Managing soil structure in established vineyards

The influence of pores, plants and people on soil structure in established vineyards

A report for

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Executive Summary

The Australian wine industry provides the fifth largest export by value and is produced in a wide variety of regions, climates and geological areas. The soils these vines grow in are old and fragile in nature and are readily degraded when managed utilising traditional European practices. The best time to conduct remedial work on vineyard soil is prior to trellis installation and planting, as the permanent structures and narrow row spacing commonly used prevent the use of large scale earthmoving equipment for deep ripping. Novel and long-term approaches are required to create sustainable systems.

These technical approaches include:

- Minimal topsoil disturbance through tillage.
- Remediation and maintenance of soil chemistry and cation balance.
- Diverse perennial vineyard floor vegetation.
- Utilisation of mulch and compost under the vines.

More sociological approaches are also needed to gain uptake of management change, which include:

- Dissemination of practical learning through discussion groups and mentor programs.
- Creating champions for change, sharing best practice and the risks involved with change.

The current fiscal conditions of the wine industry do not promote large amounts of investment back into the vineyard. Many gains can however be made through better management decisions with minimal investment. The gains are small and incremental, and difficult to see from season to season.

It is critical that farmers continue to try new techniques to continually improve and understand that not everything trialled will be successful. There is no reason why growers as custodians of the land should not be sharing success and being brave enough to share failings to drive the industry towards a sustainable land use approach. Best practice guidelines are more effectively learnt in practice in the field rather than in the text book, so demonstrations, field walks, and discussion groups or mentor programs are a great way of sharing this knowledge. This is not just applicable to soil management practices but all aspects of the industry, from production, to processing to marketing.

Vineyards take time to develop and mature before the best quality grapes can be produced, so long-term thinking needs to be employed to maintain the assets. The goal should be to have healthy, environmentally and financially sustainable vineyards for generations to come. As an industry, it is vital that growers are as open about failings as successes, in order to achieve this.

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Foreword

Soil structure and its resilience is key to the production of the best grapes for wine production. It is the role of the viticulturist to deliver the grapes to the winery in the optimal condition for any given season. Seasonal climatic extremes such as prolonged rainfall in 2011, sustained heat in 2009 or the drought of the mid to late 2000's all play their part in shaping the final wine in the bottle. It is the minimisation of abiotic stress which allows for the best product, and resilient soils help with this.

Initially, my study topic was centred around the remedial work on subsoil in established vineyards with the goal of expanding the soil volume available to the vine to reduce stress. Realising that this is possibly even less considered outside of Australia, I decided to focus on the most efficient use of the existing topsoil.

During my travels to France, Spain, Germany, Canada, Ireland and the USA it dawned on me that the greatest limiting factor in the management of soils is often the custodians themselves and the paradigm through which they make their decisions. Meeting soil scientists Bob Schindelbeck and Rick Haney in the USA, I began to realise that soil science is as much sociological as it is about the dirt.

This is what created the final shift in my study, to include the human aspect of soil management.

Acknowledgments

I would like to firstly like to thank Nuffield Australia for the opportunity to grow as a person, a farmer and a leader. This scholarship will leave an incredible legacy on both me and my family.

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I would also like to thank the Rathbone family and the team at Yering Station for the encouragement, support and freedom to pursue the opportunity to garner such broad knowledge. The vineyard and winery team also deserve thanks, particularly Rod Harrison and Willy Lunn, for carrying the extra workload whilst I was overseas.

Mark Krstic for mentoring me though the research process, Scholar Liz Riley for working her way through my early report and the countless farmers, researchers and industry folk who opened their businesses for me during my travels.

Lastly, I would like to thank my wife Nami and children Mannus and Dulcie. They are the reason that I am determined to be a better person and leader. It is much easier to be the one having the adventure, than those who support us while we are away. For that I am forever grateful.

Abbreviations

SOM - Soil Organic Matter

CEC - Cation Exchange Capacity

Ca^{2+} - Calcium cation

Ca - Calcium

Ha - Hectare

Mg - Magnesium

Mg^{2+} - Magnesium Cation

Na^{+} - Sodium Cation

Al^{3+} - Aluminium Cation

Objectives

The objectives of this technical report were to:

- Investigate and identify novel management methods for improving the long-term sustainability of soil structure.
- Identify methods of encouraging changed practices regarding soil management in farming operations.

Chapter 1: Australian vines and soils

The Australian wine industry is large and diverse. 135,000 hectares (ha) are planted within 65 different regions, employing 172,000 people and including affiliated industries contributing $40 billion to the Australian economy each year (Gillespie, 2015). It also represents Australia's fifth largest agricultural export by value.

Wine is grown in a diverse range of regions with varied climatic and geological areas, each with their own challenges. Increasing climate variability is resulting in far more extreme climatic conditions throughout the season. Periods of sustained, below-average rainfall, large inconsistent rainfall events and heat spikes can all have deleterious effects on the vines and subsequent fruit quality. It is the soil's ability to handle these conditions, minimising abiotic stress, that leads to a greater consistency of product between seasons and the long-term sustainability of the vineyard, winery and industry. Australian soils are also highly varied, though they are generally very old and fragile and often have pH, saline, sodic and structural issues preventing the optimal exploration of the soil volume by vine roots. Many of these soils were not prepared and ameliorated sufficiently prior to development and have suffered from gradual decline due to the nature of vineyard management or should not have been planted at all. Good soil management and healthy soils are important to reduce susceptibility to climatic vagaries and to making the soil more resilient to weather extremes (Magdoff, 2000).

Grape production for wine is not a purely yield-based commodity, as the final wine quality produced is equally important. The ideal soils selected are not required to be excessively fertile as this impacts on the quality, though summer and autumn stress due to hot dry conditions needs to be minimised.

In contrast to Australia, the European vine growing regions have far younger and resilient soils. The French have centuries of experience and tenure with the land and time has allowed them to learn which varieties and wine styles are best suited to their climate and soils. This is part of the *terroir* of the region. They know that the heavier low-lying soils are best suited for pasture, and the rocky outcrops are for forests or other agricultural pursuits. The sweet spot between the two is where the vines are planted, and the very best is somewhere in the centre of these plantings, such as the location of the Grand Cru vineyards of Burgundy.

While Australia has a significant history of wine production, there have been many vineyard plantings in the last 30 years, (the total volume crushed has doubled in the past 20 years), so the understanding regions is still developing in a global sense. Older plantings do give some perspective on how soils can handle the traditional European farming methods first utilised in Australia. The ability to innovate allows Australia an edge over Europe as Australia is not bound by regulations of tradition such as those in Appellation dÓrigin Controlee (AOC), and continued tenure will allow for greater understanding of the ground.

With tighter margins and falling productivity, it is tempting for the grower to chase greater returns with the application of more fertiliser. This is a false economy, as the restrictions of the vine's capacity is a direct reflection of the soil available to the vine, not necessarily the amount of nutrient or water applied. Expanding or optimising the existing rootzone is critical in the long-term sustainability and resilience of any terrestrial agricultural enterprise. The reduced investment in soil amendments such as gypsum and lime are having insidious effects on the soil and vine's long-term performance.

What is the Problem?

The ideal time to conduct remedial work on soil structure is during the development stage of a vineyard. Deep ripping of soils, particularly down the future vine row, creates fractures in the subsoil and provides an opening for the placement of ameliorant agents deep into the soil. Permanent trellising and vines, with narrow spacings' restrict the ability to operate large earth-working equipment within established vineyards, so the physical remedial options following vineyard development are far more limited, with more incremental gains.

Even after good remedial practices during development, conventional vineyard management can lead to gradual decline in aeration and structure of the soil. The ideal vineyard soil is free draining, with good water holding capacity, forming a naturally friable tilth when cultivated and retaining soil strength of 1-2MPa when at field capacity (White, 2009).

Breakdown of soil structure leads to a reduction of vineyard physical function and then vine performance. Smaller pores result in greater soil strength and anoxia, lower water infiltration rates, lower hydraulic conductivity and poorer drainage rates, which all restrict root growth and microbial activity. Once this damage is done, regeneration of organic matter within the soil is affected and continual decline is inevitable (Cass, 2004).

The 3 P's of Soil Management

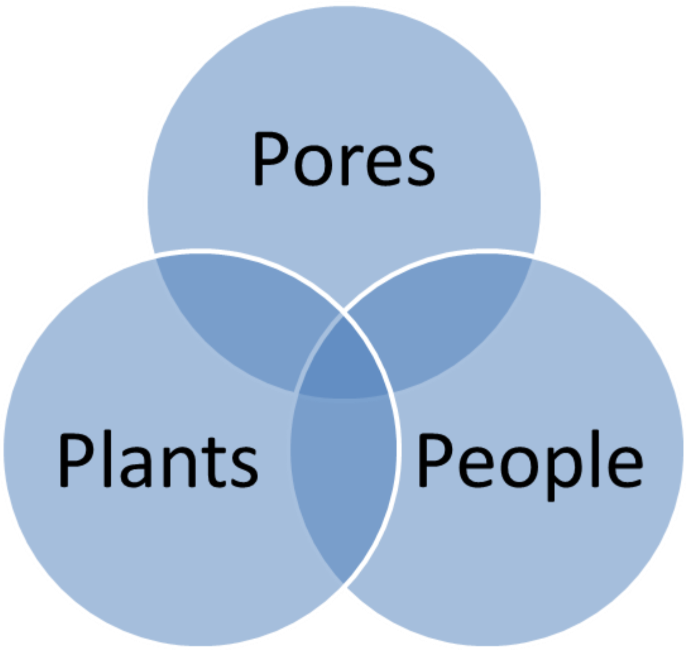


Figure 1: The 3 P's of soil structure

Soil should be treated like any living organism; it needs water, air and food to thrive and give optimal returns. Soil structure and management is a highly integrated system, where each of the main components influence all other parts of the living soil.

Maintenance, remediation and indeed destruction of soil structure can be reflected by three key groups; pores, plants and people (Figure 1).

“Pores” describes the physical and chemical composition of the soils. This is the foundation of the soil, the solid particles and the voids between them. “Plants” describes all biological activity within the soil system, including plant roots, microorganisms, macro-organisms and the carbon cycle. “People” describes the way we as custodians of the land manage these ecosystems. Farmers have the ability in their management choices to influence the long-term structure of these soils, for good and for bad, through the soil’s biology and physical state.

Chapter 2: Pores

"Hard ground makes too great resistance, as air makes too little resistance to the surface of roots" (Jethro Tull 1733).

"Pores" is a term encompassing the physical and chemical components of soil and indeed the pores of the soil themselves. These building blocks are critical in the overall soil structure and have formed through long-term processes during the soils development, which can make successful remedial work difficult to achieve change.

The physical components of most soils are approximately 45% soil particles, 5% organic matter and the remaining 50% a state of flux between air and water, depending on the soil's moisture content as seen in Figure 2 below. The size of the soil particles determines the soils textural class and is a key factor in the pore distribution and subsequent soil structure. Coarser soils will have far greater pore size, with a far reduced ability to hold water.

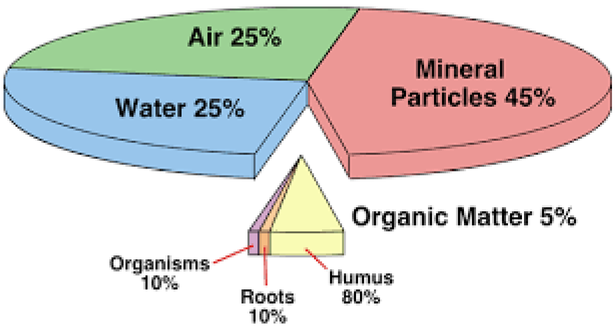


Figure 2: Distribution of solids, water and air within a typical soil

(Introductions to soils, 2006)

Soil physical components

Soil structure is best described by the size, shape and arrangement of voids and pores, which controls their ability to retain and transmit fluids and other substances and support vigorous root growth and development (Bronick 2005). Structure is critical in providing habitat, stability, air and water content for all living organisms within the soil its key components are pores or voids, stable aggregation, and soil strength.

Pores vary in size and shape and provide the space for water and air to move (drainage) and roots to grow. These are determined by the type of soil (clay, silt, sand, gravel), the climatic conditions and the management practices. These factors also determine the amount of water the soil can hold and the ability of the soil to drain. This drainage sucks air into the soil along hydraulic pressure gradients, providing oxygen for the soil's biological processes. Large pores are free draining, though hold onto very little water and nutrient. Small pores drain slowly and hold onto water very tightly. Many of the most resilient viticultural soils are a combination of pore sizes with varying particles sizes, such as those found in Corton Charlemagne in Burgundy (Figure 3 below) and the first growth vineyards of Bordeaux.

Figure 3: Heavily tilled soils of Corton Charlemagne in Burgundy France (Source: Author)

Aggregates are secondary particles formed through the combination of mineral particles with other organic and inorganic substances (Bronick 2005). This is the result of many different interactions between the environment, soil management, biological activity, plant influences and inherent soil properties. Aggregates occur in a variety of types and sizes. Stable aggregation is the soils ability to bond into larger clods, resisting external forces such as wind and rain to disintegrate and fall apart. Clay soils with less stable aggregation often tend to have higher sodium cation ratios and be dispersive which means they lose all structure in distilled water, and the clay particles become suspended in the solution (Magdoff, 2000).

Soil strength is a function of the soil's bulk density and water moisture content. As soils dry this strength increases as the soil will hold onto the remaining moisture tighter, binding the soil particles more firmly. Pore size is critical in this function, as smaller pores will have greater water retention and therefore soil tension due to the higher surface area to volume ratio of the pores. Soil strength is also the soils ability to bear weight whilst wet without suffering compaction. Sandy soils are the most prone to compaction, though all care should be taken to drive on any soils when wet to avoid this.

Cation Exchange capacity

Cation Exchange Capacity (CEC) is a measure of the soil's ability to hold positively charged ions. All clay particles and soil organic matter (SOM) particles have negatively charged sites on their surfaces, which absorb and hold positively charged cations through electrostatic force. Many nutrients in the soil critical for healthy plants exist as cations such as potassium (K), calcium

(Ca), magnesium (Mg) and sodium (Na). In general, the higher the CEC the more fertile the soil is as the clay particles retain more cations. As soils become more acidic these cations will be replaced by hydrogen (H), aluminium (Al) and manganese (Mn) which are toxic to plants inhibiting growth. Soils low in CEC often suffer from a deficiency in Ca and K which are critical in healthy plant growth.

Sandy soils tend to have a much lower CEC due to the lower presence of clay and SOM. Figure 4 below shows a sandy duplex soil with clay at 40cm, clearly demonstrating the impact of SOM in the top 10cm, and higher clay levels below 40cm on the CEC.

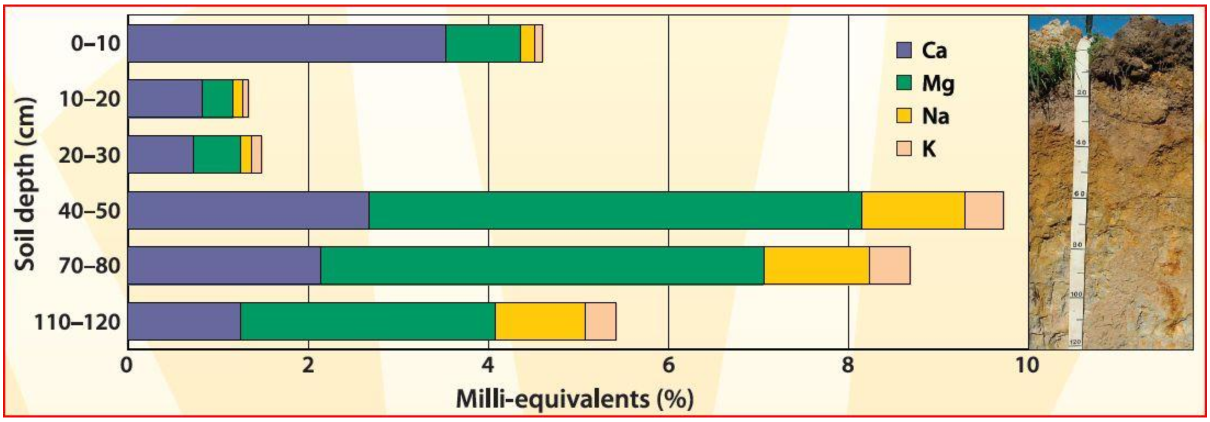


Figure 4: Sandy Duplex soil CEC readings. (Source: soilquality.org.au)

Each different cation has different properties and functions within the soil and can have a profound impact on the soil structure. Cations which are polyvalent (multiple bond sites) such as Calcium (Ca^{++}), Magnesium (Mg^{++}), Aluminium (Al^{+++}) and Silicon (Si^{+++}) have the capacity to form much stronger aggregates as they can essentially create soil polymers by bridging multiple particles together. Monovalent cations like Potassium (K+), Hydrogen (H+) and Sodium (Na+) will produce a much weaker structure within the soil. Sodium is a problem in many soils within Australia, leading to sodic and saline soils.

Calcium and Magnesium are both critical in creating well drained friable soil structure. Ca^{2+} is however more effective in improving soil structure than Mg^{2+}, as it is capable of inhibiting dispersion of aggregates and can replace Mg^{2+} and Na^{+} within the aggregate, further increasing stability. Mg^{2+} is more dispersive than Ca^{2+} and causes high swelling in clays, further increasing disruption and dispersion of the soil structure (Zhang and Norton 2002).

Sodic Soils

Sodic soils are soils that have greater than 5% Sodium (Na^{+}) in all cations bound to its clay particles. It is estimated that 27% of Australia's total land area is affected by sodicity through natural soil development (Northcote and Skene 1972), particularly in the more arid climates, which are saline or sodic. The Na^{+} is a highly dispersive agent which directly breaks up aggregates and indirectly degrades soil structure by limiting plant growth within the soil

(Bronick 2005). Na^+ bonds within the soil matrix are weak, particularly in comparison to covalent cations. When wet, the exchangeable Na^+ within the soil solution and clay particles repel each other, amplifying dispersion. When the fine soil particles disperse, they reorientate in solution and upon drying settle in a parallel structure, sealing the soil and preventing air and water movement along with root development. Soils with high sodium levels are termed "sodic" and are notable for a lack of structure. This settling often occurs upon a perched layer, such as the soils B horizon, creating a hard "bleached" layer (Figure 5).

Figure 5. A duplex clay soil in the Yarra Valley. Note the white bleached layer. (Source: Mark Krstic)

Amelioration treatments

Gypsum (calcium sulphate) is slightly more soluble than lime, and with adequate rainfall or irrigation, releases calcium which can move readily into and through the soil profile. This calcium displaces Na^+ and Mg^{2+} from the soil, which are then leached out (Mikhail, 2010). Gypsum is the most efficient and cost-effective form of applying calcium to the vineyard to combat sodicity and salinity, though the incorporation of it into the deeper subsoil is difficult, due to the high energy cost of deep ripping. Care must be taken post-application that the released sodium can be leached adequately from the soil, away from the plant and irrigation water sources. The uptake of this sodium can lead to significant physiological issues within the vine and potentially to rejection of fruit at harvest due to exceeding sodium MRL's for export in wine.

Another product currently being tested in several field trials around Australia is an organosilicate compound called Aquasil, by CHT, a company based in Tubingen Germany (Figure 6).

Figure 6: The picturesque town of Tubingen Germany is also home to CHT, trialling organosilicate soil amendment technology

One trial objective was to reduce surface tension in dense soils, allowing for greater vertical infiltration of irrigation water during summer. Early trials suggest this has occurred to some extent though the most surprising result is the mobilisation of significant amounts of Na^+. A side by side trial on vegetable crops in Werribee found that it replicates the effects of gypsum, though at a much faster rate. Na^+ was mobilised and leached from the system within one growing cycle in vegetables, whereas the gypsum achieved similar results but took several growing cycles. These trials continued during the 2017-2018 season in multiple crops and regions within Australia, including collaboration with Monash University in Melbourne, Australia.

Salinity

Further areas have been affected by salinization, through perched water tables, dryland salinity and saline irrigation water. Salinity is more of a problem in arid areas, below 500mm annual rainfall, as there is not sufficient rain to flush salt out of the soil profile. These soils also tend to be more alkaline than those in the higher rainfall areas along the coast where there is adequate clean irrigation water or rainfall; alkaline soils can be corrected through leaching and flushing of the Na^+, however there will have been some damage occur already due to dispersion.

Figure 7: Checking perched water table levels in Almonds in Helm, California (Source: Author)

Irrigated areas of inland Australia and the Central Valley of California both face issues with perched water tables. Large low-lying areas of the valley are now being bought back from the landholders for environmental purposes at great cost to government. The expansion of irrigated agriculture utilising saline water and the move from flood irrigation to micro sprinklers in almonds in the central valley has seen some plantings facing significant losses due to salt damage. Despite the deep sandy soils in the Central Valley, in some areas an impermeable clay layer, well below the soil surface, has created an underground pond with a high salt concentration from salty irrigation water and evapotranspiration. Figure 7 above shows the checking of the water table prior to irrigation. The salty water is a major chemical inhibitor of root development, again creating a shallow root system. Care must be taken on these soils to ensure that the irrigation water applied is not so great that the draining irrigation water mixes with the underlying perched salty water. If water mixing occurs then the salty water will start to move up through the profile through osmotic pressure, increasing sodium at the shallow depths and further disrupting soil structure. Short regular bursts of irrigation are required, rather than long intermittent cycles. When water is supplied on a rolling schedule, such as through an irrigation district where water may be allocated one day per week, the plants will suffer significant stress before their next irrigation. The long-term viability of the soil and productivity of these systems must be questioned.

Physical treatments

Mounding is the working up of midrow soil into a friable tilth which is then pushed under vine using a mounding blade, creating a "V" profile in the soil. The total amount of topsoil within the vine row is the same, however the depth of soil at the vine is significantly deeper as seen below in Figure 8. In sodic and saline soils this can create a greater volume of soil around the dripper zone where most active roots are away from any perched Na^+.

The V-shaped profile also creates a central furrow which can aid in drainage, allowing the Na^+ to drain free of the active roots, reducing uptake of the sodium into the plant tissue. An added benefit is reduced asphyxiation of roots during winter and wet springs.

Figure 8: Mounding of a vineyard in the Yarra Valley. The permanent sward hides the slightly sloping channel through the middle of the block. (Source: Author)

Tile drains are often used in areas of salinity to assist in the removal of excess Na^+ from the block during the wetter months. "Drainage tiles" are agricultural drainage pipes which form a network of drainage line "criss-crossing" across the paddock. Pipes are placed into a trench, and backfilled at the desired depth of drainage, often either just below the desired root zone or on an impermeable subsoil layer where salty water may perch. The underground water will drain into these pipes and flow down a gradient to an outlet point of the system - a drainage channel - to collect these salts. Care must be taken that this outlet channel is not going to contaminate fresh water supplies such as dams or water courses as the solution which drains will be high in sodium. Examples such as those in the lowest points of the Central Valley of California, where there is no gradient to move sodium away makes these soils unviable.

Another advantage of drainage is the ability to remove excess water from the soil profile. Not only will this increase strength in wet soils, reducing pressure on the clay soils to disperse, but it will give plant roots the available oxygen they need to thrive early in the season when soils would otherwise be saturated. Water and oxygen together are required, not water alone, to produce a thriving root system.

Acidification

Soil pH is a function of free hydrogen cations within the soil system. Grapevines, like most plants, thrive when soil pH is in the range of 6-8, as this is where the availability of most key nutrients required for plant growth is at its optimum. Figure 9 below shows many soils in Australia are highly acidic (such as the duplex loams of the Yarra Valley), or alkaline (the soils following the Murray River), shifting this nutrient availability. In acidic soils, subsoils are often of a lower pH again, regularly well below pH 5. As pH decreases, H^+ concentrations increase, leading to the breaking of the ionic bonds on large cations in the soil such as aluminium and iron (Fe^{3+}) and mobilising them. Al^{3+} is a chemical inhibitor to vine roots which will terminate at this horizon and not explore the soil below. As most microorganisms and plants struggle to thrive in low pH soil, soils can remain bare and exposed to environmental degradation. Often it is only the weed species tolerant to such acidic conditions that can thrive.

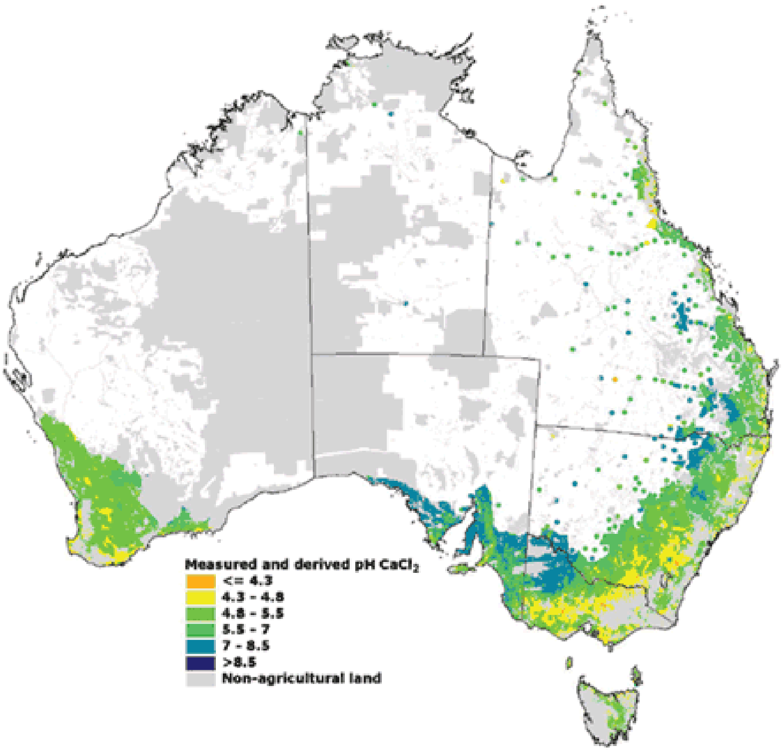


Figure 9: Soil pH in Australia (Department of Environment, 2010)

Farm management practices can lead to acidification of soils over time. Fertilisers such as synthetic urea, or large volumes of chicken manure, will lead to a decrease in soil pH. Broadacre farmers in the Pallouse, Washington State of USA, who had been growing cereal crops on deep soils with natural pH of 8 and above, are now facing significant issues with acidification. Common practice in the area is to apply significant amounts of urea when sowing their crops. Decades of this practice has seen the pH of their topsoil fall to 4.6 and below.

The effect of low pH on soil structure is complex. Low pH can result in greater dispersion in clay soils. due to the removal of large cations from the soil matrix, leading to smaller soil aggregates and a greater repulsion between particles. Low Ph disrupts the level of nutrients available, binding up many micronutrients such as Molybdenum and Zinc, whilst making large amounts of toxic Aluminium available to the plants. The cumulative effect is lower levels of root growth and microbial activity, resulting in fewer root exudates and polysaccharides in the soil, which help in binding soil particles and creating more stable aggregates.

Chemical ameliorants

Lime (calcium carbonate, $Ca(CO3)_2$) contains 40% calcium and is essentially insoluble in water. It is an alkaline form of calcium which is beneficial in increasing pH and providing much needed calcium to improve soil structure. The low solubility of lime means that the finer the product, the quicker it will dissolve, and the more effective it will be in reducing soil pH. The acid in the soil reacts with the carbonate in solution, releasing the Ca^{2+} which will then displace Na^{+} and form much stronger soil aggregates. The rising pH will also provide greater nutrient availability in acidic soils as the pH gets closer to neutral. This is a very long-term approach, as any changes in soil pH are slow to occur. Lime is not effective in adding calcium to alkaline soils as it is completely insoluble in this environment.

Long-term lime trials in Tasmania have seen continued increased productivity 20 years after initial application of lime on pasture (Krstic, 2017) (Figure 10), yet in the Pallouse there is currently no demand for the application of lime to alleviate this issue, as there is no local supply. If the acidification continues, these farms may be unsustainable due to declining productivity and profitability. It was staggering to see the degradation of these soils, and at some point, the investment in de-acidification practices must occur for these fertile soils to remain productive.

In soils with a low Ca:Mg ratio, care must be taken to ensure that the applied agricultural lime is coming from a source of high calcium purity. Dolomite, a form of lime, (magnesium carbonate, $CaMg(CO_3)_2$) is also effective at reducing the pH and does provide some calcium (25%) along with Magnesium (11%). H^{+} and Na^{+} will be displaced from the clay lattice; however, the presence of Mg may exacerbate any issues with high magnesium ratios in the soil.

Figure 10: Spreading gypsum and lime in the Yarra Valley in Autumn (Source: Author)

Cultivation

Cultivation is a common practice in European and North American vineyards for a variety of reasons, including weed control and water-use efficiencies as can be seen below in Figures 11 and 12. The soils in these regions are far younger and less weathered than in Australia, resulting in them having much better structure, larger stronger aggregates, and often rock particles which can all reduce coalescence and dispersion. Emanuel Bourgignon, a soil scientist with LAMS in Burgundy France, who has spent significant amounts of time in Australia, was adamant that cultivation should not be the preferred soil management tool in many of our soils. This is a view shared by many local soil scientists.

Figure 11. Professor Pilar Baeza of Madrid Polytechnic in heavily cultivated Grenache vineyards of La Mancha Spain (Source: Author)

Cultivation is still utilised in some vineyards of the warmer areas of Australia as a way of reducing water use by mid row plant species, though it tends to be utilised less and less. The turning of the soil exposes soil organic matter (SOM), previously bound within soil aggregates, to oxygen, allowing for the rapid expansion of microbial activity and the oxidation and loss of this previously stable carbon. The nutrient bound by this SOM is mineralised, giving the vines a short-lived boost in vigour and health. Even with consistent re-sowing of annual crops including legumes, over time a gradual reduction of overall SOM results, compared to a permanent sward. Ironically, this will reduce the amount of water the soil is able to hold, particularly in sandier soils. Continued cultivation has a detrimental effect on both the “Pore” and “Plant” aspects of soil structure.

Figure 12: A heavily cultivated midrow and undervine area in Rutherford, Napa Valley, California (Source: Author)

Tilled bare earth is prone to degradation by rainfall events, as the aggregates have been disrupted, exposing the bare earth to greater dispersion by the force of the raindrops. This causes poorer infiltration in heavier soils, as pores and bio-channels are disrupted. Higher runoff may result, resulting in the loss of topsoil, or the vines may not be able to utilise all the rainfall during the warmer months, when the water requirements are at their highest.

Compaction

Compaction has major effects on the ability of the plant to grow and thrive. Compaction is generally due to the operation of heavy machinery on wet ground, when the soil strength is reduced. The downward pressure from the weight of the tractor forces the soil particles together (Figure 13), decreasing the size of the soil pores. The effect is most noticeable in sandy soils. Continual cultivation can also lead to compaction, as the underside of the plough cut will develop a hard pan over time if not remedied. This compacted layer acts as a physical inhibitor, causing increased soil strength, reducing infiltration and root penetration, even when the soil is moist. Mouldboard ploughs have been used in vineyard development in the south of France to invert soil during vineyard development. Subsequently, a hard compacted layer forms under the weight of the tractor and plough share in wet conditions, causing stunting of vines and lost production (White, 2009).

Compaction also has an indirect result on plant growth. When roots push up against a hard mechanical barrier in the soil, either compaction or rock, there is a hormonal signal sent to the shoot to slow down growth. This is a survival mechanism for drought-like conditions; since soil drying coincides with soil hardening, it is very difficult to differential between the effects of compaction and drought.

Figure 13: Tractor tyre marks in a cultivated vineyard in Champagne, France (Source: Author)

Deep Ripping

In traditional best practice viticulture, deep ripping is undertaken pre-planting to ensure the best conditions possible for the development of young vines. Deep ripping, or subsoiling, is the disturbance of soil levels down to 100cm by tynes with wings or points attached. This procedure needs to be carried out in summer or autumn, as the soil moisture content must be right to ensure the shattered soil leaves fissures that intersect at the soil surface; too dry and the ground, particularly heavier clay soils, will be too difficult to penetrate. In wetter conditions the blades will smear the underlying soil, creating artificial barriers which will be more restrictive than the original soil (White, 2009).

The average vineyard row width in modern viticulture is below 3m, with some as narrow as 1m. The tractors required for best practice ripping are too big to be utilised in established vineyards to the depth of 1m. Smaller rippers can be utilised on conventional vineyard tractors, although the depth of shatter will be less.

Planting replacement vines in high density established vineyards in Burgundy is facilitated by the use of auger drills mounted on these specialty tractors. The pilot hole for the new vine gives adequate soil disturbance, even with the competition of the established vines, due to the fertile free draining soils present.

Care must be taken following ripping to not travel on the rip lines for as long as possible. Plastic clay subsoils will tend to reform into their massive structure if driven over while still moist; time must be given for plant roots within the vineyard system to penetrate the channels before this can occur. In new developments repeated passes of equipment during trellis instillation have the ability to undo all of the ripping benefits, if undertaken when the soil is too wet.

Another concern with deep ripping established vineyards is the effect of root pruning vines. Trials in the Barossa Valley found reductions in vine capacity lasting several years following ripping too close to the vines in every row, due to the reduced root structure.

Controlled Traffic

Like the closing of rip lines when driving on them, compaction of soil in general is most probable during early spring, when soil is moist and tractor operations such as spraying are regular.

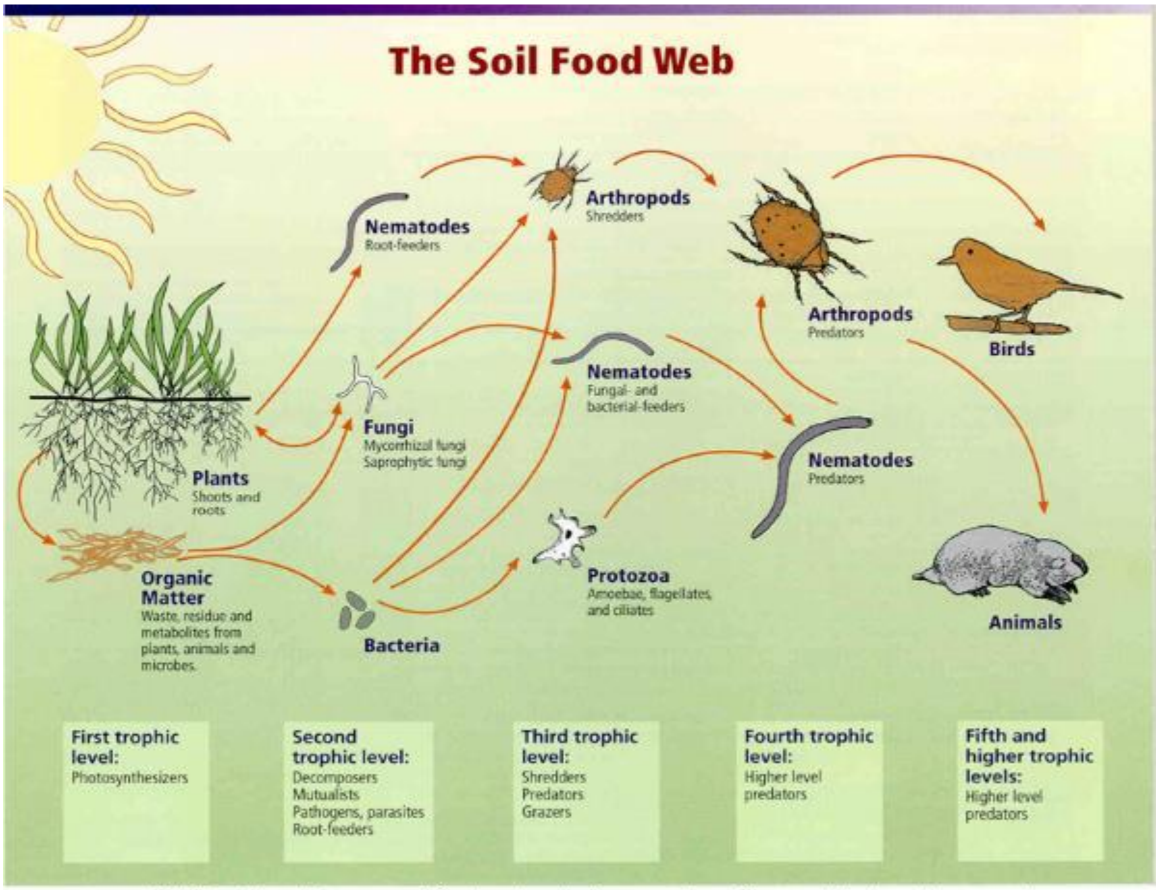
Figure 14: Specialised over-the-vine tractors and multiple row sprayers are vital in close-planted vineyards in Burgundy, France (Source: Author)

Modern advances in vineyard equipment (Figure 14 above) and trellising have allowed for far more efficient spray management practices with multiple row sprayers. This gives the manager the ability to create travel rows, in every alternate row, whereby the same rows are driven each time a spray operation is carried out. The travelled rows become compacted, whilst the alternate untravelled rows have reduced compaction risk and pressure. This can provide a greater volume of soil for the vines to explore and reduce the stress on the vines, whilst also significantly improving vineyard efficiencies. In regions such as Bordeaux, Burgundy and Champagne, where row spacings are narrower, the effect is greater, as the tyre contact zone is a higher percentage of the total row width.

Chapter 3: Plants

The soil food web

This function of soil structure management encompasses all living organisms within the soil, including plants, bacteria, fungi, arthropods, and earthworms. These organisms all form part of the soil food web (see Figure 15 below), which is the cycle of life when breakdown of all carbon-based plant residues from waste, root exudates, mulch or other soil organisms occurs. This breakdown of organic matter presents an opportunity to deliver greater volumes of SOM naturally, deeper and without disturbing the soil, and is mostly due to the breakdown of root material. This process is often referred to as bio-drilling which is the utilisation of biological practices to create fractures, channels and pores within the soil structure and all parts of the soil food web contribute to this process.



Relationships between soil food web, plants, organic matter, and birds and mammals
Image courtesy of USDA Natural Resources Conservation Service
http://soils.usda.gov/sqi/soil_quality/soil_biology/soil_food_web.html.

Figure 15: The soil food web (USDA, n.d.)

Biological activities are inherent in all soil types, even the most inhospitable. It is estimated that each gram of soil contains over 1 million different microbial species, of which only 10% are currently known.

Microbiological activity

When plants are actively growing they are continually exuding carbohydrates into the soil through their roots. This, along with other forms of carbon within the soil from decomposing roots, compost or other plant residue, creates a food source for fungi, bacteria and actinomycetes, allowing their populations to thrive. These organisms are the start of the food chain, providing food for larger organisms both above and below ground.

Fungi and bacteria species are highly sensitive to conditions within the soil regarding their ability to thrive. Like all living things they require nutrients, water and air, so the ideal soil structure will display increased soil microorganism activity. Prolonged periods of dry bare earth, repeated tillage or consistent waterlogging will have a deleterious effect on these populations. Fungal colonies will utilise their hyphae to bind soil aggregates together, reducing soil strength and increasing water infiltration. Bacterial colonies will exude glue-like compounds which also aid in the formation of soil aggregates. An active and stable fungal and bacterial biomass will also find a balance capable of helping to inhibit or compete with soil borne pathogens. As this biomass grows, it increases the SOM and the soil's water holding capacity and CEC.

There is a growing belief that the health of the soil's microbiology is directly correlated with how quickly they can respond to stimuli when coming out of a dormant state. Trials where dry soil samples have water added, show that the more resilient soils with better productive potential will quickly develop respiration levels much higher than poor soils (Haney, 2017). The key to maintaining a resilient microbial population is to retain living roots, and hence a food source, within the soil.

Figure 16: Rick Haney, USDA in Temple Texas with his equipment for measuring soil respiration (Source: Author)

Earthworms and arthropods

Of the larger soil born organisms, earthworms and arthropods such as beetles, are the most prevalent. Arthropods tend to be situated closer to the surface, shredding plant residues and feeding on other soil organisms. Earthworms, of which there are many different species, tend to fall into two categories, composter and earth-worker worms. Composter worms are not suited to survival in the soil but feed on organic materials, rapidly breaking this down and creating large amounts of vermicompost or vermicast. These castings have been shown to stimulate plant growth and can improve soil structure (Buckerfield, 2001).

The earth-worker worms are more valuable as they tend to move vertically through the soil and can transport applied ameliorants in their gut deeper into the soil. This is particularly useful for substances such as lime and gypsum, which have low solubility and can take large periods of time to incorporate into the soil. The worm castings deposited during this burrowing also stabilise aggregates, and the channels aid in drainage, root penetration and water infiltration.

The best way to optimise earthworm populations is to get the largest amount of plant biomass above and below ground, and there are various management practices that can achieve this. Cultivation is detrimental to working populations, destroying habitat even post cover crop production, so permanent swards are of greatest benefit. Mulch and compost undervine can have dramatic effects on the presence of worms, as they reduce the variability of temperature and moisture content in the soil. Lime applications have an added benefit of boosting worm populations, as earthworms do not survive as well in acidic soils (Buckerfield, 2001). This is part of the reason why many farmers and researchers are now using earthworm counts as method of monitoring soil health trends, though actual count numbers can vary depending on the climatic conditions at the time.

Root structures

All plant root structures are defined by the availability of water, space and nutrient available to them. Compaction, coalescence and dispersion will create much smaller pores, increasing soil tension and making the soil less hospitable. Recent research suggests that vines only have a single flush of root growth through the season. This is primarily in spring (Laura Radville, 2016), so this time is crucial in having the soil in a state with minimal restrictions for growth. Soil tension higher than two megapascals will create a physical inhibition, shortening roots and preventing penetration, which in soils with high soil strength can be soon after the soil starts to lose moisture. It is therefore crucial that the winter period is utilised to create diverse and permanent rooting structures to help form aggregates and other fissures in the soil structure, reducing soil strength and creating channels for vine roots to penetrate.

Midrow Management

Permanent swards are possibly the best way to develop stable structures and aggregates within the topsoil. These can be grown out in spring, utilising excess moisture from the soil, then slashed and thrown undervine, creating a layer of mulch to help build up undervine OM. Ryegrass is especially effective in creating a large biomass within its fibrous root system, though this is relatively shallow. Lucerne would be a great option in trying to get roots deeper into the profile, however it is difficult to establish in a vineyard situation and will compete with the vines for water and nutrients during the growing season. Clover, vetch and other legumes are good to include for diversity in both flowering and vegetative bodies and rooting structures. Rick Haney and Frederic Thomas and others are promoting biodiversity in plant species as a major contributing factor to improved soil structure and health. Many of the best vineyards in Burgundy would have a diverse range of vineyard floor plants prior to cultivation back into the soil. An added benefit of a diverse sward species is that, when grown out in spring, it creates different habitats for beneficial insects close to the main crop. Additional winter annual crops can also be direct-drilled into the sward in autumn to supplement the prevailing species, further diversifying the seed bank present.

Figure 17: Bob Schindelbeck of Cornell University with Bruce Murray of Boundary Breaks Wines, Finger Lakes District NY (Source: Author)

Large taproot species, such as radish, can be utilised to try to break up the soil profile allowing cavities for subsequent roots to penetrate. Radish is a winter active species in Australia, producing most of its bulk vegetation during these months. In North Western USA, it is grown in autumn, to break open soils in broadacre agriculture, prior to the winter freeze which then kills the plant. Bob Schindelbeck (Figure 17) of the Cornell University Soil Health Laboratory in New York State is another advocate of building soil health through cover crops and reduced tillage. Bob and his team found that the growers who used and demonstrated the use of tillage radish prior to winter improved trafficability, water penetration and overall yield the following year. The large taproot was also significant in that it sparked the grower's imagination to what could be achieved in the soil, a lightning rod for the spark of change.

High soil strength in dry clay loam soils during autumn seeding in Australia severely limits the radish's ability to penetrate deep into the soil profile. However, if the soil tension is too high below 5-7cm it can cause the tap root to move laterally rather than down into the profile.

Figure 18: The effects of soil strength on tillage radish grown in the Yarra Valley, Australia (Source: Author)

The image on the left in Figure 18 shows the lateral movement due to mechanical resistance during autumn (The radish on the right of each image is germinated in a softer moister soil hence has better penetration). The image on the right is of a self-sown radish growing under drip irrigation through summer. Despite sufficient water and nutrient, the radish was still forced to grow aerially.

The channels opened by the radish's vertical growth provides aeration for the soil, allows deeper irrigation and root penetration. As it decomposes, it provides a source of carbon for microbial proliferation deeper into the soil which cannot be achieved through shallow rooting grasses or application of surface compost. The lateral expansion of the radish also causes the soil to crack, creating more fissures at the surface for root exploration and water infiltration.

Undervine management

One of the greatest opportunities for improvement in soil structure undervine may lie in the utilisation of vegetation in this strip. During the growing season, undervine vegetation can prove detrimental as it can be a limiting factor in productivity, competing with the vines for water and nutrient, particularly if water supply is limited. The winter months when grapevines are dormant is a great time to generate root systems and channels in the undervine area.

Trials in the Yarra Valley in 2017 found that under vine seeding during autumn following substantial irrigation has seen much better penetration of the tap root (Figure 18) as the soil strength has been reduced earlier in the radish's life.

Undervine vegetation can then be chemically controlled at the commencement of the season or mown low with specialised equipment to keep the vegetation alive but reduce the evapotranspiration and hence water consumption during the season. Chemical control should only be carried out when vegetation is present to prevent spraying bare earth allowing the killed plants to form a mat of decomposing mulch, protecting the soil from the elements.

A significant issue in vineyards which have high herbicide usage and undervine cultivation is crusting, which is the result of dispersion of bare soil by rainfall at the soil surface. If no vegetation is present, aggregates are exposed to dispersion, causing the settling of the fine clay particles. This settling results in a dense layer of particles, forming a crust which makes plant germination and water infiltration more difficult. Cover crops and even weeds can struggle to germinate and increased rainfall runoff can be a consequence.

Mulch and Compost

Mulch and compost are used for a variety of reasons, including soil moisture retention, cooling of soil, building SOM, and improving soil structure. Various mulching media have been utilised and trialled and the cost is often dependent on the quality and source of the product. Mulch tends to be a raw product such as straw, with a high carbon content and has the capacity to draw soil nitrates away from the vine as it decomposes. It tends to be banded undervine, providing protection for the soil from the environment. Compost is a mix of raw materials that has been through the composting process so is stable from a nitrogen perspective and is high in microbial activity. This can be either banded undervine, or broadcast as a general soil conditioner.

Cover crops can be utilised as a form of mulch. Grass and legume species which produce high levels of bulk organic matter, such as ryecorn, and oats can be grown out to maximise plant biomass, then slashed undervine during spring or rolled and crimped to create a mat of straw in the midrow. Straw and leguminous crops will decompose rapidly, due to the high amounts of simple carbohydrates in the plant, particularly when sufficient N is available. This decomposition process results in an increase in soil aggregates, as they are formed by soil organisms during decomposition (Magdoff, 2000). Woody material and compost is more stable and is less likely to decompose because the carbon is held in more complex and less soluble compounds, such as lignin.

Surface-applied compost can be effective in reducing soil moisture loss and minimising weed growth, however the greatest benefit for soil structure is gained when the compost is incorporated into the soil. The incorporation of compost has been shown to produce long-lasting benefits in pore size and distribution, which has flow-on effects for biological activity, water holding capacity, infiltration, aggregate stability and aeration (Cass, 2004).

The critical factor in this is the disruption to the soil's preference to coalesce. Wet soils want to settle to form stronger, more massive structures, and each movement of a tractor over the soil is adding to this. Compost, being a stable form of carbon, provides a bonding element for the soil particles and it helps reduce soil strength by creating planes of weakness within the soil. The greater distribution of larger pores then provides greater pore continuity, aiding root penetration of vines and other plants within the vineyard environment. Microbial activity will also follow the introduction of compost material and root structures, amplifying the benefits of the compost addition. The increased number of pores also improves the amount of oxygen available to the roots and microbial population in the topsoil. Subsoils do not appear to respond as well to the addition of compost due to the anaerobic nature of subsoils. Compost is also difficult to apply to the subsoil, but when added to clay subsoils to improve the CEC, drainage and microbial activity of the soil has often been sealed over by the plastic subsoil. This process encloses the organic material and excludes oxygen, preventing decomposition of the OM.

Mulching material should be accessed from nearby if possible to reduce transport costs. Straw can be a by-product of cereal crops or cut hay from pasture and vacant land. Many of the warmer regions of Australia are within the cereal growing areas, though access to the straw can be variable. Winery-owned vineyards can reduce their waste and utilise the grape skins and stalks, cardboard and other waste products to form the base of a very efficient compost.

Further materials such as straw, wood chips, and manures can be sourced from nearby and added to provide greater diversity in carbon sources.

Figure 19: Natural Selection Farms composting facility in Washington State (Source: Author)

Natural Selection Farms is a diversified organic farming operation based in Sunnyside, Washington State USA. They have developed a compost business (Figure 19), recycling waste products from their own farm and other local businesses as well as municipal waste. This has provided their own operations and community with a cheap reliable source of compost, diversified their business interests and solved an issue for the community in dealing with waste products.

Vine Roots

Vitis vinifera is the traditional winemaking grapevine species in the world and each different varietal, such as Chardonnay, Shiraz, Sangiovese and Grenache, all belong to the same species. There are hundreds of other *Vitis* species in the world which have different growing natures and are bred and utilised as rootstock for a myriad of purposes.

Each rootstock has its own different characteristics. Some like 101-14 are more prone to having shallow fibrous root systems and are more susceptible to water stress. This is effective in controlling vigour on vigorous high capacity soils, though in restrictive soils it may not work. When soils have poor structure the 101-14 vines struggle to extract water during the summer months and irrigation is often not sufficient to keep the vines from stressing. It is possible that this is due to the roots spending large amounts of time in wet conditions during spring, subject to various root rots, then struggle to penetrate and extract moisture during the warmer months as soil strength increases.

Others are more drought tolerant and push roots deeper into the soil, rather than having a large collection of fibrous roots close to the surface like Paulsen 1103 or Richter 110. Some rootstocks like Ruggeri 140 are also far more salt tolerant and can exclude salt from the soil solution when extracting water (Dry, 2007).

In Australia, most plantings are on *V. vinifera* roots, though some individual areas have reasons such as increased yield or biosecurity (phylloxera and nematodes) for planting on other rootstock. The cost of ungrafted *V. vinifera* planting material is 20% of the cost of grafted vines on rootstock, so the economic incentive to plant on rootstock needs to be strong. Biosecurity is the primary reason for choosing different rootstock within all the USA and Europe as Phylloxera is endemic in these areas. Beyond biosecurity, the decision making around rootstocks is geared toward salt tolerance or water use efficiencies. In Europe, tight AOC controls mean that planting different varieties in certain regions is impossible when trying to mitigate against climate change. As a result, rootstocks are the way forward in trying to extract more drought tolerance and delayed ripening in these areas (Ollay, 2015).

Chapter 4: People

"The eye sees only what the mind is willing to comprehend" Robertson Davies

Soil is slow to form, taking tens of thousands of years, and improvements in soil structure can take significant amounts of time, though their inherent characteristics are not likely to change. Farmers' management practices can profoundly affect the long-term viability of soils productivity; however, these practices form the third function of managing soil structure. Soil ameliorants, tillage, and traffic management are all tools to use in the management of soils and each soil has its own unique characteristics which need to be addressed. The question for each farmer is the reason these practices are undertaken and are these the best practices for the long-term sustainability of the soils. Further adding to the complexity of this decision-making process in the wine industry is the need to find the balance between productivity and wine quality outcomes.

Change limiting factors

The soil research community has long been advocating the virtues of the structural health and various remedial techniques, with varying degrees of uptake. Practice change and adoption of techniques and technology takes time. The innovators and early adopters pave the way for the majority and there will always be the laggards who resist the change. The Robertson Davies quote above "*The eye sees on what the mind is willing to comprehend*" was shared by Jim Kamas of Texas A & M whilst discussing the need to adapt practices in the Texas Hills Country wine region. Change will occur when the grower is ready.

There are countless examples of successful changes through agriculture, such as the no-till and traffic management approaches to broadacre farming, and micro-irrigation systems replacing flood irrigation practices in irrigated crops. There can be significant barriers to uptake of these changes such as insufficient resources. Many agricultural enterprises are financially stretched and time poor, and often do not explore networks which can deliver new innovations to their business. Many practices that can deliver change to a business are not capital intensive, so often the biggest resource required is the energy required to change mindset.

Agricultural risk plays a role in the adoption on new methods of farming. The risk associated with climatic conditions and to a lesser extent market factors are uncontrollable yet present with each crop. Soil structural management is a long-term approach which is difficult to measure and does not deliver immediate results, so the feeling of reward for effort can be elusive. This lack of reward for effort can often result in practices abandoned at the start of the journey. A sown cover crop may fail due to insufficient or excessive rainfall, and the farmer may feel that the time and resources used were not worthwhile and do not persist with the practice. Innovative crop protection methods may be perceived to be not worth the investment if undertaken in a low disease pressure year, not understanding the full benefits may be realised in a high-pressure year. Mulching can see similar outcomes. The use of straw mulch can provide habitat for many forms of organisms. This is one of the benefits of mulch, as discussed earlier, however sometimes these organisms can be detrimental to the crop. One wine producer in the Willamette Valley in Oregon abandoned the use of straw mulch following the discovery that it provided habitat for rodents. Mulch was banded under-vine, surrounding the vine trunks, to retain moisture and build soil structure. These rodents whilst sheltering in the straw mulch found that the young vines were a great localised food source, and the death of large numbers of vines resulted. Whilst the losses accrued were devastating for that young block of vines it appears that older vines are not subject to this sort of damage. It is unknown if this was a seasonal problem, with a year of high rodent numbers causing the problem, as the practice was abandoned without further trials.

Other farmers in the Barossa Valley in Australia found that if they mulched their vines during the season, earwig infestations were reported, resulting in fruit quality downgrades and hence lower returns per tonne. It is not known if the same gains could be made in water use efficiency and soil improvement, and the earwig issue be resolved if the mulch was kept away from the trunk of the vine. Research needs to be done to determine if there is a way to modify these practices to get the long-term results and eliminate the negative attributes.

All trials or operations which have not been deemed successful should be examined to elucidate the cause of the response. By continually questioning the cause of the failure, the trial may be improved by using an alternate strategy and the gains may be even greater. The road to improvement is not clear, and many hurdles need to be cleared along the way.

Lack of champions

One way of promoting greater uptake of innovations and technology is through the active work of farmers acting as champions for change. Farmers are far more likely to adopt new practices if they can see something in action, ask questions and gain a greater understanding of the process through product testing. It is this practical demonstration and understanding that presents the greatest opportunity for change. Many other agricultural sectors are much better than the Australian wine industry at sharing new innovations and ideas.

Focus groups such as the “discussion groups” in the Irish dairy industry, sees small network groups of farmers walk each other’s farms focussing on a relevant topic. A follow-up meeting is scheduled the next week to give the visiting farmers a chance to provide positive constructive feedback and give their own farm reports, benchmarking themselves against industry standards (Rushe, 2017). There is a “Chatham House rules” approach ensuring transparency of the businesses; nothing is immune from discussion, including some financials. Whilst these networks are small, and the reach is limited, it shows community engagement and continual improvement. Many farmers are also part of several groups, so the learning from one farmer is capable of diffusing though a wider audience. One of the issues we could have discussed within the wine industry is the large number of absentee owners. Farms are left to be run by managers or contractors without the presence of the owners and if employee turnover is high, there is no consistent long-term view to what success in soil management looks like. It is important that, as an industry, learnings are shared as widely as possible.

The role of the champion needs to be truly authentic in sharing failures as well as successes to ensure the full benefits are spread to the community. In advance of the removal of milk quotas in the EU, the Irish dairy industry recognised there was no example of large scale, greenfield dairy developments within the country. A joint venture was established between Glanbia PLC (the largest milk processor in Ireland), the Irish Farmers Journal and the Irish farmers themselves. A long-term lease was obtained on 117 Ha of farmland, and a fully operational commercial dairy was developed three years prior to the removal of the quota system. The goal was to run this dairy to best practice standards, fulfil all regulatory obligations and report to the industry with full transparency on operating efficiencies. Having the Irish Farmers Journal as a partner gave the operation the opportunity to communicate its successes and shortcomings with far greater scope and depth of content. By developing this demonstration site in advance of the boom in greenfield developments, the industry could become aware of, and manage many issues that were common in these ventures. A secondary benefit was the effect on regulations, as the farm was not able to cut any corners in the way it conducted business. This clearly showed where regulations were having detrimental effects on the farm's ability to make gains in productivity or profitability and formed a valuable reference point when the industry was pushing for change (Rushe, 2017).

The soil acidification in the Pallouse region of Washington state is an example of both positive change and the lack of champions willing to promote different approaches. The deep fertile soils are on rolling swales of land, and years of mouldboard ploughing had seen the soil all moving from the crest of the hills down into the valleys. This was further subject to erosion, which was clogging waterways and reducing productivity on large portions of the higher ground. The introduction of no-till farming reduced erosion, built soil structure and utilised rainfall much better due to the increased rainfall infiltration with lower runoff. This was a great result and an example of positive change.

The continual use of this practice, in conjunction with synthetic fertilisers, has now seen a narrow band of acidification form. A pH of 4.6 is very low, and if this were to continue its downward spiral the soil would become irreparably damaged.

Figure 20: Measuring Soil pH in no till soil in the Pallouse, Washington State (Source: Author)

Despite the USDA soil scientists insisting on the virtues of lime application, no farmer was willing to take it on board. There were many reasons - the lime was not local, the cost was perceived as too high, and the yields were still good. The potential cost of not carrying out any remedial work could, however, be devastating in the future. Both USDA soil scientists and extension officers believed if a suitable farm trial or champion could be demonstrated, uptake would be much higher.

Frédéric Thomas, a French farmer and editor of TSC magazine, is a champion of conservation agriculture. Like Rick Haney, Bob Schindelbeck and numerous other soil scientists, he advocates the use of cover crops to regenerate soils in broadacre farming. The language that Frédéric is able to use due to his practical farming experience allows for his message to be shared authentically, with a greater uptake and acceptance of the message than perhaps even the best research communicators.

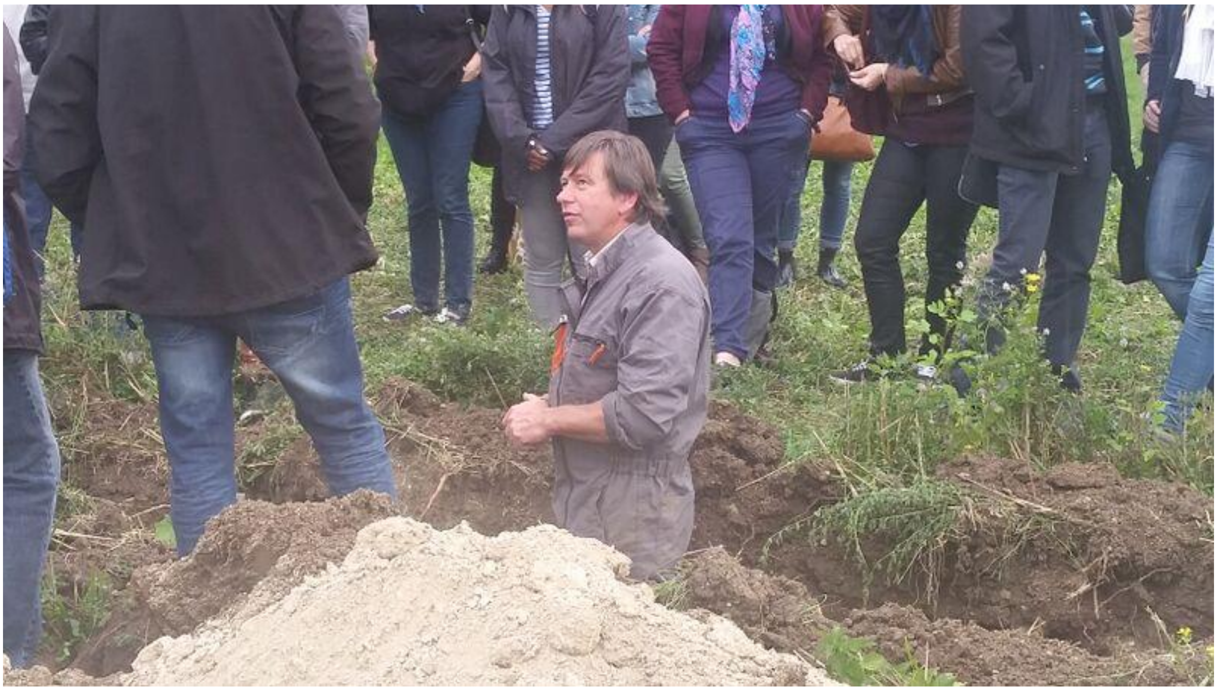


Figure 21: Frederic Thomas at a grower field day in Effiat, France 2015 (Source: Author)

Successes can inspire action, however if the next farmer does not experience the same levels of success for any reason – timing of treatment, seasonal conditions or lack of resources – then the treatment may be abandoned prematurely, or, at worst, the farmer may be forced out of business. The remaining farmers then enter the "*once bitten twice shy*" phase.

The role of any form of improvement needs to be continuous and as such there will always be advances and failures, but the dialogue needs to be ongoing. If a community of trust can form around the champion, then the learning will be far greater and longer lasting.

Conclusion

The current fiscal conditions of the wine industry are not those that promote large amounts of investment back into the vineyard. Many gains can, however, be made through better management decisions with minimal investment. Controlled traffic and less cultivation, allowing undervine growth, requires fewer inputs and is a more hands-off approach. The gains are incremental and difficult to see from season to season, particularly as seasonal variation in temperature and rainfall is an even greater influence on growth and abiotic stress, though long-term trends will develop.

It is important to work within the season and long-term climatic forecast in determining the best management strategies in any one season. Dry winter forecasts may not warrant seeding new species in the midrow or undervine. However, investing in mulch or compost may see returns in increased yield and quality, as well as the long-term soil structural benefits this brings. Wet springs require minimal tractor operations to reduce compaction. The response to the climatic risk of the season is critical in optimising soil structure as a poor decision is often more influential than a good one.

It is critical that farmers continue to try new techniques to continually improve and understand that not everything trialled will be successful. Trials must be questioned, like every operation within the business, to understand why it has failed to determine the greatest lessons and 'where to' from there.

The wine industry is largely a brand-driven industry, as opposed to a commodity, that spends large amounts of time and resources engaging with consumers, trying to gain an edge over competitors. The number of variables throughout the production process such as soil, winemaker and barrels, that can influence variability in the end product is huge, so shared practices do not diminish the competitive edge. There is no reason why grape-growers, as custodians of the land, should not share successes and be brave enough to share failures in order to drive the industry as a whole towards a sustainable land use approach.

It is incumbent upon the industry to highlight and promote the values of high performing sustainable producers. Best practice guidelines are more effectively learnt in practice and in the field rather than the text book, so demonstrations, field walks, and discussion groups or mentor programs are a great way of sharing knowledge. This is not just applicable to soil management practices but all aspects of industry, from production to processing and marketing.

Vineyards take time to develop and mature before the best quality grapes can be produced, so long-term thinking needs to be employed to maintain the assets. The goal should be to have healthy, environmentally and financially sustainable vineyards for generations to come. Openness about failures, as much as successes, is needed to achieve this.

Recommendations

"The success of the pioneering farmers draws the sceptics to the waters." Bob Schindelbeck Cornell University.

What is required is a considered and consistent long-term approach to sustainable soil management.

The three P's need to be utilised in a holistic approach to achieve a vision of long-term sustainable vineyard health. Traditional European-style farming practices are not suitable to the older and more fragile soils of Australia and a modern system needs to be utilised consistently. The keys to this are:

- Minimal topsoil disturbance through tillage.
- Controlled traffic operations and minimal equipment operations during wet periods.
- Occasional ripping to break compaction layers in alternate rows, timed to maximise root growth into rip lines.
- Remediation and maintenance of soil chemistry and cation balance with gypsum and lime.
- Perennial vineyard-floor vegetation sown with a diversity of species both midrow and undervine.
- Utilisation of mulch and compost undervine.
- Promoting the dissemination of practical lessons through discussion groups and mentor programs.
- Create champions for change, sharing both best practice and recognising failures.

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Plain English Compendium Summary

Project Title:	**Managing soil structure in established vineyards**
Nuffield Australia Project No.:	1513
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Objectives	Investigate and identify novel management methods for the long-term sustainability of soil structure. Identify methods of encouraging change practice regarding soil management in farming operations.
Background	The Australian wine industry provides the fifth largest export by value and is produced in a wide variety of regions, climates and geological areas. The soils these vines grow in are old and fragile in nature and are readily degraded when managed utilising traditional European practice. They are prone to degradation during routine vineyard operations, reducing productivity and wine quality outcomes in seasons of extreme weather.
Research	Research was mostly undertaken in Spain, France, Germany, Canada, Ireland and the USA examining vineyard and orchard soil maintenance. Australian research has also been included as soil conditions and the challenges they present are quite unique.
Outcomes	The current fiscal conditions of the wine industry are not those that promote large amounts of investment back into the vineyard. Many gains can, however, be made through better management decisions with minimal investment. A holistic soil management approach is required, with an emphasis on soil chemistry, plants and organic matter. The industry needs to improve how to share failures as well as our successes.
Implications	Vineyards take time to develop and mature before the best quality grapes can be produced, so long-term thinking needs to be employed to maintain the assets. The goal should be to have healthy, environmentally and financially sustainable vineyards for generations to come. Further research is required on some treatments, though they look promising.
Publications	Presentation of study topic findings at the Nuffield Australia National Conference, Darwin 2017