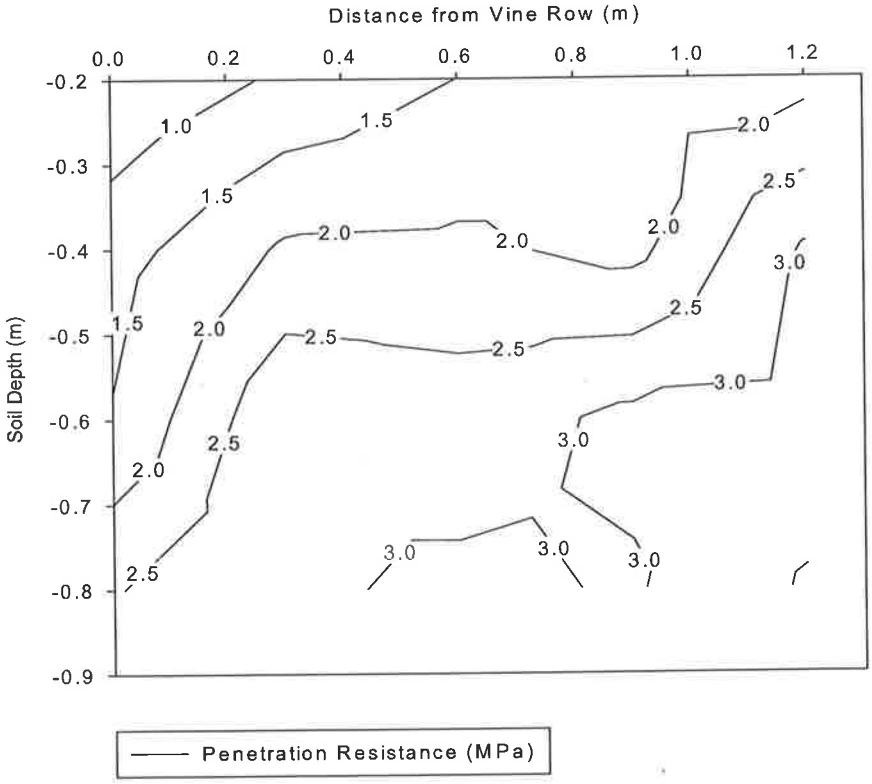

Figure 5.8 Iso-penetrometer resistance as a function of depth (and distance from the vine) for the *Rip* treatment at Padthaway Range, August 1999.

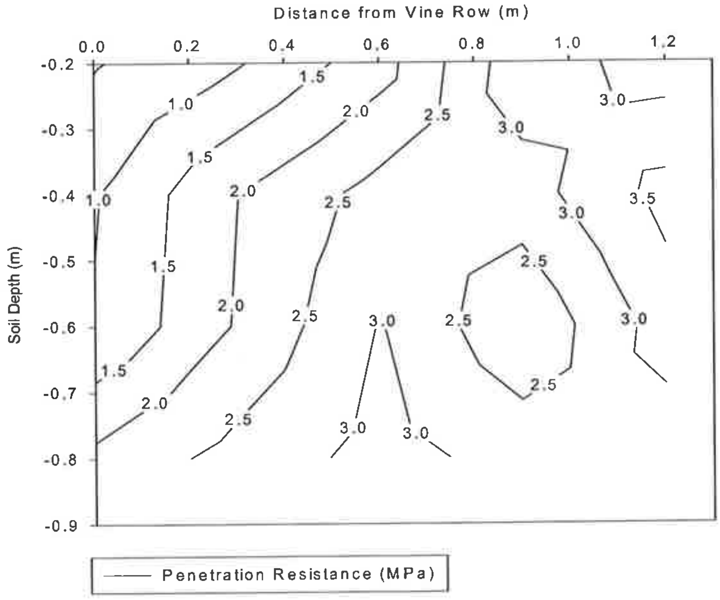

Figure 5.9 Iso-penetrometer resistance as a function of depth (and distance from the vine) for the *Rip* treatment at Padthaway Range, August 2000.

5.3.2.3 Padthaway Plain

Penetration resistance in the vine-row at the start of the experiment in September 1998 increased dramatically below about -0.1-0.15 m and was similar for all treatments above this point in the A_{new}-horizon (Figure 5.10).

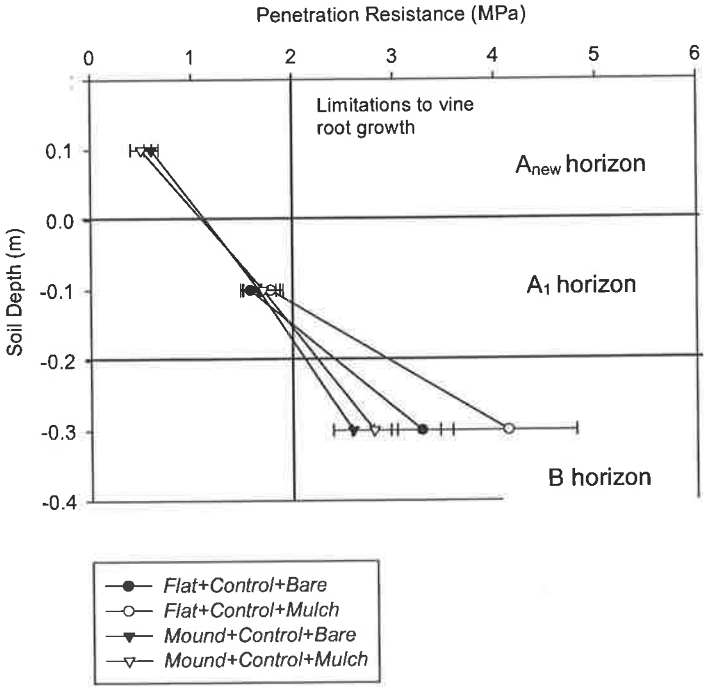

Figure 5.10 Penetration resistance as a function of depth in the vine-row for different soil management treatments at Padthaway Plain, September 1998.

After one year (August 1999), penetration resistance in the vine-row was similar to the original values and similar between treatments (Figure 5.11). There was a significant interaction between soil depth and soil management: penetration resistance was similar between all soil management treatments in the A_1-horizon but in the B-horizon penetration resistance was significantly greater in the *Flat* treatments than in the *Mounds* ($\alpha = 0.05$). This may have been due to the variations in the thickness of the mounds or the measurement of depth from the soil surface downward.

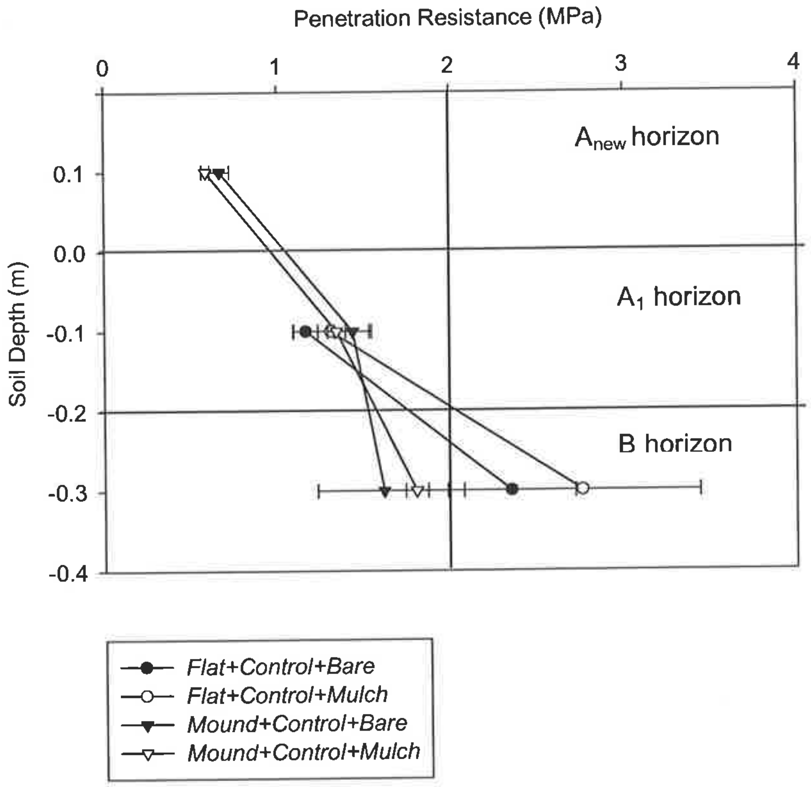

Figure 5.11 Penetration resistance as a function of depth in the vine-row for different soil management treatments at Padthaway Plain, August 1999.

By August 2000, the *Mounds* had a lower penetration resistance at the soil surface (A_{new}-horizon) than the *Flat* (A_1-horizon) treatments (Figure 5.12). The *Mound+Control+Mulch* also had a somewhat lower penetration resistance in the A_{new}-horizon than did the *Mound+Control+Bare* (significant at $P = 0.082$). Surface crusting was visible on the *Bare* soil surfaces but not on any of the *Mulched* soil surfaces, where conditions would have been wetter and therefore ideal for micro-fauna and flora to maintain larger soil pores and protect the soil surface from rapid wetting and drying.

In the A_1-horizon, however, penetration resistance was greater in the *Mounds* than in the *Flat* treatments ($\alpha = 0.05$ significance level), possible due to the compacting effect of the greater overburden from the (wetter) mounds on the A_1-horizon.

Penetration resistance in the vine-rows for *Mound* treatments reflected the general tendency for the mounds (A_{new}-horizon) to become denser over the two year period between September 1998 and August 2000 (Figure 5.13).

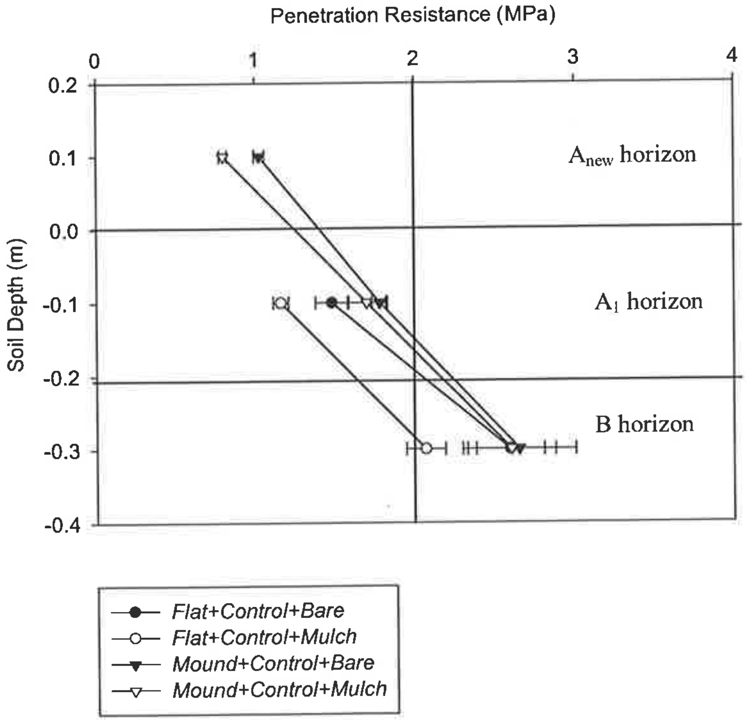

Figure 5.12 Penetration resistance as a function of depth in the vine-row for the *Flat* versus *Mounded*, and for *Bare* versus *Mulched* soil at Padthaway Plain, August 2000.

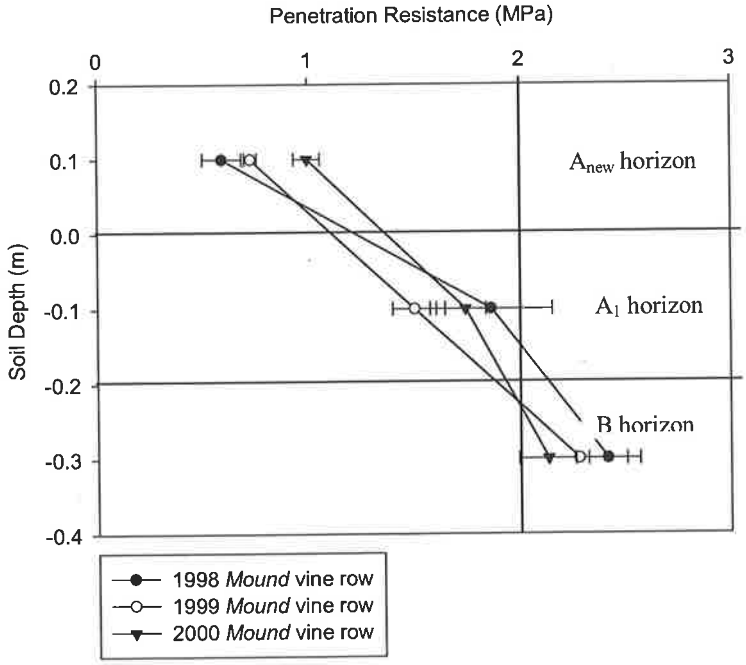

Figure 5.13 Penetration resistance as a function of depth in the vine-row for the *Mound* treatments at Padthaway Plain, September 1998, August 1999 and August 2000.

Penetration resistance for the mid-row regions of the *Flat* and *Mound* treatments were highly variable (Figures 5.14, 5.15 and 5.16). Penetration resistance was greatest at 0.8 m from the vine-row, directly under the wheel track for the *Mound* treatment in 1998 and for the *Flat* treatment in 1999 ($\alpha = 0.05$ significance level). At a depth of 0.2 m, the average penetrometer resistance was greater in the *Flat* treatment than in the *Mound* treatment.

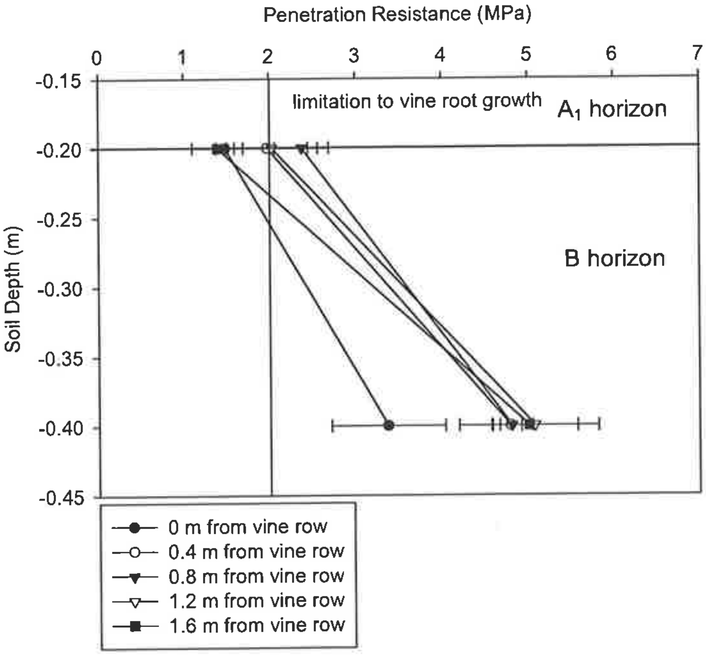

Figure 5.14 Penetration resistance with depth as a function of distance into the mid-row for the *Flat* treatments at Padthaway Plain, September 1998.

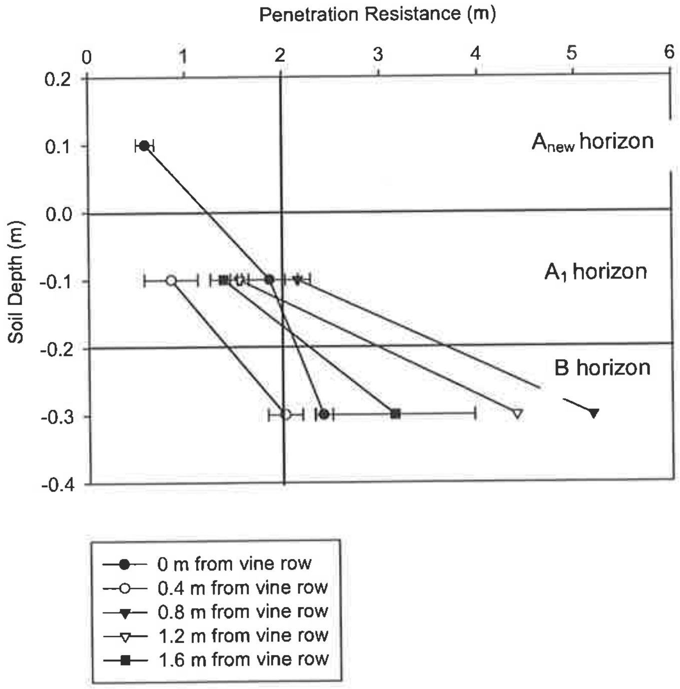

Figure 5.15 Penetration resistance with depth as a function of distance into the mid-row for the *Mound* treatments at Padthaway Plain, September 1998.

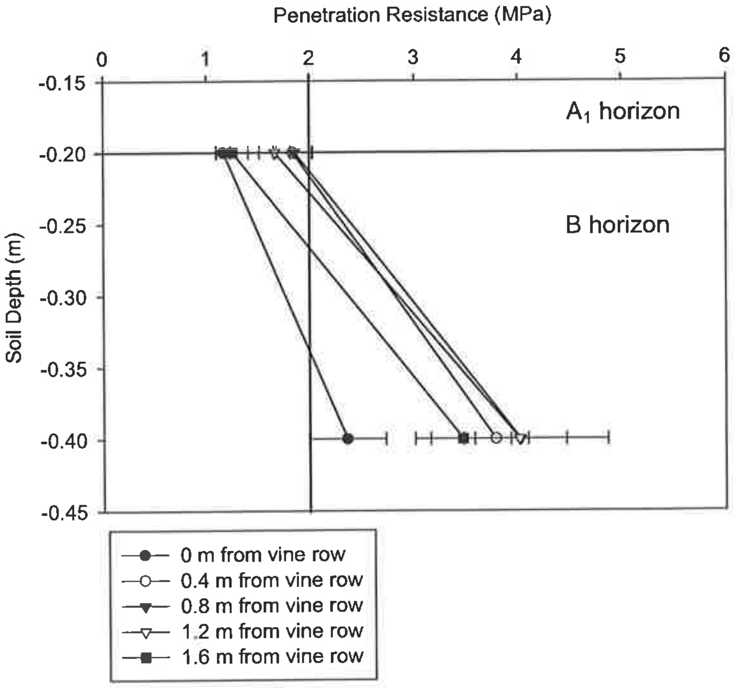

Figure 5.16 Penetration resistance as a function of depth in the mid-row for the *Flat* treatments at Padthaway Plain, August 1999.

By August 2000, penetration resistance throughout the soil profile increased with depth (as expected) but was no longer affected significantly by the *Mound* treatment.

5.3.3 Root-length density

5.3.3.1 Lyndoch

Root-length density for the *Flat* and *Mound* treatments in December 1995 ranged from approximately 0.1 cm cm^{-3} to 1.5 cm cm^{-3} (Figure 5.17). In the vine-row, most roots were found 0.4 m from the dripper in both *Flat* and *Mound* treatments. At a depth of –0.1 m (A_1-horizon) the mean root-length density in the *Mounds* was significantly greater than that in the *Flat* treatment ($\alpha = 0.05$ significance level). This was expected since the A_1-horizon of the *Mounds* was immediately under the A_{new}-horizon, and vine-roots grew upward from the A_1-horizon into the *Mound.* Significant variation in root-length density occurred at –0.8 m and may have been due to the presence of rubble (limiting root growth) as shallow as –0.7 m.

All root-length densities in July 1996 were relatively low (Figure 5.18) by comparison to those reported by Stevens and Nicholas (1994), who found values ranging from 0.005 cm cm^{-3} for roots > 2 mm diameter up to 0.168 cm cm^{-3} for roots < 2 mm diameter. The low root-length densities shown in Figure 5.18 may have resulted from loss of roots during augering for samples (the auger appeared to tear at roots and leave some behind). In hindsight, the 'pit method' for root-sampling used in 1995 was probably a more robust technique for estimating root-length densities than the 'auger method' because it did not disturb the roots significantly.

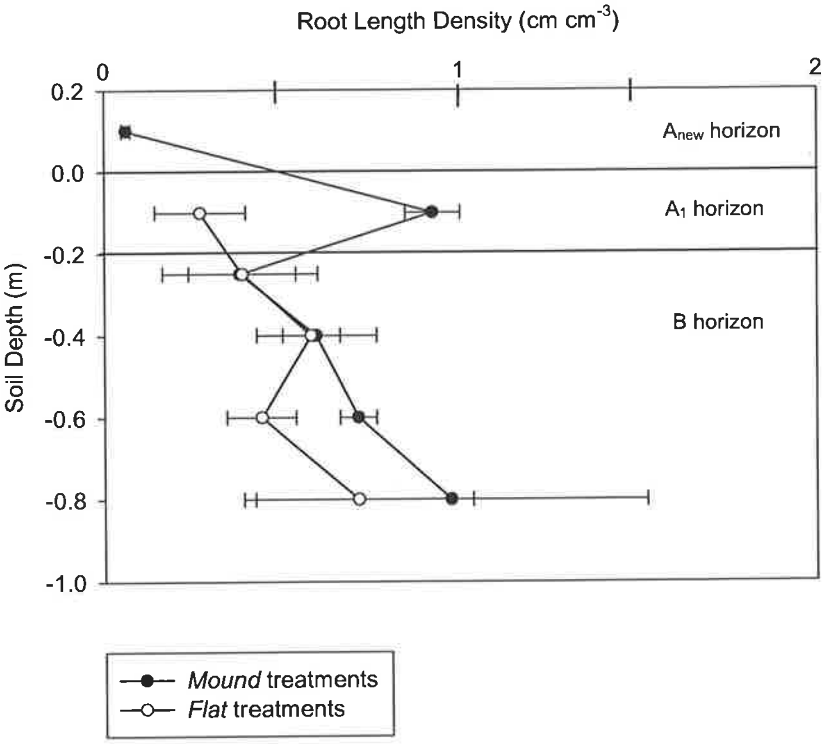

Figure 5.17. Root-length density (cm cm^{-3}) as a function of depth in the *Flat* and *Mound* treatments, 0.4 m from the dripper within the vine-row at Lyndoch, December 1995.

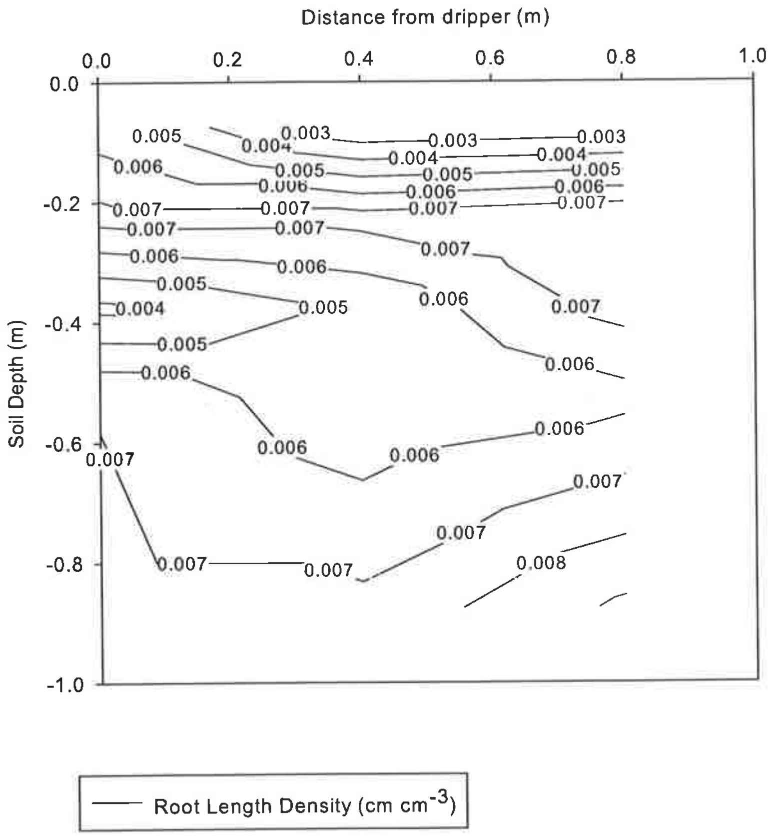

Figure 5.18 Root-length density in the vine-row as a function of depth and distance from the dripper in the *Mound* at Lyndoch, July 1996.

Although the root-length density in the A_1-horizon under the *Mounds* was significantly greater ($\alpha = 0.05$) than that in the A_1-horizon under the *Flat* treatments in December 1995, there were no significant differences among treatments by July 1996 (Figure 5.19). Variation in root-length density between treatments and soil depths was large, and probably related to the method of sampling (by auger), as discussed above.

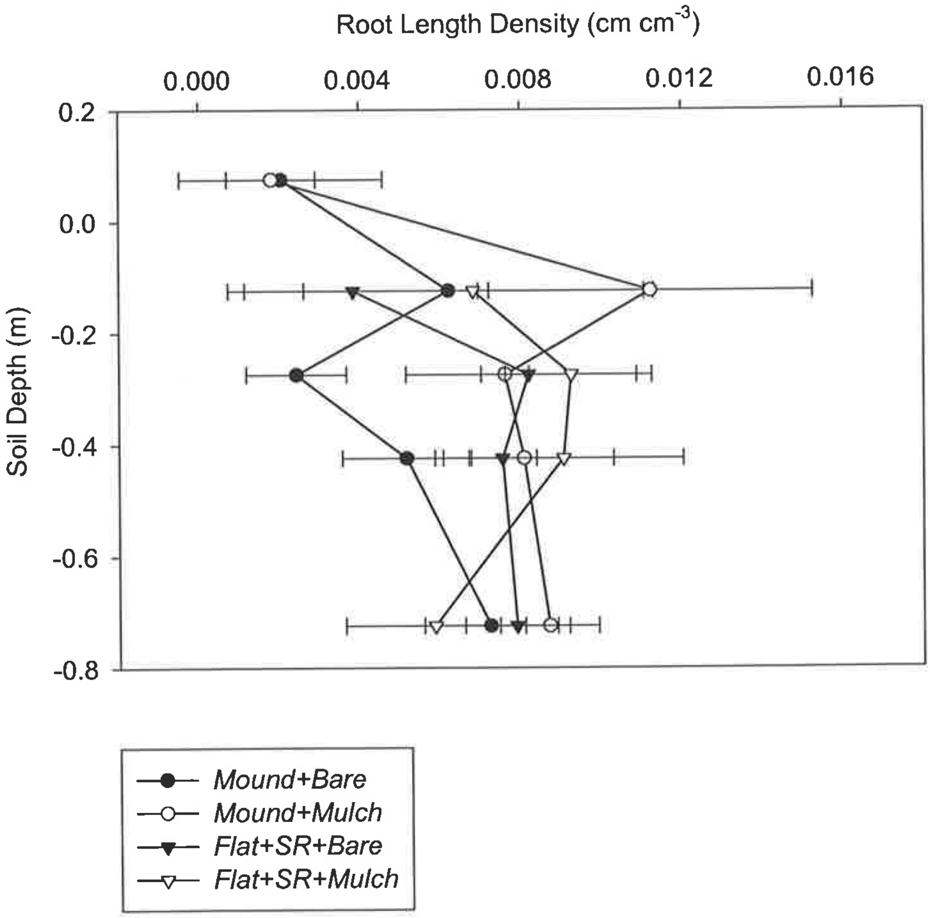

Figure 5.19 Root-length density (cm cm^{-3}) as a function of depth in the vine-row, 0.4 m from the dripper at Lyndoch, July 1996.

Root-length densities under the *Mound+Bare* and *Mound+Mulch* treatments were greatest in the A_1-horizon, followed by the B-, A_2- and A_{new}-horizons. Root-length densities for the *Flat+SR+Bare* and *Flat+SR+Mulch* treatments were similar at all depths except in the A_1-horizon, where they were less. Root-length densities were generally greater under the mulches than under bare soil at most depths (but not statistically significant at $\alpha = 0.05$).

Root-length densities decreased steadily from the vine-row out into the mid-row in both the *Mound* and *Flat* treatments (Figures 5.20 and 5.21), and this was probably related to increasing distance from the dripper and the vine rather than due to soil structural limitations.

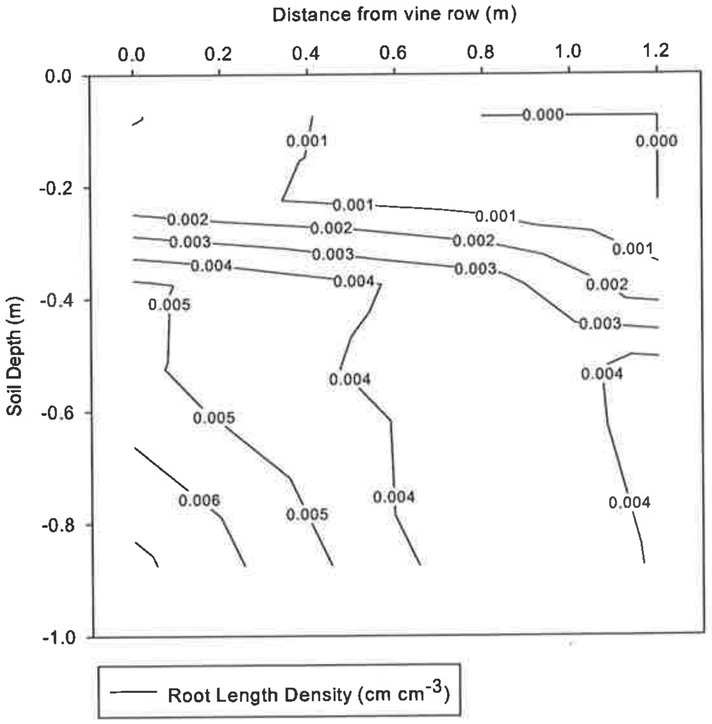

Figure 5.20 Root-length density as a function of depth in the *Mound* treatment from the vine-row to the mid-row, Lyndoch, July 1996.

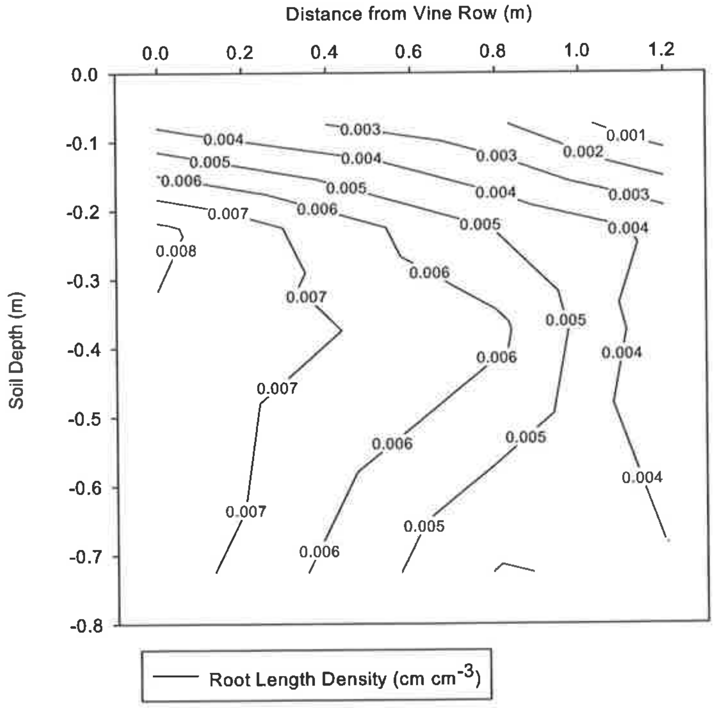

Figure 5.21 Root-length density as a function of depth in the *Flat* treatment from the vine-row to the mid-row, Lyndoch, July 1996.

5.3.3.2 Padthaway Range

At the beginning of the experiment in 1998, root-length density decreased with depth below the A_1-horizon (from –0.4 m downward), where compaction was a problem (Figure 5.22). Root growth was severely restricted below the A_2-horizon. Root-length density increased from 0.6 cm cm^{-3}, directly under the dripper, to values exceeding 1.2 further away from the dripper at the perimeter of the wetted zone. The better root growth at the periphery of the wetting zone suggests that aeration may have been restricted close to the dripper.

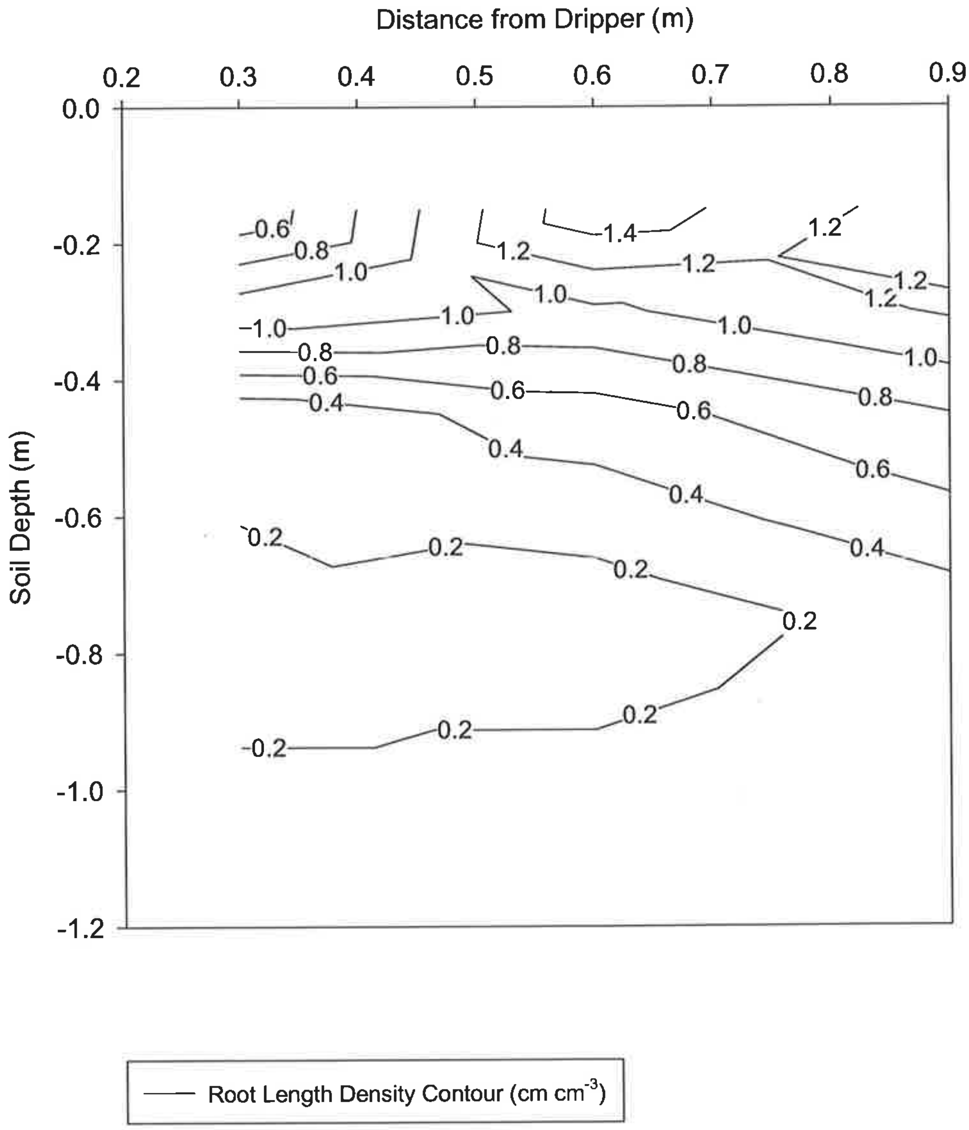

Figure 5.22 Root-length density, in the vine-row at Padthaway Range, September 1998.

Root-length density also declined sharply from the vine-row out into the mid-row, where heavy traffic caused compaction, particularly in the A_2-horizon (below 0.4m in Figure 5.23 for 1998). The root-length densities appeared to be lower in 2000 than they were in 1998, but the ripped soil had higher values than the un-ripped soil in 2000 (Figures 5.24, 5.25).

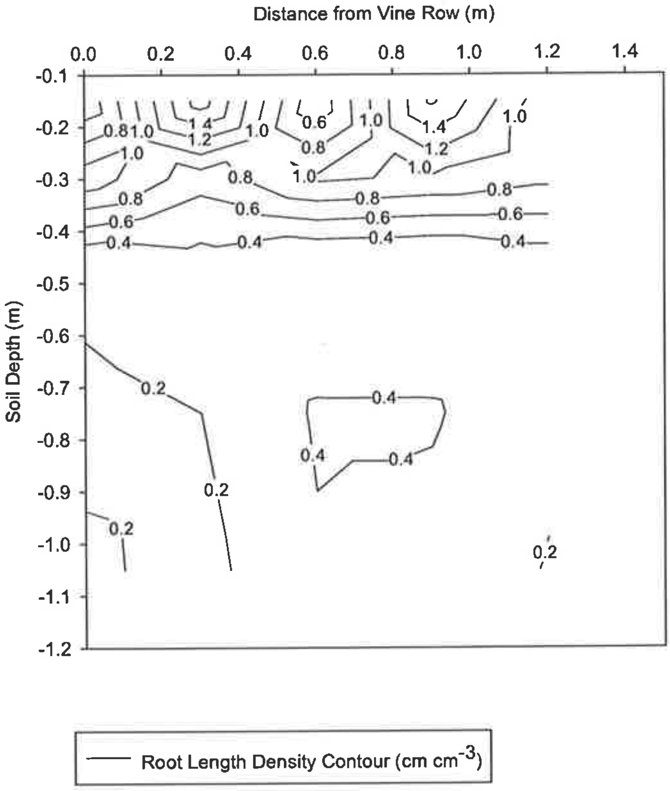

Figure 5.23 Root-length density, from the vine-row to the mid-row at Padthaway Range, September 1998.

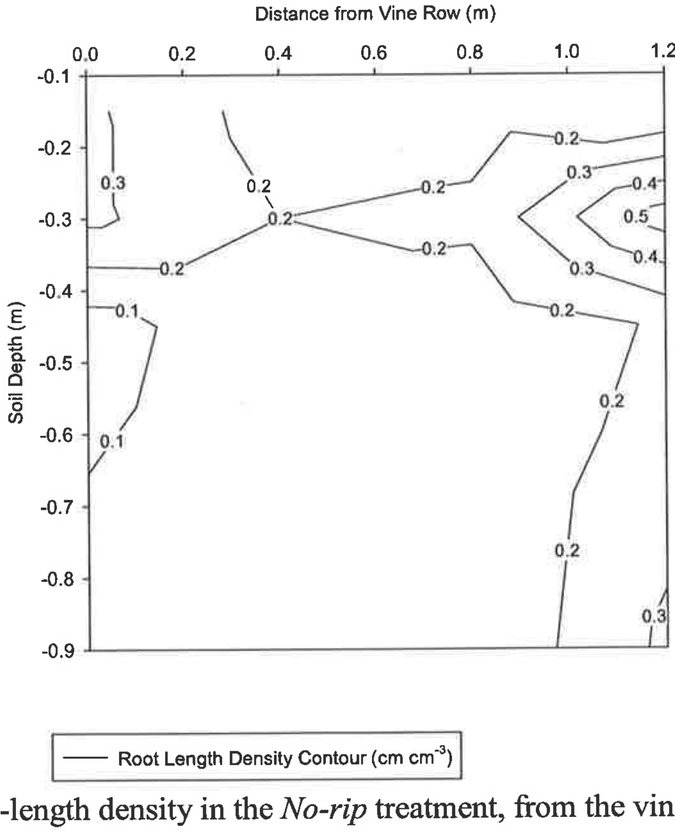

Figure 5.24 Root-length density in the *No-rip* treatment, from the vine-row to the mid-row at Padthaway Range, April 2000.

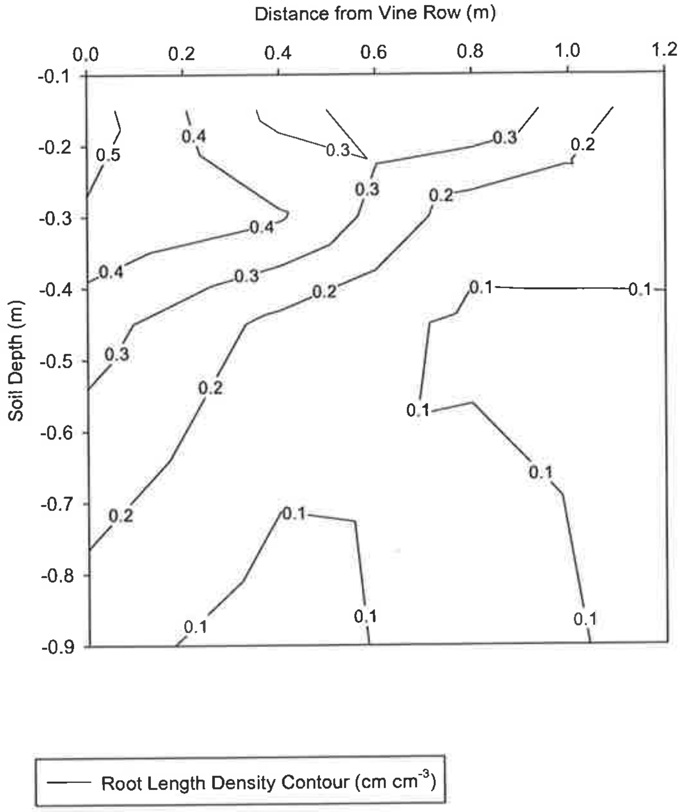

Figure 5.25 Root-length density in the *Rip* treatment, from the vine-row to the mid-row at Padthaway Range, April 2000.

In 2000, root-length density decreased with depth and distance from the vine-row in both the *No-rip* and *Rip* treatments, but the decrease was much greater overall in the *No-rip* treatments. Root-length density was greater within a larger region of the vine-row in the *Rip* treatment compared with the *No-rip* treatment. For example at -0.4 m depth and only 0.4 m from the vine-row, root-length density decreased to 0.2 cm cm^{-3} in the *No-rip* treatment, but in the *Rip* treatment it decreased to 0.2 cm cm^{-3} at -0.4 m depth and 0.6 m from the vine-row. The link between lower soil resistance (from deep-ripping) and the corresponding increase in root-length density can be seen by comparing Figure 5.6 (iso-penetrometer data for *No-rip*) and Figure 5.24 (root-length density data for *No-rip*) with Figure 5.8 (iso-penetrometer data for *Rip*) and Figure 5.25 (root-length density data for *Rip*). Ripping clearly succeeded in providing an improved environment for root growth.

Root-length densities in the vine-row at ~0.3 m from the dripper for all treatments in April 2000 are shown in Figure 5.26. Densities were similar for all treatments below a depth of approximately –0.8 m depth, but they differed above this point, particularly at approximately –0.2 m, in the following descending order: *Rip+Mulch* > *Rip* > *No-rip+Mulch* > *No-rip+Bare*. It is clear from this (also the RAW_v and TAW_v data in Table 5.5) that ripping and mulching both improved soil structure and water availability to roots.

Table 5.5 (see above) highlights the increase in RAW_v and TAW_V due to improved soil structure under mulch. The combination of *Rip* + *Mulch* had the greatest beneficial effect on soil structure, hence root growth. Root-length densities reached a minimum for all treatments at a depth of –0.4 m, which indicated that the A_2-horizon, which reached penetrometer measurements of 4 MPa (Figure 5.4), did in fact limit root growth.

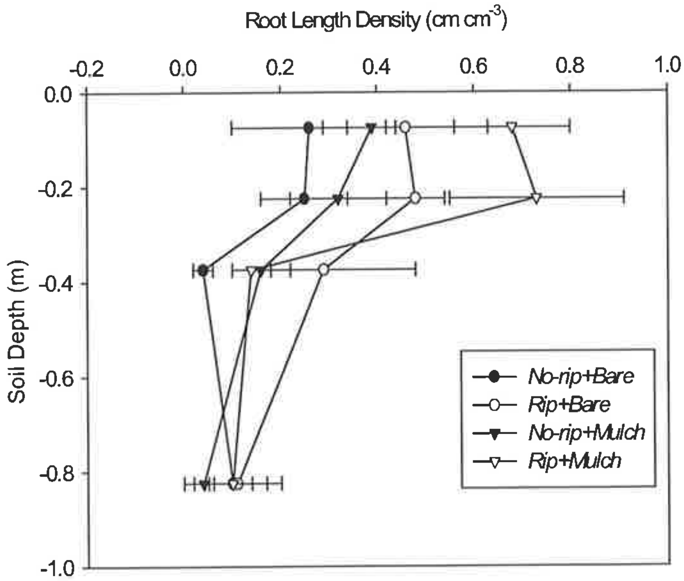

Figure 5.26 Root-length densities as a function of depth for *Rip* and *Mulch* treatments at Padthaway Range, April 2000.

5.3.3.3 Padthaway Plain

Root samples were collected first in September 1998 at 0.3 m from a dripper and a vine in every treatment. Samples were collected at a mean depth of 0.075 m above the original soil surface in the A_{new}-horizon (*Mounds*) and at a mean depth of 0.075 m into the A_1-horizon in all the *Flat* treatments (Figure 5.27).

Root-length densities at Padthaway Plain were almost four times greater than at Padthaway Range. The limestone layer at 50 cm at Padthaway Plain probably restricted all root growth to the 0 to 50 cm zone, thus producing a higher concentration of roots in this zone.

Root-length density was similar in the *Mound+Control+Bare* and *Mound+Control+Mulch* treatments, and this was expected after such a short interval following introduction of the treatments.

Root-length densities increased considerably between 1998 and 2000, but variability in the measurements was too great to distinguish significant differences among the treatments (Figure 5.28). In any case, by 2000 there was little difference in either RAW or TAW between any of the treatments (Table 5.7), and so little difference in root-length densities might be expected at this site.

Root-length densities in the vine-row increased significantly with distance from the vine to a maximum at 1 m from the vine ($\alpha = 0.05$) and also increased with depth ($\alpha = 0.01$). Due to the high variability in measurements in April 2000, there appeared to be little effect of the *PRD-irrigation* treatment relative to the *Control-irrigation* treatment regardless of the *mounding* (Figure 5.29).

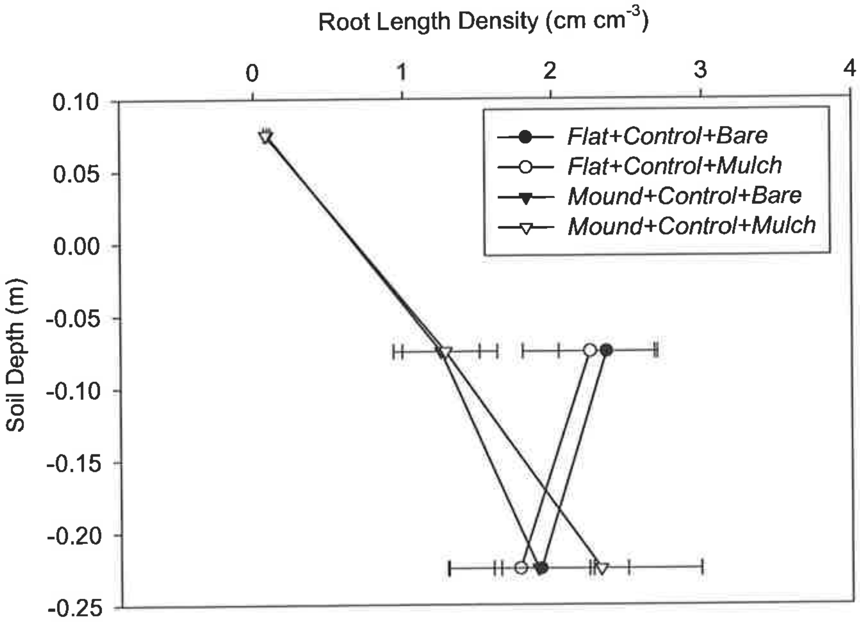

Figure 5.27 Mean root-length densities for different soil management treatments at Padthaway Plain, September 1998.

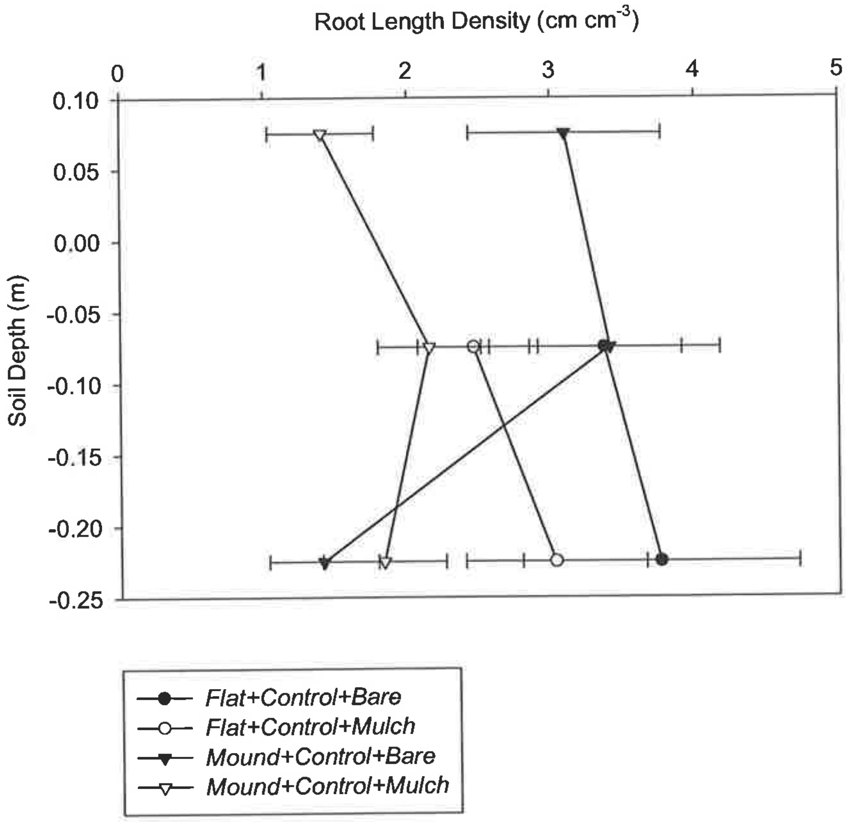

Figure 5.28 Mean root-length densities for different soil management treatments at Padthaway Plain, April 2000.

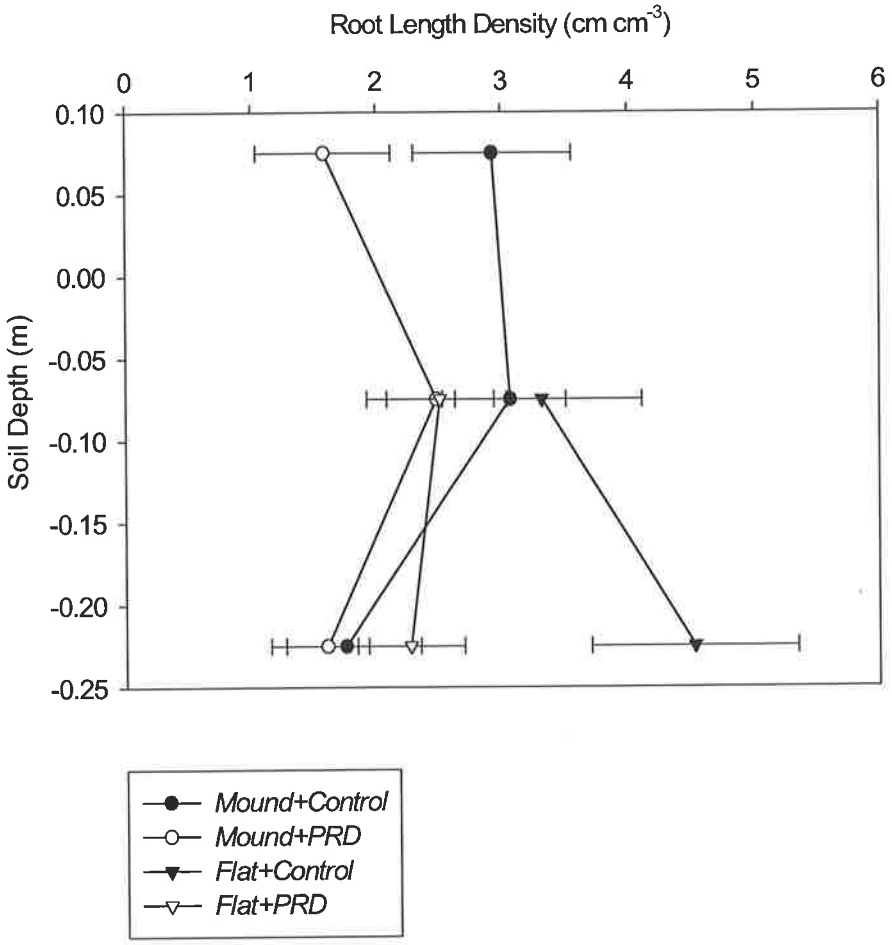

Figure 5.29. Mean root-length density as a function of depth as affected by irrigation treatment at Padthaway Plain, April 2000.

5.4 Conclusions

5.4.1 Soil Structure and available water (RAW and TAW)

At Lyndoch the application of lime, polymers, grape marc, mulch or the use of ryegrass did not improve the water holding capacity of the soil in terms of RAW and TAW. This result might be expected, particularly for the first few years following application – the high organic matter content of the various mulches may have served to enhance biological activity and stabilize macro-pores (> 30 µm), which drain readily. With no further additions of organic matter, however, the larger pores might be expected to gradually collapse into smaller, more stable pores that retain water against gravity.

Mounding at Lyndoch appeared to have no significant effect on soil structure relative to the *Flat* treatments. However, *mounding* did increase the volume of soil above the compact A_2-horizon and this enabled plant roots to explore a larger volume of soil before having to penetrate the dense A_2-horizon.

At Padthaway Plain, *mulching* reduced RAW_v and TAW_v, mainly because the continuously wet conditions under the mulches caused the soil structure to collapse. *Mounding* increased RAW_v and TAW_v probably due to gradual settling of the open-structured mound into a more compact state, holding water for plant-use.

By contrast, *mulching* increased RAW_v and TAW_v at Padthaway Range, and this was considered to be primarily due to improved soil structure, in which pores of the size drained between 10 and 60 kPa and between 60 and 1500 kPa were prevalent. In addition, RAW_v and TAW_v were significantly increased by ripping: *Rip+Bare* and *Rip+Mulch* treatments had approximately twice the bulk root-volume compared to the *No-rip and No-rip+Mulch* treatments.

The different response to *mulching* at Lyndoch and Padthaway Plain versus that at Padthaway Range suggests that the *mulch*-effect was site-specific. *Mulching* increased water retention on the sandy-textured surface soils at Lyndoch and Padthaway Plain, while it decreased water retention on the loam-textured soil at Padthaway Range.

The hypothesis that *Mounding* would provide a greater volume of soil with improved structure was also found to be site specific, and was rejected at Lyndoch because the vine roots were able to explore cracks through the A_2-horizon and develop more freely below, so that the additional volume of good soil structure in the mound was not required. By contrast, at Padthaway Plain the hypothesis was accepted – *mounding* provided a slightly greater volume of soil for vine roots to explore compared with the *Flat* soil.

5.4.2 Soil resistance

Penetrometer measurements indicated the presence of a dense A_2-horizon at Lyndoch, but this was not alleviated by *ripping* because the ripping was too shallow[1] and it was performed when the soil was too wet. In addition, *mounding* had no influence on either horizontal or vertical root development (*cf* Figure 5.20) despite the fact that it increased the volume of soil having low penetrometer resistance. Roots were able to penetrate the dense A_2-horizon through cracks or were able to develop into the mid-row area above the A_2.

At Padthaway Range, a combination of wheel traffic and a dense A_2-horizon produced penetration resistance often exceeding 4.5 MPa. *Mulching* therefore had no effect on penetration resistance. The only treatment that produced a significant (but temporary) reduction in soil resistance was *ripping*. This reduced penetration resistance for about 12 months to values less than 2 MPa at 0.6 m and 0.9 m from the vine-row ($\alpha = 0.01$ significance level). Within two years, however, the entire soil profile was much the same as it was before *Ripping*.

At Padthaway Plain, which had a limestone layer at ~ 0.5 m below the soil surface, penetration resistance was near 2 MPa throughout the soil profile. Soil resistance was greatest in the mid-row sections directly under wheel tracks. Nevertheless, *mounding* at Padthaway Plain appeared to increase the volume of soil with good soil structure and lower soil resistance.

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[1] *Ripping* was performed to a depth of only 0.5 m, whereas van Huyssteen (1988a) and Myburgh et al. (1996) indicated that ripping must be performed to at least 0.7m to be effective.

The hypothesis that *deep-ripping* would provide a greater volume of low-strength soil for vine roots compared with traditional (*No-rip*) practices was accepted to be site-specific. No conclusion could be drawn at Lyndoch because the deep-ripping procedure was not performed well. By contrast, penetration resistance at Padthaway Range demonstrated the presence of compaction, so that *deep ripping* doubled the volume of low-resistance soil.

5.4.3 Root-length density

The hypothesis that *mounding* and *ripping* would increase the root volume compared with traditional practice of *flat* and *unripped* was rejected at Lyndoch. While vine roots grew into the *mounds* within 2 months of their establishment, the greater root-length density under the *mounds* did not persist for more than 7 months (i.e. the significantly greater root-length densities in December 1995 were not present by July 1996). Root-length density increased with depth except in the A_2-horizon, where it remained static and low. Once the roots penetrated through the A_2-horizon they developed freely below it. Root growth extended beyond the vine-row into the mid-row, where it became restricted only directly under the wheel-traffic (surface) zone – below this zone, roots proliferated with depth.

Root-length density was generally greater under *mulched* soil, and this was considered to be due to more favourable conditions of soil moisture (and probably temperature) under the mulch. The hypothesis that *mulching* would increase root-length density near the soil surface was thus accepted.

At Padthaway Range, *mulching* and *deep-ripping* appeared to increase root-length densities near the soil surface, but these increases were not statistically significant at $\alpha = 0.05$ for any of the treatments. Root-length density decreased significantly with soil depth, particularly below –0.3 m, which coincided with the position of the compacted A_2-horizon. Penetration resistance in the A_2-horizon generally exceeded 2 MPa and was even greater than 4 MPa under the wheel tracks. By April 2000 roots developed into the mid-row, particularly in the area that was *ripped*. The hypothesis that *mulching* and *deep-ripping* would increase root volume was therefore accepted, although the effects due to *ripping* appeared to exceed those due to *mulching*. The results from this site comparing penetration resistance and root-length density support the conclusions made by Hamblin (1985), van Huyssteen (1983) and Myburgh (1996) that a penetration resistance > 2 MPa limits grapevine root growth. The significance of these results was most likely supported by the homogenous nature of this soil profile.

At Padthaway Plain, root-length density decreased significantly with distance into the mid-row, but vine roots were not restricted by wheel traffic compaction. The hypothesis that *mounding* would increase root growth compared with traditional *flat* practices was accepted, even though the effect was marginal. Furthermore, root-length density was not improved near the soil surface by *mulching*, so the hypothesis that *mulching* would increase root growth near the soil surface was rejected at this site. These results concur with van Huyssteen and Weber (1980c) where the number of vine roots was greatest under the un-cultivated soil treated with herbicide.

The effect of *PRD*-irrigation on root development at Padthaway Plain was in contrast to that found by Stoll et al. (2000). The shallow soil made it difficult to control *PRD*-irrigation to prevent grapevine stress compared to that in the control treatment, which manifest itself in reduced yields overall (see Chapter 8, Table 8.7 and Table 8.8). This may explain why root growth did not proliferate in the deeper layers as found by Stoll et al. (2000).

In summary, the most important finding of this work was that site variations in soil properties affected the variation in root growth caused by the different treatments. *Ripping*, for example, did not increase root volume at Lyndoch yet it did at Padthaway Range. Similarly the hypothesis that *mounding* would increase grapevine root volume was rejected at Lyndoch but accepted at Padthaway Plain. The results from Lyndoch did not concur with Saayman and van Huyssteen (1980), van Huyssteen (1988a), Eastham et al. (1995) and Myburgh (1994), but this was primarily due to the lack of evidence of root growth limitations both vertically and horizontally at this site.

At both Lyndoch and Padthaway Range it was concluded that *mulching* increased the volume of soil explored by grapevine roots. In contrast to the results of van Huyssteen and Weber (1980c) and Buckerfield and Webster (2000), the root-length density at Padthaway Plain tended to be greater near the soil surface under bare soil (*Bare*) compared to under *Mulch*. This, however, was primarily due to the difficulty of keeping the mulch on the mounds at Padthaway Plain and the detrimental short-term impact of the mulch on soil structure.

6 EFFECTS OF MANAGEMENT ON AVAILABLE WATER

6.1 Introduction

On the basis of work by Saayman and van Huyssteen (1980) and van Huyssteen (1988a), *viz.* that total root-number, shoot-mass and yield increased with depth of soil-preparation, *deep-ripping* was expected to increase the amount of soil water available to the vines and to deplete soil water to a greater extent than in the unmodified soil. In addition, the beneficial effects of *mulching* and of irrigation by partial root zone drying, *PRD* (Dry et al. 1998), were expected to increase soil-water conservation and availability. The increased water (and nutrient) availability was expected through improvements in soil physical properties including infiltration of water, soil aeration, water retention, all of which result in reduced evaporation, reduced soil resistance and greater biological activity (Eastham et al. 1995; van Huyssteen and Weber 1980b; Enz et al. 1988; Buckerfield and Webster 2000). The following hypotheses were addressed in the work reported in this chapter:

(1) *Mulching* increases the amount of soil water available to vines through reduced evaporation from the soil surface under the mulch, improved water holding capacity of the surface soil, and greater root exploration near the soil surface.

(2) *Ripping* increases the amount of soil water available to vines predominantly through an increase in root exploration in the *ripped* zone.

(3) For reasons outlined in (1) and (2) above, *mounding* will increase the amount of soil water available to vines.

(4) Partial root zone drying, *PRD,* improves water use efficiency and vine performance.

6.2 Materials and Methods

The water retention characteristics of the soil profiles under each treatment were measured on soil cores in the laboratory. The bulk-soil volume explored by grapevine roots was observed in pits for each treatment, and the root-length density was estimated from core samples taken as described in Chapter 5. The volume of readily available water per grapevine, RAW_v, and the total available water per grapevine, TAW_v were calculated as the difference in volumetric water contents between 10 kPa (*field capacity,* θ_{10}) and 60 kPa (*refill point,* θ_{60}) for RAW, and between 10 and 1500 kPa (*wilting point,* θ_{1500}) for TAW, and multiplied by the volume of soil containing roots under the vine, V_r. Volumetric water contents were monitored at different times, θ_t, using either a neutron probe or a time-domain reflectometer (TDR) during the growing season, and water extraction patterns were deduced from the changes. If the water content ever exceeded that at *field capacity* (due to heavy rain, for example) it was assumed this excess water was lost to drainage and was not available for plant uptake[2].

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[2] At Lyndoch I measured and summed the changes that occurred in the amount of available water remaining in the soil for each treatment, whereas at both Padthaway sites I measured and summed the losses of available water.

6.2.1 Lyndoch

A total of 637 mm water was received at Lyndoch between October 1995 and June 1996 (418 mm of irrigation water and 219 mm of rain). Volumetric water content was measured at ~10-day intervals from October 1995 to February 1996 and monthly after that. Pairs of stainless steel wave-guides (150, 300, 450 and 600 mm long) were pushed vertically into the soil surface, and water contents were logged using a TRASE® TDR-system. The amount of RAW and TAW in the soil above the A_2-horizon (effective root-zone at this site) was calculated for each treatment.

6.2.2 Padthaway Range and Padthaway Plain

Volumetric water content in the effective root zone (1.2 m at Padthaway Range; 0.8 m at Padthaway Plain) were monitored throughout the 1999- and 2000-growing seasons using a neutron-probe. Aluminium neutron-access tubes were installed at Padthaway Range in each of four replicates per treatment to a depth of 1.2 m. At Padthaway Plain, three access tubes were installed in each of three replicated treatments to a depth of between 0.6 and 0.8m, depending on where limestone was encountered. (A cement / kaolin slurry was poured into each access-hole and the aluminium tube inserted to minimize air-gaps).

6.3 Results and Discussion

6.3.1 Lyndoch

The average volumetric water content in the top 300 mm of the *Flat* and *Mound* treatments with and without *mulch, grape marc* or *lime* is summarized in Figure 6.1 for the 1995-96 growing season, and details are shown for *Mound* treatments in Appendix Figure 11.13.

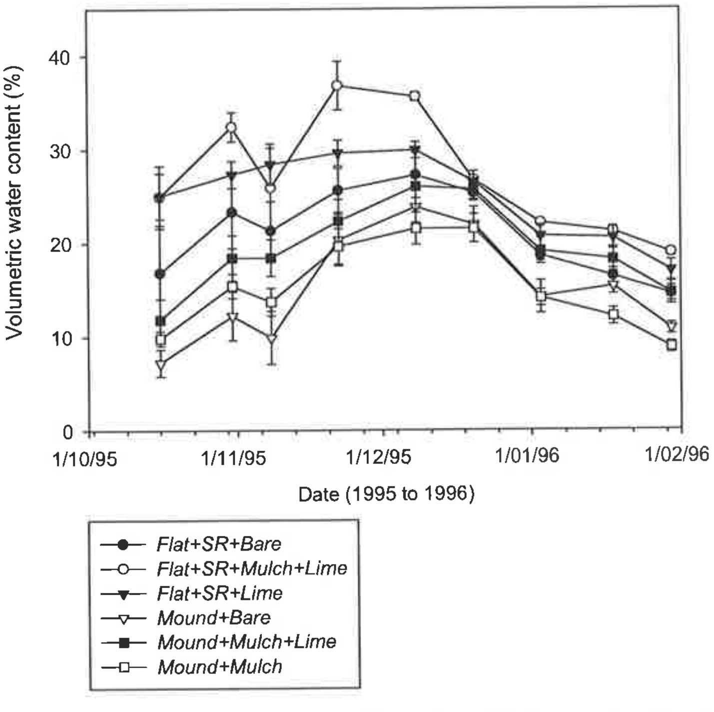

Figure 6.1. Average volumetric water content from 0 to 300 mm depth of *Flat* and *Mound* treatments with mulch and lime applied, Lyndoch '95 to '96 (see Table 4.1 p.41 for codes).

The *mounded* soil remained drier in the top 300 mm than the *flat* soil (lines for *mounded* soil in Figure 6.1 lie below those for *flat* soil), particularly in November and December of 1995. This was attributed to greater drainage and evaporation from the *mounded* soil.

The *Mulched* soil was generally wetter than the *Non-mulched*, and there appeared to be an interaction effect on water content due to the *Mulch* and the presence of *Lime*, but this was not statistically significant at $\alpha = 0.05$ (Appendix Figure 11.13). Within mounds, water contents were greatest in the *Mound+Mulch+Lime* treatment presumably because the lime and the organic mulch retained a stable distribution of pores, which retained water in the mound and reduced evaporation. This combination of treatments allowed maximum water input and minimised water loss from the soil.

It was noted that a crust formed on the soil surface after winter rains on the *Mound+Bare* treatments, which probably limited infiltration, but also limited evaporation. Consequently, the water contents of the *Mound+Bare* soil fell in the middle of all the treatments.

The volume of RAW_v stored in the soil at various points between October 1995 and April 1996 is shown in Appendix, Figure 11.14 and Figure 11.15. The amount of stored RAW_v was greater in *Flat* than in the *Mounded* soil, particularly at the beginning and end of the growing season (Oct and Mar). On four occasions the *Flat* treatment also contained more stored TAW than the *Mounded* soil (*cf.* Oct 1995 and Mar 1996, significant at α=0.01).

The sum of the change in the volume of stored RAW_v and TAW_v at different points during the growing season is shown in Tables 6.1 and 6.2. These figures include losses to evaporation and transpiration (not drainage), plus gains from rainfall and irrigation. Although the *Mounded* soil had almost double the average change in stored RAW_v and TAW_v relative to the *Flat* soil, the differences were highly variable and not statistically significant at a = 0.05. There were no significant differences in the average change in stored RAW_v and TAW_v among the *No-rip*, *Flat+SR* and *DR* treatments.

Table 6.1 Sum of the change in stored readily and total available water per vine for the deep-ripping treatments at Lyndoch between October 1995 and April 1996.

Ripping treatments	**Change in RAW_v (m^3 per vine)**	**Change in TAW_v (m^3 per vine)**
No-rip	0.28	0.28
Flat+SR	0.29	0.30
DR	0.20	0.21
Mound+SR	0.48	0.54

Table 6.2 Sum of the change in stored readily and total available water per vine for the soil surface cover treatments at Lyndoch between October 1995 and April 1996. Figures with different superscripts are significantly different at $\alpha = 0.01$.

Soil surface-cover treatments	**Change in RAW_v (m^3 per vine)**	**Change in TAW_v (m^3 per vine)**
Flat+SR+Bare	0.37^b	0.39^b
Flat+SR+Mulch	0.24^a	0.26^a
Mound+Bare	0.27^d	0.33^d
Mound+Mulch	0.70^c	0.76^c

The change in stored RAW_v and TAW_v between October 1995 and April 1996 was significantly greater in the *Flat+Bare* treatments compared with *Flat+SR+Mulch* treatments, (α = 0.01 significance level), and was undoubtedly caused by greater evaporation from the flat, bare soil. By contrast, *Mounding* produced the opposite result: the change in stored RAW_v and TAW_v was significantly greater for the *Mound+Mulch* treatments than for the *Mound+Bare* treatments (α = 0.01 significance level)[3]. Additionally, crusting occurred on the Mound + Bare treatments, which may have reduced evaporation.

6.3.2 Padthaway Range

For the year, July 1998 to June 1999, potential evapotranspiration was 1068 mm, total rainfall was 392 mm, and the amount of water applied as irrigation was 95 mm. For the second growing season, July 1999 to June 2000, potential evapotranspiration was 995 mm, total rainfall was 489 mm, and 42 mm of irrigation water was applied.

Most of the grapevine roots at this site occurred in the 0.2 to 0.4 m zone (Figure 5.22), and this is reflected in the volumetric water contents for the two seasons, 1998-99 (Figure 6.2) and 1999-00 (Figure 6.3). On average, both *Rip*-treatments tended to have lower mean water contents in the 0.2 to 0.4 m zone than did the *No-rip* treatments.

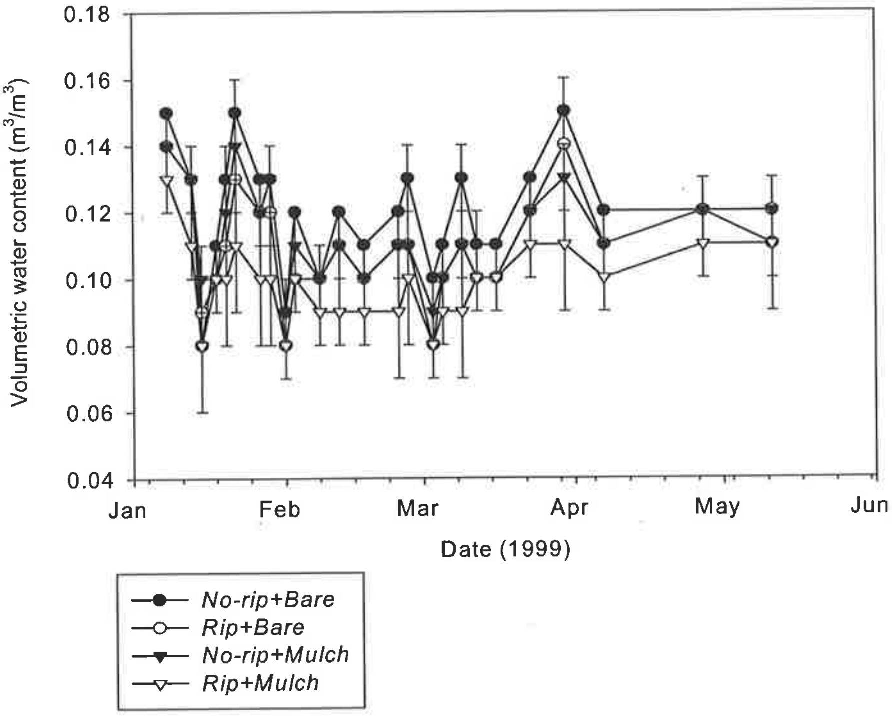

Figure 6.2. Volumetric soil water (as measured by the neutron water meter) of treatments at Padthaway Range '99, average of 0.2 to 0.4 m depths.

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[3] The mulch was not anchored and often blew off the mounds, which left the soil surface exposed.

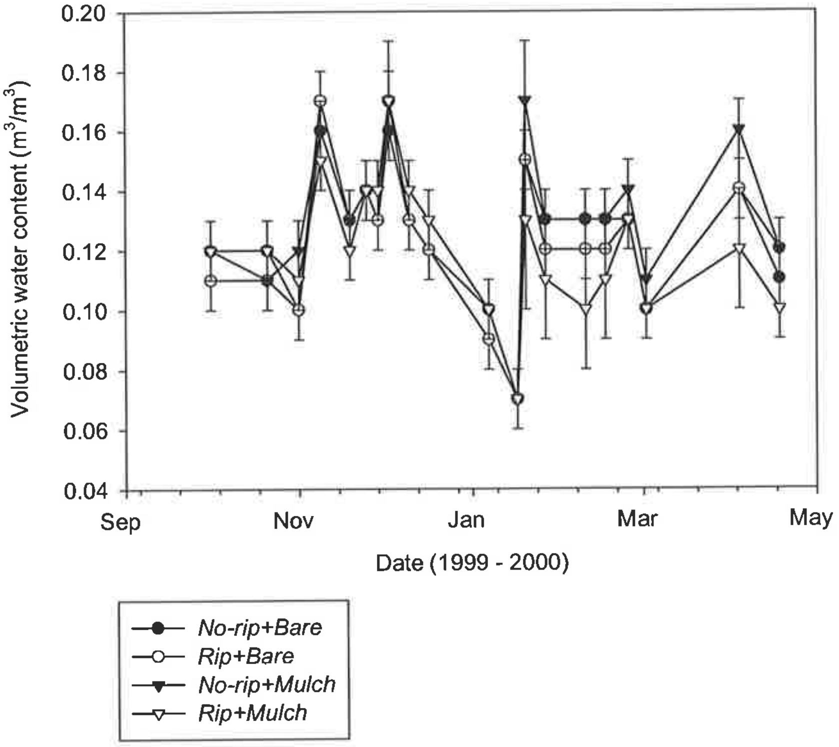

Figure 6.3. Volumetric soil water (as measured by the neutron water meter) of treatments at Padthaway Range'99 to'00, average of 0.2 to 0.4 m depths.

In the 1999/00 growing season there were significant differences ($\alpha = 0.05$) in volumetric water content at 0.2 m (and below – data not shown). The water content under *mulch* was greater than in the *bare* soil, particularly between October and December (Figure 6.4). From January to May, however, the reverse was true (water contents were greater in the *bare* soil).

Estimates of the total loss in RAW_v and TAW_v at this site are shown for 1998/99 in Table 6.3 and for 1999/00 in Table 6.4. These results are based upon weekly (point) measurements of water content and thus do not take into account fluctuations in water content that occurred between the measurement periods (additions of water, drainage, evapotranspiration) – they simply reflect the total loss measured.

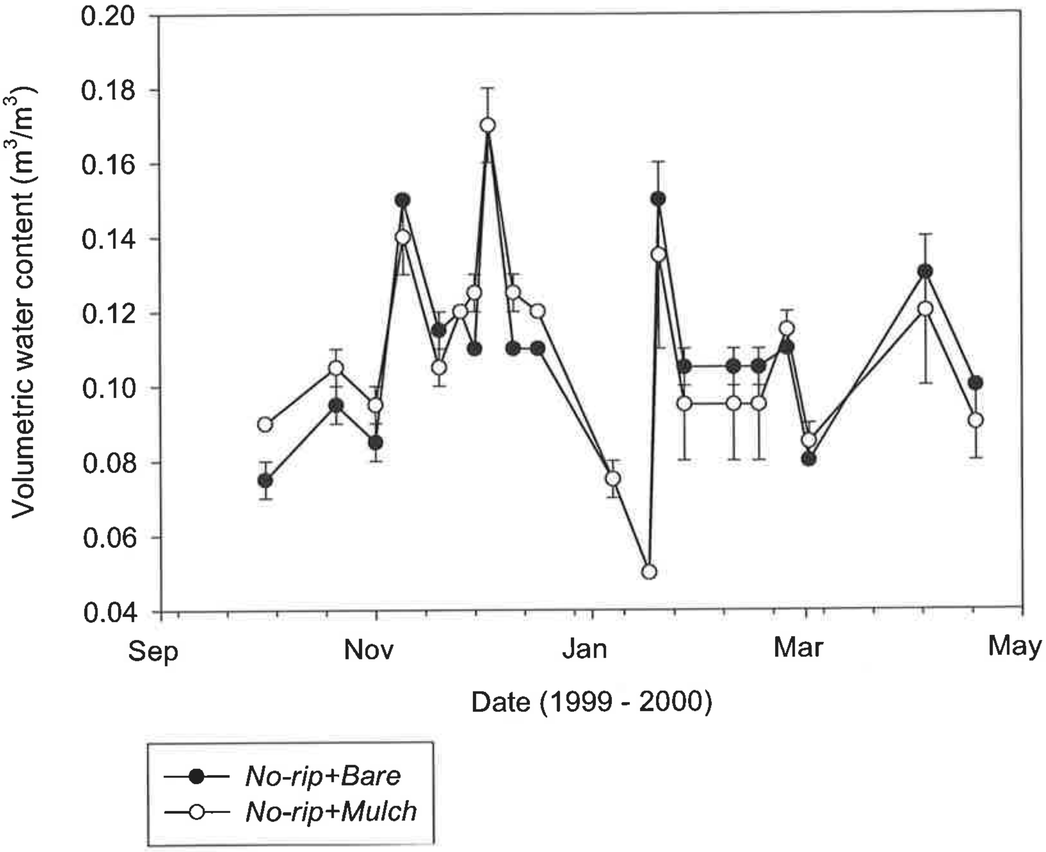

Figure 6.4. Volumetric soil water at 0.2 m depth, *No-rip+Bare* treatment compared with the *No-rip+Mulch* treatment, at Padthaway Range, '99 to '00 season.

Table 6.3. Total loss of stored readily and total available water per vine for the *deep-rip* and *mulch* treatments at Padthaway Range during the 1998/99 growing season.

Ripping/mulching reatments	**Total loss in RAW$_v$ (m^3 per vine)**	**Total loss in TAW$_v$ (m^3 per vine)**
No-rip+Bare	0.116	0.141
Rip+Bare	0.185	0.239
No-rip+Mulch	0.090	0.112
Rip+Mulch	0.121	0.167

Table 6.4. Total loss of stored readily and total available water per vine for the *deep-rip* and *mulch* treatments at Padthaway Range during the 1999/00 growing season.

Ripping/mulching reatments	**Total loss in RAW$_v$ (m^3 per vine)**	**Total loss in TAW$_v$ (m^3 per vine)**
No-rip+Bare	0.142	0.147
Rip+Bare	0.302	0.320
No-rip+Mulch	0.136	0.142
Rip+Mulch	0.205	0.273

In both the 1998/99 season and the 1999/00 season, despite the trends there were no statistically significant overall differences in the changes that occurred in RAW_v and TAW_v between treatments. There was, however, a significant effect of *deep-ripping* (α = 0.05 significance level) on the change in RAW_v in the A_2-horizon alone, and in TAW_v in the A_1- and A_2-horizons alone.

The greater change in RAW_v and TAW_v for the *Rip* treatments compared with *No-rip* treatments was likely caused by greater uptake of water in the *Ripped* soil, which had greater root-length density (Figure 5.25). The smaller change in RAW_v and TAW_v for the *Mulch* treatments compared with *Bare* treatments was likely caused by decreased evaporation under the *mulch*.

6.3.3 Padthaway Plain

For the year, July 1998 to June 1999, potential evapotranspiration and rainfall were the same as for Padthaway Range (1068 mm and 392 mm respectively), and the amount of water applied as irrigation was 387mm (Control) and 216 mm (PRD). For the second growing season, July 1999 to June 2000, potential evapotranspiration and rainfall were the same as for Padthaway Range (995 mm and 489 mm respectively), and the amount of water applied as irrigation was 170 mm (Control) and 103 mm (PRD).

In the 1998/99 and 1999/00 seasons, the *Flat* soil was consistently wetter than the *Mounded* soil at 0.2 m (Figures 6.5 and 6.6). At comparable depths, however (i.e. *Flat* soil at 0.2 m and *Mound* soil at 0.3 m), the *Mounds were* significantly wetter throughout the growing seasons (α = 0.01 significance level, Figures 6.5 and 6.6).

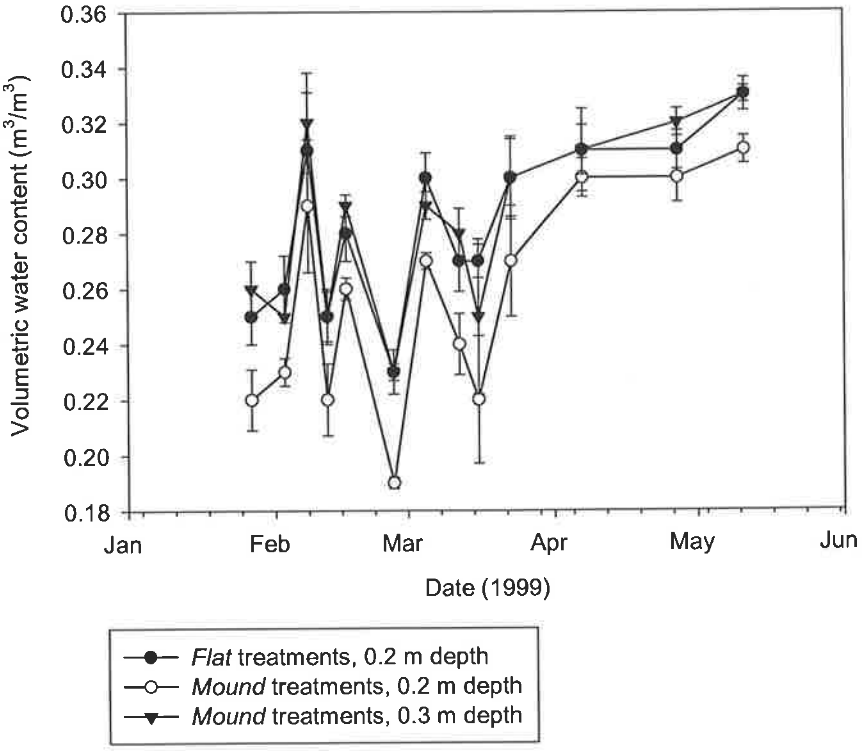

Figure 6.5. Volumetric soil water in *Flat* treatments compared with *Mound* treatments (0.2 and 0.3 m depth), Padthaway Plain, '99 season.

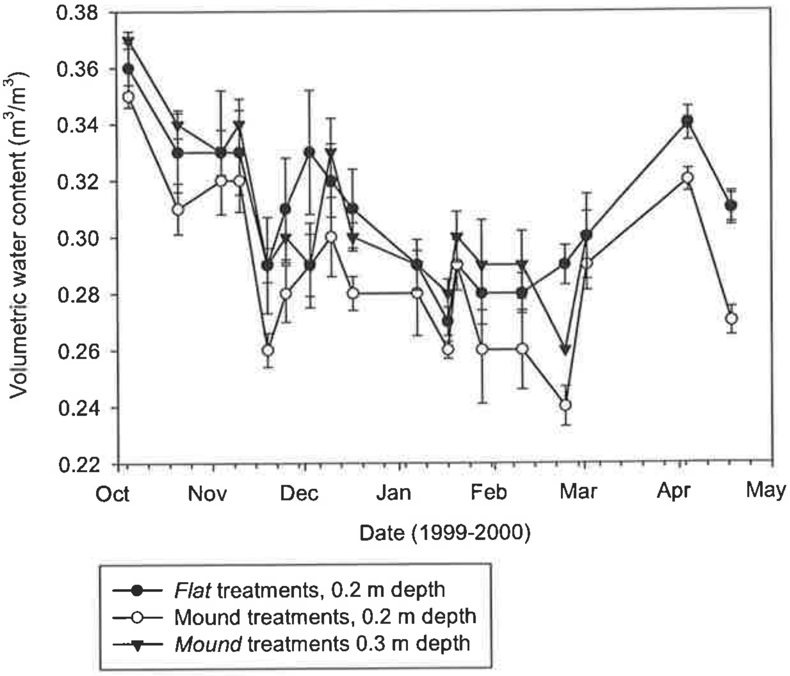

Figure 6.6. Volumetric soil water in *Flat* treatments (0.2 m depth) compared with *Mound* treatments (0.2 and 0.3 m depths), Padthaway Plain, '99 to '00.

The volumetric water content averaged for the major root zone for the *Flat* and *Mound* treatments (Figure 6.7) shows that there was a non-significant trend for the *Mounded* soil to be wetter than the *Flat* soil, particularly at the end of the 1999/00 growing season.

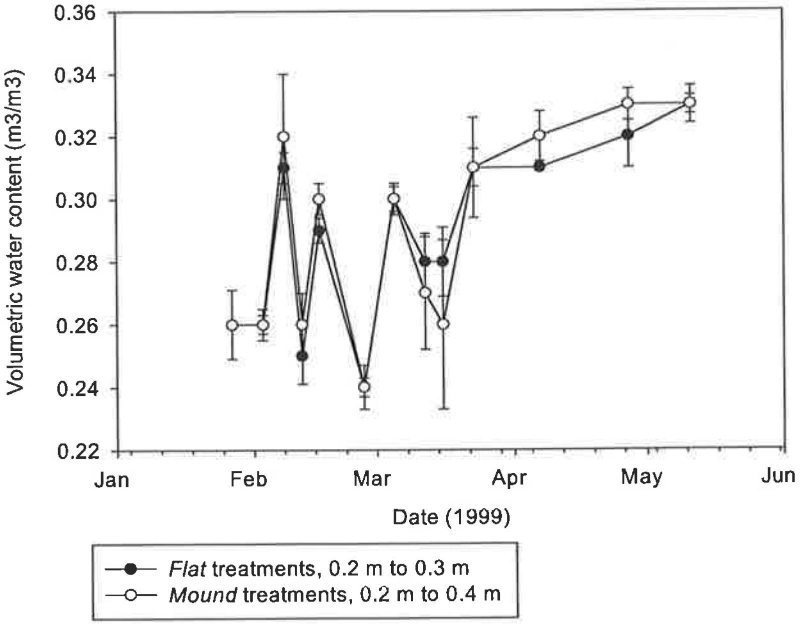

Figure 6.7. Volumetric soil water averaged for the respective major root depth for *Flat* treatments and *Mound* treatments, Padthaway Plain, '99 season.

Average volumetric water contents in the 1999/00 growing season for the major root zone was generally greater in the *Flat* soil than in the *Mounded* soil from mid-November to mid-December (Figure 6.8). From January to early April, however, this was reversed – the *Mounded* soil was wetter than the *Flat* soil. An analysis of variance indicated that while soil management effects alone were not statistically significant, there was a significant ($\alpha = 0.01$) interaction between soil management and time. The importance of this interaction is not clear, but may reflect the ability of the *mounded* soil to drain better when the soil is wetter (November to December) and its ability to inhibit evaporation when water contents become depleted (January to April).

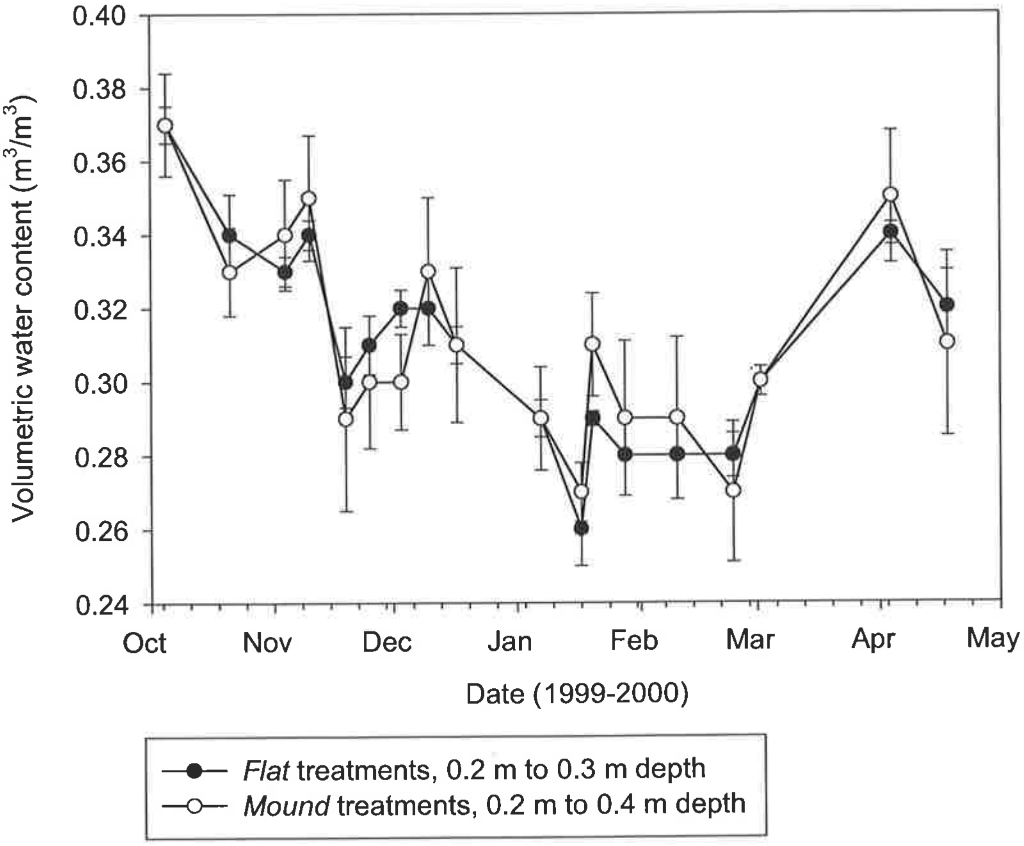

Figure 6.8. Volumetric soil water averaged for the respective major root depth for *Flat* treatments and *Mound* treatments, Padthaway Plain, '99 to '00.

As expected the *Mulched* soils remained significantly wetter than the *Bare* soils for both *Flat* and *Mound* treatments at a depth of 0.2 m during the 1998/99 growing season and at both 0.2 and 0.3m during the 1999/00 season. These data are shown for the 1999/00 season in Figure 6.9. In both seasons the volumetric water content, when averaged over the major root zone in *Flat* and *Mound* treatments, was significantly greater when *mulched* than when left *bare* ($\alpha = 0.01$).

Volumetric water contents in the 0.2 and 0.3m depths for the *Control* and *PRD* irrigation treatments differed significantly between the 1998/99 and 1999/00 growing seasons. At the beginning of the 1999 season the *Control* had significantly greater water content than the *PRD* treatments, while after April 1999 this difference was reversed. In 1999/00, however, results varied on a monthly basis (Figure 6.10).

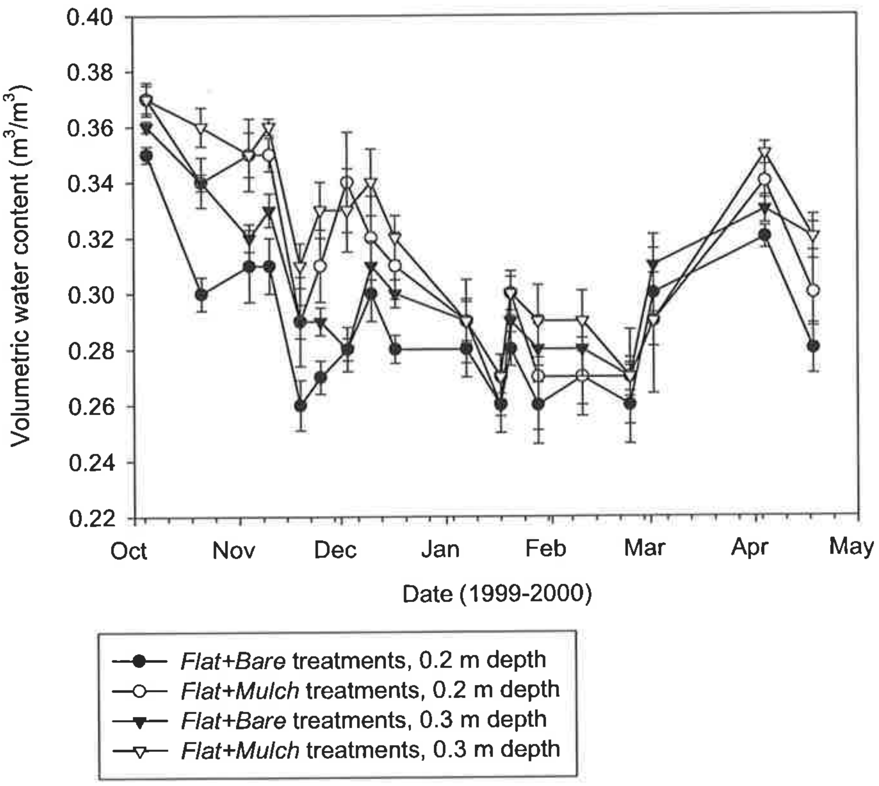

Figure 6.9. Comparison of volumetric soil water between *Flat+Bare* and *Flat+Mulch* at 0.2 m and 0.3 m depths, Padthaway Plain, '99 to '00.

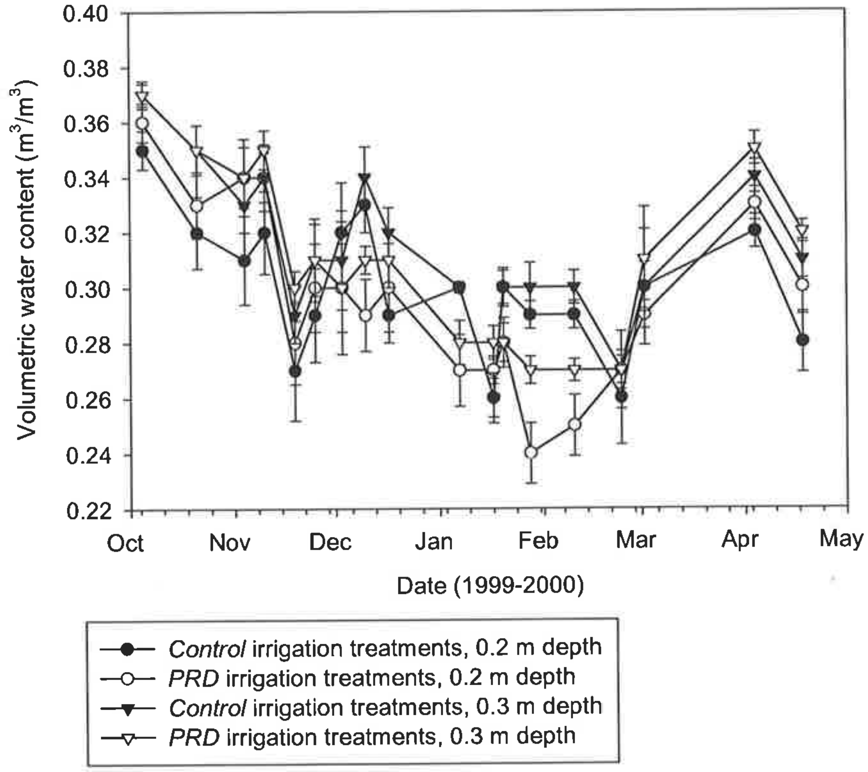

Figure 6.10. Comparison of volumetric soil water between *Control-* and *PRD-* irrigation treatments, 0.2 m depth, Plain site, '99 to '00 season.

Differences in volumetric water content between the *Control-* and *PRD*-treatments relate to the timing of irrigation relative to the location of the neutron access-tubes. All access-tubes were located on the northern side of the vine rows, so changes in water content in the *PRD*-treatments were measured only when the north-side irrigation line was turned on. Thus even though water was being applied to the *PRD*-plots (using south-side line) the drippers were too far from the neutron access-tube to be sensed. *Mounding* effects were therefore generally masked by the *PRD*-treatment effects, such that the *Control* irrigation treatments were invariably wetter than the *PRD* treatments, regardless of *mounding*.

Volumetric water contents for the *Control* and *PRD* treatments were also evaluated for northern side irrigation events only, and these are shown for both growing seasons in Figure 6.11. In the 1998/99 growing season at 0.2 m and 0.3 m depths the volumetric soil water was greater in the *Control* irrigation treatment in March. From March to the completion of the growing season, volumetric water contents were greater in the *PRD*-irrigation treatment. The interactive effect of time and irrigation treatment was significant ($\alpha = 0.05$ significance level at 0.2 m depth and $\alpha = 0.01$ significance level at 0.3 m depth). This reflected a greater demand for water by the larger-canopy vines in the *Control* irrigation treatment. This is highlighted by the greater pruning weight of vines from *Control* treatments compared with *PRD* treatments (Table 8.7). Similar results were found for the 1999/00 growing season, with the interaction between time and treatment being significant at $\alpha = 0.01$.

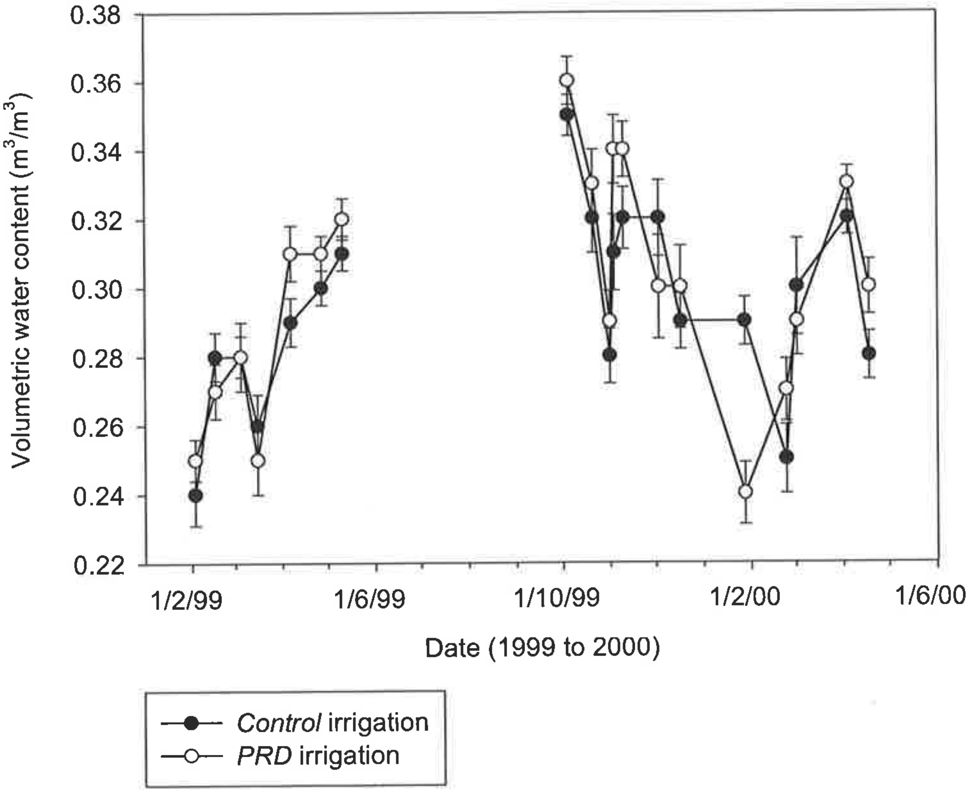

Figure 6.11. Comparison of volumetric soil water between *Control-* and *PRD*-irrigation treatments for northern side irrigation events only during the '99 and '99 to '00 seasons.

In the 1999/00 growing season, there were also significant interactions between *mounding* treatments and time ($\alpha = 0.05$) and between the *mulching* treatments and time ($\alpha = 0.01$) when water contents were averaged in the root zone. In the December to January period water contents in the root zone were greater under *Bare* soil than under *Mulched* soil. In the February to March period, however, the reverse was true: water contents in the root zone were greater under *Mulched* soil than under *Bare* soil. As there was minimal impact of mulch on root-length density, this result was most likely due to reduced evaporation under mulch late in the season.

Table 6.5 shows stimates of the loss in RAW$_v$ and TAW$_v$ at this site for 1998/99 and for 1999/00. In both growing seasons the total measured loss in RAW$_v$ was significantly greater under *Mounds* than under *Flat* treatments (most likely due to greater evaporation), and significantly greater under *Control* irrigation relative to *PRD* irrigation ($\alpha = 0.01$). Total reduction in RAW$_v$ was greater under *Mulch* treatments than under the *Bare* soils, although the difference was only statistically significant at $\alpha = 0.05$ in the 1999/00 season.

Total measured loss in TAW$_v$ was significantly greater under *Control* irrigation than under *PRD* irrigation treatments in 1998/99 (not statistically significant at $\alpha = 0.05$ in 1999/00). Greater loss under the *Control* might be expected because almost twice as much water was applied under the *Control* irrigation compared to the *PRD* irrigation, which would lead to greater evaporation, drainage and water use by vines under the *Control* treatment. When comparing northern-side irrigation events only, there were no differences in RAW$_v$ or TAW$_v$ due to the *PRD*- and *Control*-irrigation treatments in either growing season.

Table 6.5. Total loss of stored readily available water per vine, RAW$_v$, and total available water per vine, TAW$_v$, during 1998/99 and 1999/00 growing seasons at Padthaway Plain.

Mounding, Ripping or Mulching treatments	**Loss in RAW$_v$ (m^3 per vine)**		**Loss in TAW$_v$ (m^3 per vine)**	
	1998/99	**1999/00**	**1998/99**	**1999/00**
Flat+Control+Bare	0.100	0.123	0.368	0.347
Flat+Control+Mulch	0.117	0.232	0.320	0.375
Mound+Control+Bare	0.205	0.260	0.328	0.361
Mound+Control+Mulch	0.239	0.326	0.351	0.425
Flat+PRD+Bare	0.017	0.119	0.227	0.309
Flat+PRD+Mulch	0.044	0.264	0.261	0.394
Mound+PRD+Bare	0.082	0.236	0.208	0.439
Mound+PRD+Mulch	0.164	0.307	0.277	0.437
Control[4]*	*0.025*	*0.061*	*0.057*	*0.108*
*PRD**	*0.030*	*0.056*	*0.073*	*0.107*

6.4 Conclusions

At Lyndoch, there was no effect of *deep-ripping* on the soil water content, so the hypothesis that deep-ripping would increase plant available water was rejected. As described in Chapter 5, the deep-ripping operation was ineffective.

However, the soils remained wetter in the *Flat* treatments compared to the *mound* treatments, particularly when *mulch* or *lime* was applied. For *mounded* soils the changes in

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[4] *Control** and *PRD** measurements were made during northern-side irrigation events only.

RAW_v and TAW_v were greatest in the presence of a *mulch*. This was most likely due to the mulch not being anchored to the mounds. As a result the mounds were often bare in the mulch treatments. As a result, evaporation was not restricted under mulch on mounds (as it was on the Flat treatments). For the *Flat* treatments the change in RAW_v and TAW_v were greatest with *no mulch*, and so the hypothesis that *mulch*ing would increase the water available to vines was accepted for both *flat* and *mound* treatments at Lyndoch.

Because roots managed to find their way through the A_2-horizon and proliferate below both *flat* and *mounded* treatments, I concluded there was no significant benefit of *mounding* at this site. Furthermore, because the net change in RAW_v and TAW_v was smaller under the mounds, the hypothesis that *mounding* would increase the water available to vines was rejected.

At the two Padthaway sites the hypothesis that surface *mulches* would increase the amount of water available to vines was accepted, but the time during which the mulches were effective differed between the two sites. At Padthaway Range water contents were greater under mulches during December-to-January and lower under mulches from January to May, suggesting active root growth under the mulch during autumn. At Padthaway Plain, however, this pattern reversed. Water content under *mulch* was lower in December-to-January and greater from February to March, suggesting that mulches conserved soil water by reducing late season evaporation. These results concur with Eastham et al. (1995), van Huysteen and Webber (1980b), Enz et al. (1988) and Buckerfield and Webster (2000).

There was strong evidence to accept the hypothesis that *deep-ripping* increased the water available to vines at Padthaway Range. In both seasons it significantly increased the loss in RAWv and TAWv and the A_2-horizon. The improved root length density after effective deep-ripping concur with the results of van Huyssteen (1988a). As expected, the greater root length density resulted in greater water uptake, hence greater loss in RAW_v & TAW_v.

At Padthaway Plain site the *Mound* treatments tended to be drier at equivalent depths near the soil surface than the *Flat* treatments, but wetter throughout the effective rooting zone, which indicated the *mounds* provided good infiltration and drainage (as expected Myburgh and Moolman 1991). Additionally the change in RAWv was significantly greater in the *Mound* treatments than the *Flat* treatments in both seasons. As a result the hypothesis that *mounding* would increase the water available to vines was accepted.

While there was an extra 171 mm of irrigation water applied to the *Control* irrigation treatment in the 1998/99 growing season compared to the *PRD*-irrigation treatment, and 67 mm more in the 1999/00 season, there was no statistically significant evidence to suggest that vines grown under *PRD* used less water than vines grown under standard irrigation practices. In the 1998/99 season, more water was applied to the control than the 'remainder of the vineyard' in order to manage the PRD treatment. The 'remainder of the vineyard' was irrigated so as to minimize leaf loss and provide no more water than that. As a result the depth of water provided to the control irrigation treatment was considered to be excessive.

In the second season ('99/'00) the standard irrigation schedule (as applied to the remainder of the vineyard) was used to set the schedule for the control irrigation treatment (i.e. not considered excessive). However, this resulted in less than the required amount to the PRD irrigation treatment which resulted in leaf loss due to water stress.

7 EFFECTS OF MANAGEMENT ON SOIL SALINITY

7.1 Introduction

The effect of salinity on grapevine performance has been well documented. Maas and Hoffman (1977) concluded that grapevines were moderately sensitive to soil salinity and that soils having an electrical conductivity of the saturated paste extract, EC_{se}, > 1.5 dS m^{-1} experienced a linear decrease in yield of 9.6 % for every 1 dS m^{-1} increase in EC_{se}. In Australia, soils having an $EC_{se} < 2$ dS m^{-1} are classed *Non-saline* and considered to experience negligible yield reduction. Soils with $2 < EC_{se} < 4$ dS m^{-1} are classed *Slightly saline*, and only very sensitive plants are affected. Soils having $EC_{se} > 4$ dS m^{-1} are classed *Moderately saline* wherein growth of many plants is affected (Cass et al., 1996).

The impact of salinity depends, of course, upon soil texture, drainage and plant species. For example, Prior et al. (1992a) found that the effect of irrigation water salinity was most severe on grapevines growing in heavy textured soil. Stevens and Harvey (1995) indicated that the effect of soil salinity was more severe when drainage was poor and conditions were anaerobic (waterlogged).

Van Huyssteen and Weber (1980b) found that weed control using *herbicides* and *straw mulches* maintained consistently higher water contents for longer periods than *cultivation* and *permanent swards*. The *mulches* reduced evaporation and thus prevented the concentration of salt near the soil surface.

When performed correctly, *deep-ripping* reduces soil strength and improves infiltration, drainage, and aeration. A similar result would be expected with effective *mounding* (Myburgh and Moolman 1991). In 1995 (when this work began), a combination of such treatments had not been tried in Australia, so this work was based on two hypotheses:

1. Mounding and deep-ripping increases drainage of the surface soil and thereby decreases salinity near the soil surface.
2. Mulches placed under the vine-row decrease evaporation from the surface soil and thereby reduce salinity in the vine root zone near the soil surface.

7.2 Materials and Methods

Soil samples were collected from within the wetted area under the dripper for *Bare* and *Mulch* treatments at Padthaway Plain. The electrical conductivity of a 1:5 extract (i.e. one part soil to five parts distilled water, $EC_{1:5}$) was measured, from which the value for the saturation paste extract (EC_{se}) was estimated by taking into account soil texture using the conversion factors published in Cass et al. (1996).

7.2.1 Lyndoch

Soil samples were collected from representative horizons in each of the *Flat+SR+Bare*, *Flat+SR+Mulch*, *Mound+Bare*, and *Mound+Mulch* treatments using a 150 mm diameter auger in July and November 1996 and March 1997.

7.2.2 Padthaway Range and Padthaway Plain

Duplicate soil samples were taken from each soil horizon at Padthaway Range and Padthaway Plain at depth-intervals of 150 mm down the soil profile using a 50 mm diameter auger. At Padthaway Range, samples were collected during the first growing season (October 1998 to April 1999), and then again during the second growing season (October 1999 to March 2000). At Padthaway Plain, samples were collected during the first growing season (July 1998 to April 1999) and during the second growing season (September 1999 to March 2000).

The following soil chemical properties were measured by the South Australian Soil and Plant Analysis Service: $pH_{1:5}$ (in water and in calcium chloride), $EC_{1:5}$, and exchangeable calcium, magnesium and sodium. The sodium adsorption ratio (SAR) was calculated as:

$$SAR = Na/\sqrt{[(Ca + Mg)]}$$

where Na, Ca, Mg are the concentrations of ions expressed in mmol/L (Cass et al., 1996).

7.3 Results and Discussion

7.3.1 Lyndoch

The EC-values in the *Mound* and *Flat* treatments in July 1996 were highly variable within treatments (1.5 to 3.3 dS m^{-1}) and were classed as *Slightly saline* (Figure 7.1). Due to the large variation, there were no significant differences found between any of the treatments at any depth

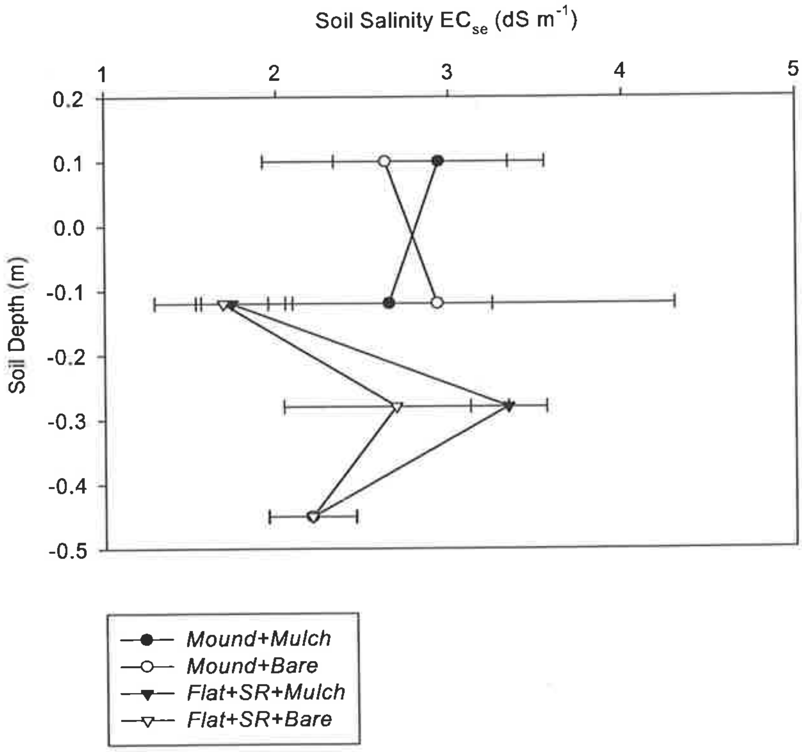

Figure 7.1. Soil salinity (EC_{se}) under different management treatments, Lyndoch, <u>July 1996</u>.

Soil salinity in November 1996 was relatively low (< 1.5 dS m^{-1}) and it declined uniformly between treatments with depth from 1.5 dS m^{-1} near the soil surface to 0.5 dS m^{-1} in the subsoil (Figure 7.2). By March 1997, soil salinity in the *Mound+Bare* and *Flat+SR+Bare* treatments had increased to be greater than the *Mound+Mulch and Flat+SR+Mulch* treatments, although only the *Flat+SR+Mulch* treatment at 0.45m was significantly different from the *Mound+Bare* and *Flat+SR+Bare* treatments at $\alpha = 0.05$ (Figure 7.3). This result indicates that *mulching* may have retained higher water contents and allowed greater unsaturated flow, which promoted greater leaching of salts beyond 0.45m depth.

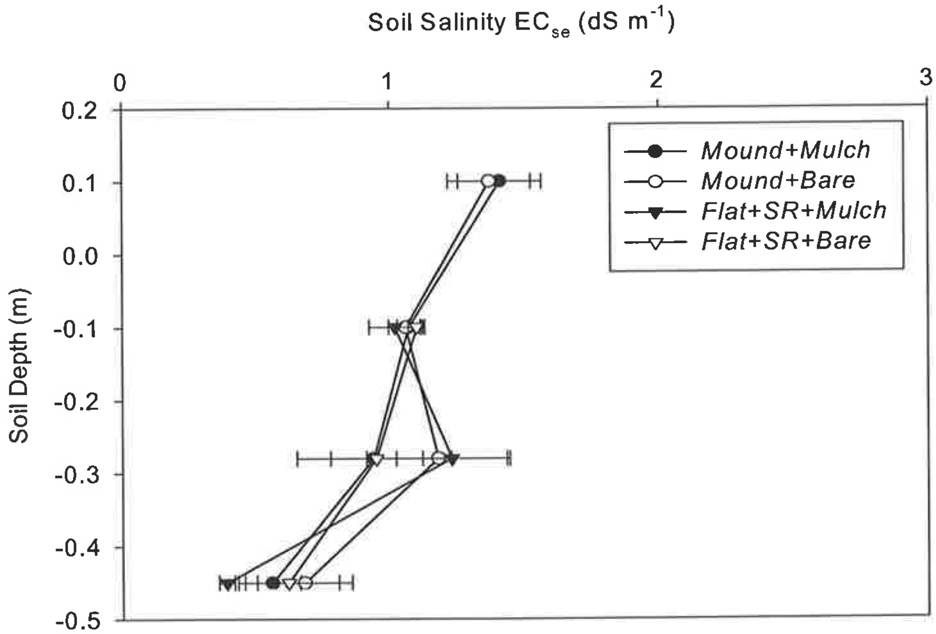

Figure 7.2. Soil salinity (EC_{se}) under different soil management treatments, Lyndoch, Nov. 1996.

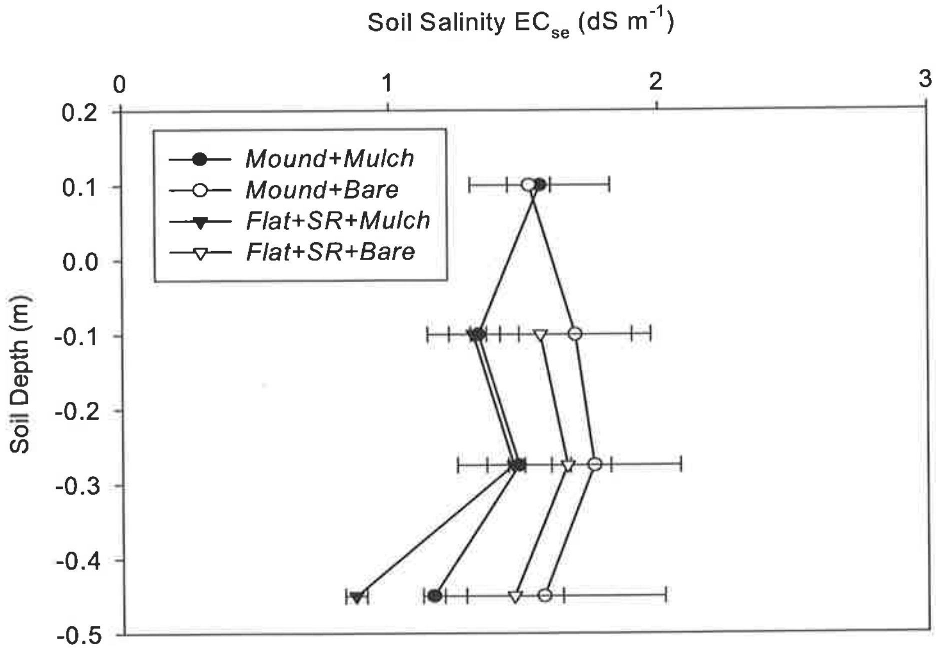

Figure 7.3. Soil salinity (EC_{se}) under different soil management treatments, Lyndoch, March 1997.

The salt load in the Lyndoch profiles can be explained to some extent by the salinity of the irrigation water applied. Between October 1995 and April 1996 the EC_{se} of the irrigation water was approximately 2.4 dS m^{-1} (moderate hazard for plant production) down from a previous value of 3.6 dS m^{-1} (severe hazard for plant production, Cass et. al., 1996). It can be calculated from the volume of irrigation water applied during this period (418 mm) that a total of approximately 565 g salt m^{-2} or about 5.7 t ha^{-1} was added to this soil. Without a leaching programme, this level of salt accumulation would be unacceptable in the long run.

7.3.2 Padthaway Range

Soil pH, salinity and sodicity for each soil horizon in October 1998 are shown in Table 7.1. The pH of the A_1- and A_2-horizons was slightly acidic, and that for the A_3- and B-horizons was slightly alkaline. All horizons were *Non-saline* and *Non-sodic*. Due to the sandy texture of these soils, degradation of soil structure through tillage was not a major concern. Soil salinity and sodicity were greatest in the B-horizon due to the likely drainage of salts through the sandy surface horizons down to the B-horizon where drainage was restricted.

Table 7.1. Soil chemistry for each horizon at Padthaway Range, October 1998.

Horizon	Depth (m)	$pH_{1:5}$ (water)	$EC_{1:5}$	EC_{se}	$SAR_{1:5}$
A_1	-0.02	6.7	0.03	0.39	0.21
A_2	-0.15	6.9	0.02	0.26	0.14
A_3	-0.75	7.5	0.02	0.26	0.72
B	-1.00	7.4	0.05	0.35	1.87

By December 1998 salinity had increased slightly compared with the October results, but all values remained < 2 dS m^{-1} (Figure 7.4). Salinity in the *Rip+Bare* treatment was less than in the other treatments particularly between depths of 0.3 and 0.75 m, which coincided with the A_2-horizon and the top of the A_3-horizon.

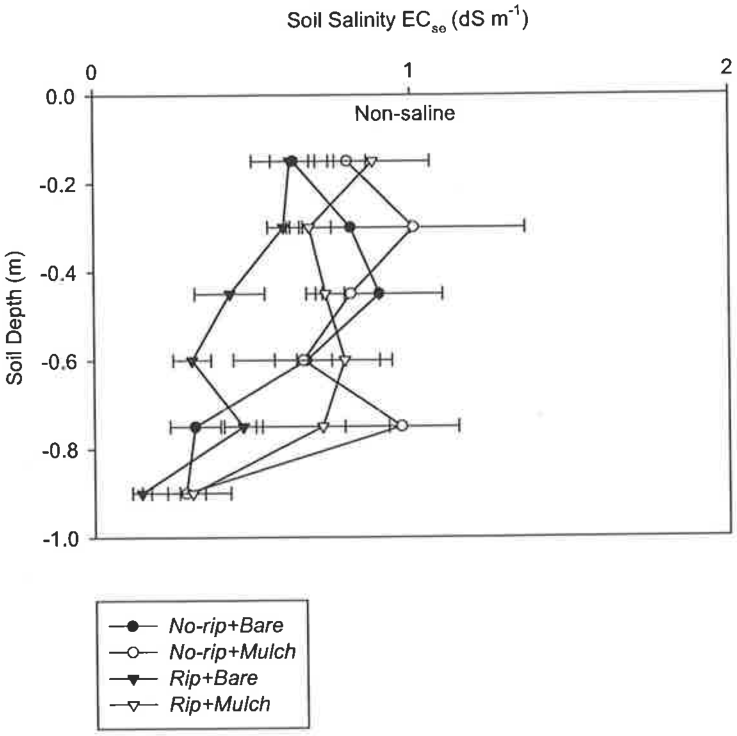

Figure 7.4. Soil salinity (EC_{se}) at Padthaway Range, December 1998.

In February 1999, despite the fact that the *Rip+Mulch* treatment had a somewhat lower salinity than the other treatments at depths between 0.3 and 0.6 m, there were no statistically significant differences in salinity among the treatments. (Appendix, Figure 11.7). Salinity at 0.9 m tended to be less than at other depths.

In April 1999, once all irrigations for the season had stopped, salinity exceeded 2 dS m^{-1} in all but the *Rip+Mulch* treatment, and even became *Slightly saline* in the compacted A$_2$-horizon at a depth of 0.45 m. Salinity between depths varied to a greater extent than at other times during the year (Figure 7.5).

In summary, salinity increased significantly with time during the 1998/99 growing season and decreased significantly with depth ($\alpha = 0.01$ significance level).

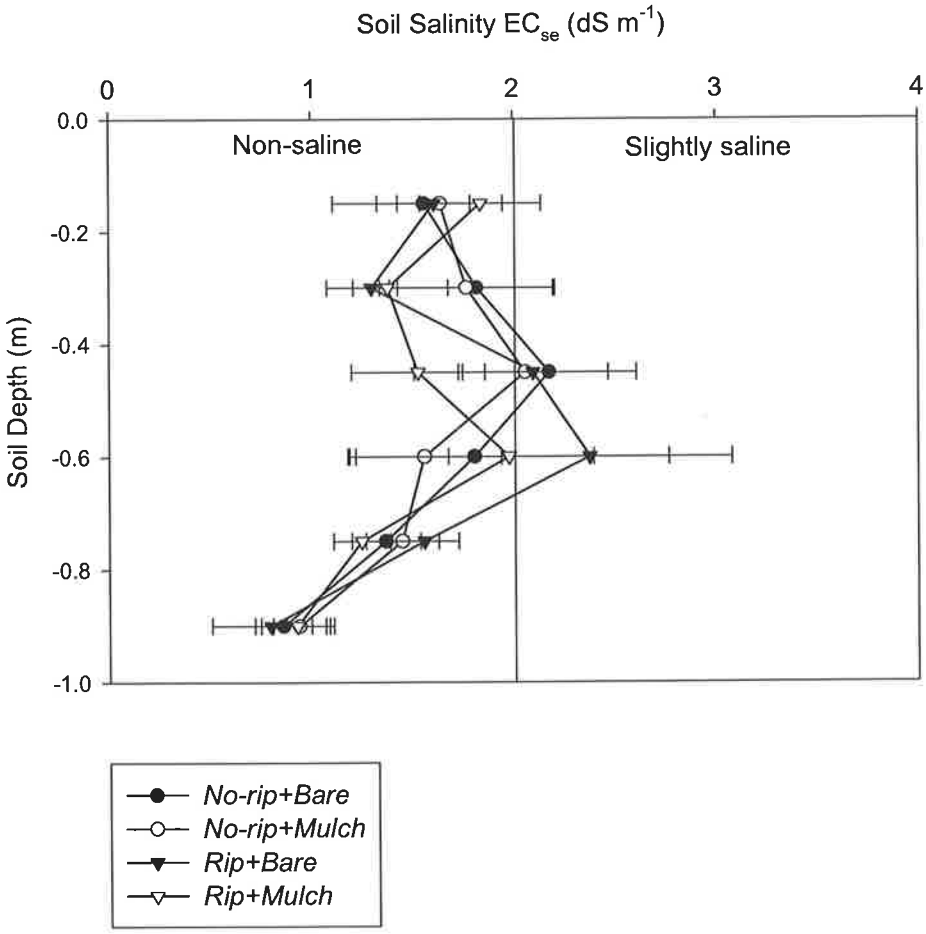

Figure 7.5. Soil salinity (EC$_{se}$) at Padthaway Range, April 1999.

Between April and October 1999 the site received 239 mm of rain, which leached sufficient salt from the soil profile to reduce salinity to approximately 1 dS m^{-1} throughout the profile (Figure 7.6). Salinity in the *Mulch* treatments tended to be greater than in the *Bare* treatments suggesting that salt may have been leached from the mulch. By December 1999 salinity had increased but was similar between treatments and declined with depth to 0.9 m. In January 2000 the *Rip+Bare* treatment had greater salinity from 0.3 to 0.75 m depth than the other treatments (Appendix, Figure 11.8). When irrigation stopped at the end of the growing season in March 2000, salinity was < 2 dS m^{-1} throughout the soil profile of all treatments (Figure 7.7), in contrast to the previous year when the profile was more saline. Differences in the amounts of rainfall and irrigation applied account for the differences in salinity between the two seasons (i.e. only 392 mm rain + 95 mm irrigation in 1998/99 versus 489 mm rain + only 42 mm irrigation in 1999/00). There was nearly 100 mm more rain and less than half the irrigation water (and salt) added in the '99/00 season.

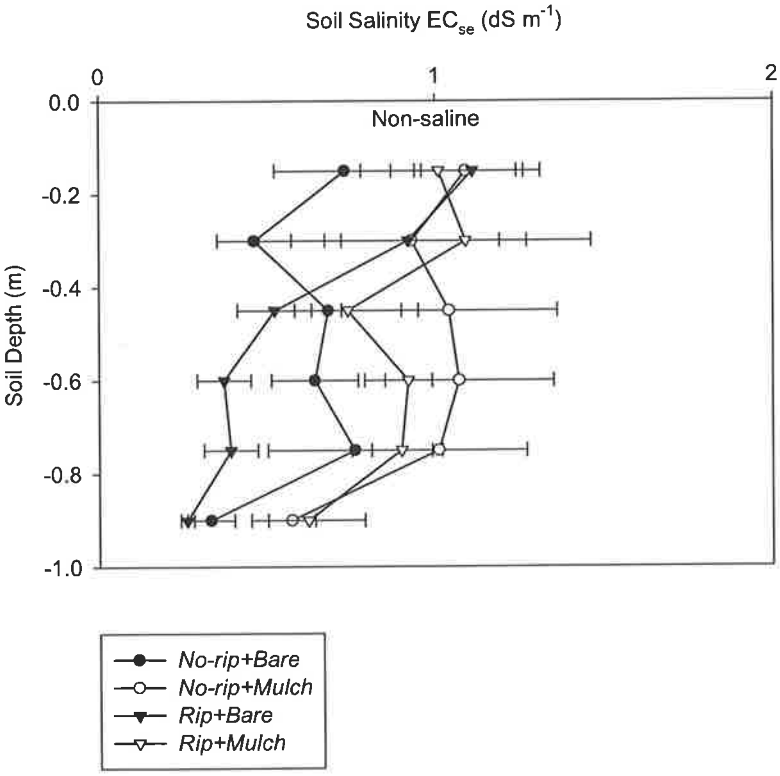

Figure 7.6. Soil salinity (EC_{se}) at Padthaway Range, October 1999.

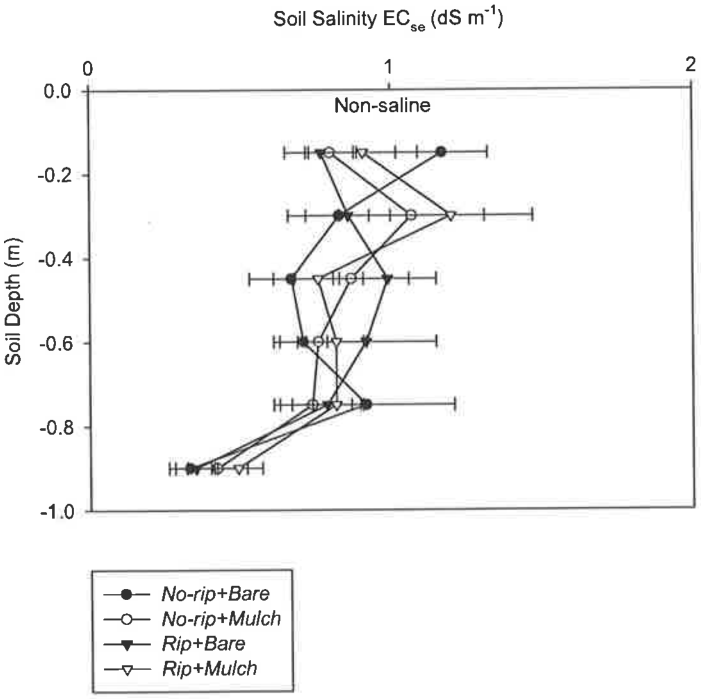

Figure 7.7. Soil salinity (EC_{se}) at Padthaway Range, March 2000.

Salinity of the irrigation water was relatively uniform across the two growing seasons (1.82 to 2.12 dS m^{-1} between November 1998 and March 1999, versus 2.12 to 2.08 dS m^{-1} between December 1999 and March 2000). Salinity in this range provides a slight to moderate hazard for plant production (Cass et al. 1996). The total salt load for the 1998/99 season was ~119 g m^{-2} or ~1.2 t ha^{-1}, and for the 1999/00 season it was only ~52 g m^{-2} or ~ 0.5 t ha^{-1}. With good management, these salt loads can be tolerated and production can still be maintained.

During the 1999/00 season salinity increased significantly with time through and decreased significantly with depth ($\alpha = 0.01$ significance level). The *mulch*-by-time interaction had a significant effect on salinity: the mean salinity under the *mulch* was greater than under the bare soil in October, but for the remainder of the growing season it was slightly greater under bare soil than under the *mulch*, except during March. This suggests that soluble salts in the mulch leached into the soil during winter, were flushed from the surface soil during the growing season, but accumulated in the soil surface again as vine roots became active under the mulch late in the season and left a residual of salt in that zone. The root-length densities, which were greatest under the *Rip+Mulch* treatment (Figure 5.26) support this supposition.

7.3.3 Padthaway Plain

Soil pH, salinity and sodicity for each soil horizon in October 1998 are shown in Table 7.2. The pH of the A_{new}-horizon was slightly alkaline while that for the A_1- to B-horizons was moderately alkaline. The A_{new}-, A_1- and B-horizons were classed as *Non-saline* while the A_2-horizon was classed as *Moderately saline* and all horizons were *Non-sodic*. Nevertheless, the combination of sub-saline ECs and sub-sodic conditions in the A_{new}-, A_1- and B-horizons made them all potentially susceptible to mechanical disturbance, particularly in relation to deep ripping (Cass et al. 1996).

Table 7.2. Soil chemistry for each horizon at Padthaway Plain, October 1998.

Horizon	Depth (m)	$pH_{1:5}$ (water)	$EC_{1:5}$	EC_{se}	$SAR_{1:5}$
A_{new}	+0.10	7.6	0.13	1.43	0.86
A_1	-0.10	8.6	0.11	1.21	0.73
A_2	-0.25	8.5	0.38	4.18	0.79
B	-0.40	8.5	0.33	1.65	1.94

Salinity was measured in July 1998 (start of experiment) in the *Flat+Control+Bare* and *Mound+Control+Bare* treatments only (mulch and irrigation treatments had not yet been applied) and appeared to be relatively uniform and *Non saline* with depth (Figure 7.8). By the beginning of the second season in September 1999, salinity had increased modestly, such that the soil surface was *slightly* to *moderately saline* for all treatments (Figure 7.9). The *Flat* treatments were less saline and salinity decreased with depth for all treatments. The salinity in December 1999 showed the same trends between treatments as previously, but was slightly more saline (i.e. EC_{se} from 1 to 3 dS m^{-1}) than its status in December 1998 (Appendix Figures 11.9 and 11.10). In December 1998 all treatments with mulch had $EC_{se} > 2$ dS m^{-1} at some depth, while those without mulch all had $EC_{se} < 2$ dS m^{-1} at all depths. In both February 1999 and January 2000 salinity had increased into the *slightly-to-moderately saline* range (2 to 4 dS m^{-1}) for most horizons (Appendix Figures 11.11 and 11.12). At the completion of both the 1999 and 2000 irrigation seasons (April 1999 and March 2000) most treatments and most depths exhibited *slightly saline* conditions (Figure 7.10 and 7.11).

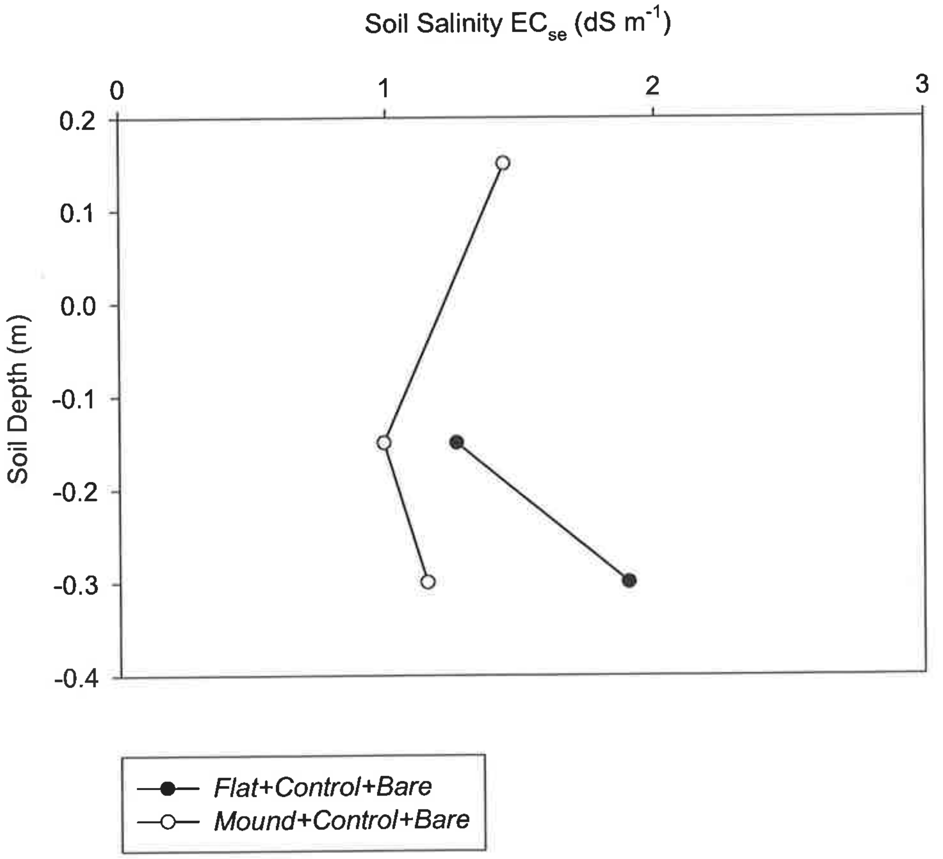

Figure 7.8. Soil salinity (EC_{se}) at Padthaway Plain, July 1998.

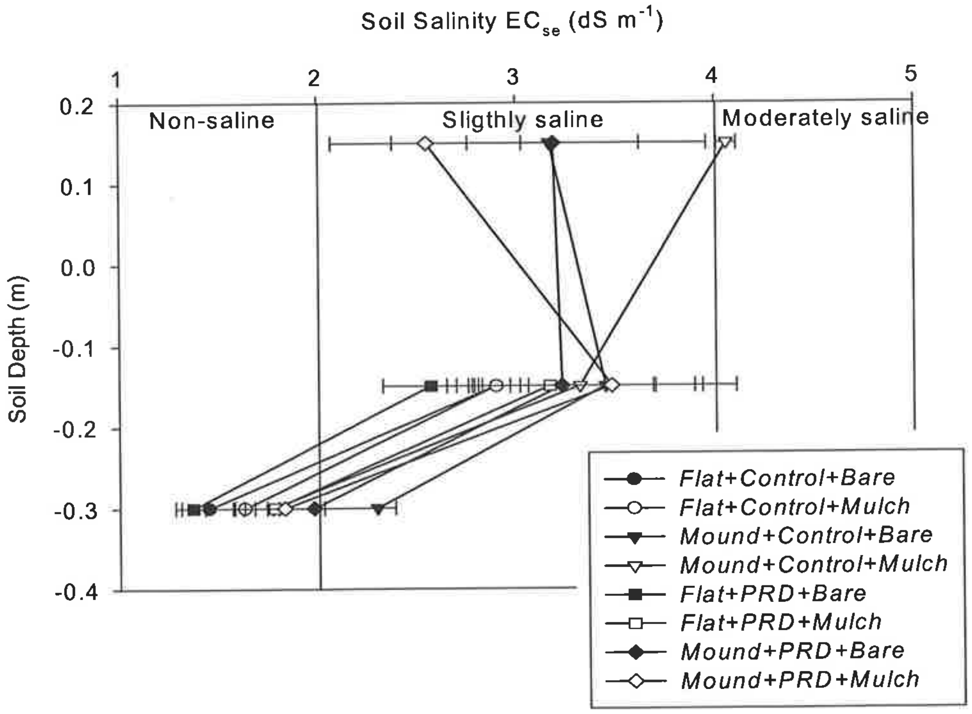

Figure 7.9. Soil salinity (EC_{se}) at Padthaway Plain, September 1999.

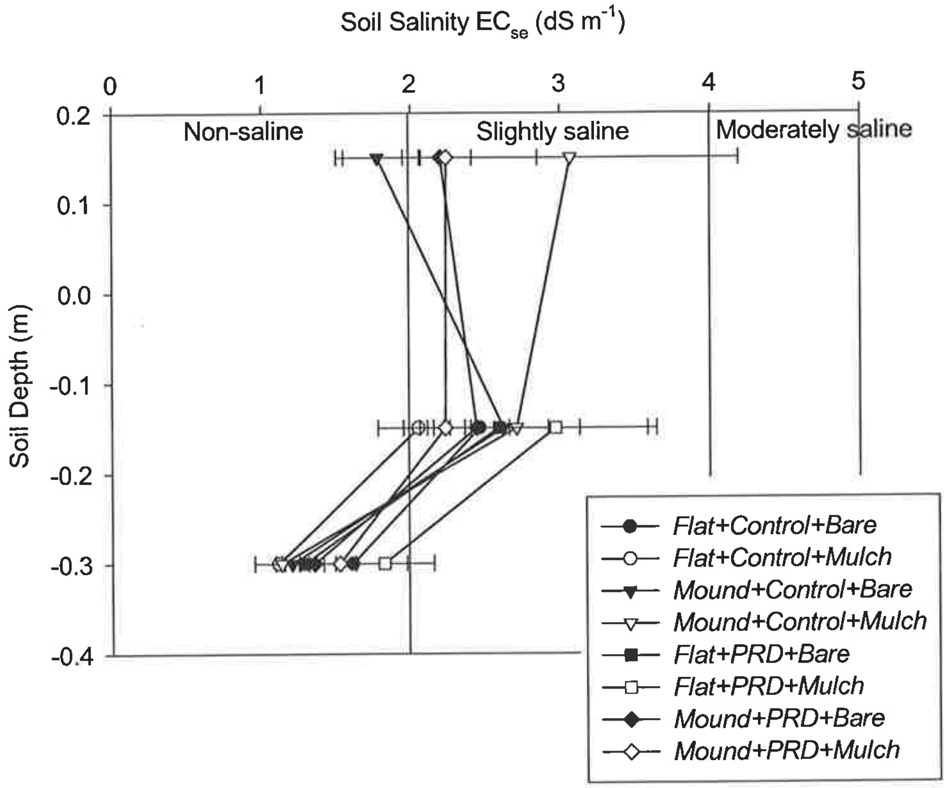

Figure 7.10. Soil salinity (EC_{sc}) at Padthaway Plain, April 1999

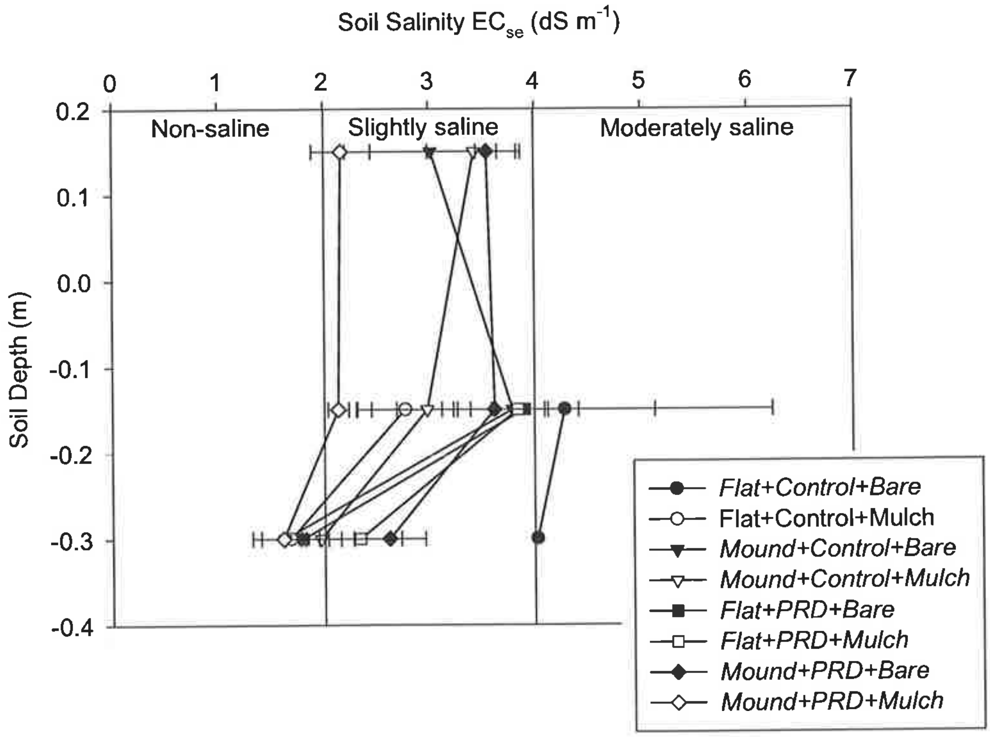

Figure 7.11. Soil salinity (EC_{se}) at Padthaway Plain, March 2000.

During the year between July 1998 and June 1999, 387 mm irrigation water was applied to the *Control*-irrigation treatment and 216 mm was applied to the *PRD*-irrigation treatment. The salinity of the irrigation water was uniform between July 1998 and July 2000 (2.25 – 2.30 dS m^{-1}), which enables one to calculate that the total salt load applied during the 1999 season was 512 g salt m^{-2} (or 5.1 t ha^{-1}) for the *Control* treatment and 285 g salt m^{-2} (or 2.9 t ha^{-1}) for the *PRD* treatment. For the 1999/00 season 170 mm irrigation was applied to the *Control* treatment and 103 mm was applied to the *PRD* treatment. The total salt load for the 1999/00 season was 232 g m^{-2} (2.3 t ha^{-1}) for the *Control* and 140 g m^{-2} (1.4 t ha^{-1}) for the *PRD*. By March 2000, the only treatment that had $EC_{se} > 4$ dS m^{-1} was the *Flat+Control+Bare* treatment, which had moderately saline soil at –0.15 m and –0.3 m depths.

In both the 1998/99 and 1999/00 seasons, soil salinity fluctuated significantly according to the amount and timing of irrigation water applied (between September and March/April; $\alpha = 0.01$ significance level), plus the amount of leaching that occurred between growing seasons (between March or April and September; $\alpha = 0.01$ significance level). EC_{se} declined with depth to 0.3m and maximum values occurred in the top 0.15m in both seasons.

7.4 Conclusions

For the sites examined in this study, it can be concluded that so long as the soil salinity was maintained below threshold values for yield response through the growing season (September to April), it is likely that subsequent rainfall will cause sufficient leaching to decrease salinity before the next growing season. To achieve this sub-saline status, soil salinity values must be kept below 2 dS m^{-1} (negligible effect on yield, Cass et al. 1996) until the end of the irrigation season.

At Lyndoch the only treatment to exceed 2 dS m^{-1} in March was the *Flat+SR+Bare* treatment. Soil salinity was generally greater in the A_2-horizon and in *Bare soil* treatments than it was at other depths, particularly under the *Mulch* treatments. The lack of adequate drainage through the A_2-horizon into the B-horizon caused the build up of salt throughout the year.

The hypothesis that mounding and deep ripping would decrease soil salinity near the soil surface was rejected at Lyndoch. The other hypothesis, that mulch would decrease soil salinity near the soil surface, however, was accepted. The *Mulch* treatment was the only one to keep soil salinity at significantly lower values.

At Padthaway Range, soil salinity values were invariably < 2 dS m^{-1} in the root zone at the beginning of the irrigation seasons but by the end of the growing season in April 1999, soil salinity exceeded the threshold EC-value of 2 dS m^{-1}, and this was not affected significantly by any of the soil management treatments. However, the *Rip+Mulch* treatment tended to have lower salinity levels in April 1999. Salt levels declined significantly with depth below the root zone ($\alpha = 0.01$ significance level). The hypotheses proposed were that *deep-ripping* and/or *mulching* would decrease salinity near the soil surface, but the experimental evidence suggested these hypotheses should be rejected, at least at Padthaway Range. This site had the least salt applied through irrigation. With more salt applied, the impact of ripping and mulching may have been signficant.

At the Padthaway Plain site soil salinity generally increased with time and decreased with soil depth. At the completion of both the 1999 and 2000 irrigation seasons soil salinity was predominantly *slightly saline* for all treatments and all depths. Soil salinity early in the growing season was generally greater under *Mulches* than under *Bare soil*, so the hypothesis that mulch would decrease soil salinity near the soil surface, was rejected. Furthermore, because there were no significant differences in soil salinity between the *Flat* treatments and the *Mound* treatments, the hypothesis that mounding would decrease soil salinity near the soil surface was rejected at the Padthaway Plain site. Upon reflection, the creation of macropores by *ripping* and *mounding* might be expected to reduce leaching of salts where water movement is primarily unsaturated.

Finally, even though *PRD*-irrigation applied only 60% as much salt as the *Control*-irrigation, there were no significant differences in soil salinity between the two treatments. It can thus be concluded that where soil drainage is adequate, it is unlikely that salt would accumulate over time, which was the case at both Padthaway sites.

Maas and Hoffman (1977) concluded that grapevines were moderately sensitive to $EC_{se} > 1.5$ dS m^{-1}, yet this was exceeded at all sites throughout the growing season and there was no evidence of marginal leaf burn and no other symptoms of salt toxicity.

Despite all soils remaining wetter under *mulch* (Chapter 6) soil salinity under *mulches* was variable between sites. At Lyndoch *mulch* reduced soil salinity and there were no detrimental effects on grapevine performance (yields, and in some cases pruning weights, were significantly increased with the application of mulch – Chapter 8, Table 8.5). At Padthaway Range, *Mulch* increased soil salinity near the soil surface. This may have been due to increased root development (Chapter 5, Figure 5.26) and water uptake near the soil surface resulting in increased soil salinity. Additionally it may have been due to salt being leached out of the straw mulch. The impact of mulch on soil salinity is complex and dependant on soil management, soil texture and root-length density.

As soils were mostly sandy, particularly in the A-horizon, the effect of salinity on grapevine performance when grapes are grown in heavy textured or water-logged soils as found by Prior et al. (1992a) and Stevens and Harvey (1995), were not found in these field trials.

8 EFFECTS OF MANAGEMENT ON ABOVE-GROUND GRAPEVINE PERFORMANCE

8.1 Introduction

The effect the soil physical and chemical properties have on grapevine performance may be immediate or they may take many years to have an impact. For sustainable grape production any effect on the above-ground grapevine performance is important, whether short or long term. In this chapter the effect of soil management on the performance of the above-ground parts of grapevines within two years of the soil management treatments being applied is examined.

While there is plenty of literature showing the link between soil management and grapevine performance, little of this has been conducted in Australia. Van Huyssteen (1988a) reported the effects of deep-ripping on the root distribution and grapevine performance in a sandy clay loam soil at Stellenbosch, South Africa. He found that as the depth of deep-ripping increased, total root number, shoot mass and yield all increased. Saayman and van Huyssteen (1980) found similar results on a sandy clay loam soil at Robertson, South Africa. Ploughing to a depth of 0.6 m resulted in fewer roots and shoots and lower yields compared with ploughing to a depth of 0.9 m. The effect of soil-mounding on grapevine performance has been documented by Myburgh (1994) and Eastham et al. (1995).

Van Huyssteen and Weber (1980b) found that herbicide and straw mulch treatments conserved soil moisture at consistently higher levels for longer periods of time than cultivation and permanent sward treatments. As a result the more physically fertile and continually moist soil of the non-cultivated treatments produced vines of superior growth, producing greater yields of superior quality, (van Huyssteen and Weber, 1980c). The one exception to this was the permanent sward treatment, which provided competition for water and nutrients in the dry-land vineyard. Buckerfield and Webster (2000) reported improved vine performance with surface application of compost six months after planting.

There is little published information on the effect of soil amendments such as gypsum and polymers on grapevine performance. It is likely that these ameliorants may increase yield by increasing available water to grapevines, particularly where water is limiting. The reported effects of gypsum (e.g. Shanmuganathan and Oades, 1983; Aljibury and Christensen, 1972) and organic polymers (e.g. Ben-Hur and Letey, 1989) have been primarily shown to improve soil-surface structure and increase infiltration.

Maximum grape yield by itself, however, is not necessarily desirable, particularly in terms of berry quality. For example, Hardie and Martin (1989), Dry et al. (1998), McCarthy (1997) found that applying water-stresses at particular growth stages (by limiting irrigation), reduced shoot growth (which reduced shading of berries), and increased the surface area to volume ratio of the berries, all of which increased berry juice quality (Smart et al. 1974; Hardie and Considine 1976; Neja et al. 1977). It was therefore expected that any soil treatments that increased the amount of water available to the vines would increase grape yield, but might also reduce the °Baume of the grape juice at harvest. Of particular interest in this work was the effect of wetting patterns in the soil as influenced by partial root zone drying, *PRD*. Dry et al. (1998) showed that irrigation by *PRD* increased water use efficiency. In the present work, it was hypothesised that the above-ground performance of vines (as measured by vine growth, grape yield and quality) would be increased by:

1) deep-ripping,

2) soil mounding,

and 3) surface-mulching,

and that this increase would be caused by greater amounts of available water in the soil. It was also hypothesized that water use efficiency (tonnes of fruit produced per ML of water used) would be greater under *PRD*-irrigation compared with control irrigation.

8.2 Materials and Methods

8.2.1 Lyndoch

Five vines were chosen in each plot from which to collect pruning weights and berry characteristics. Grapevines were hand pruned (spur pruned), and the shoots were placed in buckets to be weighed in the field. Forty berries were picked from each grapevine in each plot by selecting 1-2 from the top, middle and bottom of each bunch, making a total of exactly two hundred berries to be weighed. The berries were then taken to the Krondorf Winery in the Barossa Valley where they were crushed to measure sugar concentration as °Baume (Appendix Methods AM11.1). A sub-sample of the berry juice was collected to measure chloride concentration (Appendix Methods AM11.2).

Following individual berry analysis, the remaining grapes were stripped from the five sample vines in each plot for counting and weighing. The following characteristics were assembled from this sampling: mean berry number per bunch, mean berry weight, number and weight of bunches. As the 5 sample vines were pruned to 2 bud spurs the prunings were collected and weighed to determine the average pruning weight per vine.

8.2.2 Padthaway Range and Padthaway Plain

8.2.2.1 Yield

Bunches of grapes from four vines (Padthaway Range) or ten vines (Padthaway Plain) within each replicate of each treatment were sampled, counted and weighed to estimate total yield.

8.2.2.2 Pruning weight

As the sample vines were pruned to 2 bud spurs (80 nodes per vine) the pruning weights were collected and weighed to determine the average pruning weight per vine.

8.2.2.3 Berry quality components

Every seven days from February until harvest, 50 berries were taken (from different places on a bunch from different bunches located in different parts of the canopy) to determine average berry weight, red pigment colour and sugar concentration (°Baume using the 'Chem. 5b' method of Southcorp). The sample immediately prior to harvest was also used to measure red pigment colour (Appendix Methods AM11.3).

8.2.2.4 Petiole chloride

Two hundred petioles were taken representing each treatment. Petioles were taken opposite the basal bunch in April, prior to harvest, and submitted for analysis of chloride concentration, analysed as follows (D. Stewart, Pers. Comm.[5]): a) Rinse petioles in rain water, blot dry and then oven dry in paper bags at 65C for several days. Grind dried samples to pass through 20 mm sieve. b) measure chloride on Buchler Instruments Digital Chloridometer using an aqueous extract titrated with silver.

8.3 Results and Discussion

8.3.1 Lyndoch

The pruning masses, berry weights, °Baumes and berry chloride concentrations are shown in Table 8.1 for the 1996 season along with grape yields in 1996 and 1997. While the pruning masses per vine were not significantly different at $\alpha = 0.05$ in 1996, they were generally lower in the *Rip*-treatments than in the *No-rip*-treatments, and greater in the *Mulch*-treatments than in the *Bare*-treatments.

Table 8.1. Pruning mass per vine, berry weight, °Baume at Lyndoch in 1996, plus grape yields for 1996 and 1997.

	1996					1997
Soil surface treatment	**Pruning mass per vine (kg)**	**Berry weight (g)***	**°Baume 1-week before harvest**	**Berry Cl-conc^n (ppm)***	**Grape yield (t/ha)***	**Grape yield (t/ha)***
Flat+SR+Bare	0.63	1.32	12.1	345.8	11.5	11.5
Flat+DR+Bare	0.63	1.35	12.2	318.9	11.3	12.2
Flat+NR+Bare	0.84	1.25	12.3	326.3	11.9	13.0
Mound+SR	0.64	1.25	12.4	336.4	10.6	
Mound+Bare						11.8
Mean all *Flat+Mulch*	0.70	1.37_a	12.2	354.3_a	12.0_a	
Mean all *Mulch*						13.5_a
Mean all *Flat+Bare*	0.65	1.22_b	12.3	309.6_b	10.7_b	
Mean all Bare						11.7_b

*Figures in each column with different subscripts are significantly different at $\alpha = 0.01$.

The grape yields were significantly greater for the *Mulch*-treatments than for the *Bare*-treatments in both years ($\alpha = 0.01$ significance level), but there was no significant difference in yield between the individual *Mound* and the *Flat* treatments in either year. The 1996 sugar concentrations (°Baume) just before harvest were marginally greater in the *Mound*-treatments than in the *Flat*-treatments, suggesting that the drier *mounds* hastened ripening and decreased yield.

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[5] I would like to acknowledge Diane Stewart, who collected the berry quality, berry quantity, shoot weight and petiole data for the Padthaway Range and Padthaway Plain sites.

The *Mulch*-treatments produced berries with significantly higher chloride concentrations ($\alpha = 0.01$) than the *Bare*-treatments in 1996 but there were otherwise no statistically significant treatment-differences in chloride concentrations.

Berry-sugar concentration (°Baume) and berry-chloride concentrations from grapevines grown in *mounds* with different soil-cover treatments in 1996 are shown in Table 8.2 along with grape yield results for 1996 and 1997. Berry-chloride concentration was greater in the *Mound+Mulch* treatment compared with all other treatments. °Baume one week prior to harvest was similar between treatments with the *Mound+Ryegrass* treatment having the greatest °Baume and the *Mound+Mulch* and *Mound+Grape marc* treatments having the least. Once again, the drier treatments appear to have slightly hastened ripening and reduced yield. The *Mound+Mulch* treatment produced a significantly greater yield than all other treatments in both years (α = 0.05 significance level) and there were minimal differences in yield between all other treatments in both 1996 and 1997.

Table 8.2. ˚Baume, and berry chloride concentration for the soil surface treatments at Lyndoch in 1996, and grape yields at Lyndoch for 1996 and 1997.

	1996			1997
Soil surface treatment	**˚Baume 1 week before harvest**	**Berry chloride concentration (ppm)**	**Grape yield (t/ha)**	**Grape yield (t/ha)**
Mound+Mulch	12.1	375.3	12.6_a	14.7_a
Mound+Lime	12.5	302.0	9.5_b	9.6_c
Mound+Ryegrass	12.7	310.1	10.2_b	11.1_b
Mound+Ryegrass+Lime	12.7	268.8	9.6_b	10.3_b
Mound+Grape marc	12.1	312.5	10.7_b	10.6_b
Mound+Polymer	12.6	364.5	8.8_b	10.3_b
Mound+Bare	12.6	316.4	9.8_b	10.1_d

The greater grape yield of the *Mound + Mulch* treatment comprised entirely of greater berry weights (there were no significant differences in the mean number of berries per bunch, or bunches per vine – Table 8.3). Similarly, grapes grown on both *Flat* and *Mound* treatments with *Mulch* (i.e. Mean all *Mulch*) produced significantly (at α=0.01) heavier berries and higher grape yields than the *Bare* treatments (i.e. Mean all *Bare*).

Table 8.3. Mean numbers of berries per bunch and bunches per vine for the different soil surface treatments at Lyndoch in 1996.

Soil surface treatment	Mean number of berries per bunch	Mean number of bunches per vine
Flat+NR+Bare	104.7	71.2
Mound+Bare	97.0	65.1
Flat+SR+Bare	91.9	68.5
Flat+DR+Bare	88.1	69.1
Mean all *Bare*	93.1	69.3
Mean all *Mulch*	96.1	67.7

8.3.2 Padthaway Range

The grape yield, berry-juice colour, bunch-number, pruning weight and final petiole chloride concentration for treatments in the 1999 and 2000 seasons are shown in Table 8.4 Vines responded similarly to the applied soil management treatments in both years. The greatest yield, bunch number and pruning weight occurred under *Rip+Mulch*, and although these differences did not become statistically significant until the second season ($\alpha = 0.05$), the trends began in 1999. In the second season, 2000, grape yields were significantly greater in the *Mulch* treatments and the *Rip* treatments than in the *Bare* treatments and the *No-rip* treatments respectively ($\alpha = 0.05$ significance level). Also, bunch-number and pruning weight were greater in the *Mulch* treatments and the *Rip* treatments than in the *Bare* treatments and *No-rip* treatments, respectively, however these differences were not statistically significant at $\alpha = 0.05$. Conversely berry-colour tended to be less under the *Rip+Mulch* treatment. *Bare* treatments produced berries with more colour than the *Mulch* treatments in both years ($\alpha = 0.05$).

Table 8.4 Yield and other vine characteristics for the 1999 and 2000 growing seasons at Padthaway Range. Values for a given year with subscripts 'a' or 'b' are significantly different at $\alpha = 0.05$.

Treatment	**Year**	**Yield (t/ha)**	**Berry juice colour (mg anthocyanin per g berry weight)**	**Bunch No. per vine**	**Pruning weight (kg/vine)**	**Petiole chloride conc^{n} (g/100g)**
No-rip+Bare	1999	16.8	1.327	113	1.28	3.37
	2000	8.6	1.327	90	1.30	4.26
Rip+Bare	1999	16.7	1.074	112	1.26	3.38
	2000	9.3	1.074	99	1.23	4.59
No-rip+Mulch	1999	17.8	1.201	115	1.37	3.74
	2000	10.5	1.201	99	1.56	4.80
Rip+Mulch	1999	21.1	1.104	123	1.42	4.28
	2000	11.7	1.104	101	1.61	4.98
Mean all *Bare*	1999	16.8	1.201	113	1.27	3.38
	2000	8.95_b	1.201_a	94.5	1.27	4.43
Mean all *Mulch*	1999	19.5	1.153	119	1.40	4.01
	2000	11.1_a	1.153_b	100	1.59	4.89
Mean all *No-rip*	1999	17.3	1.264	114	1.33	3.56
	2000	9.55	1.264	94.5	1.43	4.53
Mean all *Rip*	1999	18.9	1.089	118	1.34	3.83
	2000	10.5	1.089	100	1.42	4.79

As found at the Lyndoch site, all treatments that provided more available water tended to have greater concentrations of chloride in the plant (compare Table 5.5 with Table 8.4). The *Mulch* treatments and *Rip* treatments tended to have greater petiole chloride concentrations than the *Bare* treatments and *No-rip* treatments, respectively.

Berry weights during the period February until harvest are shown in Figures 8.1 and 8.2 for the 1999 and 2000 growing seasons, respectively. While not statistically significant until the second season, berry weights tended to be greater in the *Rip+Mulch* treatment, with all other treatments being similar. This suggests the presence of an interactive effect between mulching and ripping on berry weight.

The °Baume results for the period between February/March and final harvest are shown in Figure 8.3 for 1999 and Figure 8.4 for 2000. °Baume tended to be lower until near harvest in the *Rip+Mulch* treatment in both seasons, but by harvest it was similar among all treatments in both years. This result is as expected with ripening tending to be slower with high yields.

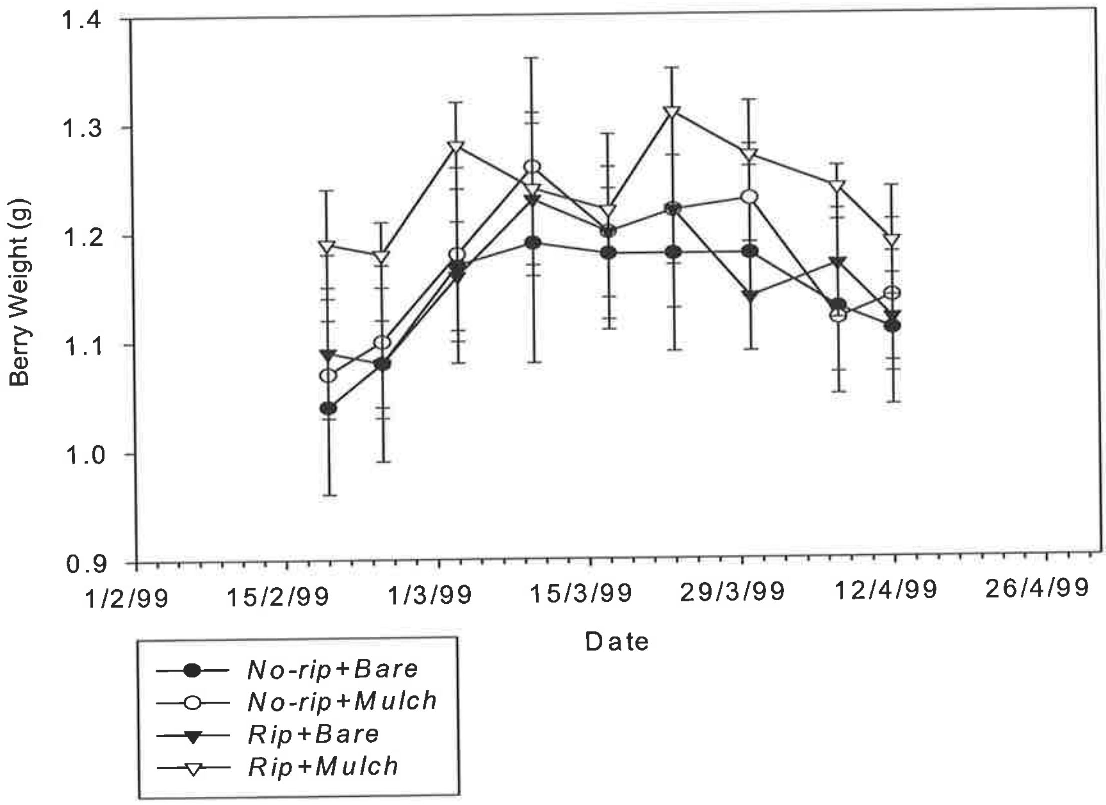


Figure 8.1. Berry weight under different tillage and surface management, Padthaway Range, 1999.

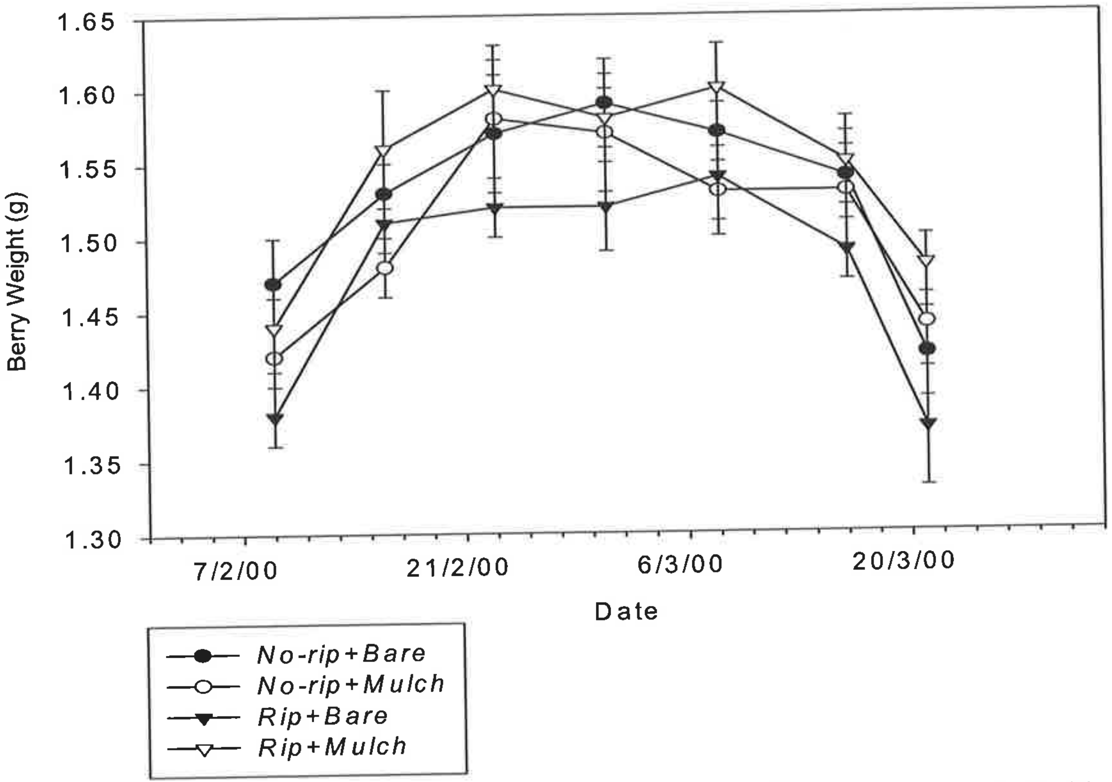


Figure 8.2. Berry weight under different tillage and surface management, Padthaway Range, 2000.

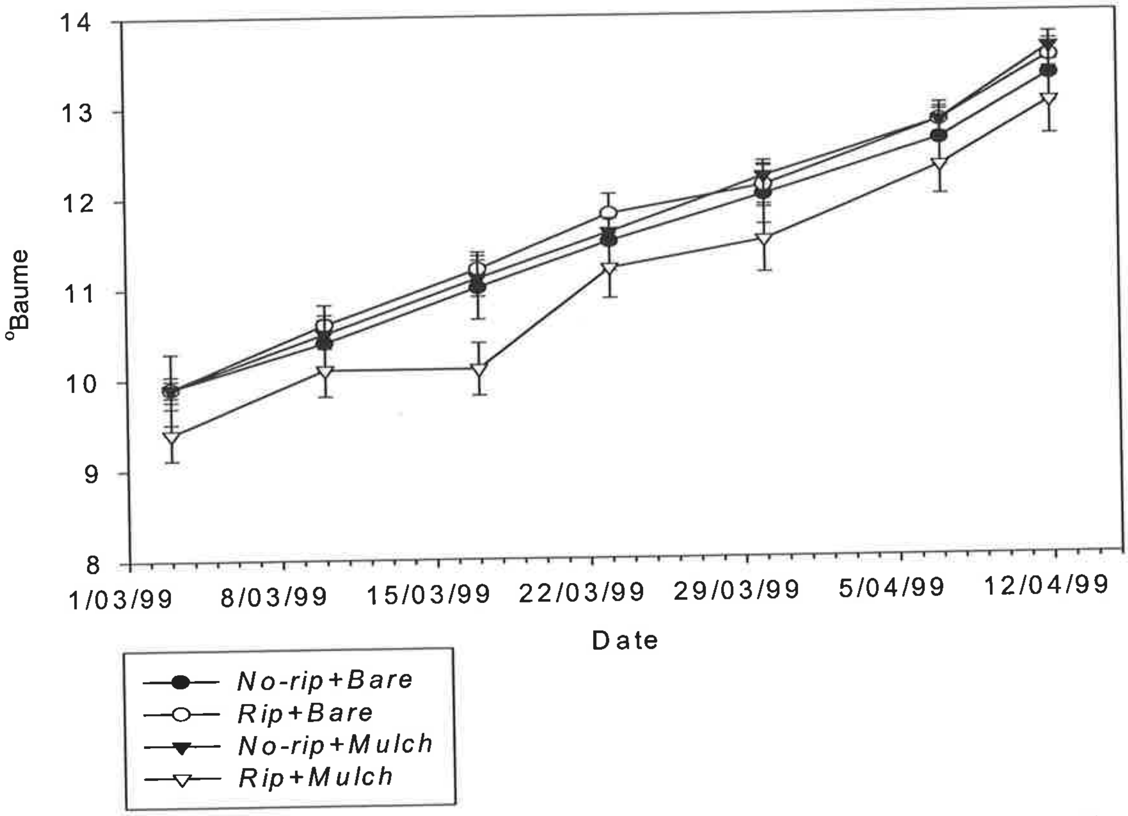


Figure 8.3. °Baume for grapes under different tillage and surface management, Padthaway Range, 1999.

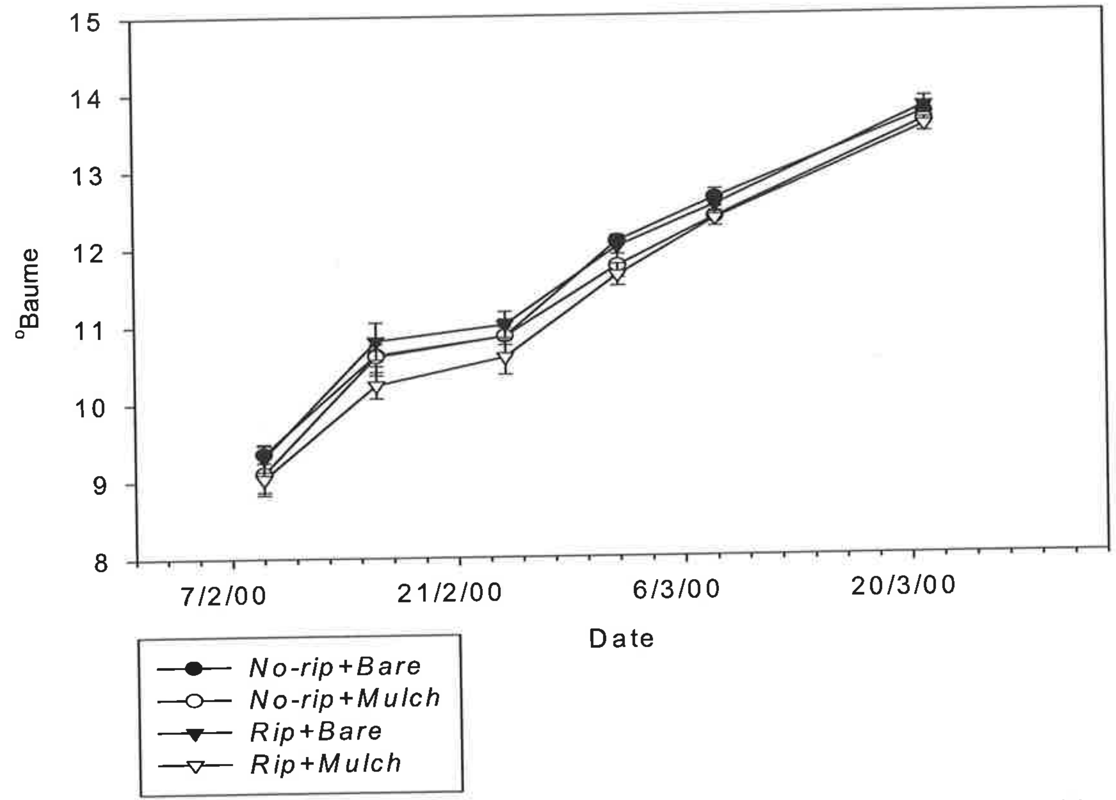


Figure 8.4. °Baume for grapes under different tillage and surface management, Padthaway Range. 2000.

8.3.3 Padthaway Plain

Grape yield, berry-juice colour, bunch-number per vine, pruning weight and petiole chloride concentrations for the 1999 and 2000 growing seasons are shown in Table 8.5. The PRD irrigation treatments (*Flat+PRD* and *Mound+PRD*) reduced grape yield significantly in both 1999 and 2000 ($\alpha = 0.05$ and $\alpha = 0.01$ respectively) particularly relative to the controls (*Flat+Control* and *Mound+Control*). Grapevines grown in *Mound* and *Mulch* treatments tended to produce greater yields than grapevines grown in *Flat* and *Bare* treatments, but these differences were not statistically significant at $\alpha = 0.05$.

Soil management in 2000 also had a significant effect on yield, with *Mound* treatments providing a significantly greater yield than *Flat* treatments ($\alpha = 0.05$). An interaction between soil management and soil cover was apparent, with the *Mound+Mulch* treatment providing the greatest yield for both *Control* and *PRD* irrigations ($P = 0.05$, analysis of variance). *Mulch* alone had no significant effect on yield in 2000, but there was a significant ($\alpha = 0.05$) three-way interaction of *Irrigation* x *Soil management* x *Soil-surface cover* on yield. That is, the control irrigation treatment produced the greatest yield when the soil was mounded and when a mulch was applied (*Mound+Control+Mulch* had greatest yield), while the PRD-irrigation performed poorly, particularly with no mulch and no mounding (*Flat+PRD+Bare* had lowest yield).

Table 8.5. Mean yields and other vine characteristics for the 1999 and 2000 growing seasons at Padthaway Plain. Values for a given year with subscripts 'a' or 'b' are significantly different at $\alpha = 0.05$, while values for a given year with subscripts 'c' or 'd' are significantly different at $\alpha = 0.01$.

Treatment	Year	Yield (t/ha)	Berry Juice Colour (mg anthocyanin per g berry weight)	Bunch No. per vine	Pruning Weight (kg/vine)	Petiole Chloride conc^{n} (g/100g)
Flat+Control+Bare	1999	11.5	1.131	93	1.57	2.90
	2000	9.9	1.601	103	1.75	2.68
Flat+Control+Mulch	1999	12.6	0.976	96	1.33	2.91
	2000	6.9	1.520	81	1.80	2.81
Mound+Control+Bare	1999	12.9	1.094	114	1.53	2.90
	2000	11.1	1.431	106	1.93	2.97
Mound+Control+Mulch	1999	16.0	1.008	116	1.74	3.28
	2000	13.7	1.297	117	2.15	2.84
Flat+PRD+Bare	1999	9.1	1.344	93	1.07	2.61
	2000	5.3	1.624	75	1.38	2.66
Flat+PRD+Mulch	1999	8.5	1.286	100	0.97	3.01
	2000	5.4	1.428	82	1.43	2.61
Mound+PRD+Bare	1999	9.4	1.272	110	1.18	2.73
	2000	7.2	1.525	100	1.71	2.81
Mound+PRD+Mulch	1999	11.4	1.171	110	1.07	3.01
	2000	7.4	1.379	92	1.76	2.82
Mean all *Bare*	1999	10.4	1.210	103	1.07	2.79
	2000	8.4	1.545	96	1.69	2.78
Mean all *Mulch*	1999	12.1	1.110	106	1.28	3.05
	2000	8.4	1.406	93	1.79	2.77
Mean all *Flat*	1999	10.4	1.184	96	1.24	2.86
	2000	6.9_{b}	1.543	85_{d}	1.59	2.69
Mean all *Mound*	1999	12.4	1.136	113	1.38	2.98
	2000	9.9_{a}	1.408	104_{c}	1.89	2.86
Mean all *Control irrigation*	1999	13.3_{a}	1.052_{d}	105	1.54_{c}	3.00
	2000	10.4_{c}	1.462_{b}	102	1.91_{c}	2.83
Mean all *PRD irrigation*	1999	9.6_{b}	1.268_{c}	103	1.07_{d}	2.84
	2000	6.3_{d}	1.489_{a}	87	1.57_{d}	2.73

In 1999 the bunch-number per vine was similar for all treatments. Grapevines grown under *Control* irrigations produced significantly greater pruning weights than grapevines grown under *PRD* irrigations ($\alpha = 0.01$). Pruning weights in *Control* irrigation treatments ranged from 1.33 kg/vine to 1.74 kg/vine with the *Mound+Control+Mulch* treatment having the greatest pruning weight. Pruning weights for *PRD* irrigation treatments ranged from 0.97 kg/vine to 1.18 kg/vine with the *Mound+PRD+Bare* treatment having the greatest pruning weight. Berry juice colour was significantly greater under *PRD* irrigations than under *Control* irrigations ($\alpha = 0.01$). Treatments having the greatest change in the amount of available water had the greatest yield and pruning weight (Table 6.6), while treatments that remained dryer had greater berry juice colour (Figure 6.10).

Just as for the Lyndoch and Padthaway Range sites, all treatments at Padthaway Plain that remained wetter during the growing season provided the greatest volume of available water and had the greatest concentration of chloride in grapevines (Figures 6.9, 6.10 and Table 8.5). In 1999 the *Mulch* treatments had greater concentrations of petiole chloride than the *Bare* treatments, *Mound* treatments had greater concentrations than *Flat* treatments, and *Control*-irrigation treatments had greater concentrations than *PRD* irrigation treatments.

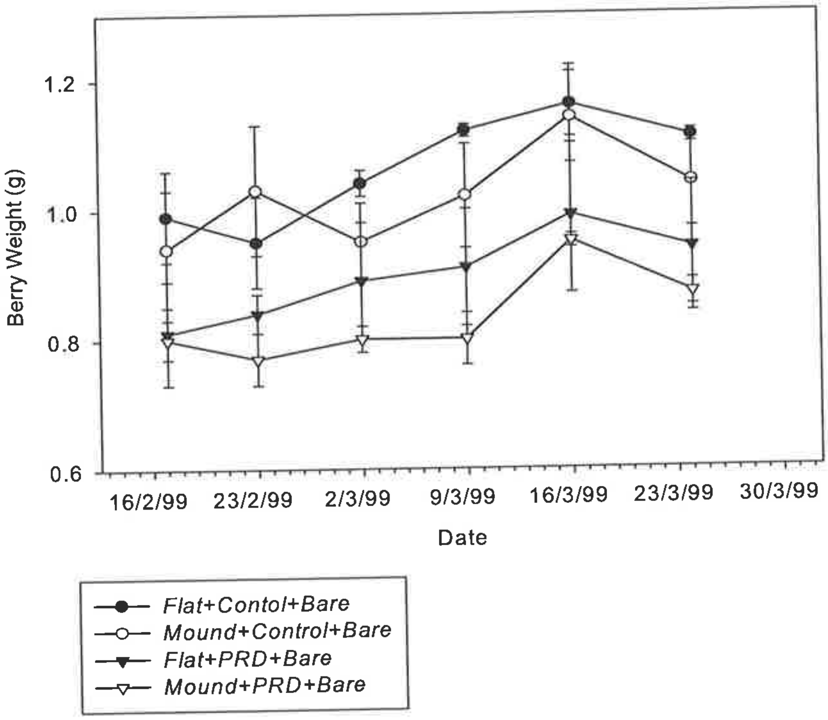


Figure 8.5 Berry weight for *Flat Bare & Mound Bare* treatments, Padthaway Plain, <u>1999</u>.

Berry weight from February 1999 to harvest in *Mound Bare* and *Flat Bare* was significantly greater ($\alpha = 0.01$) for *Control* irrigation treatments compared with *PRD* irrigation treatments throughout February and March in the 1999 season (Figure 8.5). The *Mound* treatment tended to have lower berry weight than the *Flat* treatment in this season, however the difference was not statistically significant at $P = 0.05$.

The °Baume from February 1999 to harvest in *Mound Bare* and *Flat Bare* treatments changed significantly with time during the growing season and tended to be lower in *Control* irrigation treatments throughout the season until harvest, particularly in *Mound* treatments (Figure 8.6). The *Flat+PRD+Bare* treatment had a smaller increase in °Baume between the final two points of measurement compared with the other treatments. This reflected relatively slow ripening of the grapes, which was caused by water stress and significant leaf senescence. °Baume was lower in *Mound* treatments compared with *Flat* treatments (Figure 11.16, Appendix), but this difference was only significant ($\alpha = 0.05$) at harvest.

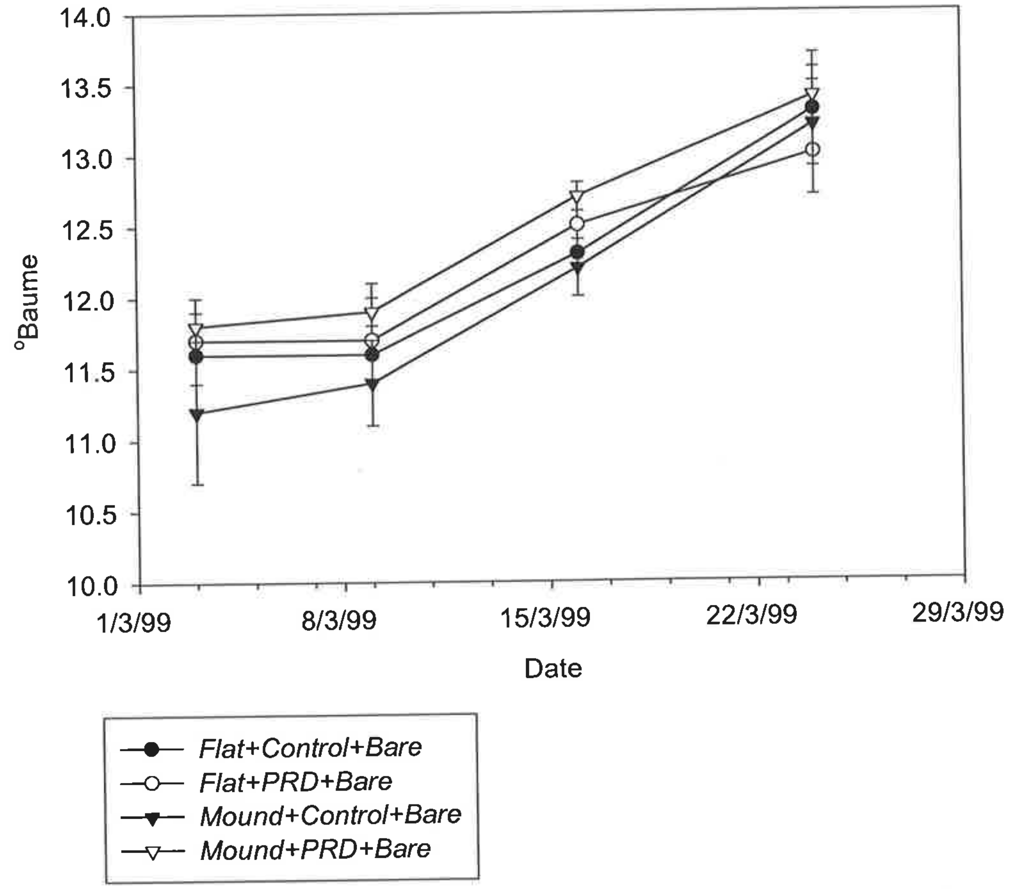


Figure 8.6. °Baume for *Flat Bare* and *Mound Bare* treatments at Padthaway Plain, 1999.

In 2000, bunch-number per vine was significantly greater in the *Mound* treatments than in the *Flat* treatments (α = 0.01). The same significant three-way interaction as in 1999 (α = 0.05) occurred in 2000 between *Soil management* x *Soil-surface cover* x *Irrigation management* in relation to bunch number per vine as follows: the *Flat+PRD+Bare* soil had the lowest bunch-number per vine (75), while the *Mound+Control+Mulch* treatment had the greatest bunch-number per vine (117).
The pruning weights in 2000 ranged from 1.75 kg/vine to 2.15 kg/vine for the *Control irrigation* treatments, and this was significantly (α = 0.01) greater than for the *PRD* irrigation treatments (ranging from 1.38 to 1.76 kg/vine).

Irrigation was the only treatment to have a significant effect on berry juice colour in 2000, but in contrast to the 1999 season the *PRD*-treatments had significantly lower berry-juice colour than the *Control* irrigation treatments (α = 0.05), which may have been due to excessive water stress in *PRD* irrigation treatments in 2000 (so colour development in the 2000 berries was delayed). *Flat* soil management treatments tended to have greater berry juice colour than *Mound* treatments, however this difference was not statistically significant at P = 0.05.

The 2000 season petiole chloride results were similar to the 1999 season with those treatments that provided the greatest amount of available water to grapevines produced the greatest concentration of petiole chloride (Table 5.7). This was true for all treatments except the *Mulch* v. *Bare* treatments, which had similar petiole chloride concentrations.

Mean berry weight in 2000 was significantly greater ($\alpha = 0.01$) in the *Mulch* treatments than in the *Bare* treatments, (Figure 8.7). This result is as expected since soils remained wetter under Mulch than Bare treatments, particularly early in the season (Fig. 6.9). Soil management (mounding) did not have a significant effect on berry weight in the 2000 season.

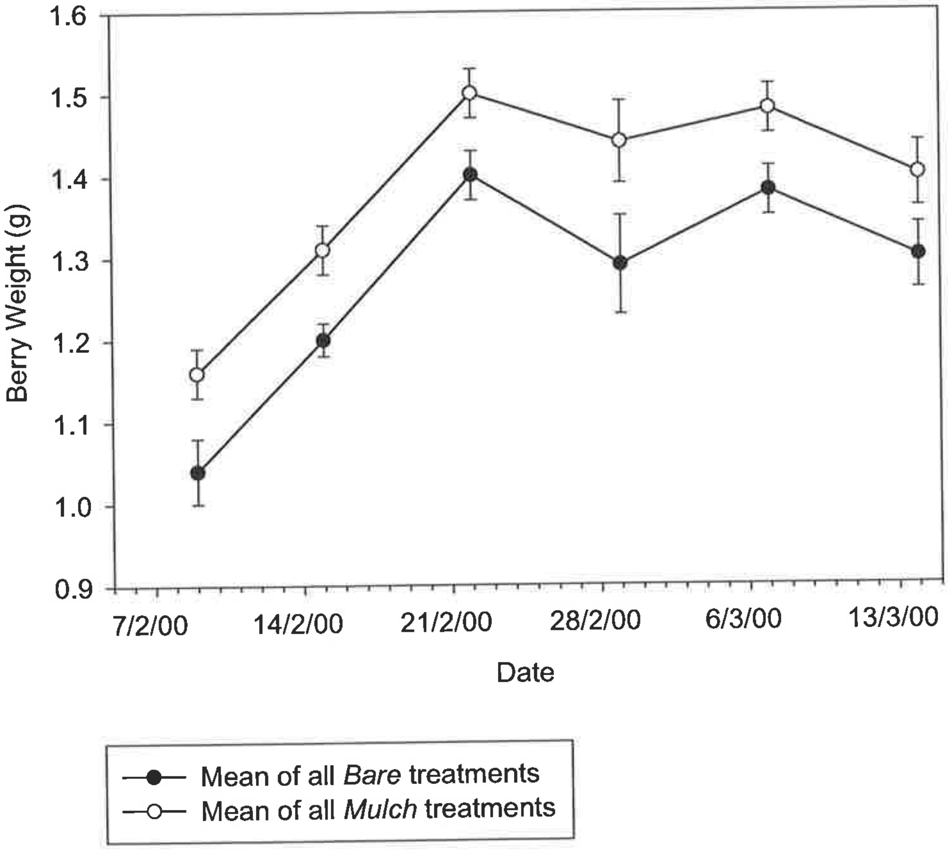
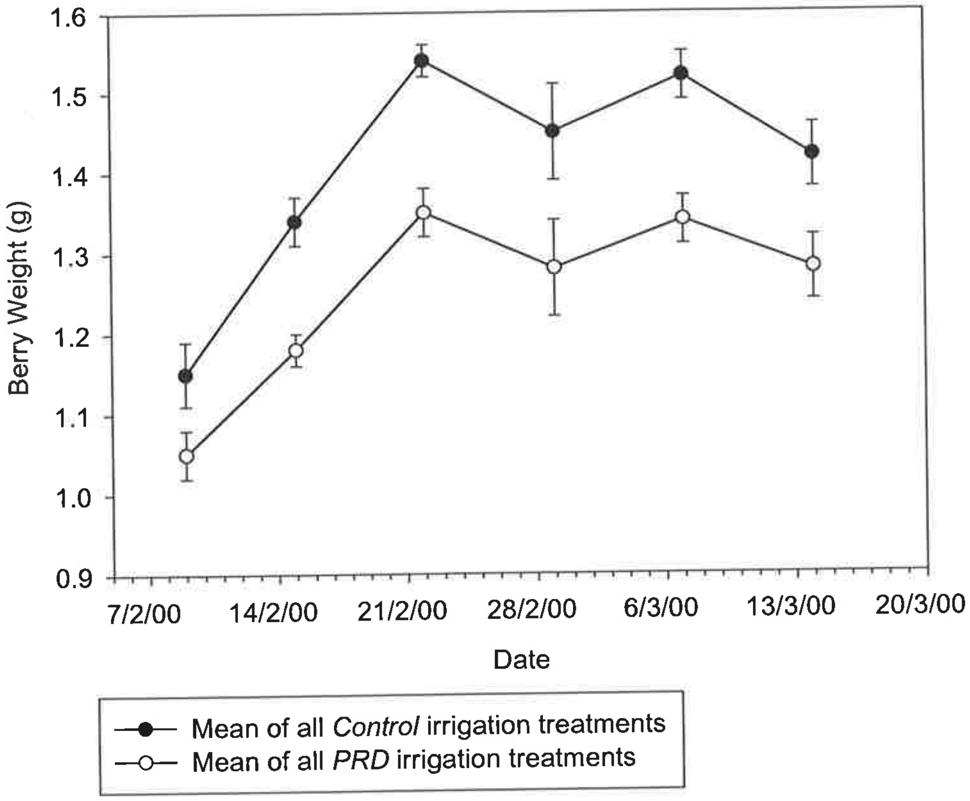


Figure 8.7 Mean berry weight for all *Bare & Mulch* treatments, Padthaway Plain, 2000.

Similarly to 1999, mean berry weights for the *Control* irrigation treatments in 2000 were significantly greater ($\alpha = 0.01$) than the *PRD* irrigation treatments throughout the season (Figure 8.8). Soil management and soil surface cover treatments did not have a significant effect on berry weight.

Figure 8.8 Mean berry weight *Control & PRD* irrigation treatments, Padthaway Plain, '00.



In the 2000 growing season, mean °Baume tended to be greater for *PRD* irrigations compared to *Control* irrigations until the end of February. From the beginning of March °Baume tended to be greater for *Control* irrigations compared with *PRD* irrigations (Figure 8.9). This difference was only significant with time, ($\alpha = 0.05$), which concurs with the berry colour results for the same season. The reduced rate of increase in °Baume under *PRD* irrigation may have been caused by water stress, which resulted in considerable basal leaf loss. 70 mm more water was applied to the Control treatment than the PRD treatment during the growing season.

Soil management had a significant effect on the mean °Baume in the 2000 season but only by interaction with the irrigation treatments. That is, the °Baume was significantly greater in the *Flat+Control+Bare* compared with the *Mound+Control+Bare* but there was no significant difference between the *Flat+PRD+Bare* and the *Mound+PRD+Bare* (Figure 8.10). These results are as expected since the impact of water stress imposed on vines under the PRD treatment negated any impact mounds had. However under the Control treatment, the Mounds were significantly wetter at comparable depth to the Flat treatment (Figures 6.5 and 6.6). *Mulch* treatments tended to have consistently lower °Baume than *Bare* treatments but this difference was not statistically significant at $\alpha = 0.05$.

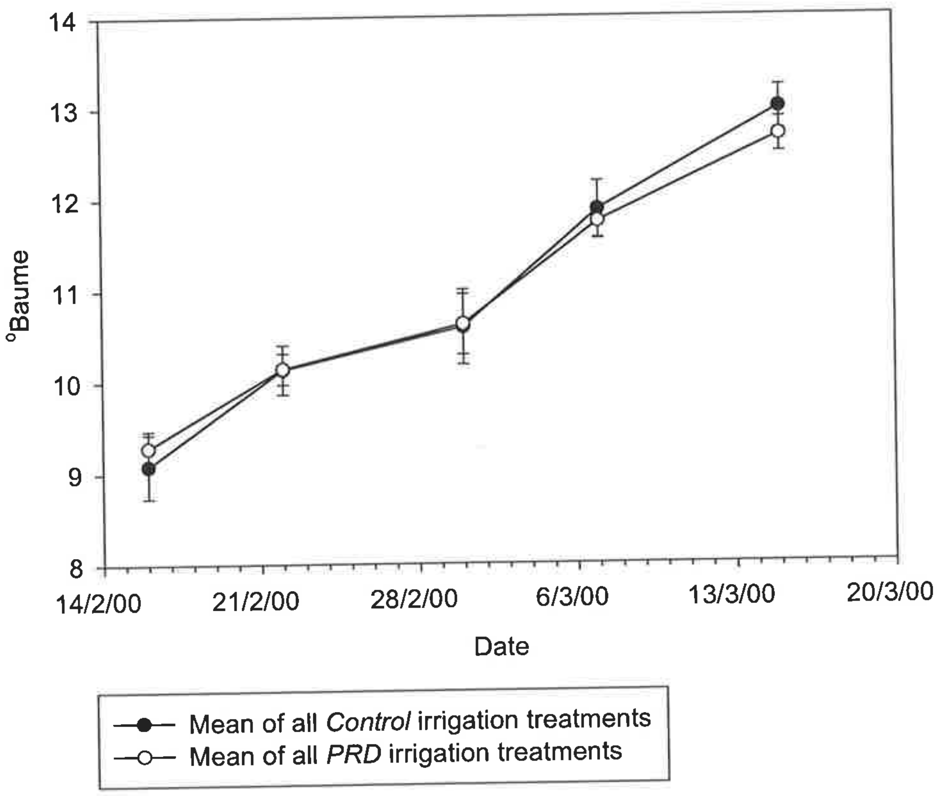


Figure 8.9. Mean °Baume for *Control & PRD* irrigation treatments, Padthaway Plain, 2000.

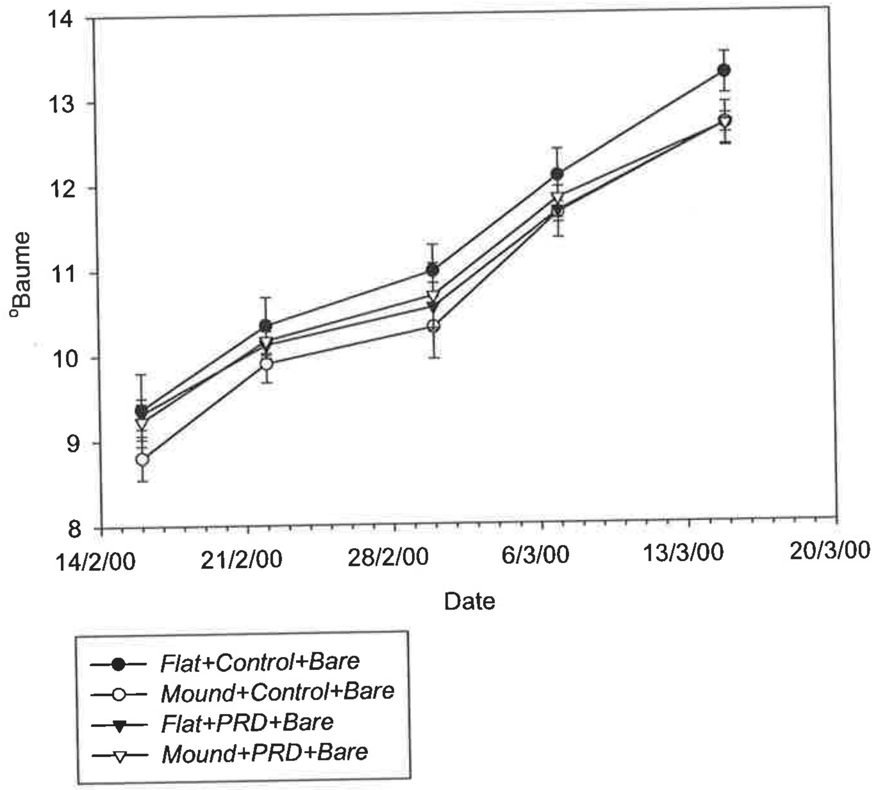


Figure 8.10. Mean °Baume for *Flat Bare & Mound Bare* , Padthaway Plain, 2000.

8.4 Conclusions

8.4.1 Lyndoch

Mounding produced lower yields than not-mounding (*Flat*) and there were no significant effects on yield due to *deep ripping*. It was shown in Chapter 6.4 that *deep-ripping* and *mounding* did not provide greater available water to grapevines, which was mostly due to mounds remaining drier in the top 300 mm of soil (Figure 6.1). As a result in this climate and water management, mounding dried out the soil so that the benefits of mounding as reported by Myburgh and Moolman (1991) were not found here. Deep ripping had no impact on soil structure, root length density, soil salinity or available water due to the ineffective ripping operation (as reported in Chapters 5, 6 and 7, therefore no impact on vine performance. The hypotheses that *deep-ripping* and *mounding* would increase grape yield through an increase in available water were therefore rejected at the Lyndoch site.

Mulching produced significantly greater yields (larger berries) than all other treatments. There were very small differences between final °Baume levels of grape juice between treatments despite significant yield differences. It was shown in Chapter 6.4 that *mulching* provided greater available water compared with not mulching (*Bare*). The greater available water was not through improved soil structure or greater root length density (since roots were able to penetrate the restrictive A2 horizon), but due to the soil remaining wetter under mulch (Figure 6.1). The impact of Mulch on soil water conservation and yield is consistent with that found by van Huyssteen and Weber (1980 b, c). The hypothesis that *mulching* the soil surface would increase grape yield through an increase in available water was accepted.

8.4.2 Padthaway Range

Yields increased (berry weight in both years, bunch number in second year only) when soil was either *deep-ripped* or *mulched*. These treatments alone increased yield significantly in the second season. These results concur with the findings of Saayman and van Huyssteen (1980) and van Huyssteen (1988a) except that at the Padthaway Range site shoot mass (pruning weight) did not increase with the extent of ripping. Similarly, *mulching* had no significant effect on pruning weight. Both *mulching* and *deep-ripping* reduced berry juice colour in both years, but the effects were statistically significant only in the second season. The effect of mulching on yield and shoot mass reported by van Huyssteen and Weber (1980c) concur with these results. However these authors found that wine quality was greater when mulch was applied compared with conventional tillage practices. The lower quality wine from conventionally cultivated treatments was due to low nitrogen in the wine.

These impacts of deep ripping and mulch on grapevine performance were expected given their impact on available water. Deep-ripping significantly reduced soil resistance (Figure 5.1, 5.4 and 5.5). As a result root length density of grapevines in the ripped soil was improved (Figure 5.24 and 5.25). The larger root volume in the rip treatment was able to utilise more RAW_v and TAW_v (Table 6.3 and 6.4) particularly when combined with mulch. The impact of effective deep ripping on root length density and yield concur with van Huyssteen (1988 a).

As per the Lyndoch experiment the impact of Mulch on grapevine performance is consistent with van Huyssteen and Weber 1980 b, c. Mulch improved RAW_v and TAW_v

through improved soil structure (Table 5.5). As a result of the improved soil structure root length density was greater near the soil surface under mulch (Figure 5.26).

The hypotheses that *deep-ripping* and *mulching* would increase grape yield through an increase in available water was accepted. The effects on °Baume and in particular berry colour indicated that the increase in yield may have been at the expense of berry composition and quality.

8.4.3 Padthaway Plain

In both seasons yield, bunch number per vine, berry weight and pruning weight were significantly greater under the *Control* irrigations than under *PRD*. In 1999, berry colour was significantly greater under *PRD* compared with the *Control* irrigations. In 2000 the three-way interaction of Soil management x Soil surface-cover x Irrigation significantly effected bunch number; *Flat+PRD+Bare* provided the lowest bunch number per vine. In the 2000 season water stress and leaf loss caused berry colour and sugar development to be significantly reduced or at least retarded under *PRD*.

Yields were 3.43 tonnes/ML water applied (1999) and 6.12 tonnes/ML (2000) under the *Control* irrigation by comparison to 4.44 tonnes/ML (1999) and 6.12 tonnes/ML (2000) under the *PRD* irrigation. The hypothesis that the water use efficiency (tonnes of fruit produced per ML of water used) would be greater under *PRD* irrigation compared with *Control* irrigation was accepted for the 1999 season but rejected for the 2000 season, where there were no differences between irrigation treatments. Although additional water was applied to *Control* irrigation treatments there was no evidence to suggest more water was used by grapevines in this treatment (Chapter 6.4). These results are not as conclusive as Dry et al. (1998) reported.

Due to the shallow soil at this site it was difficult to manage the irrigation so that grapevines were not water stressed for at least some of the time. The grapevines were clearly water stressed under *PRD* irrigation, and this translated into lower yields, berry weights and bunch numbers under *PRD* irrigation. If *PRD* irrigation had been performed so that grapevines were not water stressed, it is likely that yields would have been similar to the *Control* irrigation treatments, and the conclusions about water use efficiency might have concurred with Dry et al. (1988) more strongly.

Yield was greater under *Mounding* than under the *Flat* treatments, but this was statistically significant only in the second season, where a three-way interaction was present. The *Flat* treatment combined with *PRD* irrigation (*Flat+PRD+Bare*) had the lowest yield while mounding and mulching combined with control irrigation (*Mound+Control+Mulch*) had the greatest yield. In the 2000 season, the differences in yield were primarily accounted for by greater numbers of bunches per vine (no difference in berry weights).

PRD irrigation had no impact on soil structure or root length density or distribution (Figure 5.29). Greater root length density at depth was not found in this experiment as it was by Stoll et al. (2000). This confirms that the impact of PRD irrigation on vine performance was due to the water stress at this site and not due to an impact on available water through an effect on soil structure or root distribution.

There were minimal effects of *mounding* on °Baume, and these were accounted for mainly by interactions; for example °Baume was greater under *Flat* soil only under the *Control irrigation*. This can be explained through Mounds remaining wetter than Flats over the major root depth (Figure 6.5). As a result grapevines in Mounds had more available water than in Flats. This could be considered contradictory to Myburgh and Moolman (1991), who found Mounds drained more freely in waterlogged conditions. However the Padthaway Plain soils were not waterlogged during the growing season and the A_{new} horizon acted as a "protective layer" reducing evaporation from the A_1 horizon.

In addition to remaining wetter than Flats over the major rooting depth Mounds had a lower soil resistance at the soil surface than Flats (Figure 5.12), which concurred with Eastham et al. 1996. Mounds also provided a slightly greater volume of soil for grapevine roots to inhabit. This resulted in greater RAW_v and TAW_v per vine in Mounds than Flats.

The hypothesis that mounding would increase grape yield through an increase in available water to grapevines was accepted, but there was evidence from the 2000 season that the additional yield from *mounding* may come at the expense of delayed sugar development.

Mulching had a variable effect on yields (bunch numbers only) – not significant in 1999, and only significant in 2000 by way of interactions: *Irrigation* x *Soil management* x *Soil surface-cover*. The *Mound+Control+Mulch* treatment had the greatest yield.

The hypothesis that mulching would increase grape yield through an increase in available water was accepted at this site. However, unlike the Lyndoch site and the Padthaway Range site, yields at Padthaway Plain were only increased under *mulching* when this was combined with *mounding* and *control irrigation*. The expected impact of Mulch on grapevine performance was via its impact of reducing bulk density on Mounds and reduction in evaporative loss from the surface of Mounds. As a result its impact was greatest on grapevine performance in combination with Mounds.

Mulch dampened the settling effects of the Anew horizon in mounds so that bulk density increased to only 1.09 g cm-3 under Bare soil, (Chap 5.3.1.3). Additionally mulched soils remained significantly wetter than Bare soils for both Flat and Mound treatments in the soil surface (Figure 6.9). The effect of Mulch on conserving soil water, and improving grape yield concur with Van Huyssteen and Weber (1980 a, b, c).

8.4.4 All sites

Mulch had different impacts on soil salinity and resultant chloride concentrations in grapevines depending on the site. At Lyndoch Mulch tended to reduce soil salinity near the soil surface (Figure 7.3) but berry chloride was greatest in grapevines in Mulch treatment (Table 8.1).

Similarly at the Padthaway Range site soil salinity tended to be less under the Rip+Mulch treatment (Figure 7.5). However petiole chloride tended to be greater in Rip+Mulch treatments (Table 8.4).

Conversely at the Padthaway Plain site in December 1998 all treatments with mulch had ECse > 2dSm-1 at some depth while those without mulch all had $EC_{se} < 2\ dSm^{-1}$ at all depths (Appendix Figures 11.9 and 11.10). At the completion of the season there were no significant differences between treatments (Figure 7.10 and 7.11). An explanation for greater salinity under mulch early in the season is that salts may have leached out of the mulch. Petiole chloride tended to be greater in Mound compared with Flat, and Mulch compared with Bare treatments.

In all except the Padthaway Plain experiment there was a reduction in soil salinity near the soil surface through reduced evaporation, as expected. These results concur with van Huyssteen and Weber (1980 b, c). However the reduced soil salinity did not result in a reduction in chloride concentrations in grapevines. Greater grapevine chloride concentrations were found in treatments which provided more available water i.e. Mulch at Lyndoch (Appendix Figure 11.13), Rip and Mulch at Padthaway Range (Table 5.5), and Mound, Mulch and Control at Padthaway Plain (Figure 6.5, 6.9). That is, the more irrigation water taken up by grapevines the more salt was also taken up.

9 OVERALL CONCLUSIONS

The size and health of root systems governs vine vigour (Southey 1992, Smart 1995). To sustainably produce high quality wine-grapes a moderate root volume is required, and this depends on climate, soil characteristics, irrigation practices, water quality, grape variety and canopy management.

In this study I have considered the impacts of 1) mounding, 2) deep-ripping, 3) application of mulches and other surface-soil treatments, and 4) irrigation practices, on soil structure, available water, root growth and grapevine performance. The soil and irrigation treatments had site-specific impacts on the soil, available water and ultimately grapevine performance, and this illustrated that soil limitations to grapevine root growth and plant available water need to be taken into account at every site to enable the best soil and irrigation management practices to be applied for optimum vine performance.

From the myriad of soil management treatments applied at Lyndoch in 1996, a narrower selection of soil management treatments was made for the two Padthaway sites to account for specific soil limitations – this more targeted approach led to stronger (more statistically significant) treatment effects.

9.1 Mounding

Mounding at Lyndoch failed to increase grapevine root volume, available water and ultimately vine performance. This was partly due to vine roots being able to penetrate the compact A_2-horizon and also grow into the mid-row prior to any soil management treatments being in place. As a result the increase in root volume above the A_2-horizon due to mounding had a negligible effect on the total root volume, despite it being more structurally suitable for root growth. The mounds were almost always drier than the traditional flat soil treatment probably due to greater drainage and evaporation from the mounds. These results concur with Myburgh and Moolman (1991).

At Padthaway Plain, where depth of root growth was limited by shallow limestone, mounding increased available water by improving soil structure and increasing the volume of soil for roots to explore. On average, *mounding* retained as much water as non-mounded soil throughout the growing season, which increased yields particularly in combination with a straw mulch on the soil surface to reduce evaporation.

9.2 Deep-ripping

Ripping had no effect at Lyndoch (because it was conducted under very poor conditions (virtually saturated) and it was not ripped deeply enough – Myburgh et al. 1996; van Huyssteen 1998a). Furthermore, deep-ripping is of greatest value when vine root growth is restricted in the horizontal, which was not the case at Lyndoch. By contrast, vine roots at the Padthaway Range site were severely limited horizontally by wheel traffic compaction, so that when correct ripping was performed at this site (ideal water content and depth), vine roots took advantage of the ripped soil and explored water and nutrients to depth. Yields at Padthaway Range were thus significantly greater in the *Rip* treatments, even though soil resistance increased to their original values within 2 years. Of all treatments applied to the 3 experimental sites deep-ripping had greatest impact on increasing available water to vines through increasing root volume. Except at Lyndoch, deep-ripping invariably translated into higher yields. Where an impediment to vertical root development existed and ripping was performed correctly, results concurred with van Huyssteen (1988a).

9.3 Mulch and other soil-surface treatments

Mulches and other surface covers generated lower values of RAW and TAW in the mounds at both Lyndoch (sandy loam) and Padthaway Plain (sandy clay loam). This was either because the covers maintained significantly wetter conditions in these heavier textured soils (which led to mound-densification) or because the mulches were poorly anchored and often blew off the mounds. Under these conditions vines produced lower root-length densities near the soil surface and lower grape yields compared to the bare treatments.

By contrast, mulching increased the water-holding capacity of the sandy soil at Padthaway Range. Where physical conditions were improved under mulching (compared to bare treatments), vines produced higher root-length densities near the soil surface (Padthaway Range), took up more water and produced greater yields. These results concur with van Huyssteen and Weber (1980a, b, c).

The impact of mulches on soil salinity was variable and site specific. At Lyndoch soil salinity was reduced under mulch but at both Padthaway sites, salinity varied with time. It was greater under the mulch at Padthaway especially during late winter when soluble salts may have come out of the decomposing straw mulch. Higher water use by a greater density of roots growing under the mulch may also have contributed to a concentration of soluble residual salts left behind.

9.4 Irrigation

Soil water contents under *Control irrigation* was always greater than that under *PRD*. Due to the shallow soils at Padthaway Plain (< 0.5 m), greater amounts of irrigation were applied to the *Control* than would normally be applied under standard vineyard practices. This was an experimental necessity to manage the *PRD*-irrigation and to facilitate comparisons among the various irrigation treatments. Significantly less water (and thus salt) was applied using *PRD* than using *Control irrigation*, but there was no evidence that *PRD*-vines used less water than *Control irrigation* vines. Yield, berry weight and bunch number were reduced by *PRD* irrigation, primarily because the *PRD* vines experienced severe water stress. Had they not been so severely stressed, it is likely that yields would have been similar between *Control* and *PRD* irrigation treatments. While most of the irrigation treatment differences were not statistically significant at Padthaway Plain, grapevine roots tended to be denser at depth under *Control irrigation*, particularly for the *Flat* treatments. This is in contrast to the findings of Stoll et al (2000), but may have been due to the difficulty managing PRD irrigation on a very shallow soil.

9.5 Recommendations

9.5.1 General

The results from the field trials conducted in this study suggest that limitations to root growth need to be evaluated before soil management strategies are put in place. Without such an evaluation, it is likely that soil management techniques such as mounding, deep-ripping and application of compost could be futile and possibly detrimental to soil structure, available water and vine performance.

The simplest way to understand soil limitations to vine root growth is to dig a soil pit and observe the distribution of vine roots down the soil profile. If roots occur in the mid-row and at depth (eg. ≥ 0.7 m) this would suggest that soil conditions are relatively favourable for root exploration. In this case, neither deep-ripping nor mounding are likely to improve vine performance. If, on the other hand, vine roots are seen to be sparse and restricted primarily under the vine-row, it is possible that deep-ripping may improve root-length density, available water and vine performance, so long as the soil is sufficiently deep (i.e. no shallow rock). The work reported here indicates that soil conditions after ripping will steadily return to their original, hard states within 2-3 years, which suggests a frequency for ripping operations of once every 2-3 years.

Most of the evidence presented in this study suggests that mounding has little impact on available water in the root zone, and may in fact present a safety hazard in relation to equipment and people working on steeply sloped mounds. If vine roots are limited vertically, deep-ripping is the preferred option where the soil is deep enough. Where the soil is too shallow for deep-ripping (e.g. over bedrock) mounding may be the only option to reduce rootzone constraints. Where mounds are employed, it is essential that significant quantities of mulch or compost are applied and maintained. Without protection from evaporation it is difficult to maintain soil moisture in the mounds, which not only increase drainage but also enhance evaporation – this is particularly important where saline irrigation water is used.

Soil surface covers invariably reduce evaporation if applied in layers exceeding 10 cm and as the availability of high quality irrigation water becomes increasingly limited, the use of composts and other mulches makes good sense. Their ability to increase available water and vine performance has been demonstrated in my field work, and is also supported in the scientific literature. The impact of these composts on soil structure, however, may be negative (eg. on heavy textured, wet soils) for various reasons, and needs to be studied in greater detail.

The effectiveness of PRD irrigation on vine performance was not conclusive, primarily because it was difficult to manage on shallow soils. Consequently, the best irrigation systems, resulting water distribution patterns, and their impacts on soil structure, root growth and vine performance continue to be poorly understood. The field work conducted in this study point to the great importance of correct application of good soil management practices in attaining optimal plant performance. For example, for ripping operations to be effective, it is essential they be conducted when soils are drier than field capacity, and located in the mid-row to a depth of approximately 0.7 m (Cass et. al. 1998).

Even with an understanding of vine root growth limitations and application of the correctly performed soil management technique vineyard variability can make it difficult to define where the soil management technique should be applied. The recent work of Lanyon and Bramley (2004), utilizing precision viticulture technology, in conjunction with background information on vine root limitations, may provide the solution to applying the best soil management technique at the right location.

Given the above mentioned constraints and recommendations based on site-specific attributes the following soil and water management recommendations are made.

9.5.2 Lyndoch

Described by Maschmedt et al. (2002) as a restrictive duplex soil with thin well-structured topsoil and as a Yellow Chromosol in Isbell's Australian Soil Classification (1996). See Appendix Figure 11.1 for the schematic of the soil profile.

Soil management

- Deep-ripping would improve soil structure, in particular reduce soil strength and improve permeability through the A_2 horizon and into the surface of the clay. A shaker –type ripper would be required to penetrate to sufficient depth (> 70 cm). It would be important not to mix soil horizons during the deep ripping process. Application of gypsum on ripping will help maintain the improved soil structure.
- Application of mulches (of any kind, eg. composts) would improve surface soil structure, organic matter content and would reduce evaporation.

Irrigation management

- Irrigation frequency will depend on grapevine root depth which will be highly dependant on previous soil management in this soil. Inspection of root depth and volume through soil pit observation would allow determination of irrigation frequency and depth.

9.5.3 Padthaway Range

Described by Maschmedt et al. (2002) as a deep, sandy, uniform soil and as an Arenic Tenosol in Isbell's Australian Soil Classification (1996). See Appendix Figure 11.3 for the schematic of the soil profile.

Soil management

- These sands may compact due to wheel traffic impeding grapevine root development horizontally. Deep-ripping the wheel track may be required every 3 years to maximize root development depending on soil management on vineyard establishment.
- It is likely that application of mulches (of any kind, eg. composts) would improve surface soil structure, organic matter content and would reduce evaporation.
- Soil nutrient levels should be monitored; lime, phosphorous and potassium are likely fertilizer requirements.

Irrigation management

- On establishment of young vineyards frequent, shallow irrigation would be required (example: 3 irrigations per week of 2 hours each using 2 L/hour drippers). Once vines are mature and root systems penetrate to approximately 70cm (top of the sandy clay) irrigation may not be required or only be required 1 to 2 times per week beginning late in the growing season (January) for premium red varieties at Padthaway.

9.5.4 Padthaway Plain

Described by Maschmedt et al. (2002) as a restrictive duplex with thin well-structured topsoil and as a Calcic Yellow Chromosol in Isbell's Australian Soil Classification (1996). See Appendix Figure 11.6 for the schematic of the soil profile.

Soil management

- Depending on root depth (impeding limestone depth) grapevines on these soils may respond to deep-ripping the wheel track and gypsum application in the deep-rip line. If limestone is particularly shallow than deep-ripping may not be a viable option (as it would be important to avoid bringing limestone to the surface). The utilization of a shaker-type ripper would be required to penetrate these heavier soils to an acceptable depth (50 cm or the top of the limestone layer).
- Application of mulches (of any kind, eg. composts) would improve surface soil structure, organic matter content and would reduce evaporation. However it would be important to determine the optimum depth of mulch because deep applications (> 10 cm) could have a negative impact on soil structure.
- Grapevines on these soils may respond to mounding if deep-ripping is not a viable option. However careful consideration should be given to mound shape minimizing the potential for injury to people and minimizing evaporative loss. Additionally it should be noted that mounds are likely to dry out more readily than non-mounded soil so more irrigation may be required to keep them wet enough. Before mounding deep-ripping and / or composting alone should be considered.
- Fertilizer application, in particular nitrogen and phosphorous, are likely requirements on establishment but reduced applications should be required in the mature vineyard.

10 REFERENCES

ABS (2004) Australian Bureau of Statistic Report No.1329.0.55.001 Vineyards estimates, Australia, preliminary 2004p (http://www.abs.gov.au/Ausstats/abs@.nsf/lookupMF)

Adem HH and Tisdall JM (1983) Reconditioned soil: The key to better crops. Australian Grapegrower & Winemaker, **238 (Oct)**, 18-19.

Aljibury FK and Christensen LP (1972) Water penetration of vineyard soils as modified by cultural practices. American Journal of Enology & Viticulture, **23**, 35-38.

Barley KP (1976) Mechanical resistance of the soil in relation to the growth of roots and emerging shoots. Agrochimica, **20**; 171-181.

Ben-Hur M, Faris J, Malik M and Letey J (1989) Polymers as soil conditioners under consecutive irrigations and rainfall. Soil Science Society of America Journal, **53**, 1173-1177.

Ben-Hur M and Letey J (1989) Effect of polysaccharides, clay dispersion, and impact energy on water infiltration. Soil Science Society of America Journal, **53**, 233-238.

Braunack MV, Hewitt JS and Dexter AR (1979) Brittle fracture of soil aggregates and the compaction of aggregate beds. Journal of Soil Science, **30**, 653-667.

Buckerfield J and Webster K (2000) Vineyard trials show value of mulches - organic matter for management of young vines. Australian Grapegrower & Winemaker, **441**, 33-39.

Cass A, Cockroft B and Tisdall JM (1993) New approaches to vineyard and orchard soil management. In *ASVO Seminar-Vineyard Development and Redevelopment.* 18 – 24.

Cass A, Maschmedt D, and Chapman J (1998) Managing physical impediments to root growth. Australian Grapegrower & Winemaker, **June**, 13-17.

Cass A, Walker RR and Fitzpatrick RW (1996) Vineyard soil degradation by salt accumulation and the effect on vine performance. *Paper presented at 9th Australian Wine Industry Technical Conference,* Adelaide, 16-19 July 1995.

Cockroft B (1966) Soil management of peach trees in the Goulburn Valley, Victoria. Australian Journal of Experimental Agriculture & Animal Husbandry, **6**, 62.

Cockroft B and Olsson KA (2000) Degradation of soil structure due to coalescence of aggregates in no-till, no traffic beds in irrigated crops. Australian Journal of Soil Research, **38**, 61-70

Cockroft B and Tisdall JM (1978) Soil management, soil structure and root activity. In: Modification of Soil Structure. Edited by WW Emerson, RD Bond & AR Dexter. (Wiley, Chichester). pp 387-391.

Cockroft B and Wallbrink JC (1966a) Root distribution of orchard trees. Australian Journal of Agricultural Research, **17**, 49-54.

Cockroft B and Wallbrink JC (1966b) Soil properties and tree vigour in the Goulburn Valley. Australian Journal of Experimental Agricultural & Animal Husbandry, **6**, 204-208.

daSilva AP and Kay BD (1996) The sensitivity of shoot growth of corn to the least limiting water range of soils. Plant & Soil **184**, 323-329.

daSilva AP, Kay BD and Perfect E (1994) Characterization of the least limiting water range of soils. Soil Science Society of America Journal **58**, 1775-1781.

Dexter AR (1987) Mechanics of root growth. Plant & Soil, **98**, 303-312.

Dexter AR (1988) Advances in characterisation of soil structure. Soil & Tillage Research, **11**, 199-238.

Dry PR, Loveys BR, Iland PG, Botting DG, McCarthy MG and Stoll M (1998) Vine manipulation to meet fruit specification. *Proceedings 10th Australian Wine Industry Technical Conference*; Sydney, Australia, 2-5 August 1998, (Eds R. J. Blair, A. N. Sas, P. F. Hayes and P. B. Hoj), 208-214.

Dry PR and Smart RE (1998) The grapegrowing regions of Australia. In: Viticulture, Volume 1. Resources. BG Coombe and PR Dry (Editors). Winetitles, Adelaide. Pp. 37-60.

Eastham J, Cass A, Gray S, and Hansen D (1996) Influence of raised beds, ground cover and irrigation on growth and survival of young grapevines. Acta Horticulturae, **427**, 37-43.

Enz JW, Brun LJ and Larsen JK (1988) Evaporation and energy balance for bare and stubble covered soil. Agricultural & Forest Meteorology, **43**, 59-70.

Freeman BM, Lee TH and Turkington CR (1980) Interaction of irrigation and pruning level on grape and wine quality of Shiraz vines. American Journal of Enology & Viticulture, **31**, 124-135.

Freeman BM and Smart RE (1976) Research note: A root observation laboratory for studies of grapevines. American Journal of Enology & Viticulture, **27**, 36-39.

Grant CD, Angers DA, Murray RS, Chantignay M, Hassanah U (2001) On the nature of soil aggregate coalescence in an irrigated swelling clay. Australian Journal of Soil Research, **39**, 565-575.

Grierson IT (1978) Gypsum and red-brown earths. In: Modification of Soil Structure. Edited by WW Emerson, RD Bond & AR Dexter. (Wiley, Chichester). pp 315-324.

Groenevelt PH, Grant CD, Murray RS (2004) Water availability in saline soils. Australian Journal of Soil Research, **42**, 833-840.

Groenevelt PH, Grant CD, Semetsa S (2001) A new procedure to determine soil water availability. Australian Journal of Soil Research, **39**, 577-598.

Gusli S, Cass A, MacLeod DA and Blackwell PS (1994a) Structural collapse and strength of some Australian soils in relation to hardsetting. 1 Structural collapse on wetting and draining. European Journal of Soil Science, **45**, 15-21.

Gusli S, Cass A, MacLeod DA and Blackwell PS (1994b) Structural collapse and strength of some Australian soils in relation to hardsetting. 2 Tensile strength of collapsed aggregates. European Journal of Soil Science, **45**, 23-29.

Gusli S, Cass A, MacLeod DA and Hignett CT (1995) Processes that distinguish hardsetting from rain-induced crusting. Edited by HB So, GD Smith, SR Raine, BM Schafer and RJ Loch. Sealing, crusting and hardsetting soils: Productivity and conservation. (Australian Soil Science Society Inc. Qld Branch). pp 457-461.

Hamblin A (1985) The influence of soil structure on water movement, crop root growth, and water uptake. Advances in Agronomy, **3**,: 95-152.

Hardie WJ and Considine JA (1976) Response of grapes to water-deficit stress in particular stages of development. American Journal of Enology & Viticulture; **27**, 55-61.

Hardie WJ and Martin SR (1989) A strategy for vine growth regulation by soil water management. In: *Proceedings of the Seventh Australian Wine Industry Technical Conference*, Adelaide, Australia. Edited by P. J. Williams, D. M. Davidson, and T. H. Lee (Winetitles, Adelaide). 51-57.

Helalia AM and Letey J (1988) Cationic polymer effects on infiltration rates with a rainfall simulator. Soil Science Society of America Journal, **52**, 247-250.

Helalia AM and Letey J (1989) Effects of different polymers on seedling emergence, aggregate stability, and crust hardness. Soil Science, **148**, 199-202.

Hepner Y, Bravdo B, Loinger C, Cohen S and Tabacman H (1985) Effect of drip irrigation schedules on growth, yield, must composition and wine quality of Cabernet Sauvignon. American Journal of Enology & Viticulture, **36**, 77-85.

Isbell RF (1996) The Australian soil classification: The Soil and Land Survey Handbook, CSIRO Publishing, Collingwood, Australia.

Kay BD (1990) Rates of change of soil structure under different cropping systems. Advances in Soil Science, **12**, 1-52.

Kirchhof G, Blackwell J and Smart RE (1991) Growth of vineyard roots into segmentally ameliorated acidic subsoils. Plant & Soil, **134**, 121-126.

Laird DA (1996) Bonding between polyacrylamides and clay mineral surfaces. In proceedings from: Managing irrigation-induced erosion and infiltration with polyacrylamides. Edited by R. E. Sojka and R. D. Lentz. (University of Idaho, USA) University of Idaho Miscellaneous Publication No 101-96.8

Lanyon DM and Bramley RGV (2004) Precision viticulture – a tool for improved vineyard experimentation, *Proceedings of the 8th Annual Symposium on Precision Agriculture Research and Application in Australasia*, University of Sydney, August 20. pp16-18

Letey J (1985) Relationship between soil physical properties and crop production. Advances in Soil Science, **1**, 277-293.

Loveys B, Stoll M, Dry P and McCarthy M (1998) Partial rootzone drying stimulates stress responses in grapevine to improve water use efficiency while maintaining crop yield and quality. Australian Grapegrower & Winemaker; 26th Annual Technical Issue: 108-113.

Ludvigsen K (1995) Temperature of soil at three depths with straw mulch and bare soil treatments. Australian Grapegrower & Winemaker, **378a**, 103-109.

Maas EV and Hoffman GJ (1977) Crop salt tolerance - current assessment. Journal Irrigation & Drainage Division. ASAE, **103**, 115-134.

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

Matthews MA, Anderson MM and Schultz HR (1987) Phenologic growth responses to early and late season water deficits in Cabernet franc. Vitis, **26**, 147-160.

McCarthy MG, Cirami RM and McCloud P (1983) Vine and fruit responses to supplementary irrigation and canopy management. South African Journal of Enology & Viticulture, **4**, 67-76.

McCarthy MG, Dry PR, Hayes PF and Davidson DM (1992) Soil management and frost control. In Viticulture, Vol. 1 Resources, Edited by B.G. Coombe and P.R. Dry, (Winetitles, Adelaide), 148-174.

McCarthy MG (1997) Effect of timing of water deficit on fruit development and composition of Vitis vinifera cv. Shiraz. PhD Thesis, University of Adelaide.

McIntyre DS, Barrow KJ (1972) An improved method for taking small cores in wet soil. Soil Science **114**, 239-241.

McKenzie BM and Dexter AR (1988) Radial pressures generated by the earthworm *Aporrectodea rosea*. Biology & Fertility of Soils, **5**, 328-332.

Mullins CE, MacLeod DA, Northcote KH, Tisdall JM and Young IM (1990) Hardsetting soils: behaviour, occurrence, and management. In: Advances in Soil

Structure, Volume 2, Soil Degradation. Edited by R Lal and BA Stewart (Springer-Verlag, New York). pp 38-108.

Myburgh PA (1994) Effect of ridging on the performance of young grapevines on a waterlogged soil. South African Journal of Enology & Viticulture, **15**, 3-8.

Myburgh PA, Cass A and Clingeleffer P (1996) A qualitative assessment of root systems in relation to soil physical conditions in Australian vineyard and orchard soils. CSIRO, Adelaide, Australia, Barossa Valley Rotary Foundation Report.

Myburgh PA and Moolman JH (1991) Ridging - a soil preparation practice to improve aeration of vineyard soils. South African Journal of Plant & Soil, **8**, 184-188.

Myburgh PA and Moolman JH (1993) Effect of ridging on the temperature regime of a waterlogged vineyard soil. South African Journal of Plant & Soil, **10**, 17-21.

Neja RA, Wildman WE, Ayers RS and Kasimatis AN (1977) Grapevine response to irrigation and trellis treatments in the Salinas Valley. American Journal of Enology & Viticulture, **1**, 16-26.

Newman EI (1966) A method of estimating the total length of root in a sample. Journal of Applied Ecology, **3**, 139-145.

Northcote KH (1992) Soils and Australian viticulture. In: Viticulture Volume 1 Resources. Edited by BG Coombe and PR Dry. (Winetitles, Adelaide). pp 61-90.

Oades JM (1993) The role of biology in the formation, stabilisation and degradation of soil structure. Geoderma, **56**, 377 – 400.

Pinamonti F, Zorzi G, Gasperi F, Silvestri S and Stringari G (1995) Growth and nutritional status of apple trees and grapevines in municipal solid-waste-amended soil. Acta Horticulturae, **383**, 313-317.

Poni S, Lakso AN, Turner JR and Melious RE (1993) The effects of pre- and post-veraison water stress on growth and physiology of potted Pinot Noir grapevines at varying crop levels. Vitis, **32**, 207-214.

Prior LD, Grieve AM and Cullis BR (1992a) Sodium chloride and soil texture interactions in irrigated field grown Sultana grapevines. 1. Yield and fruit quality. Australian Journal of Agricultural Research, **43**, 1051-1066.

Prior LD, Grieve AM, Slavich PG and Cullis BR (1992 c) Sodium chloride and soil texture interactions in irrigated field grown Sultana grapevines. 3 Soil and root system effects. Australian Journal of Agricultural Research, **43**, 1085-1100.

Proebsting EL (1943) Root distribution of some deciduous fruit trees in a California orchard. Proc. American Society for Horticulture Science, **43**, 1-4.

Richards D (1983) The grape root system. Horticultural Reviews, **5**, 127-168.

Saayman D and van Huyssteen L (1980) Soil preparation studies: 1. The effect of depth and method of soil preparation and of organic material on the performance of Vitis Vinifera (var. Chenin Blanc) on Hutton/Sterkspruit Soil. South African Journal of Enology and Viticulture, **1**, 107-121.

Saayman D and van Huyssteen L (1983a) Soil preparation studies: 2. The effect of depth and method of soil preparation and organic material on the performance of Vitis vinifera (var. Colombar) on a Clovelly/Hutton Soil. South African Journal of Enology and Viticulture, **3**, 61-74.

Saayman D and van Huyssteen L (1983b) Preliminary studies on the effect of a permanent cover crop and root pruning on an irrigated Colombar vineyard. South African Journal of Enology and Viticulture, **4**, 7-12.

Saleh MA and Letey J (1988) Polymer and water quality effects on flocculation of montmorillonite. Soil Science Society of America Journal, **52**, 1453-1458.

Shanmuganathan RT and Oades JM (1983) Modification of soil physical properties by addition of calcium compounds. Australian Journal of Soil Research, **21**, 285-300.

Smart RE (1995) Two golden rules of viticulture. Australian & New Zealand Wine Industry Journal, **10**, 38-39.

Smart RE, Turkington CR and Evans JC (1974) Grapevine response to furrow and trickle irrigation. American Journal of Enology and Viticulture, **25**, 62-66.

Southey JM (1992) Root distribution of different grapevine rootstocks on a relatively saline soil. South African Journal of Enology and Viticulture, **13**, 1-9.

Stace HCT, Hubble GD, Brewer R, Northcote KH, Sleeman JR, Mulchay MJ and Hallsworth EG (1968) A handbook of Australian Soils. Rellim Tech. Pub., Adelaide, South Australia.

Stevens RM and Douglas T (1994) Distribution of grapevine roots and salt under drip and full-ground cover micro-jet irrigation systems. Irrigation Science, **15**, 147-152.

Stevens RM and Harvey G (1995) Effects of water-logging, rootstock and salinity on Na, Cl, and K concentrations of the leaf and root, and shoot growth of sultana grapevines. Australian Journal of Agricultural Research, **46**, 541-551.

Stevens RM and Nicholas PR (1994) Root-length and mass densities of *Vitis vinifera* L. cultivars 'Muscat Gordo Blanco' and 'Shiraz'. New Zealand Journal of Crop and Horticultural Science, **22**, 381-385.

Stoll M, Dry P, Loveys B, Stewart D and McCarthy M (2000) Partial root-zone drying - effects on root distribution and commercial application of a new irrigation technique. Wine Industry Journal, **15**, 74-77.

Sumner M (1995) Soil crusting: Chemical and physical processes. The view forward from Georgia, 1991. Edited by HB So, GD Smith, SR Raine, BM Schafer and RJ Loch. Sealing, crusting and hardsetting soils: productivity and conservation. Proceedings 2nd International Symposium on Sealing, Crusting and Hardsetting Soils, Australia, (Australian Soil Science Society Inc., Queensland Branch

Terry RE and Nelson SD (1986) Effects of polyacrylamide and irrigation method on soil physical properties. Soil Science, **141**, 317-320.

Tisdall JM (1978) Ecology of earthworms in irrigated orchards. In WW Emerson, RD Bond and AR Dexter (eds). Modification of Soil Structure. (Wiley, Chichester) pp 297-303.

van Huyssteen L (1983) Interpretation and use of penetrometer data to describe soil compaction in vineyards. South African Journal of Enology and Viticulture, **4**, 59-65.

van Huyssteen L (1988a) Soil preparation and grapevine root distribution - a qualitative and quantitative assessment. In: The Grapevine Root and Its Environment. (Compiled by JL van Zyl, Dept Agriculture & Water Supply, South Africa), **1**, 1-15.

van Huyssteen L (1988b) Grapevine root growth in response to soil tillage and root pruning practices. In: The Grapevine Root and Its Environment. (Compiled by J. L. Van Zyl, Dept Agriculture & Water Supply, South Africa), **4**, 44-56.

van Huyssteen L and Weber HW (1980a) The effect of conventional and minimum tillage practices on some soil properties in a dryland vineyard. South African Journal of Enology and Viticulture, **1**, 35-45.

van Huyssteen L and Weber HW (1980b) Soil moisture conservation in dryland viticulture as affected by conventional and minimum tillage. South African Journal of Enology and Viticulture, **1**, 67-75.

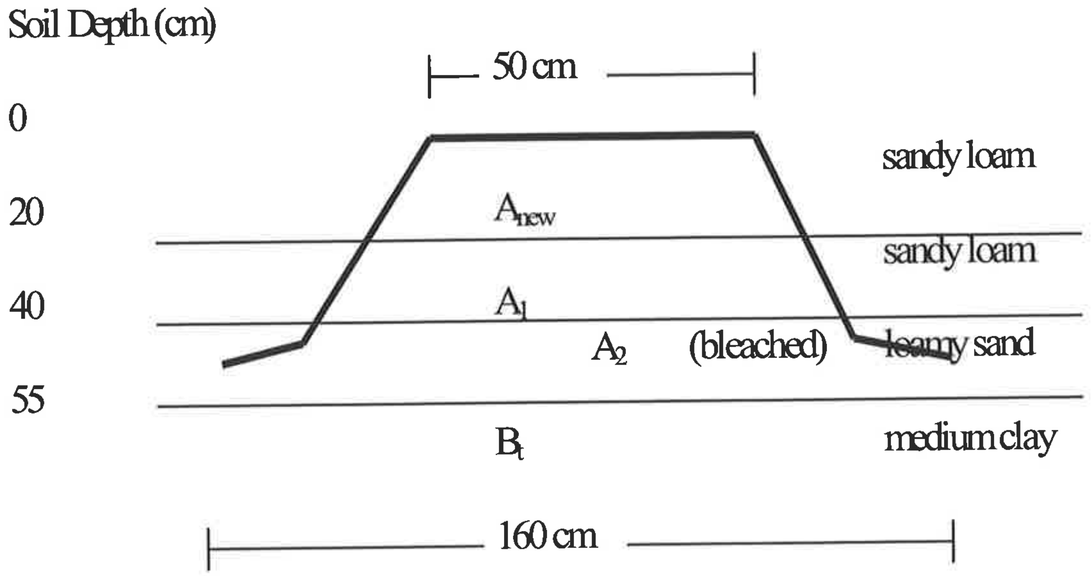
van Huyssteen L and Weber HW (1980c) The effect of selected minimum and conventional tillage practices in vineyard cultivation on vine performance. South African Journal of Enology and Viticulture, **1**, 77-83.

van Zyl JL (1988) Response of grapevine roots to soil water regimes and irrigation systems. In: The Grapevine Root and Its Environment. (Compiled by JL Van Zyl, Dept Agriculture & Water Supply, South Africa), **4**, 30-43.

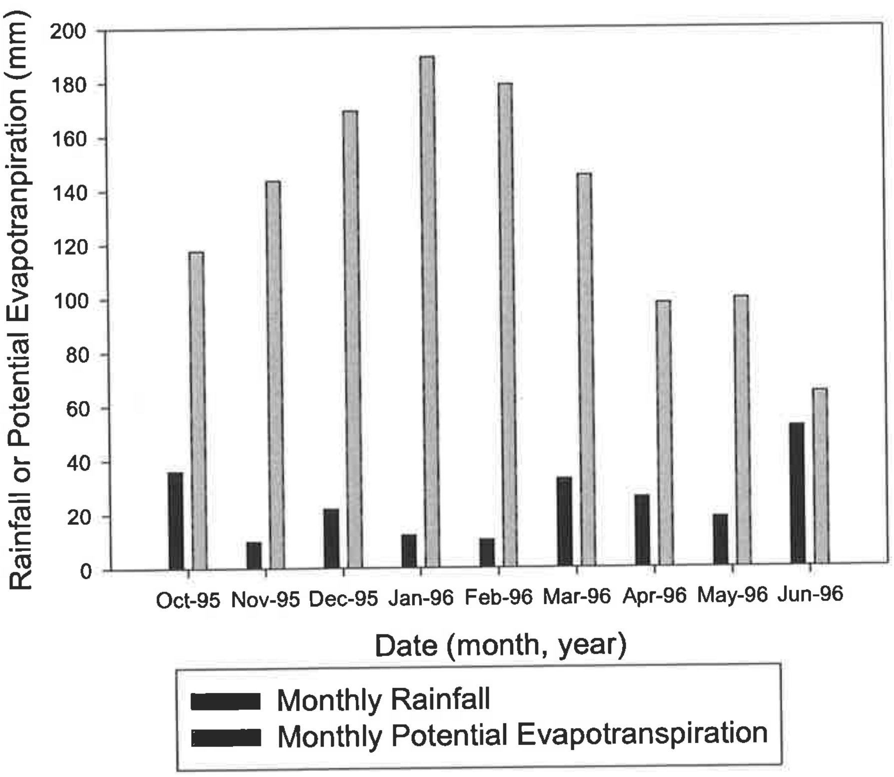
Wallace A and Wallace GA (1996) Need for solution or exchangeable calcium and/or critical EC level for flocculation of clay polyacrylamides. *Proc Managing Irrigation-Induced Erosion and Infiltration With Polyacrylamide*. Idaho, USA. Edited by RE Sojka and RD Lentz. (University of Idaho, USA) University of Idaho Miscellaneous Publication No 101-96, 59-63

Woodham RC and Alexander DMcE (1966) The effect of root temperature on development of small fruiting sultana vines. Vitis, **5**, 345-350.

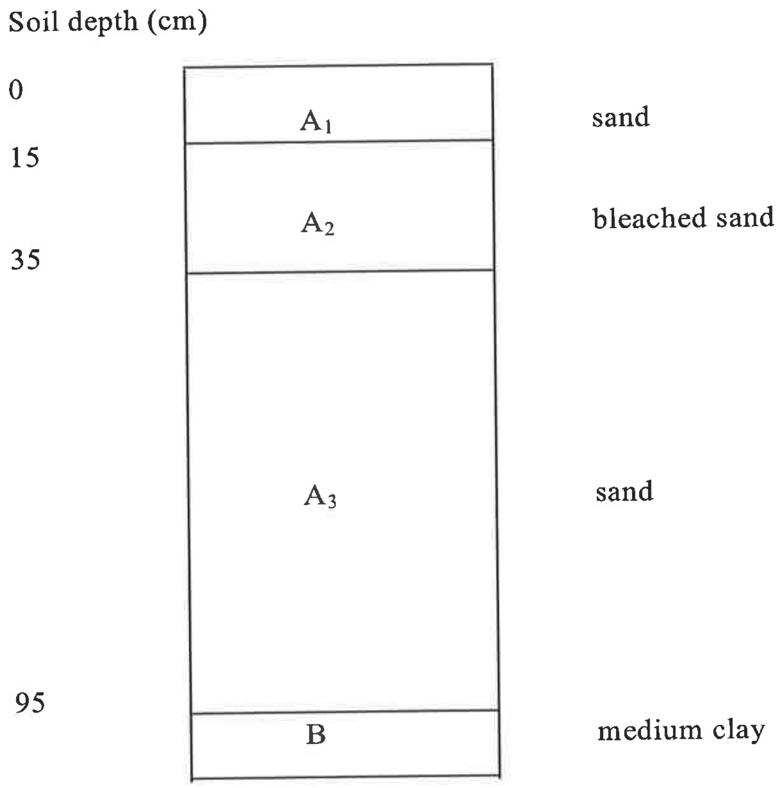
11 APPENDIX FIGURES



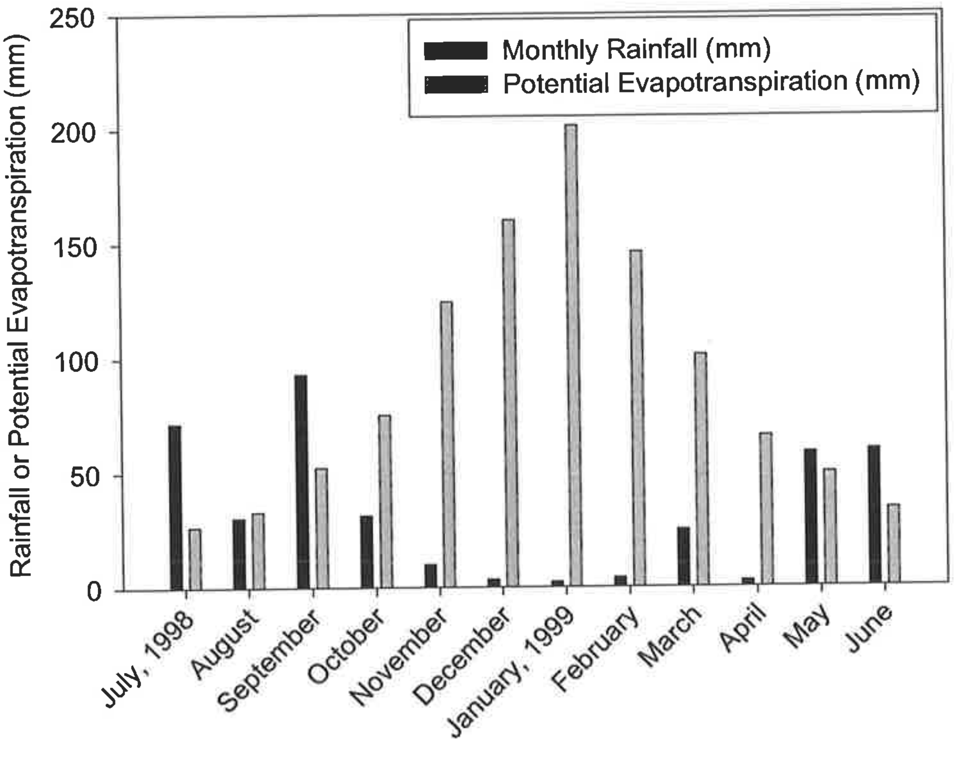
Appendix Figure 11.1
Soil profile, mound dimensions and description of mounded soil (A_{new}-horizon and below) and traditional flat soil (A_1-horizon and below) at Lyndoch.



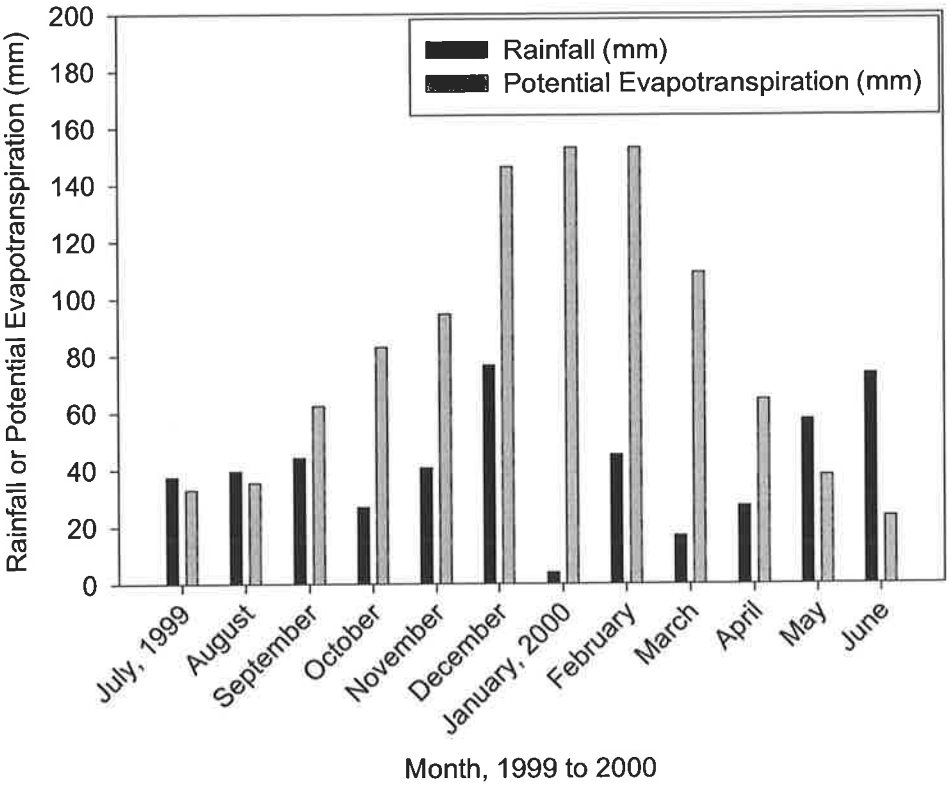
Appendix Figure 11.2 Monthly rainfall, potential evapotranspiration, Lyndoch, 1996.



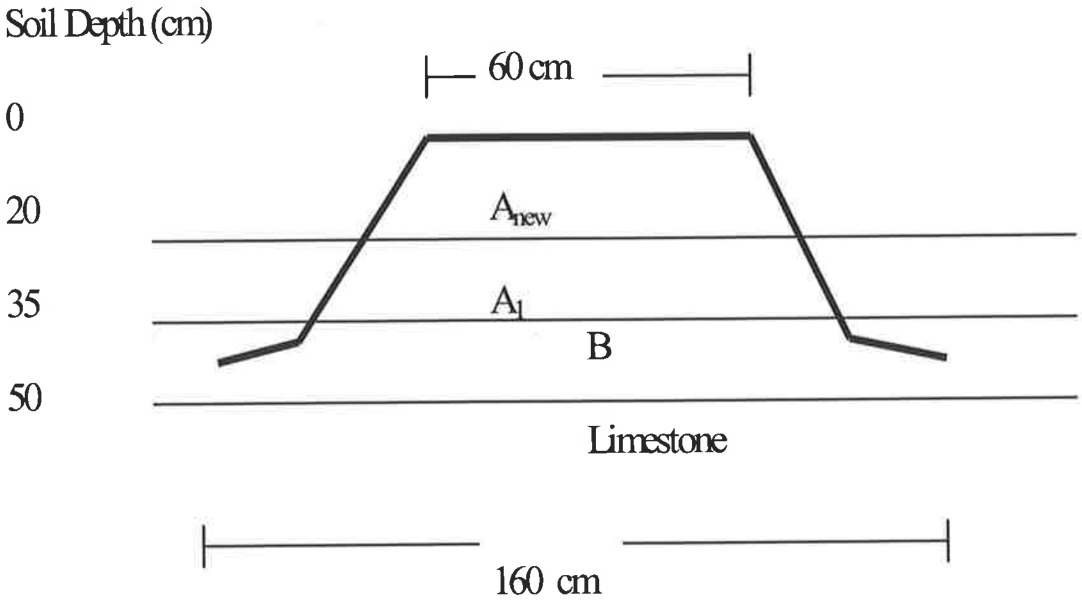
Appendix Figure 11.3 Soil Profile at Padthaway Range.



Appendix Figure 11.4 Monthly rainfall and potential evapotranspiration at Padthaway, 1998 to 1999.

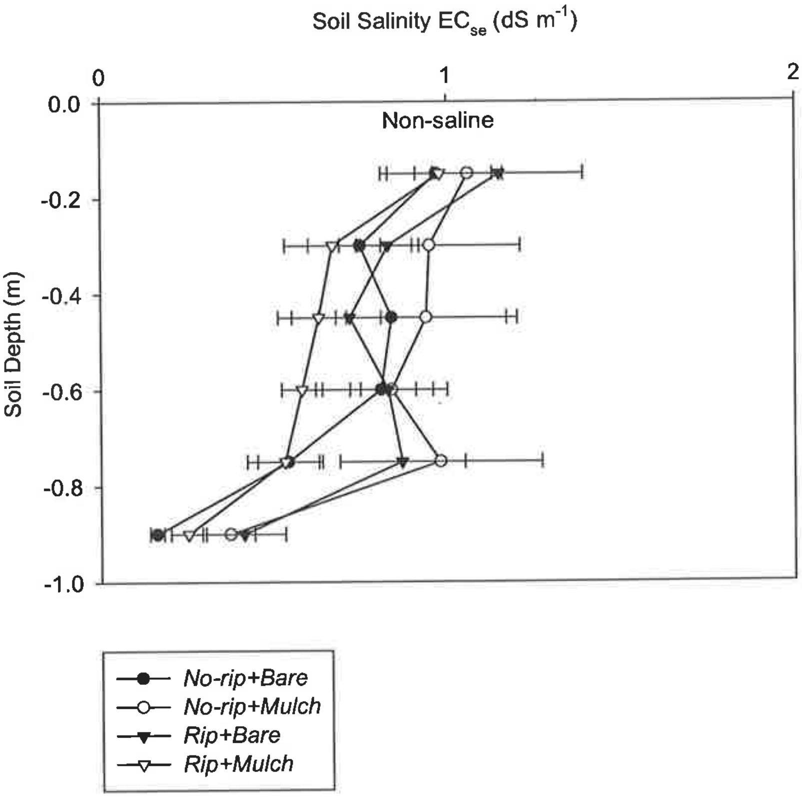


Appendix Figure 11.5 Monthly rainfall and potential evapotranspiration at Padthaway, 1999 to 2000.

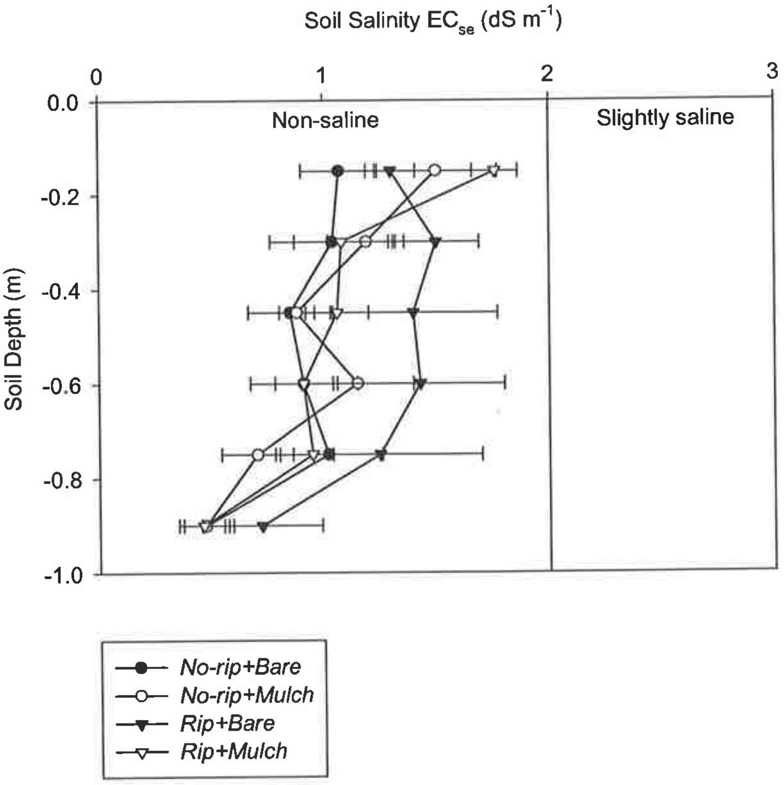


A_{new}- and A_1-horizons: sandy clay loam
B-horizon: medium clay

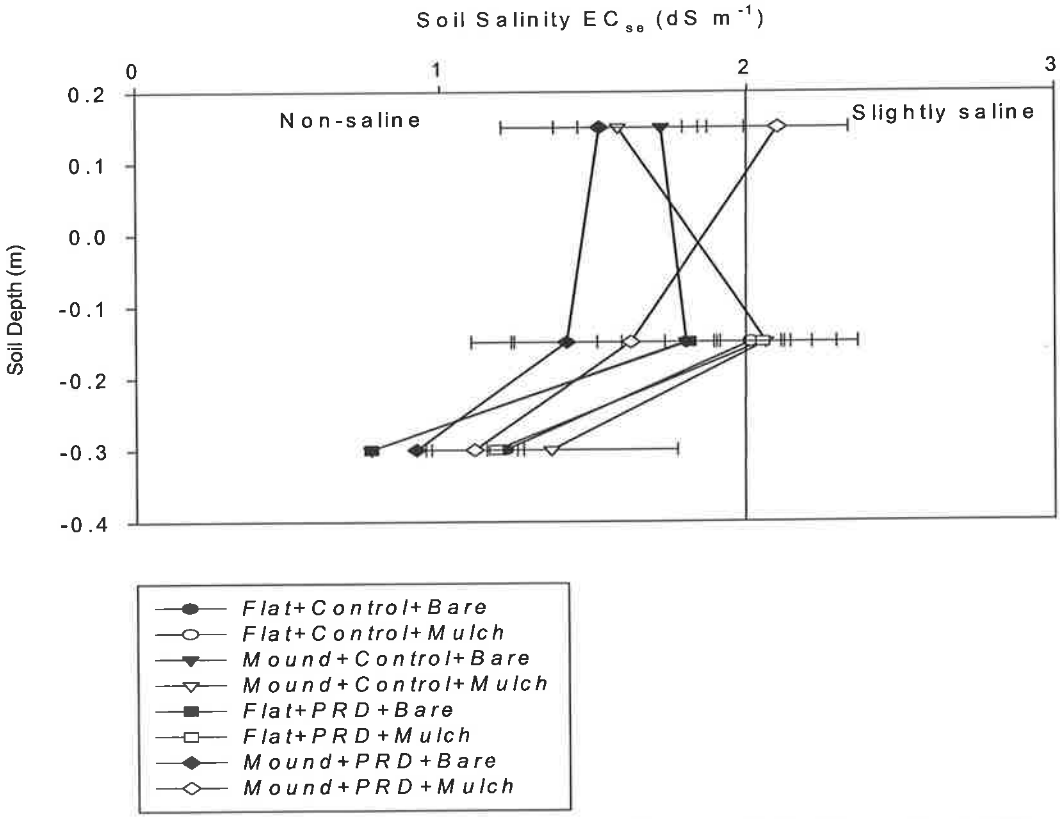
Appendix Figure 11.6 Soil profile, mound dimensions and description of mounded soil (A_{new}-horizon and below) and traditional flat soil (A_1-horizon & below) at Padthaway Plain.



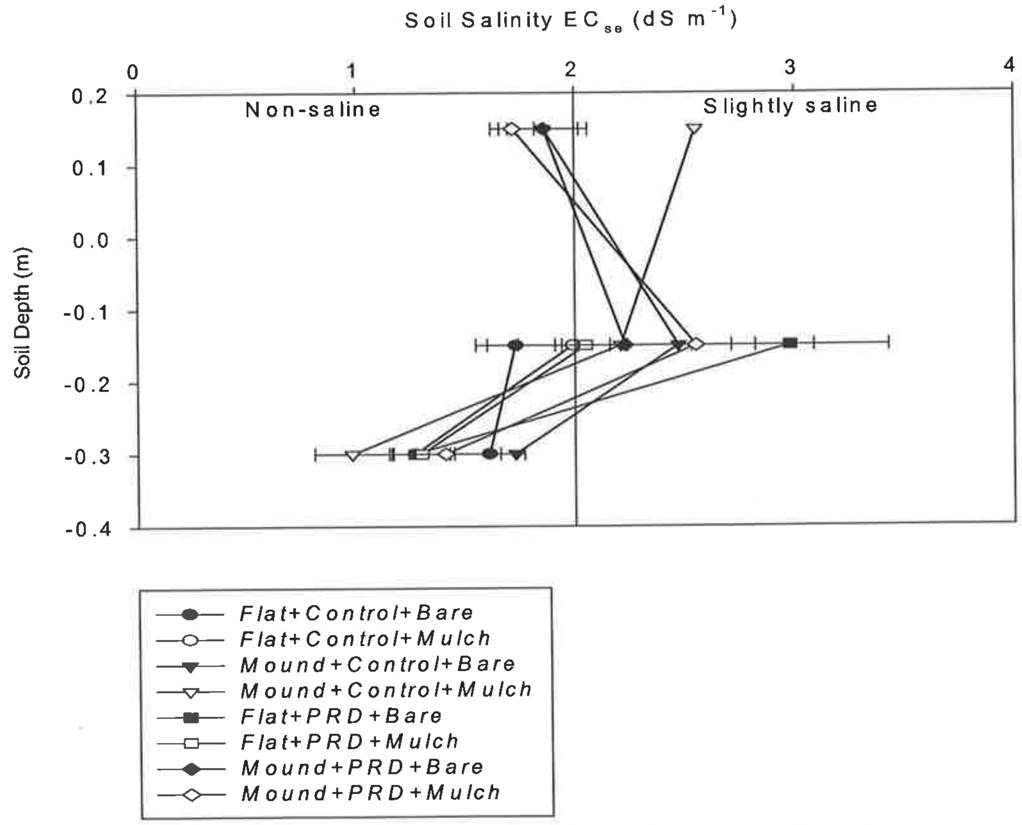
Appendix Figure 11.7 Soil salinity (EC_{se}) at Padthaway Range, February 1999.



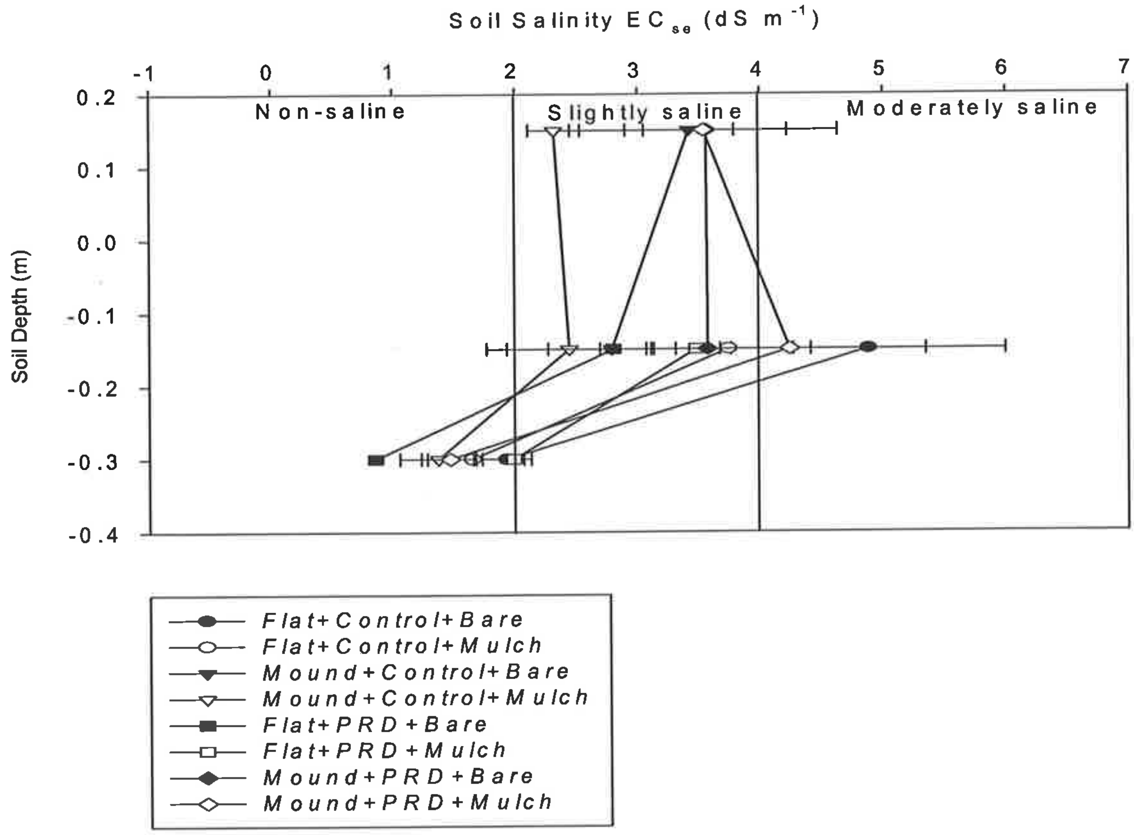
Appendix Figure 11.8 Soil salinity (EC_{se}) at Padthaway Range, January 2000.



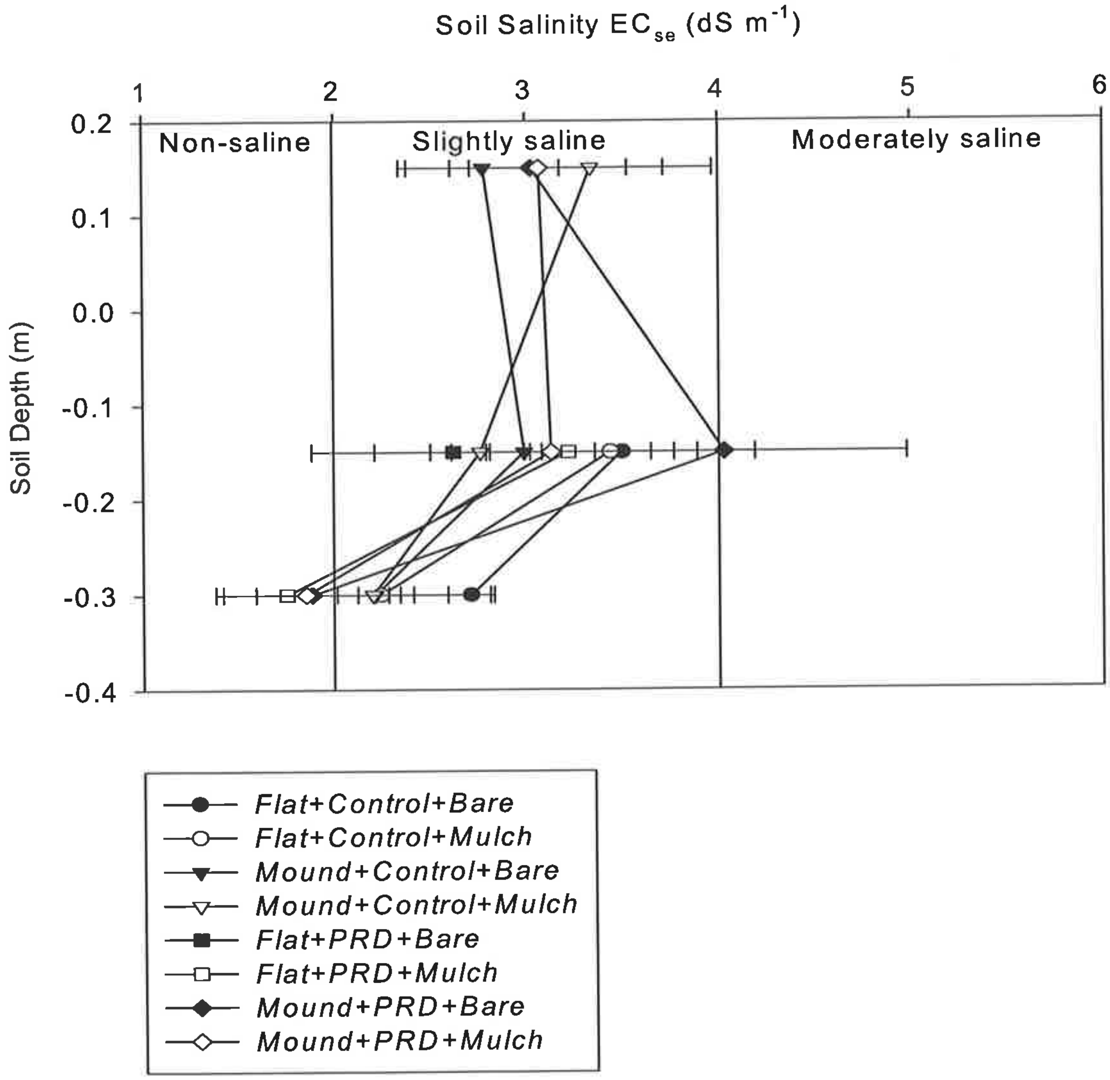
Appendix Figure 11.9 Soil salinity (EC_{se}) at Padthaway Plain, December 1998.



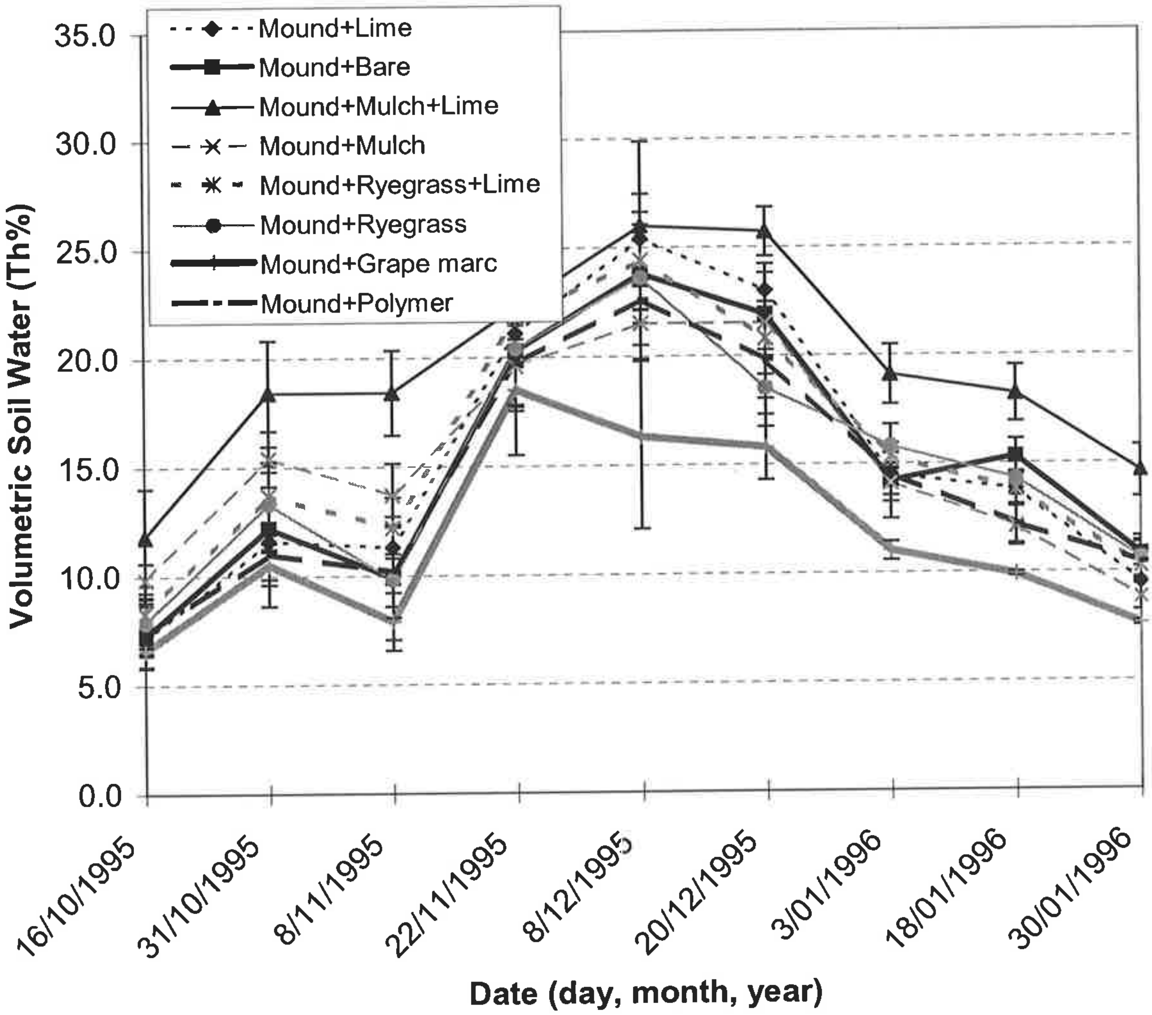
Appendix Figure 11.10 Soil salinity (EC_{se}) at Padthaway Plain, December 1999.



Appendix Figure 11.11 Soil salinity (EC_{se}) at Padthaway Plain, February 1999.

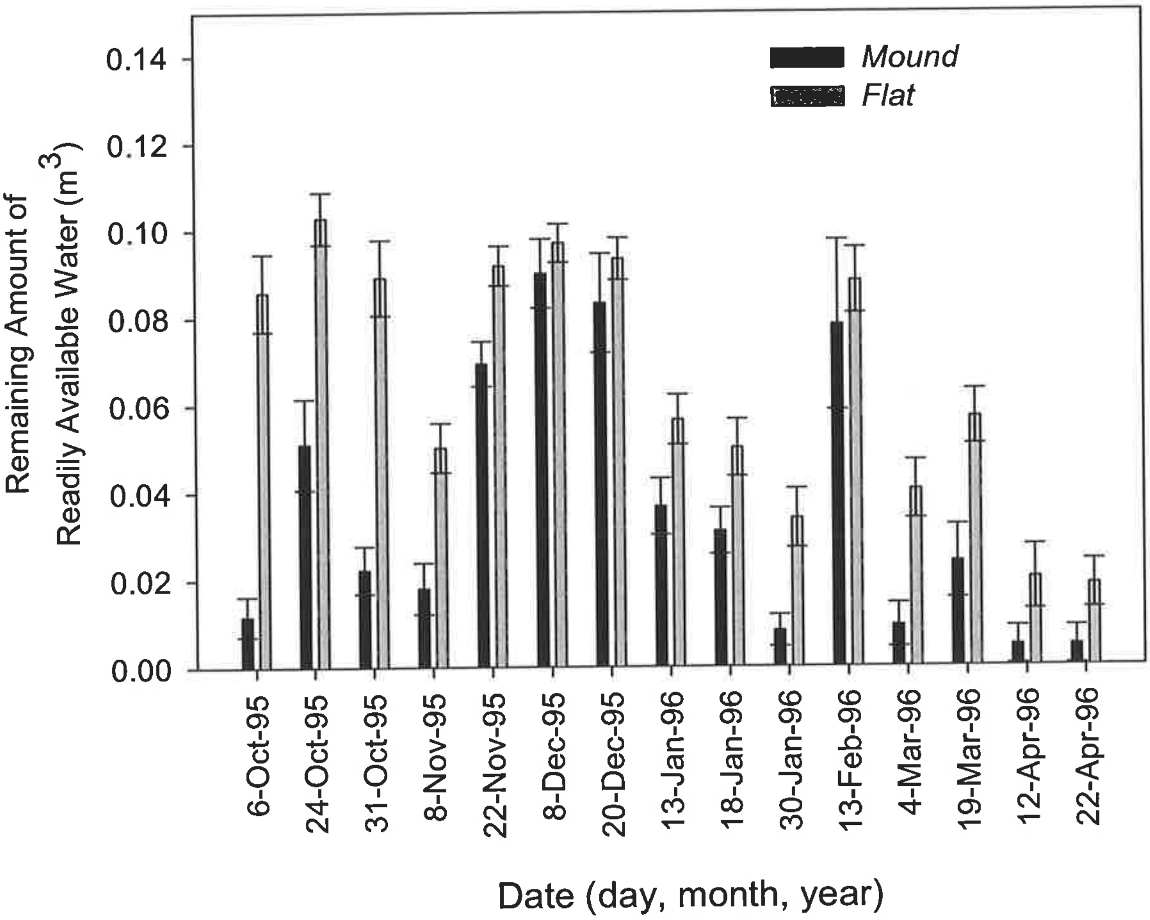


Appendix Figure 11.12 Soil salinity (EC_{se}) at Padthaway Plain, January 2000.

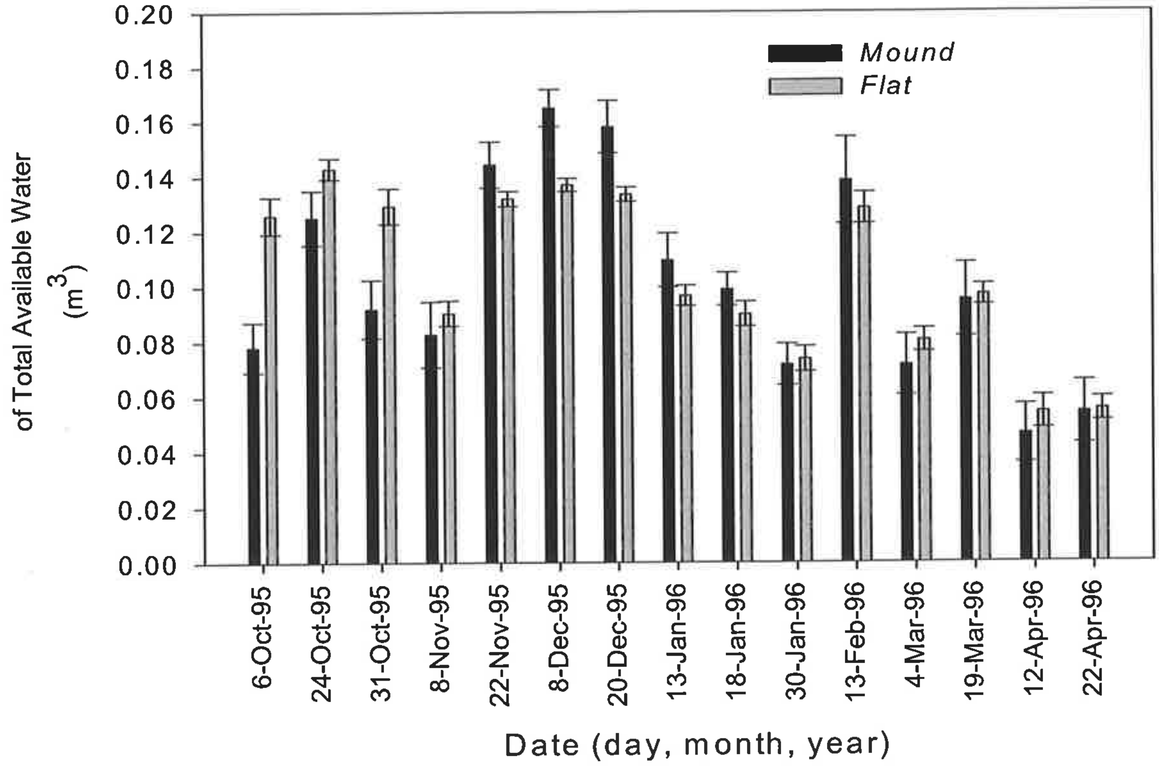


Appendix Figure 11.13

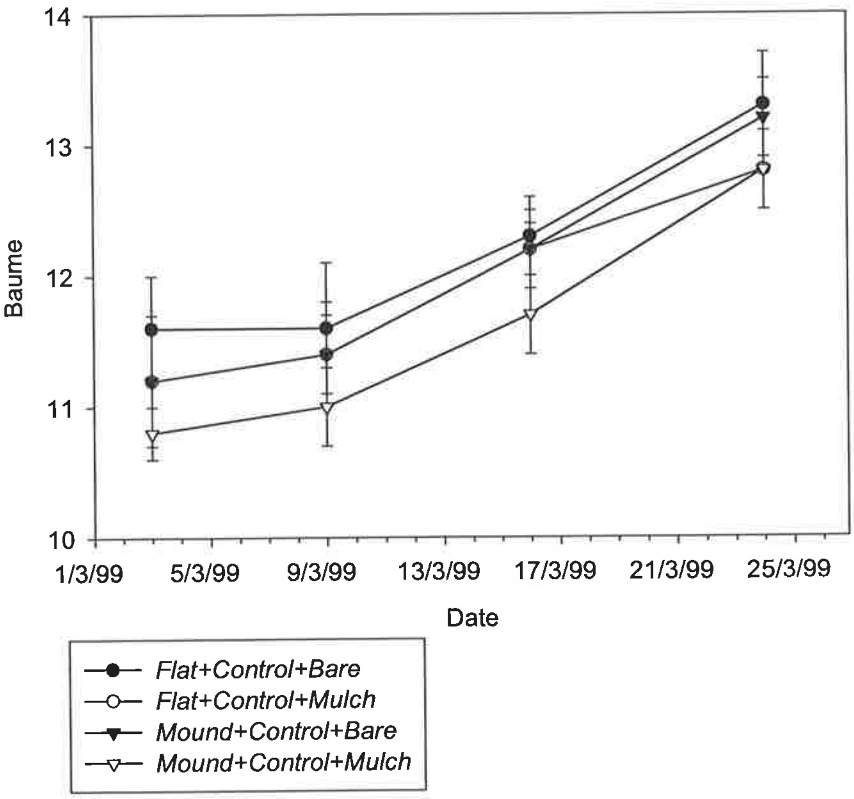
Average volumetric soil water content from 0 to 300 mm depth of mounded soil with alternative soil surface covers at Lyndoch, 1996.



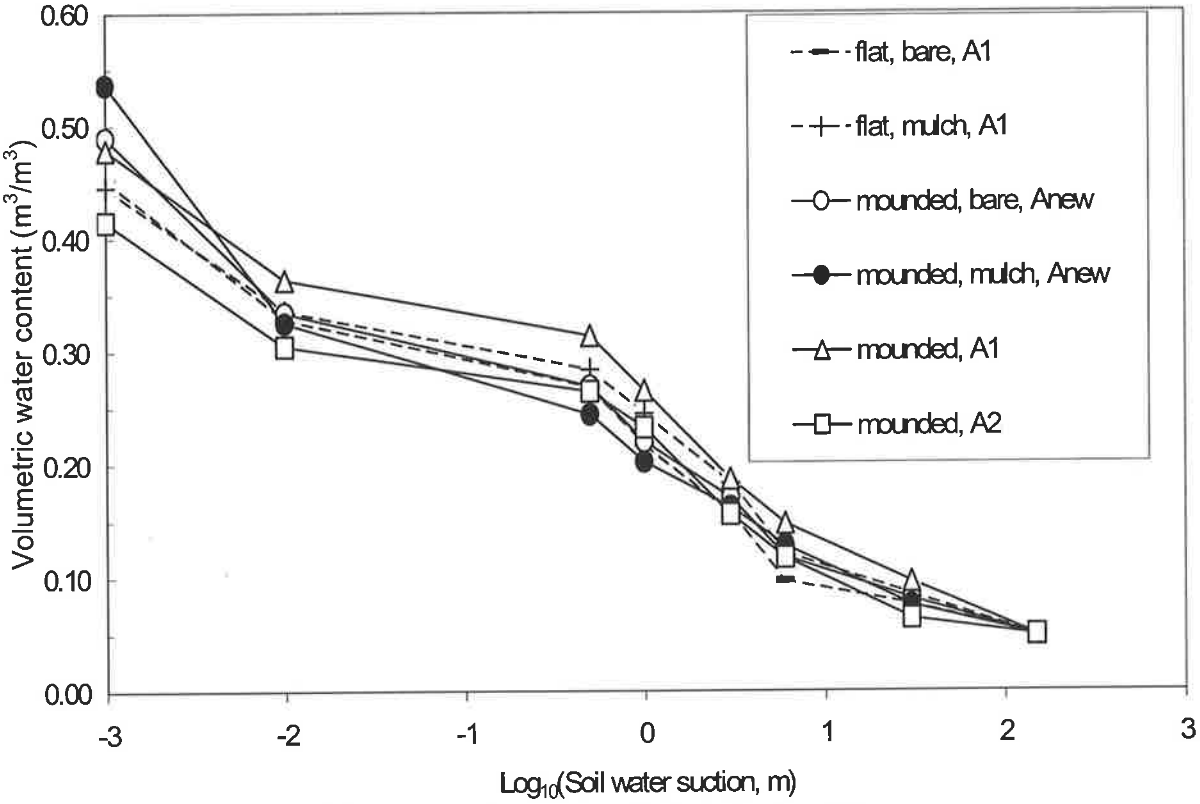
Appendix Figure 11.14
Remaining readily available water from October 1995 to April 1996 at Lyndoch.



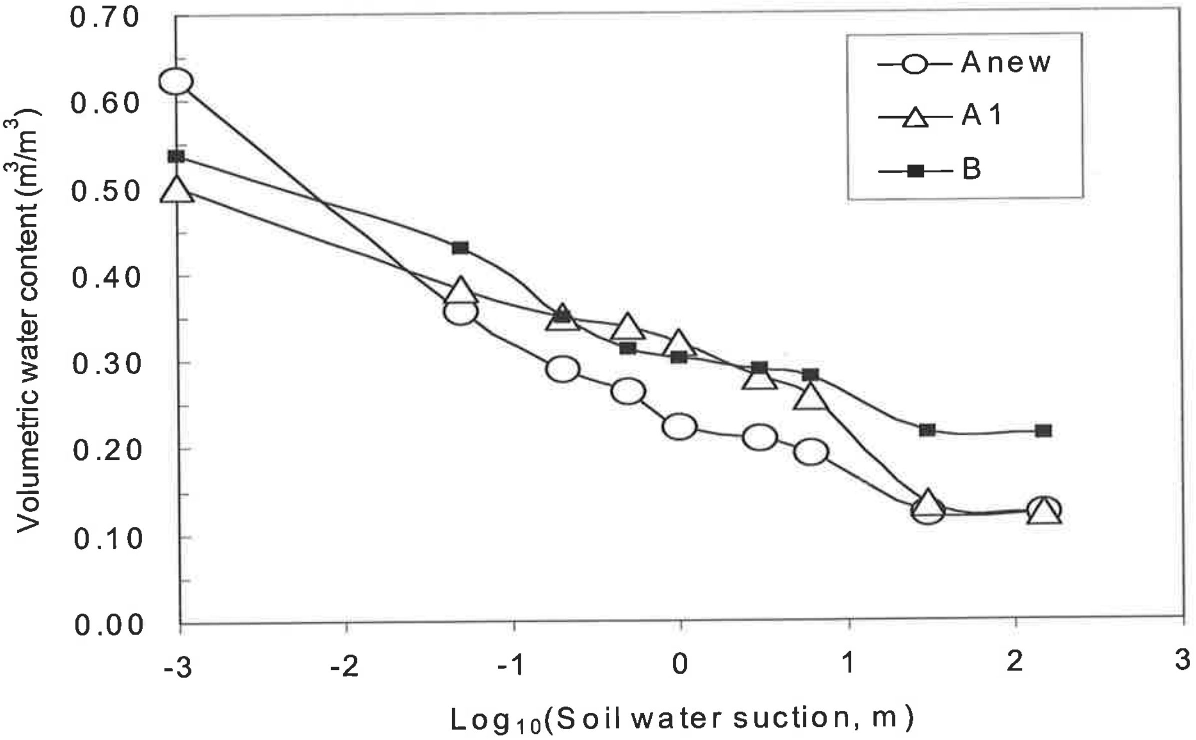
Appendix Figure 11.15 Remaining total available water from October 1995 to April 1996 at Lyndoch.



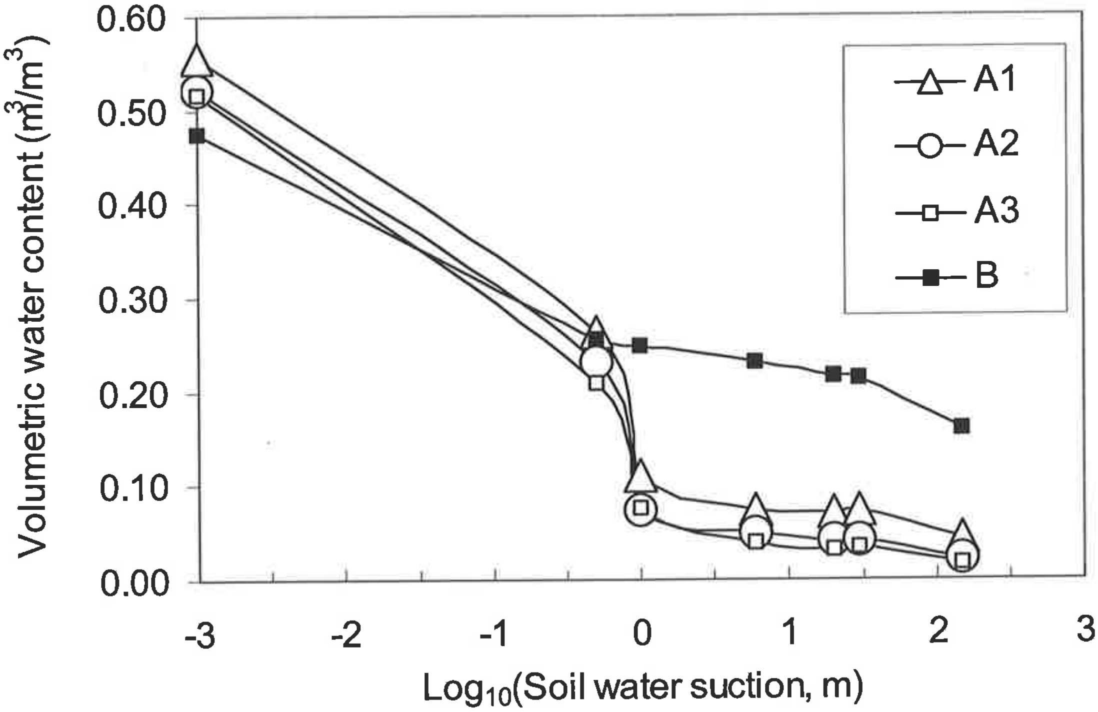
Appendix Figure 11.16 °Baume at Padthaway Plain, Control irrigation, 1999.



Appendix Figure 11.17. Water retention curves for Lyndoch, 1995.



Appendix Figure 11.18. Water retention curves for Padthaway Plain, 1998.



Appendix Figure 11.19. Water retention curves for Padthaway Range, 1998.

Appendix Table 11.1

Bulk density of soils at Padthaway Range. Bulk densities with different subscripts are significantly different at the $\alpha = 0.05$ significance level.

Year	Soil management	Soil Horizon	Bulk Density (g cm^{-3})
1998	*No-rip*	A_1	1.18_a
1998	*No-rip*	A_2	$1.27_{a,b}$
1998	*No-rip*	A_3	1.28_b
1998	*No-rip*	B	1.39_c
2000	*No-rip+Mulch*	A_1	1.34_b

Appendix Table 11.2

Bulk densities of soils at Padthaway Plain. Bulk densities with different subscripts are significantly different at the $\alpha = 0.01$ significance level.

Year	Soil Management	Soil Horizon	Bulk Density (g cm^{-3})
1998	*Mound+Control+Bare*	A_{new}	0.99_a
1998	*Mound+Control+Bare and Flat+Control+Bare*	A_1	1.32_b
1998	*Mound+Control+Bare and Flat+Control+Bare*	B	$1.23_{b,c}$
2000	*Mound+Control+Bare*	A_{new}	1.35_b
2000	*Mound+Control+Mulch*	A_{new}	$1.09_{a,c}$
2000	*Flat+Control+Mulch*	A_1	1.31_b

Appendix Method 11.1 Sugar Concentration Chem 5b Method

All °Baume and SG hydrometers are calibrated at 20°C.

Rinse a measuring or hydrometer cylinder with about 20 ml wine, and then fill the cylinder to about 3/4 full. Bring the wine to 20°C, immerse the clean, dry hydrometer, raising and lowering it several times, to ensure that the liquid is thoroughly mixed.

Wipe the stem dry and allow the hydrometer to come to equilibrium.

When the hydrometer is at its correct level, it should be gently spun to expel any air bubbles adhering to its surface.

Read the scale at the bottom of the meniscus, i.e. where the level of the liquid in the cylinder cuts the scale when read from below the plane of the liquid surface.

Ignore any effects of the meniscus around the stem of the hydrometer.

Take the temperature of the sample immediately after °Baume reading with a standardised thermometer.

Appendix Method 11.2 The Potentiometry Method

Equipment

* Radiometer pH meter
* Silver wire - 10 cm. of 99.99% (can be purchased from Crown Scientific)
* Glass electrode
* 0-10 m burette
* Small magnetic stirrer and bars
* 100 ml glass beakers
* 50 ml volumetric pipette
* Pasteur pipettes

Reagents

1. 0.1N Silver Nitrate
   Make up from an ampoule.
   This solution should be stored in a foil-covered bottle and kept in a cupboard when not in use.
   Exposure to light causes the solution to turn a brown grey colour.
2. 1+5 Nitric Acid
   In a fume cabinet, carefully add 100 ml of conc. Nitric Acid to 500 ml of water.
   Mix thoroughly.
3. 200 ppm Chloride Standard
   Accurately weigh 0.3297g Sodium Chloride.
   Transfer the Sodium Chloride to a 1 Litre volumetric flask, half filled with distilled water.
   Add 100 ml SVR to the flask.
   Mix and top up the flask with distilled water at 20°C.

Procedure

1. Set up Radiometer pH meter with the silver wire and glass electrode connected to read in ‘mV’.
2. Pipette 50 ml of sample into a 100 ml beaker.
   Add 5 drops of 1+5 Nitric Acid to the beaker.
3. Record the initial "mV" of the sample.
   Stir the sample well throughout the test and record "mV" readings after each 0.1 ml addition of Silver Nitrate.
   As the equivalence point is approached, the "mV" change per volume of Silver Nitrate added increased rapidly, reaching a maximum at equivalence point.
4. Repeat Steps (2) and (3) to obtain duplicate results.
   Chloride (ppm) - ml Silver Nitrate x 71
5. A 200 ppm Chloride standard should also be analysed, (using same method, substituting Chloride standard for the sample), as a procedure and solution strength check.
   The Chloride result obtained should lie between 185-215 ppm.
6. Store the electrode in distilled water when not in use.

Appendix Method 11.3 Determination of red pigment (colour) and total phenolics of grape berries

1. Tare a beaker with a clean empty centrifuge tube in it on the balance.
2. Thoroughly mix the homogenate in the vial by stirring and shaking.
3. Take a scoop of approx. 1 -1.2 g of homogenate and transfer into the pre-tared centrifuged tube.
4. Record the weight of homogenate taken on the record sheet.
5. Add 10 ml (approx.) of aqueous ethanol (50%, pH 5.0) stored in the alcohol cabinet, to the centrifuge tube, cap the tube and mix the contents periodically by inverting the tube about every 10 minutes for a period of one hour.
6. Centrifuge the tube and contents at 2500 rpm for 10 minutes.
7. Using the Finn stepper hand pipette set at 5, with the 5.0 ml Finn tip, transfer 0.5 ml of the supernatant into a capped tube along with 5 ml of 1M HCL (1.0N HCL) mix thoroughly and let stand for three hours. (Need beaker of distilled water for cleaning Finn stepper between samples).
8. Pour the remaining supernatant carefully into a measuring cylinder and record the total volume.
9. Lamps D_2 and W from the Spectrophotometer must be preheated for at least 30 minutes before use so ensure that these are turned on after 2.5 hours waiting time has elapsed.

Spectrophotometer Method

1. Using quartz cuvettes, important to hold correctly and wipe down before being placed in the Spectrophotometer.
2. Fill two cuvettes with distilled water (called blanks).
3. Fill cuvettes almost to the top.
4. Place the blanks in the Spectrophotometer, one at the back (which stays there for reference) and one at the front. Close the lid, ensuring that the front tube is lined up with the light source.
5. Set lamp selector to D_2 lamp (preheated). Pull preheat lever towards you, holding for 15 seconds, then switch lamp on.
6. Set wavelength to 280 nm.
7. Turn ABS dial until the readout is zero.
8. Remove front blank and replace contents with that from the first capped tube and place in Spectrophotometer.
9. Take reading, writing the result on the record sheet.
10. Pour contents of cuvette back in to capped tube and refill with the next one.
11. Continue until all the readings at 280 nm have been completed.
12. Refill front cuvette with distilled water and place in Spectrophotometer.
13. Set lamp selector to W lamp (preheated).
14. Set wavelength to 520 nm.
15. Turn ABS dial until the readout is zero.
16. Remove front blank and replace contents with that from the first capped tube and place in Spectrophotometer.
17. Take reading; write the result on the record sheet.
18. Pour contents of cuvette back in to capped tube and refill with the next one.
19. Continue until all readings at 520 nm have been completed.
20. Clean all equipment used thoroughly and place back in proper place.