

SUSTAINABLE **IRRIGATION** MANAGEMENT UPDATE



Guidelines for Managing Soil Structure in Irrigated Vineyards

Robert Murray, Michael McCarthy and Cameron Grant

Published by: National Program for Sustainable Irrigation,
Postal address: PO Box 802 Narrabri NSW 2390 02 6792 4088
Internet: www.npsi.gov.au
Designed by: Meta Design Studio, Canberra ACT

© 2011 National Program for Sustainable Irrigation. All organisations grant permission for the general use of any and all of this information, provided its source is acknowledged.

Disclaimer

The information contained in this publication is intended for general use, to assist public knowledge and discussion and to help improve the sustainable management of land, water and vegetation. It includes general statements based on scientific research. Readers are advised and need to be aware that this information may be incomplete or unsuitable for use in specific situations. Before taking any action or decision based on the information in this publication, readers should seek expert professional, scientific and technical advice. The authors, The University of Adelaide, South Australian Research & Development Institute, Grape and Wine Research and Development Corporation, the National Program for Sustainable Irrigation and its partners do not assume liability of any kind whatsoever resulting from any person’s use or reliance upon the content of this publication.

National Program for Sustainable Irrigation

The National Program for Sustainable Irrigation focuses research on the development and adoption of sustainable irrigation practices in Australia. The Program has fourteen funding partners.

The National Program for Sustainable Irrigation is a partnership of Australian Government Department of Sustainability, Environment, Water Population and Communities, Cotton Research & Development Corporation, Gascoyne Water Co-operative, Goulburn-Murray Rural Water Corporation, Grains Research & Development Corporation, Harvey Water, Horticulture Australia Limited, Lower Murray Water, Ord Irrigation Co-operative, South Australian Research and Development Institute, Sugar Research & Development Corporation, SunWater, and Western Australia Department of Water.

This project was also co-funded by

The University of Adelaide
School of Agriculture, Food and Wine, South Australia 5005

Grape and Wine Research and Development Corporation
PO Box 221 Goodwood, SA 5034
www.gwrdc.com.au

South Australian Research & Development Institute
SARDI Sustainable Systems - Viticulture, GPO Box 397,
Adelaide 5001

Publication information

ISBN: 1 921025 30 1
Date: 3/1/2011

The research team would like to acknowledge the contribution of the following organisations:

Cooperating Growers
Riverina Wine Grapes Marketing Board
New South Wales Department of Primary Industries
Victoria Department of Primary Industries
National Program for Sustainable Irrigation
Grape and Wine Research and Development Corporation
SARDI
The University of Adelaide

For more information:

Dr Robert Murray
Visiting Research Fellow
School of Agriculture, Food and Wine
Prescott Building
Waite Campus
The University of Adelaide, AUSTRALIA 5005
Ph : +61 8 8303 7373
Fax : +61 8 8303 6511
e-mail: robert.murray@adelaide.edu.au

TABLE OF CONTENTS

Soil structure – it’s all about pores	2
Why is soil structure important?	3
Which soils are affected?	6
What causes soil structure decline?	6
How can good subsoil structure be restored in existing vineyards?	6
What can be done in the meantime?	7
Minimizing subsoil structure problems in new vineyards	9
Saving the pores - how can good subsoil structure be maintained?	11
How is soil structure measured?	12
Is there a downside to improving subsoil structure?	12
Is it worth the trouble?	12
Acknowledgment	13
Further reading	13

Key messages for managing soil structure in irrigated vineyards in winter rainfall zones

- Root growth and function, and therefore the efficiency of water and nutrient use, is inhibited by poor subsoil structure in many irrigated vineyards in south-eastern Australia.
- Improved soil structure in the vine root zone of existing vineyards requires vine row cover crops in winter, vine row mounding and reduced inter-row traffic.
- Improved soil structure in new vineyards generally requires gypsum, *much* more careful deep tillage, row mounding and stabilization of soil structure by a large root population, all *before* vine planting takes place.
- Ongoing maintenance of soil structure requires reduced inter-row traffic, a permanent strategy of using the roots of winter-active plants to create and maintain soil structure in the vine row, and regular gypsum applications especially where water quality is poor.

Soil structure – it’s all about pores

Good *soil structure* is essential for healthy, resilient plants because it allows them to develop extensive, active root systems. This promotes efficient use of water and nutrients, encourages biological activity and cushions plants against drought and other hardship.

The general perception of a soil with good structure is that it is well-drained, easy to penetrate and crumbles readily into aggregates of about 1–10 mm that remain intact when they are wet.



Soil structure is determined by the size, number and arrangement of the spaces or *pores* in the soil. These pores are filled with water, air, organic matter, roots and other living organisms.

All soils, even those with poor structure, have pores. The smaller pores (smaller than about 0.1 mm) are between the individual particles of sand, silt and clay that make up the soil and determine its *texture* and water-holding capacity. These small pores are more or less permanent features that are seldom changed by land management¹. For this reason the term *soil structure* is most commonly used to discuss the larger pores.

These larger pores are the spaces between soil aggregates, the cracks caused by clay shrinkage and the channels left by biological processes such as the growth and decay of roots and the activities of soil fauna. It is these larger pores that are vulnerable to land management.

Why is soil structure important?

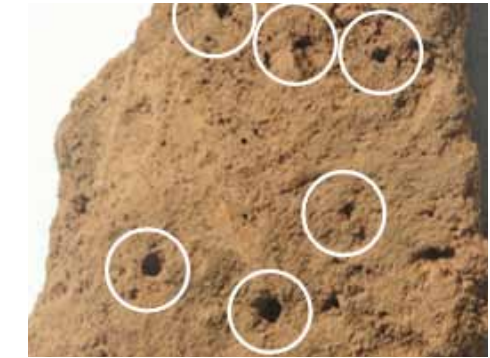
The two most important soil properties controlled by the larger pores in soil are *permeability* and *strength*.

Permeability governs the movement of water, air and organisms through soil. This means that it controls the infiltration and drainage of water, oxygen supply to roots (aeration), leaching of salts, movement and transformation of nutrients and the activities of roots and soil organisms.

Soil strength, often measured as penetration resistance, is critical during root growth. Roots must either grow into existing pores or else create new ones. When soil structure is bad, neither of these is an option; there are no pores large enough to accommodate roots and the soil is too strong to allow them to be created.



Room to move? Roots must either grow into existing pores or else create new ones. (image courtesy Rosemary White, CSIRO Plant Industry)



Larger pores (1–2 mm) in a subsoil clod. Old root channels promote infiltration, supply oxygen and provide pathways for new root growth.

¹ The only common exceptions to this occur when large amounts of organic matter are added to soil or large amounts of clay are added to sand to overcome water repellence. Both of these can improve water retention by changing the soil texture.



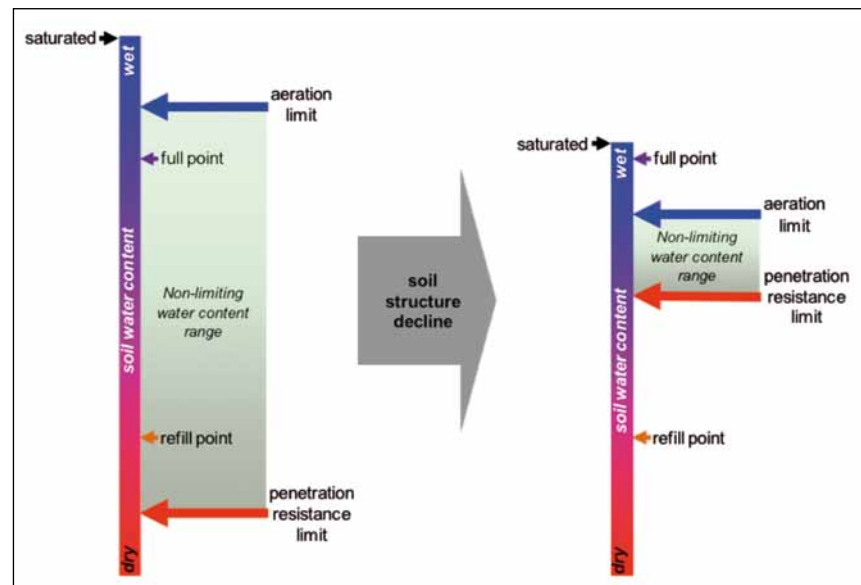
A duplex (texture-contrast) soil. It might have enough water and nutrients but are there any large pores, especially below 40 cm?

If water and nutrients are to be used efficiently and plants are to be resilient, it's important that their roots can grow and function in a large zone of soil. In many Australian soils the structure is acceptable only near the surface so that root activity is effectively trapped in the topsoil and denied the water and nutrient resources in the subsoil. Such *subsoil constraints* have several chemical and physical causes; poor subsoil structure is often the major one.²

The larger pores essential for good soil structure are easily lost under conventional management practices. This loss is usually described by the terms *soil structural decline* or *soil structural degradation*. As this occurs, the soil becomes denser and the range of soil water contents, over which roots can grow and function properly, gets narrower as shown in the diagram below.

In a soil with good structure (left of diagram), excess water drains quickly through larger pores after heavy rainfall or irrigation so that roots are soon re-supplied with oxygen and can grow and function over a large range of water contents down to the refill point and beyond. High resistance to penetration by roots occurs only when the soil is fairly dry.

When soil structure declines (right of diagram), the larger pores are lost. The soil now drains slowly through smaller pores after heavy rainfall or irrigation and there is a period of root inactivity (including reduced water uptake) until the supply of oxygen is restored to the roots. As the soil dries further the penetration resistance rises rapidly and prevents root growth. In this way the "window" of water contents that is non-limiting to roots closes as soil structure declines.



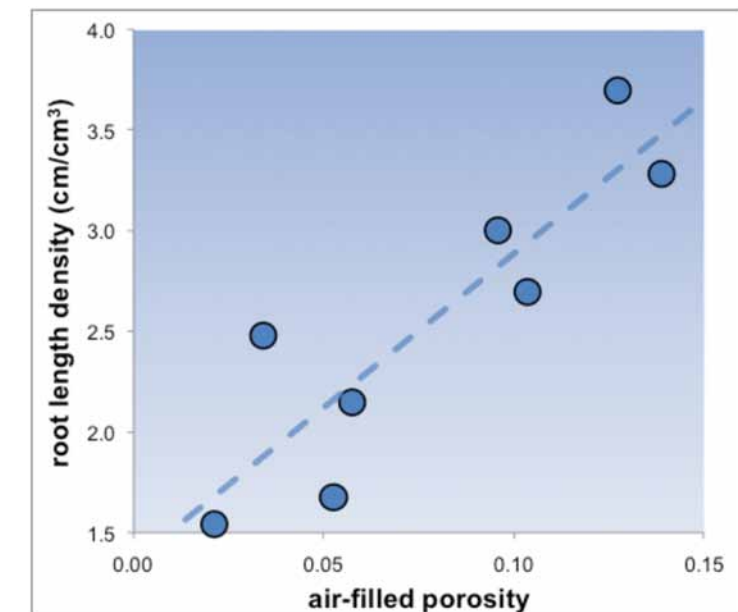
The "non-limiting" soil water content ranges in soil with good (left) and with poor (right) structure. (adapted from Letey, 1985)

² Other examples are Boron toxicity, extreme pH, nutrient deficiencies, waterlogging and salinity.

Recently, the structure of many subsoils in vineyards in the Barossa Valley, Currency Creek, Sunraysia and the Murrumbidgee Irrigation Area has been found to be very poor. The research examined subsoils (at depths of 20-50 cm) because this is where the major structure problems are and because subsoils are much harder to manage than surface soils. The "window" of non-limiting soil water content in practically all of these subsoils is close to zero. In other words, penetration resistance to roots is too high or aeration is too low at all water contents.

Measurements of root length densities show that poor aeration, closely followed by high penetration resistance are the major problems; there are no other obvious subsoil constraints. This means that during the growing season, much of the vine root activity in these vineyards is confined to the surface soil because roots can't take refuge in a hostile subsoil so they are dependent on timely irrigation. These subsoils are a lost resource because, although they have high water- and nutrient-holding capacities, they can't be fully exploited by roots.

The graph opposite shows how subsoil structure in some Barossa Valley vineyards has affected root growth. The density of vine roots in the subsoil (i.e. total length of vine roots in a fixed volume of soil) is plotted against the available air in the subsoil some time after irrigation³. It is clear that poor availability of oxygen in the root zones of these vineyards has retarded root growth to varying degrees and is reflected in a 240% difference in vine root length densities.



Smaller root length densities reduce the ability of vines to gather water and nutrients and makes the vines more dependent on timely irrigation. Not only are there less roots to support the vines but, because the reduced root density results from poor aeration, these roots spend more of their time deprived of oxygen and therefore inactive. Attempts to compensate with more irrigation simply extend these inactive periods by excluding oxygen from the root zone. The combined effect of reduced root length and disabled root function necessarily inhibits vine performance.

³ Air-filled porosity (a reflection of oxygen availability) at -50 kPa; field capacity is at about -10 kPa.

Which soils are affected?

Soil structure is potentially at risk in most soils. In the project mentioned above, all of the soils studied had substantial clay contents at modest depths (<50 cm) and *all* of them had poor subsoil structure. Most of the soils were *duplex* soils (usually sandy loam changing abruptly to clay) but some were *gradational* (steady change in texture with depth). Soils with low clay content to depth are generally less vulnerable but not immune to these problems. Some sandy soils have high bulk density which increases their penetration resistance and reduces aeration.

What causes soil structure decline?

Under dense stands of native vegetation where soil structure and the plant community have evolved together over a long period, the growth of new roots, the decay of old roots and the associated activities of soil organisms act together to create and maintain larger pores for drainage and aeration.

When this is replaced with fewer, shallow-rooted plants and less biological activity, these larger pores are gradually lost. It appears that the roots of irrigated vines alone are not enough to stop this loss.

This structure decline is dramatically accelerated by the stresses of tillage, which destroys large pores and their continuity and hastens the loss of organic carbon; by traffic compaction, which crushes the larger pores; by excessive irrigation⁴, which weakens soil structure and makes it more vulnerable to collapse and by irrigation with saline water, which makes the soil structure even less stable towards the other stresses.

How can good subsoil structure be restored in existing vineyards?

In an existing vineyard this is a difficult task. The restoration of lost subsoil structure means the creation of pores at depth; this can only be done by some sort of disturbance.

The options for doing this are limited to deep tillage and root growth⁵. In existing vineyards it is only practical to till the subsoil *adjacent* to vines, not *under* them. Even this can cause severe root pruning and is often reversed by later traffic compaction. This leaves root growth as the only feasible alternative. Although this is worthwhile, it's a long-term strategy that may only improve subsoil conditions over a period of years.

⁴ Excessive irrigation itself lengthens episodes of poor aeration by excluding oxygen from the root zone.

⁵ Despite its reputation in improving the structure of surface soil, there is no evidence to suggest that gypsum *alone* can do anything more than *prevent* the decline of subsoil structure; it cannot reverse the process.

To achieve this, root activity is needed in the vine row over the entire year, not just the growing season. Winter active cover crops in the vine row should be tested if the vine roots themselves are to exploit the subsoil in the long term. This is certainly not common practice at present but may represent a lost opportunity for the improvement of subsoil structure. It needs to be managed carefully so that the leaching requirement of the soil is met and the water stored in the soil profile for the following season is not seriously undermined. Clearly, plants used for this purpose must be easy to establish, have a relatively short growth habit, a root system that strives for depth and must not be difficult to manage. The extent of short-term penalties in soil water storage is unknown and depends upon the plant chosen but the long-term benefits may be substantial as vine roots enter the reclaimed subsoil. This strategy also places carbon at depth and encourages soil biological activity in the vine row.



A healthy cover crop of Wallaby Grass (*Austrodanthonia richardsonii*) in the inter-row area but is it improving subsoil structure in the vine root zone? (image courtesy Chris Penfold, University of Adelaide)

What can be done in the meantime?

A more immediate strategy is to increase the volume of “root-friendly” soil for vines so that they are less reliant on a hostile subsoil.

Mounding of the vine row is achieved by moving topsoil from the inter-row area where it is of less use. This has been done in established vineyards and appears to cause no problems unless vine butts are wounded in the process or grafts become buried.

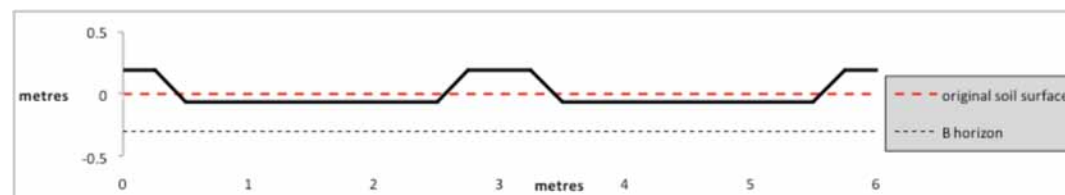
There are some obstacles to mounding. In an ergonomic sense, mounds make hand pruning and picking more difficult because of the uneven surface they present. They must accommodate the total wheel track of machinery used in the inter-row area. Their design must also take account of the slope and shape of the mound shoulders so that runoff and erosion don't occur. This may require a flat-topped, or even “dished” mound along with winter stabilization of the whole mound with a shallow, fibrous-rooted cover crop such as a grass. This has the added benefit of adding organic carbon to the mound and improving its water-holding capacity.

As mounding also increases the surface area of the soil a little, there is the potential for slightly greater evaporative water losses and temperature excursions in the root zone⁶. This means that application of a *surface mulch* during the growing season must be considered. Even in the absence of mounding, surface mulch improves the root environment, adds organic matter, enhances water-holding capacity and encourages soil biological activity but needs to be monitored for pests.



A cool, moist root run for shiraz vines under a heavy cereal straw mulch. (image courtesy Anthony Scholz, Scholz Estate, Ebenezer)

⁶ Example: In a vineyard where the depth to “hostile” subsoil is 30 cm and row spacing is 3 metres, a mound with a 50 cm wide flat top, 45° shoulders and 19 cm above the original soil surface (25 cm above the final inter-row surface) offers a total wheel track of 200 cm, a 42% increase in available topsoil (over no mounding) but only a 7% increase in surface area (see below). The authors have produced a simple spreadsheet to aid in mound design.



Of course, vine roots can also explore the inter-row area and if this occurs, it adds considerably to the root zone volume. However, the greatest threat to soil structure in this inter-row area is the compaction caused by machinery traffic, particularly when the soil is wet. Accordingly, the biggest increase in available topsoil is likely to come from the effective removal of traffic by conversion to a narrower wheel track, the extreme being self-propelled multi-function “over-the-row” machinery with a single wheel track in each mid-row area. This is quite understandably a matter of the cost and availability of such equipment.



Compacted soil under those wheel tracks is probably confining vine roots to the vine row.

Minimizing subsoil structure problems in new vineyards

It need hardly be said that any new permanent planting must be supported by a detailed soil survey so that the properties and variability of the whole soil profile can be anticipated during preparations and then managed in the future⁷. Because subsoil structural problems are so widespread, there is also a clear need for much more rigorous soil preparation than is currently accepted.

When long-standing native vegetation has been removed, the natural state of many subsoils becomes one of poor aeration and high strength. Without the constant process of death and renewal of an extensive root system and the allied activities of soil organisms, there is little happening to create and stabilize the larger pores in the soil. To create hospitable conditions for a new plant community, good subsoil structure needs to be restored. This would be a slow process if one relied upon plant roots alone to re-colonize a hostile subsoil so the first step in this restoration must be deep tillage. This provides a window of opportunity for roots to spread into the subsoil before it can resume its customary dense state. However, before this can happen, a further problem needs to be addressed.

Many subsoils are structurally unstable; that is, once structure (pores) has been created, it may have a short life-time. In Australian soils this instability is often caused by subsoil sodicity, an accumulation of

⁷ This is the time when subsoil constraints of all kinds, not just poor structure but some more intractable “chemical” problems (see footnote 2) should be disclosed. Some of these are “lethal” and may undermine the value of further steps in preparation such as deep tillage.



sodium (and magnesium) at depth. It is important to improve this stability *before* disturbance by deep tillage so that the value of tillage operations is maximized. This can usually be done with a substantial surface application of a calcium amendment, usually gypsum which then needs sufficient time to modify the soil *before* tillage and earthworks commence⁸.

After dealing with subsoil structural stability, deep tillage and mounding should be the next step to maximize the potential root zone; this can largely be done as a single operation. Over a long period several researchers have pointed out that *much* more careful attention to deep tillage is needed to maximize its value and have discussed this in some detail⁹. In particular, it must be carried out on structurally stable soil with an appropriate implement at the correct soil water content and without inverting the soil. At present a good deal of deep tillage is performed on structurally unstable soils using the wrong tines at relatively high soil water contents. This causes local compaction, smearing and plastic remoulding of the subsoil so that the whole operation is of dubious value. Deep tillage is best carried out with oscillating or winged tines on soil that has a water content that makes it friable rather than plastic in its behaviour.

Even when sodicity is not an issue the structure (pores) “created” by deep tillage may have a limited life-time if it is not stabilized in some way. While this is sometimes aided by incorporation of organic matter (e.g. plant residues, compost), we suggest some caution about the deep placement of large amounts of such material in irrigated clay subsoils as it may, despite its structural and nutritional benefits, compete with roots for oxygen as it decays. We believe that living roots themselves offer the best strategy for colonizing and stabilizing the structure created by deep tillage. We have seen that vine roots *alone* do not seem to accomplish this. For these reasons we believe that dense plantings of species with taproots that colonize the subsoil, together with species that have fibrous root systems to stabilize the surface soil, need to be established and given time to create a deep potential root zone for vines. This crop can then be sprayed prior to vine planting and the vineyard managed as discussed above for existing vineyards.

⁸ Dissolved calcium removes sodicity but also stabilizes structure even in the absence of sodicity. Gypsum (rather than lime) is overwhelmingly the calcium source of choice here. The use of lime alone as a calcium source is only appropriate when soil pH is below 5.5. At intermediate pH (5.5-7), co-application of lime and gypsum may be useful. However, because of the very low solubility of lime, its application will be most effective in combination with tillage. The amount of gypsum applied needs to be informed by soil survey data; if the soil is sodic, large amounts will be required (> 10 t/ha). As gypsum needs to be dissolved and leached, application before the wet season will be more effective.

⁹ See *Further reading*, in particular, the work of Cockroft (see Murray, 2007) and of Lanyon and their co-workers.

Saving the pores - how can good subsoil structure be maintained?

There are three general strategies to maintain good soil structure.

1. *Avoiding activities that damage soil structure*: As discussed above, the removal of heavy vehicle wheel compaction near the vine row is important. Moist soil is vulnerable to compaction; in fact for many soils the ideal water content for effective tillage is also the one that maximizes compaction. The damage due to compaction is cumulative, can penetrate the soil to considerable depth and is difficult to remedy. The damage depends upon the soil water content, the weight of machinery and the time it rests on the soil so slow moving, heavy equipment on moist soils can cause considerable damage even at depth. Operations requiring heavy machine traffic should be minimized, especially on moist soil.

Water can also degrade subsoil structure and there are two issues here. When soil is very wet, it is weak. When this occurs for prolonged periods there are more opportunities for structural decline. In this regard, flooding of the inter-row area during winter may be an important agent of structural collapse especially if vehicular traffic is present. The second issue is water quality. The application of saline irrigation water makes soil saline and sodic. When salinity is leached in winter, sodicity remains, especially in clay soils, and reduces structural stability.

2. *Creation and stabilization of subsoil structure with roots*: As discussed above, roots are agents of change in subsoil structure but the process is slow and needs to be continuous. When the vine roots are dormant, other roots should be active. Year round root activity ensures that lost pores are replaced by new ones. The presence of roots also ensures that any pores, once created, cannot collapse easily. The continual death and decay of old roots and their replacement by new ones is a powerful engine for generating subsoil structure.

3. *Stabilization of structure with calcium*: The structure of many Australian subsoils is unstable. This means that individual soil particles can easily become detached from their neighbours, move through the soil, block pores and make the soil less permeable to water and air and more resistant to root penetration. This is a particular problem in sodic soils but is even present to some extent in non-sodic ones. Soil can be naturally sodic or can be made sodic by the use of saline irrigation water. The best way to combat this instability is to add a source of calcium, usually gypsum, to the soil. This has the added benefit of providing calcium and sulphur as nutrients.

Ideally calcium should be delivered through the irrigation system itself if possible as this ensures that the calcium is delivered to sites in the soil where there is potential for damage. If gypsum is broadcast, for example, along a drip-irrigated row, much of it may not reach its intended destination. It should also be remembered that gypsum adds to the overall salinity of soil water (though not in proportion to the amount used) so under pre-existing saline conditions, large applications should be made *after* completion of the growing season. Certainly it is better to apply smaller amounts annually rather than large, infrequent applications; this reduces opportunities for structural decline. The amounts required depend on the quality of irrigation water and soil type but are generally in the order of 5-10 t/ha in irrigated permanent plantings.



How is soil structure measured?

It has been famously said that "if you can't measure it, you can't manage it". Unfortunately soil structure is difficult to measure without specialized equipment and training so the task of confirming improvements over time isn't a straightforward one. The simplest observations are those based upon how soft or well-drained the soil is or else upon the success of root growth¹⁰. These observations are not easy to put a number on. In practice the most accessible "measurements" are penetration resistance when the soil is at field capacity water content¹¹, the persistence of water ponding during the wet season and visual estimates of root densities in auger samples or a pit. These are crude observations but good indicators.

Is there a downside to improving subsoil structure?

Apart from the effort required to produce and maintain good subsoil structure, the only potential drawback might be increased vine vigour. An expanded, hospitable root zone may produce unwanted vigour, especially early in the growing season, because of the increased availability of water and nutrients. There are however opportunities to manage this vigour with the cover crop used to improve subsoil structure in the vine row in the dormant season and also by restricting irrigation.

Is it worth the trouble?

For new vineyards particularly, there is no doubt that these recommendations represent a degree of effort and a length of time (1-2 years) leading up to vine planting that is daunting. However, the effort is appropriate for an enterprise that has a lifetime of perhaps 50 years during which the work may be amortized in water use efficiency, vine performance and a wider window of management for the grower.

¹⁰ Root growth might also be suppressed by other subsoil problems that are more easily measured (see footnote 2).

¹¹ Usually established 1-2 days after a soil has been thoroughly wetted and then allowed to drain in the absence of significant evaporation. This is best done in winter.

Acknowledgment

This project has been jointly funded by the National Program for Sustainable Irrigation and the Grape and Wine Research and Development Corporation.

Further reading

Soil structure and its management

Murray, R.S. and Grant, C.D. **2007** The impact of irrigation on soil structure. *National Program for Sustainable Irrigation* (<http://www.npsi.gov.au/>)

Murray, R.S. **2007** A Review of Dr Bruce Cockroft's Work for Australian Irrigated Horticulture, *Milestone Report 2 by R.S. Murray*. Land and Water Australia. National Program for Sustainable Irrigation. Product Code ER071300. ISBN 1921253525. (<http://www.npsi.gov.au/>)

Lanyon, D.M., Cass, A. and Hansen, D. **2004** The effect of soil properties on vine performance. CSIRO Land and Water Technical Report No. 34/04 (www.clw.csiro.au/publications/technical2004/tr34-04.pdf)

Murray, R.S. and Burk, L. **2010** Long term sustainability of precision irrigation. Milestone 9 Final Report (July 22, 2010). National Program For Sustainable Irrigation. (<http://npsi.gov.au/>)

Cover crops

Apart from local agronomic advice most information about vineyard cover crop benefits, choice and management appears in professional magazines (e.g. *Australian Viticulture*, *Australian and New Zealand Wine Industry Journal*, *Australian & New Zealand Grapegrower & Winemaker*).

Reference

Letey, J. **1985** Relationship between soil physical properties and crop production. *Advances in Soil Science*. Volume I. pp 277-294