RESEARCH BULLETIN

Subsoil structure in irrigated Australian vineyards

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Soil structure: pores for thought

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 buffers plants against drought and other hardship. It is a neglected, but vital component of soil fertility.

Soil structure represents the size, number and arrangement of spaces or *pores* in the soil. These are filled with water, air, organic matter, roots and other living organisms. The common observation of good soil structure is that the soil is well-drained, easy to penetrate and crumbles easily into aggregates of about 1-10 mm that remain intact when they are wet.

The smaller pores in soil (<0.1 mm) are between the individual particles of sand, silt and clay that determine soil *texture* and water-holding capacity. These are effectively permanent features rarely changed by land management. For this reason the term *soil structure* is most commonly used in connection with the larger pores. These 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. These larger pores are extremely vulnerable to land management.

Soil structure has a profound impact on the environment of plant roots by regulating the drainage and penetration resistance of soil. Poor drainage denies oxygen to growing roots, hinders the leaching of salt from the root zone, retards soil biological activity and obstructs root uptake of water and nutrients. High soil penetration resistance impedes the development of an extensive root system, especially when there are no existing pores large enough to accommodate roots. Plants with small root systems confined by poor soil structure are prevented from foraging for water and nutrients and are therefore more dependent on regular applications of both.

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. The roots of irrigated vines alone are not enough to stop this loss which is dramatically hastened under conventional management by traffic compaction, which crushes the larger pores; by tillage, which truncates continuous pores; by excessive irrigation, which weakens soil structure and makes it more vulnerable to collapse and by irrigation

Withdrawing one metre soil cores from a vine row at Tanunda in the Barossa Valley, South Australia.

Vine roots separated from subsoil ready for scanning and soil root length density assessment.

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with saline water, which makes the soil structure even less stable towards the other stresses.

The problem is best illustrated by considering the range of soil water contents that permit good root growth and function (see 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.

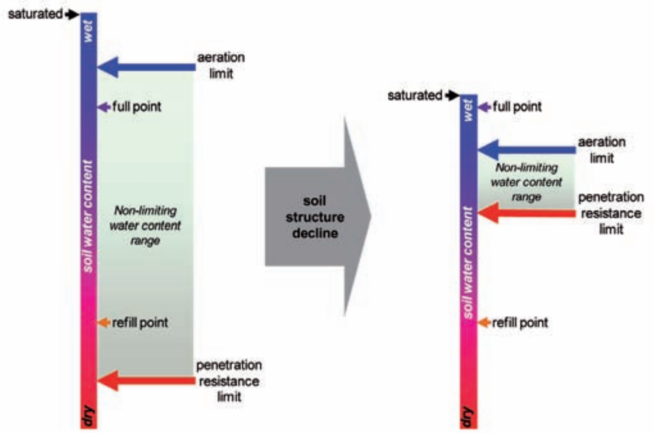
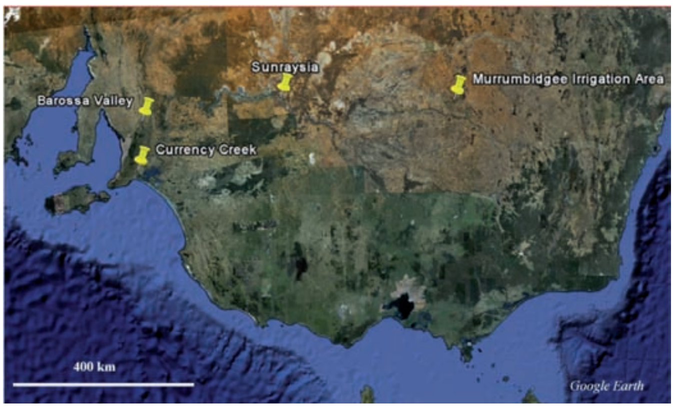


Figure 1: The "window" of non-limiting water contents being closed by soil structure decline. Subsoils with poor structure are a lost resource because their water contents make them inhospitable for root activity much of the time. Adapted from Letey (1985).

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.



A tough neighbourhood to grow up in - root zone conditions in south-eastern Australian vineyards

We assessed subsoil structure in 18 vineyards on 22 distinct soils in 4 grape-growing regions. The focus was on subsoils (at depths of 20-50 cm) with appreciable clay contents because this is where structural problems are more likely to be found and because subsoils are much harder to manage than top-soils. Subsoil infiltration rates in vine rows were of similar magnitude in different regions. The value of infiltration rates is twofold; they determine the duration of water-logging events and they provide a crude indication of opportunities for root growth as a good deal of infiltration occurs through continuous pores large enough to accommodate new roots. Our measurements showed that about one third of values are below 1 mm/hr and three quarters are below 10 mm/hr. One need only consider the durations and intensities of rainfall and irrigation events to realize that such soils will be prone to intermittent and sometimes lengthy water-logging events.

Of more concern were our observations of aeration and penetration resistance as these have a more direct impact upon root growth and function. These were measured at -10 kPa (field capacity) and at -50 kPa (i.e. nearer the refill point) on intact subsoil cores in the laboratory. Penetration resistance should be less than 0.5 MPa for unrestricted root growth and there is wide agreement that values above 2 MPa prevent root growth altogether. Over 90% of measurements in vine rows fell in the range 0.5-2 MPa with an overall average around 1 MPa. Values measured directly in the field 24-48 hours after irrigation generally exceeded 2 MPa and many exceeded 4 MPa. Under drier soil conditions, these values are even higher and pose a major obstacle to root growth. It is generally acknowledged that air-filled porosity (a reflection of aeration or oxygen availability) should be greater than 0.1 for adequate aeration. Over 90% of measurements in vine rows fell below this minimum value; many (>60%) were less than half this critical value.

These results are summarized in Figure 2.

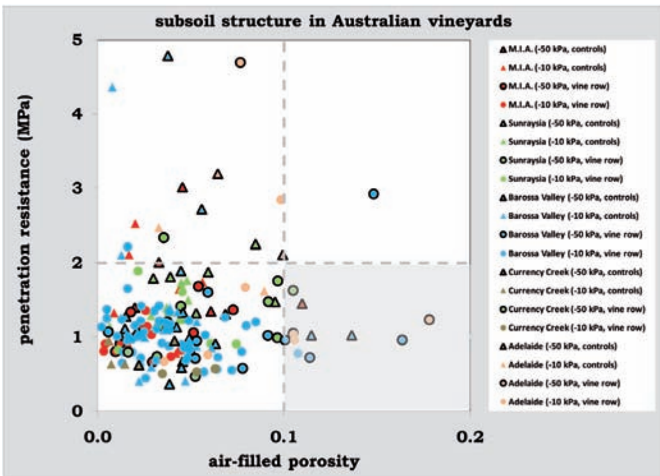


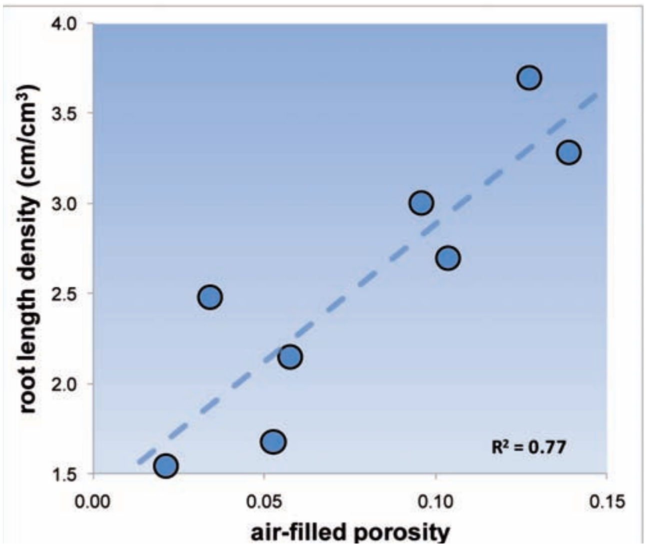
Figure 2: A summary of air-filled porosity (a measure of aeration) and penetration resistance at two soil water contents for subsoils in 4 grape growing regions. Only about 7% of subsoils in vine rows (shaded region) could support root growth and function.

The data shows that most of the subsoils examined were hostile to root activity. Only about 7% of the subsoils examined in vine rows (shaded region) were soft enough or sufficiently aerated to support root growth and function.

The impact of such high penetration resistances and poor air-filled porosities on root growth is magnified by low infiltration rates. Roots must either grow into existing pores or else create new ones. The low infiltration rates suggest that there are few existing pores available so high penetration resistance is problematic. Low infiltration rates also prolong the periods for which the low air-filled porosities we measured persist and therefore the periods in which roots are deprived of oxygen. Indeed there may only be very narrow "windows" of opportunity during the growing season when the soil is wet enough, and therefore weak enough to permit root elongation. Aeration is generally at critical levels in these subsoils when they are at field capacity and, although this will improve as the soil dries, the soil penetration resistance will simultaneously increase to critical levels. In short, these subsoils have only a narrow range of water contents in which neither high penetration resistance nor poor aeration is a problem. This conclusion supports our common field observation, at the boundary of top-soil and subsoil, of roots growing across rather than into the subsoil. In many cases, this boundary was only about 35cm deep creating a rather constricted effective root volume. While the severity of this problem will obviously depend on soil texture and depth of top-soil, it will demand careful irrigation management to maximize the time in which root growth is not impeded by either high penetration resistance or poor aeration while maintaining plant water requirements.

Figure 2 suggests that, while poor aeration and high penetration resistance both pose serious obstacles to roots, aeration is the major problem in these subsoils. This is borne out by measurements of vine root length density at the same points where soil structure was assessed.

The graph below 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 air-filled porosity in the subsoil at -50 kPa. It is clear that poor availability of oxygen in the root zones of these vineyards has retarded root growth to varying degrees reflected here as 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 length 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 and reduces water use efficiency especially as it occurs at such shallow depths.

The study disclosed no serious chemical root constraints in the subsoils such as salinity, extreme pH or obvious toxicities.

Improving the root zone in vineyards.

In many Australian soils, structure is acceptable only near the (generally lighter-textured) surface so that most root activity is effectively trapped in the top-soil and denied the water and nutrient resources in the subsoil below. Creation of subsoil structure (pores) requires a mechanical disturbance such as root growth or tillage. In the case of root growth, the process is relatively slow but the pores created are generally stable as old roots decay and new roots invade; this dynamic process underpins the creation of soil structure under native vegetation. Tillage creates pore spaces rapidly but these are usually unstable and need to be colonized immediately by extensive root activity.

In *existing vineyards* the renovation of subsoil structure under the vine row is very difficult and can only be achieved gradually using plant roots to create larger pores. It is clear from our work that vine roots alone do not achieve this; more intense and sustained root activity is needed. This can only be achieved by the long-term use of appropriate winter cover crops in the vine row. The use of roots in this way to create subsoil structure has the added benefit of placing carbon at depth and enhancing soil biological activity.

The use of cover crop roots in the vine row offers almost immediate improvements in the quality of top-soil but rather slower improvements in subsoil and needs to be boosted by strategies aimed at increasing the volume of "root-friendly" soil in other ways. These include top-soil mounding (taking top-soil from the inter-row area where it is of less use), removal of compaction from heavy inter-row traffic and application of mulches to minimize evaporative water loss and temperature fluctuations in the root zone.

For *new plantings* the structural stability of the subsoil needs to be maximized with gypsum in advance of careful deep tillage, at the right soil water content with appropriate tines, and mounding followed by "priming" of the subsoil with a large root population. All of this is needed *before* the planting of what may well be a 50 year enterprise. The depth and structural quality of this deeper root zone must then be sustained by two broad strategies. The first of these is to minimize practices that

degrade soil structure such as machine traffic, prolonged periods of soil wetness and the use of saline irrigation water, particularly where there are no regular gypsum applications. The second strategy is to continuously regenerate and improve soil structure at depth; realistically this can only be achieved by the continuous death and regrowth of an extensive root system and its associated soil fauna.

These principles of soil management are not new. They apply equally to other permanent crops and offer the potential to improve water-use efficiency by reducing water use, by increasing production or both. Similar approaches have been described elsewhere (Lanyon et al., 2004) particularly in the work of Bruce Cockroft and his co-workers in relation to stone fruit (see Murray, 2007).

More detailed grower guidelines are available at http://www.npsi.gov.au/

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The National Program for Sustainable Irrigation defines and invests in research on the development and adoption of sustainable irrigation practices in Australian agriculture. The aim is to address critical emerging environmental management issues, while generating long-term economic and social benefits that ensure irrigation has a viable future.

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