New Approaches to Vineyard and Orchard Soil Preparation and Management

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Background
The deciduous fruit and viticulture industries are in an expansion mode at this time. Much of this expansion is likely to take place on soils poorly suited for grape and fruit production. This foreshadows a lack of sustainability and low yields for the new orchards and vineyards. A steady deterioration to soil productivity and increasing difficulties associated with water management, already serious in much of the industry, will certainly intensify in the new areas because of the poorer soil resources available.

Productivity and management problems abound in vineyards and orchards established on marginal soils (Davidson 1993). These problems relate largely to inappropriate soil preparation at establishment of the vineyard or orchard and soil management during the life of the orchard or vineyard that fails to maintain adequate soil structure for optimum plant growth. Most growers have become so accustomed to poor soil structure that they do not recognize it as a major limitation to productivity. Some obvious examples are mentioned here and discussed more fully later in this article.

At establishment, sites may be deep ripped, but this is often ineffective. Gypsum and lime requirements may not be properly assessed. Few growers hill the topsoil into beds in the tree or vine row. Very often soil on the row is left exposed to raindrop impact and often crusts and sets hard in the row (Figure 1). Drip irrigation, which is particularly deleterious to earthworm activity by manipulating mulch and soil water conditions, developed during the last ten years by researchers and consultants in the orchard industries, has increased yields of deciduous fruit and citrus from the best industry average of 30 tonne/ha to over 75 tonne/ha (Cockroft and Mason 1987). The no-till bed technology has been developed in the deciduous fruit industries and is being improved in a variety of field experiments located in the Goulburn Valley, Victoria. We believe it is appropriate for the viticultural industry, provided it is preceded by appropriate field research to adapt to the particular requirements of viticulture. The important relationship between the quantity of grape production and the quality of the resulting wine produced, although contentious, is not well understood. Whatever this relationship, it would seem obvious that any practices that facilitate better management of vineyards and create more uniform conditions in the vineyard will enhance the grower’s control of production and quality.

Aims of this paper
The aims of this paper are to:
1. Define ideal soil physical conditions necessary to achieve high production in orchards and vineyards.
2. Show that without good soil management it is difficult to maintain ideal soil conditions throughout the life of the vineyard or orchard.
3. Discuss methods that can be adopted in new and redeveloped orchards and vineyards for creating and maintaining better soil physical conditions in the root zone in order to facilitate better management and improve production and quality of fruit.

The role of soil structure in plant production
Soil structure means different things to different people. In the case of land managers, whatever other ideas may seem important, soil porosity considerations should dominate the concept of soil structure. This is because many processes, critical to the well-being of the plant, take place within soil pores. Vital processes such as gas exchange to aid root respiration, water infiltration to replace depleted plant available water, storage of plant available water and drainage of excess water from the root zone are all dependent on a certain critical level of porosity in the soil. We also now know that soil strength, within the available water content range, depends on the presence of pores of a certain size. Clearly, the attention of soil managers should be focused on management of soil porosity if optimum production is to be obtained.

Total soil porosity is distributed within many millions of pores of different sizes. Furthermore, different processes rely on different pores sizes. For example, water storage for plant growth is confined to pores that are between 0.5 and 30 micrometres (µm) in diameter. A soil deficient in this pore size group will not store as much plant available water as one in which these pores sizes are plentiful. Pores of 30 to 75 µm are responsible for water flow towards the root. Larger pores, called macro pores, of diameter 75 to 500 µm are responsible for infiltration of water into soil, drainage of excess water from the rootzone and gas exchange with the atmosphere, and they also make the soil friable, which promotes unrestricted root growth within the
available water content range. Without an adequate number of pores of this size class, the soil will be difficult to irrigate effectively, excessively wet, poorly aerated and strong enough to limit root growth even when quite moist. These are all characteristics of hardsetting soils.

Effective management of soil physical condition rests largely on management of the pores in the soil. The fundamental aim should be to maintain a range of pore sizes from macropores (75 to 500 µm) to water storage pores (0.5 to 30 µm). All pores size groups are important, but some are more easily lost than others. Macropores are very easily destroyed by trafficking, raindrop impact and excessively high rates of irrigation, whether by flooding, spay or, especially, drippers. Drippers in particular cause collapse of macropores in the wetting zone.

Of course, all pores, and particularly large pores, can be recreated by tillage and other means. However, if the destructive elements are still present after tillage or if the pores are not stabilized they will simply collapse again. For example, when soil is tilled, bulk density decreases, porosity increases and many macropores will be present. In this condition, failure to protect the soil by stubble or a mulch will result in collapse of the tillage-induced structure during the next rainstorm or irrigation. If this process is repeated year after year, structural collapse will become worse and a situation of steadily declining soil quality exists and the orchard or vineyard will probably be unsustainable. Figure 2, from Tisdall et al. (1984), shows structural deterioration, as measured by an increase in soil strength, in a well-managed peach orchard, over a period of 9 years. These data suggest that soil strength has become a limiting factor to water use within 9 years after establishment.

In order to maintain optimum productivity and sustain this productivity over the genetically-determined life of the tree or vine, the soil conditions in the upper root zone should conform to certain minimum physical requirements (Cockroft and Tisdall 1978). The most important requirements are:

- rapid infiltration of irrigation water,
- storage of sufficient plant available water in the soil,
- drainage of excess water from the rootzone to allow air into the soil,
only a fraction of those of other perennial plants (0.1 to 0.3). Vine root densities (length of root per unit volume of soil) are roots. For example, anecdotal evidence indicates that grapevines have surprising gaps in knowledge concerning grapevine establishment, tillage and deep ripping is beneficial and probably /optimum plant production

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration rate</td>
<td>&gt; 500 mm/d</td>
</tr>
<tr>
<td>Available water:</td>
<td>&gt;150 mm in the root zone</td>
</tr>
<tr>
<td>Air-filled pore space:</td>
<td>&gt; 15% of soil volume</td>
</tr>
<tr>
<td>Penetration resistance:</td>
<td>&lt; 1 MPa at field capacity</td>
</tr>
<tr>
<td>Water logging:</td>
<td>&lt; 1 day at saturation in each irrigation cycle</td>
</tr>
</tbody>
</table>

Table 2. Biological agents for engineering pores and class limits for certain important pore groups and soil functional properties (modified after Hamblin, 1985)

<table>
<thead>
<tr>
<th>Pore diameter (µm)</th>
<th>Biological agent, pore group, pore function</th>
</tr>
</thead>
<tbody>
<tr>
<td>50,000 to 2,000</td>
<td>Ant channels</td>
</tr>
<tr>
<td>3,500 to 500</td>
<td>Earthworms</td>
</tr>
<tr>
<td>10,000 to 300</td>
<td>Dicotyledon tap roots</td>
</tr>
<tr>
<td>10,000 to 500</td>
<td>Grass nodal roots</td>
</tr>
<tr>
<td>1,000 to 100</td>
<td>Grass seminal roots</td>
</tr>
<tr>
<td>100 to 50</td>
<td>Grass lateral roots</td>
</tr>
<tr>
<td>0.5 to 6</td>
<td>Fungal hyphae (Dr R. C. Foster, pers. comm. 1993)</td>
</tr>
<tr>
<td>5,000 to 500</td>
<td>Biopores</td>
</tr>
<tr>
<td>500 to 75</td>
<td>Macropores</td>
</tr>
<tr>
<td>75 to 30</td>
<td>Mesopores</td>
</tr>
<tr>
<td>30 to 0.5</td>
<td>Micropores</td>
</tr>
<tr>
<td>500 to 75</td>
<td>Gas exchange, water infiltration, drainage, structural friability</td>
</tr>
<tr>
<td>75 to 30</td>
<td>Water redistribution to roots</td>
</tr>
<tr>
<td>30 to 0.5</td>
<td>Plant water storage</td>
</tr>
</tbody>
</table>

However, little documentary evidence is available to support this contention.

Richards (1983) does quote evidence that soil porosity controls growth and distribution of grapevine roots and that poor soil structure limits vertical root development. In a well-structured soil, roots will penetrate as deep as 2 m, with horizontal root growth in excess of 3 m in the surface layers of soil. Mulching of the soil surface will enhance shallow root growth of the grapevine, due to retardation of surface soil drying (Van Huyssteen and Weber 1980), as well as absence of cultivation, reduced soil temperature and generally more friable soil conditions.

Tillage of any type will limit root growth by root pruning and will probably reduce productivity (Richards 1983). Although shallow cultivation is used to control weeds in vineyards (Richards 1983), this practice has been largely discontinued in the deciduous fruit industry because of the limitation imposed on the root system. Given that insufficient depth for volumetric topsoil is a major limitation to root development and tree vigour (Cockroft and Wallbrink 1966), it seems obvious that tillage of the root zone should not be practised at all after establishment of the orchard or vineyard. Prior to establishment, tillage and deep ripping is beneficial and probably essential on many soils (for example, Saayman and Van Huyssteen 1980).

Trickle and drip irrigation will encourage concentration of roots in relatively small moist zones in clay soils, leaving large root-free zones and limiting lateral spread of the roots (Richards 1983). The aim of bed-forming is to encourage development of an extensive root system by creating a uniform, deep, root zone with a high water storage capacity, uniform aeration and low strength. Clearly drip irrigation will be counterproductive to this objective because it limits root extension. Richards (1983) presents evidence that sprinkler irrigation does improve root distribution with a wider spread.

Creating and maintaining good soil structure

Davidson (1993), in discussing grape growing in cool climates, makes the point that the ideal soil comprises a topsoil of 300 mm depth or more, overlying a well drained subsoil with good
water holding capacity. This statement is probably also true for grapes grown in warm climates and is certainly true for many orchard and horticultural plants. However, generally, ideal soils are of strictly limited distribution in areas with climates suitable for grapes (Fitzpatrick et al. 1993) and in many fruit-growing areas (for example, see Skene and Poutsma 1962). More likely, the expanding grower is likely to encounter soils with shallow topsoil, an abrupt transition from a heavy clay subsoil to a sandy loam, and/or sodic and with a low plant available water capacity.

Given that a poor soil resource is likely to be the starting point in establishing or indeed redeveloping a vineyard or orchard, what cost-effective technology is available for improving the quality of the soil? Can Davidson’s (1993a) misgivings about modifying a less than ideal soil environment be overcome? We believe the answer is a cautious ‘yes’, provided some important points are kept in mind:

- a fundamental appreciation of the problems in creating and maintaining an adequate level of soil structure is developed,
- this fundamental perspective is used to sensibly modify implementation of the suggested methods for creating and maintaining soil structure in relation to local conditions,
- a heightened sense of the importance of soil as a fundamental determinant of productivity is developed,
- a ‘best management practice’ as described by Davidson (1993a) is adopted for the enterprise as a whole.

The fundamental requirement for establishing good soil structure is to create and preserve the necessary pore size distribution to meet the water, aeration and root extension requirements of the new vines or trees. There are ten basic steps to achieve this:

1. Site selection
   Careful site selection can reduce orchard and vineyard development costs substantially. Existing soil survey information, soil maps and site evaluations of the type published by Fitzpatrick et al. (1993) are valuable sources of information on soil quality. Evaluation of the land capability using modern methods and physical and chemical analysis of the soil is recommended. Generally these investigations need to be done by experts, but this almost always proves to be cost beneficial (less than $250 per hectare) when compared to the total cost of $25,000–30,000 per hectare to establish an orchard or vineyard (Davidson 1993a).

2. Deep ripping
   The purpose of deep ripping is to create a continuous system of macropores from the surface to the lower depth of ripping in order to facilitate infiltration, gas exchange, drainage and unimpeded root access to the subsoil and generally to reduce soil strength. If none of these limitations is present in the subsoil, there should be no need to deep rip. However, many soils have severe limitations associated with the subsoil and deep ripping is usually an important first step in establishing new areas or redeveloping existing vineyard or orchards. Bakker (1977), among many others, has demonstrated increased plant growth (peach trees in Bakker’s case) as a result of deep tillage. Figure 3 shows that deep ripping can have beneficial effects on soil properties that are important for management, although the tillage must be accompanied by some method of stabilizing the pore structure so created (e.g. gypsum).

   The criterion by which the success of deep ripping should be judged is that the majority of soil fragments in the ripper subsoil should be less than 20 mm in size. A criterion of this condition depends on the water content of the soil at the time of ripping, the design of the ripper and the method by which the operation is carried out. The following conditions are of critical importance in achieving these requirements:

   - water content of the soil should be below the plastic limit and/or gypsum is needed and added as required with fertilizers prior to tillage and deep ripping.
   - use mulching combined with periods of drying out of soil beds to control activity of earthworms.
   - grow fibrous rooted grasses in the winter and destroy the grass (but not seeds) when it begins to compete with trees or vines during the growing season to provide an in situ mulch, adding additional straw if necessary.
   - irrigate carefully and appropriately to prevent the root zone from approaching a condition of saturation.
   - prevent all traffic on the soil bed or tree or vine row, limit the width of the wheel track of machinery to the smallest inter-row area possible, and use tractors with the lowest possible axle mass.
   - recognize critical periods in the development of the site and in the annual growth cycle and take precautions to ensure that soil structure is not damaged at these times.

Root zone engineering
well before ripping to leach into the subsoil to enhance the considerable advantage can be gained if gypsum is applied ripping will move a proportion of these materials to depth, but line surface prior to ripping. The soil disturbance arising from sum are often required, and this should be applied on the row decision to apply one or both of these amendments should be made by expert examination of the site and on the basis of chemical and physical analysis of soil samples. Experience shows that, at least, 5 tonne/ha of lime and gypsum are often required, and this should be applied on the row line surface prior to ripping. The soil disturbance arising from ripping will move a proportion of these materials to death, but considerable advantage can be gained if gypsum is applied well before ripping to leach into the subsoil to enhance the quality of ripping.

Figure 3. Seasonal changes in infiltration rate in a citrus orchard under furrow irrigation and with no cover crop or mulch. Furrows were formed at the beginning of the irrigation season and ripped to 190 mm after the 5th irrigation (unpublished data, Cass 1993).

depth: wings should be attached to the tine with a sweep angle of 90°, a width of 0.7 to 0.8 of the working depth and a lift of 60 to 100 mm; and shallow tines should be placed ahead of the deep tines.

• the rate of ripping must be low (< 5 km/h),
• several passes may be necessary, with tines positioned at lower and lower depth during each pass until the desired depth is reached.

The technology for deep ripping of soil has been developed and described by Godwin and Spoor (1977) and Spoor and Godwin (1978). However, success is difficult and the design of the ripper is critical, making it a difficult operation, best left to specialist advisers and contractors.

3. Gypsum and lime

Macropores created by deep ripping may not be stable. These pores will collapse when the subsoil is wetted by rain or irrigation. The cheapest and best available stabilizing agent to prevent this is application of a calcium salt, particularly if the subsoil is sodic. Gypsum (CaSO₄·2H₂O) is commonly used for this purpose, but lime (CaCO₃) may have an additional benefit. Not all soils respond to the application of gypsum, and for some soils, application may result in increased acidity. Prediction of a response and the precise level of gypsum required to obtain a response is difficult and should be left in the hands of experts. Many subsoils have high levels of natural lime and cannot be expected to respond to added lime. The decision to apply one or both of these amendments should be made by expert examination of the site and on the beds of chemical and physical analysis of soil samples.

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4. Bed forming

After deep ripping the vine or tree row, the subsoil should be moved laterally from the inter-row area, where there are few roots, to create beds that improve surface drainage and maximize the depth of subsoil in the tree or vine row, where many roots will grow if conditions are favourable. Beds provide a root zone where soil structure can be maintained at an optimum level, assuring an adequate level of water, aeration, soil strength and drainage. Under no circumstances should the beds be trafficked, and they would not normally be filled during the lifetime of the vineyard or orchard. The use of soil beds, deep ripping and mulching has been shown to increase yields up to three times the average in the Goulburn Valley, Vic. Consequently, beds have been adopted in new orchards, with success (Tisdall and Huett 1987). In many deciduous fruit producing areas in Australia, Figures 4 and 5 show soil beds in newly formed commercial peach orchards. However, use of beds is not yet common practice in vineyards.

The lateral dimensions of the bed depend on the expected extent of lateral root growth of the tree or vine, the row spacing and the width of machinery used in the orchard or vineyard. Because the essential advantages conferred by no-till beds will be negated entirely by trafficking the bed, a number of important considerations arise in relation to the dimensions of orchard or vineyard machinery. There are advantages to be gained by use of machinery that is both narrow and of low mass.

Soil structure management

5. Fibrous roots and surface cover

Fibrous rooted cover crops are used to stabilize pores and at the same time create new pores. The macro- and mesopores created by forming the beds tend to collapse on wetting and should be stabilized and, if possible, extended. The use of fibrous-rooted cover crops to create and maintain soil structure has been extensively researched (Oades 1978; Tisdall and Oades 1982). Use of ryegrass on the beds is recommended for this purpose. Figure 4 shows a recently formed bed with a newly emerged stand of ryegrass. These plants will protect the soil surface from damage by raindrop impact through the winter and the root system will stabilize the soil structure and create new pores. Figure 6 shows the difference in structure between a soil in which ryegrass has been grown and the same soil which was left without a cover crop.

The beds should not be left without either a living cover of fibrous roots or a much of dead plant material. This is a critical factor in the successful management of pore structure. When the grass becomes competitive to the trees or vines it should be killed by a herbicide which does not harm the seeds to allow regeneration of the grass during the next tree or vine dormancy. If regeneration of ryegrass is unsatisfactory, it may need to be direct-drilled every year. Figure 5 shows a peach orchard that has been ripped, hilled, sown to ryegrass which has grown vigorously and which has been killed prior to tree planting. This practice is critical for creating and maintaining soil structure.

6. Earthworms and surface mulching

Earthworms create biopores (> 500 µm), improve soil macrostructure and incorporate surface organic material. They are important in improving soil aeration, infiltration and drainage. Earthworms can play a role in preventing decline in infiltration rate of water into soil resulting from soil structural changes (largely, collapse of macropores resulting from rapid wetting) during the irrigation season as shown in Figure 3. The orchard in which these measurements were made showed no
Earthworm activity of any kind. Earthworms are encouraged by a high level of soil moisture and a supply of organic matter in the form of a surface mulch, on which to feed. They are not tolerant of dry conditions in the soil and will migrate down to the subsoil if the water content of the beds falls much below field capacity.

Not all aspects of earthworm activity are beneficial to soil structure. We suspect that under wet conditions earthworm numbers may increase to an extent that soil structure may be damaged by excess wetness (see below) as well as intense remoulding of soil aggregates by excessive earthworm activity. Excessive remoulding probably results in destruction of smaller macro- and mesopores (30–100 µm), reducing the proportion of pores that contribute most to water redistribution, gas exchange and soil friability. The resulting soil structure is dense, compact and hard enough to limit root growth in the available water content range.

The activity of earthworms may be controlled by allowing the beds to dry to below field capacity and by limiting the availability of surface mulch. The former is good irrigation practice and involves no more than full exploitation of the water storage capacity of the beds, while the latter is accomplished by relying on a living or killed ryegrass to protect the soil rather than an applied surface mulch.

7. Controlled irrigation and soil drying

Close control of irrigation is a heightened management practice which will preserve good soil structure and help to create new pores. Excessive soil wetness is deleterious to soil structure because it encourages excessive earthworm activity, and weakens soil aggregates, causing them to collapse under their own weight. This collapse tends to reduce macroporosity and results in an increase in anaerobism because of excess water and lack of air-filled macro pores.

Excessive soil wetness results from too frequent irrigation or irrigation after rain. Growers should adopt a rigorous irrigation schedule where irrigation is only carried out at well defined and predetermined soil water deficits. This will conserve soil water, allow soil to dry out to the point where soil shrinkage creates systems of continuous pores and limit the activity of earthworms without destroying existing biopores. Soil beds should be irrigated when the soil water suction reaches about 60 kPa at the mid-depth of the bed. An appropriate monitoring program and irrigation schedule should be developed around this criteria. When trees and vines are dormant, the soil beds should be allowed to dry to close to permanent wilting point. The soil structure management system presented here should be regarded as part of 'best management practice' discussed by Davidson (1993a). Outside the wetted zone, structure may be better, but the soil is drier and roots are poorly distributed there, being concentrated closer to the wetted zone.

8. Slower irrigation and reduced saturation

High rates of irrigation (more than 10 mm/h) can also create excessively wet soil conditions (low soil water suction). A great deal of water that is applied may be lost and the soil may be drier and roots are poorly distributed there, being concentrated closer to the wetted zone. The resulting soil structure is dense, compact and hard enough to limit root growth in the available water content range.

Minispray irrigation systems are preferable to drippers and fast delivery emitters. Dripper systems concentrate the water under the dripper and produce very wet conditions in relatively restricted zones. Observations show that soil structure in these zones is poor, with high soil strength within the plant available water content range and reduced macroporosity (Gusli et al. 1994). Outside the wetted zone, structure may be better, but the soil is drier and roots are poorly distributed there, being concentrated closer to the wetted zone.

9. Traffic management and reduced compaction

A decade of research has shown that machine traffic will compact soil largely at the expense of macroporosity. The wetter the soil when trafficked, the greater the degree of compaction and the lower the critical vehicle mass required to achieve a given level of compaction. The plopping effect is cumulative, each pass of the vehicle will compact the soil progressively, although to a diminishing extent. Compaction can, of course, be reversed to some extent by tillage, but a certain level of residual structural damage resulting from shearing and remoulding of aggregates is permanent.

In orchards and vineyards, where opportunity for tillage is limited, compaction can have serious and chronic consequences for productivity and sustainability of the orchard. The only solution to this problem is to confine traffic to areas where root growth is limited, i.e. in the inter-row area, separated as far as possible from the trees or vines. Under no circumstances should traffic be allowed on no-till beds.

10. Systems of management

The soil structure management system presented here should be regarded as part of 'best management practice' discussed by Davidson (1993a). Each component of the package addresses a particular aspect of creating or maintaining pore structure. Each aspect is linked to one or more of the other aspects in some particular way. Failure to accommodate all aspects of the package may result in failure of the entire package because of...
a break in one or more of the linkages. For example, Figure 3 shows that deep ripping could increase infiltration rate, but additional measures such as addition of gypsum, management of earthworms and growth of fibrous roots are required to stabilize the structure created by tillage. Without both tillage and the stabilisers, the improved pore structure is not persistent.

A further important consideration is that certain critical periods exist during which the system is particularly vulnerable. During these periods particular care needs to be adopted to prevent damage to the soil structure, from events as obvious as rain-induced soil erosion to more insidious changes such as slow collapse of macropores due to excessive wetness. These critical periods are (a) immediately after ripping, (b) immediately after hilling, (c) commencement of winter rains, (d) ryegrass collapse at budburst, (e) the expected time at which high intensity rain falls.

All of the components of the system described here have been tested in the field and are regarded as sound management practices in their own right. However, the system as a whole has not been tested outside the Goulburn Valley, and are particularly not in a viticultural setting. There are several critical issues which need to be addressed. Some of these are the effect of 3 or 4 m row spacings in vineyards as opposed to 6 m spacings in orchards, a suite of different operations in vineyards in contrast to orchards, the utilization of the improved soil conditions in relation to canopy management and fruit quality, the consequences of frost in spring, etc. Further research and demonstration needs to be done to complete the development of the system and to draw together the timing and integration of individual components to create a unified management system.

Conclusions

• Fruit trees and grapevines, like all plants, depend on soil structure for ideal operation of processes that provide essential growth requirements
• Modern technology can be used to build soil structure at the time of establishment of the vineyard or orchard: correct deep ripping, gypsum, lime, hilling of beds, ryegrass roots and tops.
• Correct management of soil biology can maintain soil structure: earthworms, cover crop roots and tops and soil microflora.
• Correct management of irrigation, which includes slow application, correct scheduling, avoiding saturation of the soil and periodic drying out.
• Correct timing of establishment and management operations such as deep ripping, sowing ryegrass, herbicide applications, irrigation timing and rate in relation to weather and vine growth stages are of critical importance in reducing rate of soil structural decline.
• More research to develop an integrated system is essential and urgent.

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References


