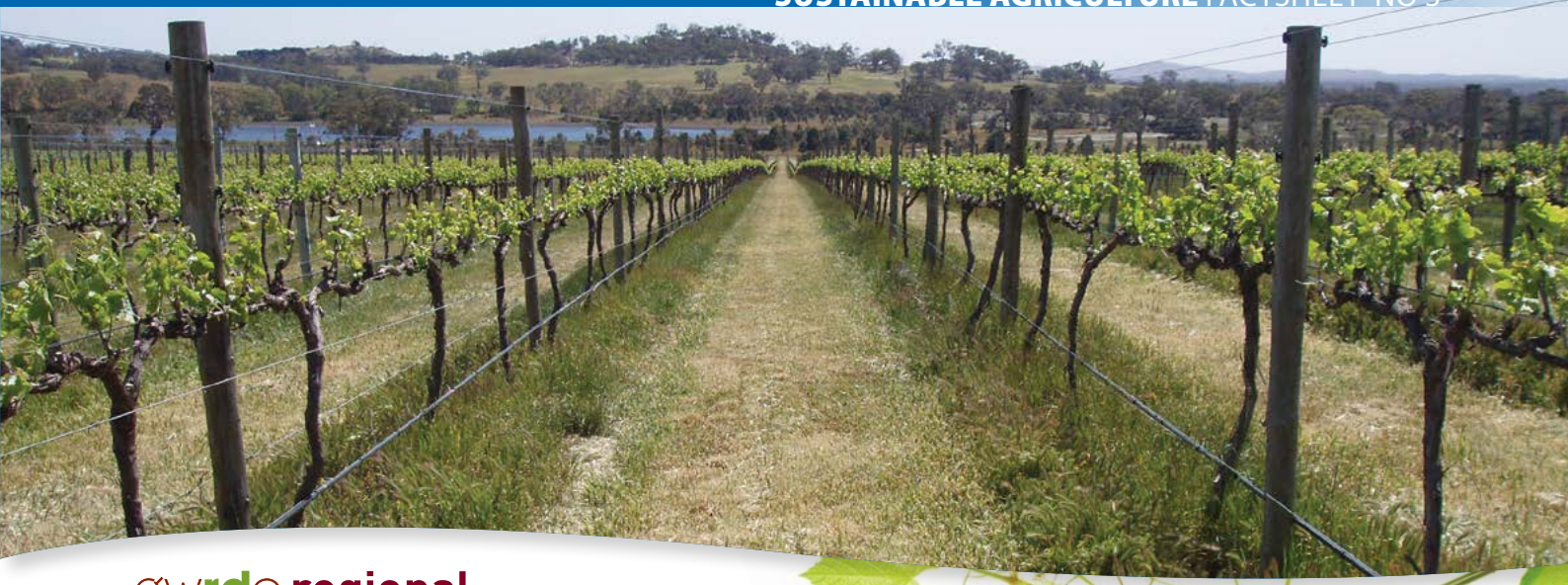

gwrdc regional grassroots solutions

Assessing soil quality and interpreting soil test results

Introduction

Soil quality, in a viticultural context, can be thought of as the soil's ability to support grapevine growth and the production of a crop (with consideration to both yield and quality) without resulting in soil degradation or harm to the environment. It includes the functions of soil such as the provision of a medium for vine growth, the retention and release of water, nutrient cycling and the regulation of biological populations. The assessment of soil quality should therefore include the analysis of its physical, chemical and biological properties. By conducting a range of field and laboratory analytical tests, grape growers can determine whether corrective action is required to alleviate any constraints to soil use or whether their practices are having any beneficial or deleterious impacts on soil quality. In established vineyards, soil testing is undertaken regularly (i.e. annually or biennially) in order to provide information that is required for making decisions on the need for and application rate of inputs such as fertilisers, soil amendments (e.g. lime and gypsum) and bio-fertilisers/inoculants (i.e. products which contain living micro-organisms).

Regular soil monitoring over time using sound sampling and measurement strategies is important. There is no single descriptor of soil quality; instead a 'tool kit' of indicator tests is used. Results from these tests should be evaluated by comparing them with known benchmark (or optimum threshold) values and vine performance criteria such as crop yield and fruit quality. Benchmark values should be evaluated against vine performance on a regional basis using different soils and management practices over time.

The field and laboratory measurements described in this publication have been selected on the basis of scientific merit and practicality (e.g. Oliver *et al.* 2013, Riches *et al.* 2013). For some soil tests (e.g. biological properties), little information is available on benchmark values to aid data interpretation.

Sampling and taking measurements

Soil properties are spatially variable, and in some cases, temporally variable. In order to characterise the area of interest within the vineyard, the following points need to be considered when sampling or taking measurements:

- The most appropriate time to sample or take measurements
- The number of samples or measurements required
- The location of the samples or measurements
- The depth of the samples or measurements

Once samples have been collected (see Figures 1, 2 and 3), it may be possible to bulk them to give a composite sample for analysis. Bulking should only been done when samples come from a relatively uniform area.

Figure 1: Using an auger to collect soil samples in the field.
(Photo: K. Pekin)

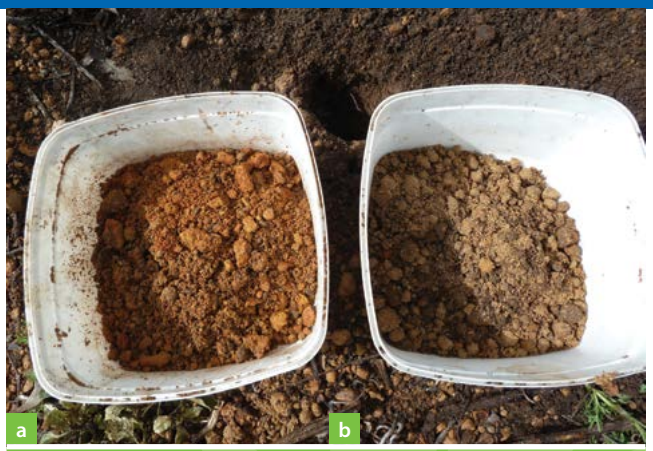

Figure 2: (a) Top-soil and (b) sub-soil samples should be kept separate in the field. (Photo: K. Pekin)

Soil physical properties

Measures of soil physical properties are not routinely performed by laboratories and require specialised equipment which makes it difficult for grape growers to perform the measurements themselves. Due to the nature of these properties, it may take many years before changes are detectable.

Texture

Soil texture (the proportion of sand, silt and clay) is an inherent property of soil and changes little with land use or management practice. It can be measured qualitatively in the field (see Figure 4) or quantitatively in the laboratory and is an important property because it determines the amount of water a soil can hold when fully wet and the rate at which water and dissolved solutes are potentially available for vine uptake. The information is of value for initial soil characterisation but not for monitoring change over time.

Figure 3: Assessing soil and vine root characteristics in the field. (Photo: R.E. White)

Figure 4: Assessing soil texture by hand in the field. (Photo: K. Pekin)

Soil structure and aggregate stability

Soil structure has profound effects on water infiltration, available water capacity, drainage, aeration and root penetration (see Figure 5). These effects are partly due to the arrangements of aggregates of sand, silt and clay and the pores between them and partly due to the stability of the aggregates when immersed in water.

Aggregate stability can be measured in the field or laboratory using the slaking/dispersion test (see Figure 6 and Table 1) or, less commonly, in the laboratory using the wet sieving technique (Table 2). Soils which slake readily (i.e. aggregates separate into micro-aggregates) and/or disperse readily (i.e. micro-aggregates separate into single particles) indicate a weak structure that is easily degraded by raindrop impact and mechanical disturbance. This in turn impacts on the availability of water for meeting transpirational demand, the availability of oxygen for respiration at the soil-root interface and the functionality of the root system. Aggregate stability can be improved by increasing the organic matter content of the soil and by applying gypsum (calcium sulphate; $CaSO_4$).

Strength

Soil strength determines the resistance of soil to breaking or deformation and is usually measured in the field quantitatively using a penetrometer (see Figure 7 and Table 3) or semi-quantitatively by hand and foot (Table 4). A soil with high strength (e.g. due to compaction, see Figure 8) is likely to limit the volume of soil that can be accessed by plant roots, as well as by soil flora and fauna. Since the results are highly dependent on soil water content, measurements should be taken and results compared at the same water content (preferably field capacity). The standard unit for expressing soil strength measurement is mega-pascal (MPa).

Figure 5: Sub-angular blocky top-soil structure is generally a desirable feature of vineyard soils. (Photo. R.E. White)

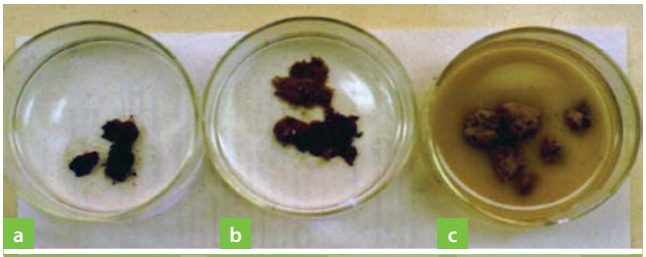

Figure 6: Assessing aggregate stability in the laboratory (a) aggregates remain stable (b) aggregates swell and slake (c) aggregates swell, slake and disperse. (Photo: DEPI, Victoria)

Table 1 Interpreting soil aggregate stability results derived from the dispersion test

Degree of dispersion[1]	Emerson aggregate class	ASWAT[2] score
High (complete dispersion)	1	>12
High to moderate (partial dispersion)	2	9–12
Moderate to slight (complete or partial dispersion after remoulding)	3	1–8
Negligible (well-aggregated, with no dispersion after remoulding)	4	0

[1] Dispersion may be suppressed in saline soils [2] Aggregate Stability to Water

Source: Adapted from Hazelton and Murphy (2007)

Table 2 Interpreting soil aggregate stability results derived from the wet sieving technique

Aggregate stability rating	% stable aggregates (1–2 mm)
Very low	<10
Low	10–20
Moderate	20–30
High	>30

Source: Adapted from Hazelton and Murphy (2007)

Table 3 Interpreting soil strength (penetration resistance) results in relation to plant growth

Degree of soil strength/ consolidation	Surface penetration resistance (MPa)	Effect on plant growth
Loose	<0.5	No effect
Medium	0.5–1.0	Seedling emergence and root growth maybe retarded
Dense	1.0–2.0	Seedling emergence and root growth will be retarded
Very dense	2.0–3.0	Vine root growth retarded at 2 MPa when soil at FC[1] Vine root growth retarded at 3 MPa when soil at PWP[2]
Extremely dense	>3.0	Root growth ceases; water uptake is restricted

[1] Field Capacity [2] Permanent Wilting Point

Source: Adapted from Hazelton and Murphy (2007)

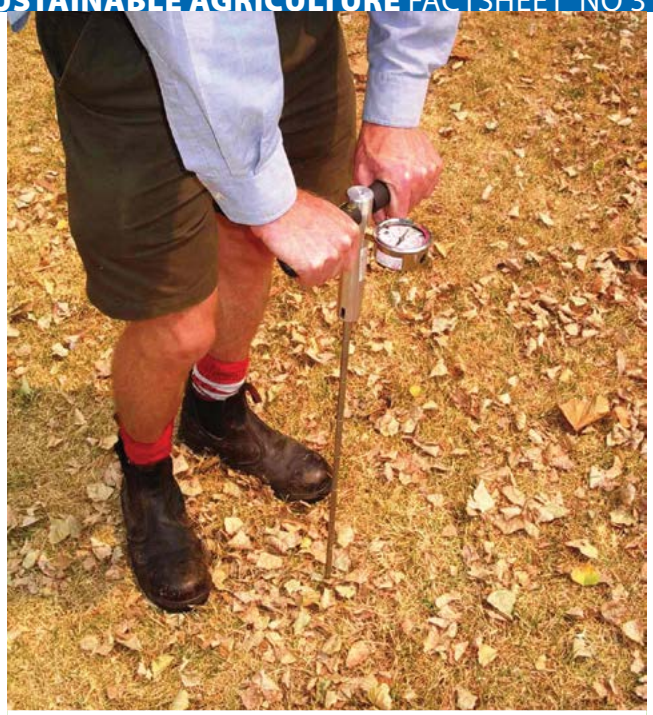

Figure 7: Assessing soil strength in the field using a penetrometer. (Photo: R.E. White)

Table 4 Interpreting soil strength (hand or foot breaking) results in relation to soil behaviour

Degree of soil strength/ consolidation	Ranking	Amount of force required to break/deform a 20 mm diameter piece of soil
Loose	0	None required
Very weak	1	Almost none required
Weak	2	A small but significant amount required
Firm	3	A moderate or firm amount required
Very firm	4	A strong amount required but within the power of thumb and forefinger
Strong	5	Insufficient force can be exerted using thumb and forefinger. An effect can be realised when placed underfoot on a hard flat surface
Very strong	6	Crushes underfoot using full body weight applied slowly
Rigid	7	Cannot be crushed underfoot using full body weight applied slowly

Source: Adapted from McDonald et al. (1998)

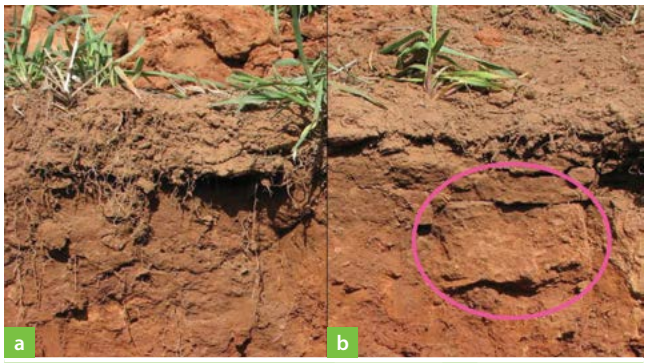

Figure 8: (a) No evidence of sub-soil compaction and good root exploration (b) compacted soil (note the brick-like unit in the upper sub-soil) is often the result of using vehicles in wet soil conditions. (Photo: DEPI, Victoria)

Soil chemical properties

The primary function of soil in relation to chemical properties is to provide nutrients for plant and crop growth. In addition, the soil's chemical properties need to be suitable for nutrient uptake. Commercial laboratories offer a range of soil chemical tests such as pH, electrical conductivity, cation exchange capacity and exchangeable cations, sodicity and the availability of macro- and micro-nutrients.

pH

Soil pH is a measure of its acidity or alkalinity and is an important property because of its influence on the supply of nutrients (cations and anions) to plants, the chemical behaviour of toxic elements and the activity of micro-organisms. There are two standard laboratory tests; using water (pH $_{H_2O}$) and using 0.01M calcium chloride (pH $_{CaCl_2}$), both of which use a 1:5 soil to solution ratio (see Figure 9 and Table 5). Because these two methods give different values, pH test results should indicate the technique used. There is no simple conversion factor between the two measures. In non-saline soils, pH $_{H_2O}$ values are commonly between 0.6 and 0.8 units higher than pH $_{CaCl_2}$ values. In saline soils, the difference between the two measures is about 1.2 units. Acidic soils can be ameliorated by applying lime and non-acidifying forms of fertiliser inputs.

Table 5 Interpreting soil acidity and alkalinity (pH H_2O) results in relation to vine growth and nutrient availability

Degree of acidity/alkalinity	pH $_{H_2O}$[1]	Effect of vine growth and nutrient availability
Strongly acidic	≤5.5	Stunted shoot and root growth. Some elements (e.g. P, Ca, Mg, Mo) may become poorly available while others (e.g. Al, Mn) may become available at toxic levels
Moderately acidic	5.6–6.0	No effect
Slightly acidic	6.1–6.5	No effect
Neutral	6.6–7.3	No effect
Slightly alkaline	7.4–7.8	No effect
Moderately alkaline	7.9–8.4	Minor effect
Strongly alkaline	≥8.5	Some elements (e.g. Fe, Cu, Zn) may become poorly available; sodicity can become a problem

[1] pH measured in water

Source: Adapted from Hazelton and Murphy (2007)

Figure 9: Assessing soil chemical properties such as pH is usually performed in the laboratory. (Photo: Shutterstock)

Salinity/Electrical conductivity

Soil salinity refers to the presence of soluble salts within the root zone. Vine growth, crop production and fruit quality can be affected through osmotic and/or ionic processes. If the concentration of soluble salts is high enough, the vine's ability to take up water and nutrients may be reduced. In addition, there may also be direct toxicity effects. The degree of salinity can also affect the amount of ions (e.g. chloride and sodium) that accumulate in the vine, fruit and ultimately in the wine. The response by grapevines to salinity is dependent on variety and rootstock.

Electrical conductivity (EC) measurements, using either a saturated extract from soil paste (EC_e) or a 1:5 soil:water suspension ($EC_{1:5}$), provide an estimate of the total soluble salts (Table 6). The saturated extract technique is the preferred method as it takes soil texture into account. However, it is less widely used than the soil:water suspension technique because it is more time-consuming and expensive to perform. Multiplier factors are available to convert EC_e to $EC_{1:5}$ and vice versa. The standard unit for expressing EC measurement is deciSiemens per metre (dS/m) which is numerically the same as milliSiemens per centimetre (mS/cm).

Total soluble salts (TSS) is an expression of soil salinity that is still used by some laboratories. The standard unit for expressing TSS measurements is milligrams per litre (mg/L) which is numerically the same as parts per million (ppm). The following conversion equation can be applied:

TSS (mg/L) = 640 x $EC_{1:5}$ (dS/m)

Soil salinity issues can be addressed by leaching salts from the root-zone through rainfall and/or applied irrigation and through the use of salt-excluding rootstocks.

Table 6 Interpreting soil salinity (EC_e and $EC_{1:5}$) results for a range of textures in relation to vine growth

Degree of salinity	ECe[1] (dS/m)	$EC_{1:5}$[2] (dS/m)					Effect on vine growth
		Loamy sand	Loam	Sandy clay loam	Light clay	Heavy clay	
Non-saline	<2	<0.15	<0.17	<0.25	<0.30	<0.4	Little effect
Slightly saline	2–4	0.16–0.30	0.18–0.35	0.26–0.45	0.31–0.60	0.41–0.80	Own rooted vines begin to be affected
Moderately saline	4–8	0.31–0.60	0.36–0.75	0.46–0.90	0.61–1.15	0.81–1.60	Own rooted vines are severely affected — some rootstocks have tolerance
Highly saline	8–16	0.61–1.20	0.76–1.45	0.91–1.75	1.16–2.30	1.60–3.20	Severely affected
Extremely saline	>16	>1.20	>1.45	>1.75	>2.30	>3.20	Death occurs

[1] Electrical Conductivity determined from a saturation paste extract [2] Electrical Conductivity for various soil textures using a 1:5 soil:water suspension

Source: Adapted from Cass (1998)

Cation exchange capacity

The cation exchange capacity (CEC) of a soil represents the capacity of the soil to hold and exchange positively charged cations. It is an important property since it influences the structural stability and pH of soil, the availability of nutrients for plant growth, and the soil's reaction to fertilisers and other ameliorants. CEC can be measured directly in the laboratory by determining the amount of cations exchanged from the extracting solution ($CEC_{measured}$). Alternatively in non-acid soils, CEC can be calculated as the sum of the base cations (CEC_{bases}) (Table 7).

The CEC is a single value and therefore does not indicate which cation(s) predominate. Soils with a low value (CEC <5) generally have a low fertility status and a low resistance to changes in soil chemistry caused by land management practices. Sandy soils and acid soils often have a low CEC, while clay soils generally have a high CEC. The type of clay mineral also has a strong influence on CEC. The standard unit for expressing CEC and individual exchangeable cation measurements is centimole per kilogram of soil (cmol[+]/kg) which is numerically the same as milliequivalents per 100 grams of soil (meq/100 g).

The five most abundant exchangeable cations in soils are sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and, in strongly acidic soils, aluminium (Al^{3+}) (Table 8). Aluminium may become freely available to vines at toxic levels when Al^{3+} is >5% of the CEC and when the soil is strongly acidic (pH_{H_2O} ≤5.5). Other cations are usually in amounts that do not contribute significantly to the cation complement.

Table 7 Interpreting soil cation exchange capacity (CEC measured and CEC bases) results

CEC rating	$CEC_{measured}$[1] (cmol[+]/kg)	CEC_{bases}[2] (cmol[+]/kg)
Low	<5	<3
Moderate	5–15	3–10
High	>15	>10

[1] Cation Exchange Capacity determined as the amount of cations exchanged from the extracting solution
[2] Cation Exchange Capacity calculated as the sum of the base cations
Source: Adapted from Nicholas (2004)

Table 8 Interpreting exchangeable cation results[1]

Cation	Low (cmol[+]/kg)	Moderate (cmol[+]/kg)	High (cmol[+]/kg)
Ca	<5	5-10	>10
Mg	<1	1-5	>5
Na	<0.3	0.3-1.0	>1
K	<0.5	0.5-1.0	>1
Al	<0.1	0.1-1.0	>1

[1] Note that desirable levels of individual cations vary according to soil type and the crop being grown
Source: Adapted from Nicholas (2004)

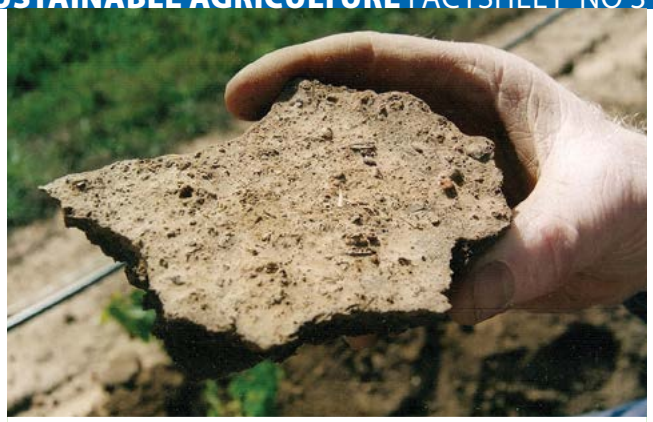

Figure 10: The dispersion of clay particles results in a crusted/sealed soil surface which limits the infiltration of water and the emergence of plants. (Photo: T. Proffitt)

Sodicity

The sodicity of a soil is assessed in the laboratory and is expressed as either the exchangeable sodium percentage (ESP) or the sodium adsorption ratio (SAR) (Table 9). ESP is the amount of Na^+ adsorbed on to soil particle surfaces as a proportion of the CEC. SAR is the relative concentration of Na^+ to Ca^{2+} and Mg^2 in the soil solution and is determined using either a saturation extract (SAR_e) or a 1:5 soil:water extract ($SAR_{1:5}$). The soil:water extract method is cheaper but less accurate.

When in contact with water, a sodic soil will generally swell and disperse into small clay particles. As the soil dries, the clay particles block the soil pores resulting in poor water infiltration, decreased available water capacity, hard setting and drainage/aeration issues (see Figure 10). These physical soil conditions generally have an adverse effect on vine growth and productivity. They can be ameliorated by applying gypsum and by reducing the frequency and severity of tillage operations, avoiding over-irrigation and increasing soil organic matter levels through the use of cover crops and mulches.

Macro- and micro-nutrients

A number of macro- and micro-nutrients are required for vegetative and reproductive growth. Certain nutrients can also influence the quality of fruit produced which, in turn, may affect the quality of must and wine. For a number of reasons, plant tissue analysis (e.g. petioles) as opposed to soil analysis is considered to be more effective and more reliable in assessing a grapevine's nutritional status and hence the deficiency or excess of nutrients in established vineyards. Even so, it remains common practice to have nutrient concentrations analysed in soil samples (particularly at the time of vineyard establishment) and a number of benchmark values have been derived, albeit based on limited calibration data (Table 10). The concentrations of nutrients (e.g. nitrogen) change over time, which make soil test results inconsistent and therefore difficult to interpret reliably.

Table 9 Interpreting soil sodicity (ESP, SARe and SAR1:5) results in relation to soil structural stability

Degree of sodicity	ESP (%)[1]	SAR_e[2]	$SAR_{1:5}$[3]	Effect on soil structural stability
Non-sodic	<6	<6	<3	Generally stable
Marginally sodic	6–15	6–15	3–7	Aggregates susceptible to dispersion when wet
Strongly sodic	>15	>15	>7	Dispersion occurs spontaneously by rainfall and/or irrigation

[1] Exchangeable Sodium Percentage [2] Sodium Adsorption Ratio determined using a saturation extract [3] Sodium Adsorption Ratio determined using a 1:5 soil:water extract
Source: Adapted from (Nicholas 2004)

Table 10 Interpreting commonly analysed soil nutrient results (expressed in mg/kg) in relation to wine grape production

Nutrient[1]	Deficient	Marginal	Adequate	High	Toxic
Nitrogen (NO_3^-) (N)	<1	1–2	2–10	>10	-
Potassium (K)	<50	50–100	100–250	>250	-
Phosphorus (P)	<25	25–35	35–80	>80	-
Copper (Cu)	<0.1	0.1–0.2	0.2–0.4	>0.4	>2
Zinc (Zn)	<0.5	0.5–1.0	1–2	2–20	>20
Manganese (Mn)	-	<2	2–4	-	-
Iron (Fe)	-	-	>4.5	-	-
Aluminium (Al)	-	-	-	-	>100
Boron (B)	<0.1	-	0.2–1.0	-	>3
Sulphur (S)	<10	-	-	-	-

[1] NO_3^- Nitrate form of N; K, P — Colwell bicarbonate extractable; Cu, Zn, Mn, Fe — DTPA extractable; Al — ammonium chloride extract; B — hot water extract

Source: Adapted from Lanyon et al. *(2004)*

Petiole benchmark values for assessing vine nutrient status are available in Robinson *et al.* (1997) and in Goldspink and Howes (2001). These should also be viewed with some caution since they are considered appropriate for commercial, high yielding (8–15+ t/ha), irrigated vineyards but not necessarily appropriate for lower yielding (4–8 t/ha), irrigated or dry-grown vineyards. They are also not appropriate for all grapevine varieties or rootstocks.

Soil biological properties

Soil biological properties encompass living soil organisms (micro-flora, meso-fauna and macro-fauna) and residues (dead material making up soil organic matter) living on and in the soil (see Figure 11). Soil organisms have an impact on plant production systems through the modification of the soil physical, chemical and biological environment. They can be grouped according to their main functions; (i) the micro-food web organisms (e.g. bacteria and fungi), (ii) the litter transformers (e.g. micro-, meso- and macro-fauna) that assist in the decomposition of organic matter, and (iii) the habitat creators/modifiers (e.g. earthworms, ants and termites).

Soil biological tests relate primarily to measurements of the amount, activity and diversity of soil organisms and their related biochemical processes. However, because they are difficult to measure and quantify, benchmark values are not as readily available as for physical and chemical soil tests. Where information is available, it has generally been derived from broad-acre agriculture rather than from viticultural research.

Organic matter/carbon

Organic matter (OM) is usually expressed in the form of organic carbon (OC). OC is readily available as a carbon and energy source and is important because of its association with nutrients and the beneficial contributions it makes to all soil properties. OM levels are usually determined by measuring the amount of OC present in the soil, and then multiplying this value by 1.72.

A number of laboratory tests are used to measure OC, with the majority focusing on the total amount present rather than the labile forms. OM and OC values are generally expressed as either a % or as g/100 g of soil. OC values for different textures are usually interpreted with respect to soil condition (or quality) since interpretive criteria that are meaningful to vine performance are not readily available (Tables 11 and 12).

Soil micro-flora

Soils contain a diverse range of micro-flora (archaea, bacteria and fungi). At present, the ecological function of many species within this group of soil organisms is unknown and hence benchmark values have yet to be established. Where benchmark values do exist, they are primarily for soil pathogens.

One group of organism with a known ecological function is the arbuscular mycorrhizal fungi (AMF). AMF have been shown to be beneficial through their symbiotic relationship with plant root systems, including grapevines. The level of AMF infection may be a good indicator of soil quality in low input vineyards, but may not be of universal use for viticulture.

Soil fauna

Soil fauna are categorised into three size classes based on body width; micro-fauna (<100 µm; e.g. protozoa), meso-fauna (100 µm to 2 mm; e.g. nematodes, mites, springtails) and macro-fauna (>2 mm; e.g. earthworms, ants). As for micro-flora, benchmark values exist for only a few groups due to difficulties associated with sampling, isolation and identification.

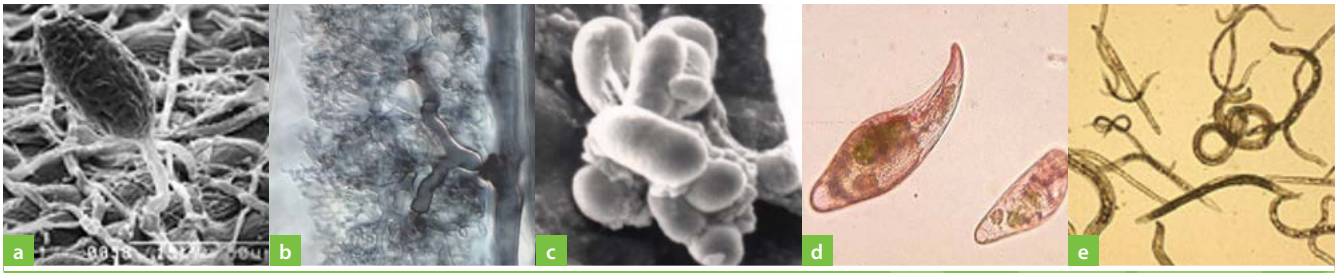

Figure 11: The diversity of soil organisms found in soils can be extremely high. (a) Fungi (b) Arbuscular mycorrhizae (c) Bacteria (d) Protozoa (e) Nematodes. (Photo: DEPI, Victoria)

Table 11 Interpreting soil organic carbon (OC) results in relation to soil condition/quality

OC rating	Level of OC % (g/100 g)	Effect on soil condition/quality
Very low	<0.4	Degraded or severely eroded topsoil
Low	0.4–1.0	Poor structural condition and stability
Moderate	1.0–1.8	Moderate structural stability, condition, pH buffering, nutrient levels, water holding capacity
High	1.8–3.0	Good structural condition and stability, high pH buffering capacity, high nutrient levels, high water holding capacity
Very high	>3.0	Dark colour, large amount of organic material, soil often associated with undisturbed woodland/forested areas

Source: Adapted from Hazelton and Murphy (2007)

Table 12 Interpreting organic matter (OM) results for a range of soil textures. Values have been derived for soil types in South Australia

OM rating	Level of OM (%) for different soil textures			
	Sand	Sandy loam	Loam	Clay loam/clay
Low	0.9	1.2	1.6	2.1
Moderate	0.9–1.7	1.2–2.4	1.6–3.1	2.1–3.4
High	>1.7	>2.4	>3.1	>3.4

Source: Adapted from Vitinotes (2006)

Macro-fauna, such as earthworms, are relatively easy to sample and isolate and have been used as indicators of soil quality. In vineyards, earthworm populations have been shown to decrease in response to increased tillage operations and high concentrations of copper in the soil. Where mulch and compost additions have been used, earthworm populations have been shown to increase. However, earthworm populations are not considered to be a good soil quality indicator test since they are not ubiquitous and are liable to respond to changes in soil moisture and inputs such as OM.

Within the meso-fauna size class, nematode soil tests have been used the most frequently because information exists about their taxonomy and feeding roles. Although the time and expertise required for assessment of nematodes communities is high, benchmark values have been established and are used where there are potential soil and vine health issues. There are numerous soil-inhabiting nematode species and not all of them are harmful to plants. However, some are plant-parasitic, feeding on and damaging roots, including those of grapevines. These activities reduce the vine's ability to take up water and nutrients from the soil. Root damage can also lead to the entry of disease-causing pathogens (Table 13).

Soil microbial biomass

Soil microbial biomass (SMB) is defined as the living component of soil organic matter, excluding plant roots and macro-fauna. It is a measure of the total size of the microbial population but not its composition or functional potential. SMB is considered to be a more sensitive indicator of change in soil quality than measures of OC. At present, benchmark values are not available.

Table 13 Interpreting soil nematode results in relation to potential damage to grapevines (*Vitis vinifera*)

Nematode species	Degree of potential damage to grapevines	In roots (no. nematodes/g)	In soil (winter & summer (no. nematodes/ 200 g)
Root Knot *Meloidogyne* spp.	Low Medium High Very high	40–80 150 300–500 >500	15 W[1] 5 S[2] 15–100 W 40 S >100 W >40 S
Root Lesion *Pratylenchus* spp.	Low Medium High	10 20–30 60–80	<5 5–20 >20
Dagger *Xiphinema index* *X. americanum*	Low Medium High	- - -	<5 5–40 >40
Citrus *Tylenchulus semipenetrans*	Low Medium High	20–40 60–70	<10 10–100 >100
Ring *Criconemella xenoplax*	Low Medium High	- - -	<5 5–50 >50
Pin *Paratylenchus* spp.	Low Medium High	- - -	<20 20–200 >200
Stubby Root *Paratrichodorus* spp.	Low Medium High	- - -	<5 5–40 >40

[1] Winter [2] Summer

Source: Adapted from Nicol et al. *(1999)*

There are two laboratory techniques used for measuring SMB; the substrate induced respiration technique (SIR) and the chloroform fumigation extraction technique (CFE) (Table 14). SIR values can be converted to CFE values by multiplying by 30. The standard unit for expressing SMB is milligrams of carbon per kilogram of soil (mg C/kg) which is numerically the same as micrograms of carbon per gram of soil (µg C/g). The wide spatial variability in SMB, along with their sensitivity to moisture and temperature, means that a representative sampling strategy has to be adopted and that samples have to be taken at the same time of year.

Table 14 Soil microbial biomass (SMB) values, determined using the chloroform fumigation extraction technique, for soils in different winegrowing regions/countries

Region/country	Vineyard management system	Soil/parent material	SMB (mg C/kg soil)
Alsace, France	Conventional and organic	Limestone and granite	400 (conventional) 493 (organic)
Loire Valley, France	Compost and manure inputs vs no inputs (control)	Calcareous sand	167 (control) 440 (with inputs)
Marlborough, New Zealand	Conventional and organic	Sandy and gravelly	200–527

Source: Adapted from Riches et al. *(2013)*

Potentially mineralisable nitrogen

Potentially mineralisable nitrogen (PMN) is considered to be a possible biological indicator of soil quality. It represents the capacity of the soil microbial population to convert (or mineralise) nitrogen that is tied up in complex organic residues into the plant available form of ammonium (Table 15). Soils with a high PMN are generally well-aggregated and have high OC and OM values. PMN can be used as a surrogate measure for microbial biomass because it is easier to determine. The standard unit for expressing PMN is milligrams of nitrogen per gram of soil per week (mg N/g/wk).

Table 15 Potentially mineralisable nitrogen (PMN) values for soils under different agricultural production systems and environments

Region / country	Crop	PMN (mg N/g soil/wk)
North east USA	Grain and vegetables	8–11
Victoria, Australia	Winegrapes	6–18

Source: Adapted from Riches et al. *(2013)*

Considerations

- Soil analyses can provide valuable information to optimise overall vineyard performance, particularly when combined with vine tissue analysis.
- Soils are inherently variable which means that the correct sampling/measurement strategy needs to be adopted. Be aware of the factors that may impact on the values obtained and the repeatability and interpretability of the measurements (e.g. soil water content and temperature at the time of sampling).
- Use the same commercial NATA[1] or ASPAC[2]-accredited laboratory as this avoids variation in results which arise from the use of different analytical techniques.
- For some soil properties, little information is available on benchmark values to aid data interpretation. This is particularly the case for soil biological properties.
- Benchmark values may vary regionally and with grapevine variety grown, as well as spatially and temporally within a vineyard.
- Interpret soil test results in relation to known crop yield and fruit quality specifications. For example, low test values may be the target where vigour control and limited yield are the required objectives.
- Determine the greatest limiting factor in the soil resource and manage this issue.
- "Unless you test, it's just a guess!"

[1] National Association of Testing Authorities [2] Australasian Soil and Plant Analysis Council

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Publication reference

Proffitt, T. (2014). Assessing soil quality and interpreting soil test results. **www.winewa.asn.au**

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Coordinating sustainable environmental outcomes

Wines of Western Australia

Perth Region Natural Resource Management in partnership with Wines of Western Australia

ACKNOWLEDGEMENTS The Grape and Wine Research and Development Corporation (GWRDC) provided funding for this publication through their 'Regional Grassroots Solutions' program which is managed in Western Australia by Wines of Western Australia (WWA). WWA acknowledge the input of Tony Proffitt (AHA Viticulture) who researched and wrote the contents of this publication, Robert White (University of Melbourne) for his comments and photographs and Keith Pekin (Perth Region NRM) who managed the project on behalf of WWA through funding provided by the Federal Government's 'Caring for our Country' program.

Published April 2014