Managing grapevine nutrition and vineyard soil health

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Perth Region NRM

WINES OF WESTERN AUSTRALIA

CARING FOR OUR COUNTRY

CONTENTS

The concept of soil health integrates soil physical, chemical and biological attributes. The interaction of these properties determines how effectively the soil is able to perform a number of ecosystem functions such as the retention and release of water and nutrients, the provision of sufficient oxygen for respiration at the soil-root interface and the breakdown and release of organic compounds.

1. INTRODUCTION

Nutrition is a cost-sensitive issue in vineyards. In recent years urea has increased in price by about 50% while diammonium phosphate (DAP) has increased by about 80% (Hoare 2008). Importantly, prices are likely to continue increasing as world demand exceeds supply.

However, nutrition remains an important part of managing a vineyard since it impacts on vine growth, crop yield, berry composition and ultimately, must and wine quality. A 'one program fits all' approach is not achievable since nutritional requirements must tailor to a range of variables including grape variety, rootstock, vine age, soil type and properties, water and irrigation supply, production and wine quality expectations, and management history.

In order to develop a suitable nutrition program on an individual block basis, growers need to approach nutrition in a holistic manner using the latest technology and suitable fertiliser products, with a focus on improving or maintaining soil health so vines can access the majority of their nutrient requirements.

The term 'soil health' is a relatively new term and frequently used synonymously with the term 'soil quality'. Soil quality is an older concept that is generally used when assessing the suitability of land for agricultural purposes; however, it is still relevant today.

Soil quality encompasses the inherent properties of a soil which are influenced by:

- Parent material;
- Climate;
- Topography;
- Vegetation; and
- Time.

The recent use of the term 'soil health' places an emphasis on the living organisms found in soil. Most definitions of this term consider the holistic nature of soil, thereby encompassing the physical, chemical and biological components. Doran and Parkin (1996) define 'soil health' as 'the capacity of soil to function as a vital living system to sustain biological productivity, maintain environmental quality, and promote plant and animal health'.

This document provides guidelines on ways to ensure that the nutritional requirements of grapevines are met in an informed, sustainable fashion. As background, we discuss the principles of nutrient function, mobility and availability, ways to assess vine nutrient status, and why it is important to balance nutrient outputs and inputs.

Fertiliser products, the selection process, and when and how fertilisers are best applied then follow, along with recommendations on how to manage the soil resource and environment.

The implications of climate change on vine growth and nutrient management are also summarised.

2. NUTRIENT FUNCTION IN RELATION TO VEGETATIVE AND REPRODUCTIVE GROWTH

Vine nutrition is important for grape production since nutrients have a number of crucial functions in vegetative and reproductive growth.

High levels of water and nutrient inputs do not necessarily result in beneficial responses in fruit.

Grapevines require a number of macro-nutrients. These are shown below in descending order of percentage dry weight for normal growth and reproduction.

- Nitrogen
- Potassium
- Calcium
- Magnesium
- Phosphorus
- Sulphur.

Micro-nutrients (trace elements) are also required but in lesser amounts than macro-nutrients. These are shown below in descending order of percentage dry weight for normal growth and reproduction.

- Boron
- Iron
- Manganese
- Zinc
- Copper
- Molybdenum.

The functions of each nutrient are shown in Table 1.

Good fruit set in table grapes.

Table 1 The major nutrients required for grapevine vegetative and reproductive growth

Nutrient	Function
Nitrogen (N)	Required for most metabolic functions and a component of most compounds making up and synthesised by the vine. Influences shoot growth in spring and prevents premature leaf fall in autumn. Influences inflorescence initiation, and berry growth and development after fruit set.
Potassium (K)	Required as a component of cell vacuoles and for protein synthesis and stomatal functioning. Influences shoot growth in spring, and berry size and ripening.
Calcium (Ca)	Required as a component of cell membranes and cell wall structure and for enzymatic processes. Influences physiological disorders such as bunch stem necrosis and the skin strength of berries.
Magnesium (Mg)	Required as a component of chlorophyll molecules and for metabolic processes. Influences fruit formation, berry ripening and the germination of seeds.
Phosphorus (P)	Required as a component of cell membranes and genetic material and for carbon dioxide fixation, sugar metabolism, and energy storage and transfer. Influences shoot growth in spring, inflorescence initiation and fruit set.
Sulphur (S)	Required as a component of amino acids, proteins, vitamins, enzymes and chlorophyll molecules.
Boron (B)	Required for the production of growth hormones, movement of sugars, pollen germination and pollen tube growth and general metabolic processes. Influences cane maturation and fruit set.
Iron (Fe)	Required for chlorophyll synthesis and photosynthetic and respiratory processes. Prevents premature leaf fall in autumn.
Manganese (Mn)	Required for chlorophyll synthesis and as a metabolic catalyst.
Zinc (Zn)	Required for cell metabolism, chloroplast development, hormone synthesis and pollination. Influences fruit set and intermodal elongation.
Copper (Cu)	Required as a component of oxidation enzymes and for chlorophyll synthesis and lignin formation. Influences cane maturation.
Molybdenum (Mo)	Required in converting nitrates for protein synthesis and for flower functionality. Influences fruit set and is required by nitrogen-fixing bacteria.

3. NUTRIENT FUNCTION IN RELATION TO BERRY COMPOSITION, MUST AND WINE QUALITY

Various nutrients influence the quality of fruit produced by the grapevine which, in turn, has an influence on must and wine quality. These effects can either be direct through the influence on berry composition which determines the taste and aroma profile of the wine, or indirectly through the influence on vegetative growth. There is good information available in the literature on the impact of N, K and P on must and wine quality. The following provides a summary of this knowledge.

3.1 NITROGEN

Vines growing in soils deficient in N can be slow to ripen fruit due to insufficient photosynthetically active leaf area. At harvest, the fruit reflects these soil conditions by being low in N.

During the winemaking process, yeast requires N in the form of free amino nitrogen and ammonia nitrogen, collectively termed yeast assimilable nitrogen (YAN). If the YAN concentration in the juice or must is low (about 150 mg/L, Spayed *et al*. 1995), yeast metabolism can be impaired resulting in slow or 'stuck' ferments and the production of undesirable thiols (e.g. hydrogen sulphide).

Conversely, high YAN concentrations in the must can result in ferments which run too fast ('hot ferments'), resulting in the production of ethyl acetate, acetic acid, and volatile acidity which produce undesirable wine attributes.

Approximately 250–350 mg N/L is quoted as being necessary to ensure there are no fermentation problems (Bell and Henschke 2005). There are also some varietal differences to consider, with Chardonnay and Verdelho often found to have relatively low values of YAN.

Excess N in the soil is likely to stimulate shoot growth which can cause excessive bunch shading and result in berry juice with a high pH and low aroma and colour. In addition, large canopies can result in poor ventilation which increases the risk of disease (e.g. powdery mildew and botrytis rot).

Plant tissue analysis of N is not a reliable indicator of YAN. Therefore, the YAN content of juice or must samples is usually measured in the laboratory as a combination of the ammonium nitrogen content and the amino acid nitrogen content. Both of these are measured separately and the values combined to give YAN in mg/L.

The measurement is a relatively simple procedure for wineries with a visible light spectrophotometer. Such an instrument is commonly used for measuring malic acid and glucose/fructose in juice and wine.

3.2 POTASSIUM

Vines growing in soils deficient in K can affect grape sugar production, vine water uptake and enzyme activity including processes involved with colour formation.

Excess K in the soil can result in high levels of K in berry juice which increases the pH of the must. This in turn may cause problems with malolactic fermentations and may also produce poor colour and stability in the resulting wines. Acid additions are unlikely to change the pH.

3.3 PHOSPHORUS

Vines growing in soils deficient in P can result in poor vegetative and reproductive growth. This in turn can have an influence on berry composition and subsequent must and wine quality.

Excess P in the soil can adversely affect vine growth which may impact on berry composition and subsequent must and wine quality.

The fertility of a soil, and in particular the top soil, is important because it determines how much nutrient is potentially available to vines. Vines cultivated for wine production in general do not benefit from large amounts of water or nutrient input because they are likely to exploit these resources to produce excessive vegetative growth to the detriment of wine quality.

4. SOIL AND ITS ROLE IN PROVIDING WATER AND NUTRIENTS

Healthy soils have a natural ability to:

- Sustain the life of soil biota (i.e. micro-flora, micro-, meso- and macro-fauna);
- Suppress pathogens (i.e. pest and disease-causing organisms);
- Provide sufficient water and nutrients to maintain vine health; and
- Decompose organic matter easily.

The characteristics of a particular soil have a large influence on the availability of water and concentration of nutrients stored within it and, in turn the availability of the nutrients to the vine.

The key properties of soil within the root environment which influence water and nutrient storage and availability include:

- Depth and fertility;
- Physical texture and structure;
- Chemistry; and
- Biology and organic matter content.

A deep soil allows extensive root penetration, thereby allowing vines to explore large volumes of soil and potentially large supplies of water and nutrients. Extensive root penetration both laterally and vertically is particularly important when a soil is relatively infertile.

The fertility of a soil, and in particular the top soil, is important because it determines how much nutrient is potentially available to vines. Vines cultivated for wine production in general do not benefit from large amounts of water or nutrient input because vines are likely to exploit these resources to produce excessive vegetative growth to the detriment of wine quality (Rawson 2002). Indeed, many 'world famous' vineyards are located on relatively infertile soils.

Since soil fertility is spatially variable laterally and vertically, knowledge of the variation in soil characteristics is important as this will influence the nature of vine growth, and water and fertiliser requirements across a particular vineyard.

Soil texture is a measure of the relative amounts of sand, silt and clay particles. Texture is an important component because it determines the amount of water a soil can hold when fully wet, and the rate of water and dissolved nutrient potentially available for vine uptake. For information related to soil texture analysis in the field, refer to Longbottom (2009) or the fact sheet available at: **http://soilquality.org.au/factsheets/soil-texture**

Soil structure refers to the composition of aggregates: sand, silt and clay and the size and shape of the spaces (pores) between them. Soils with good structure allow air, water and nutrients to move freely through pores within and between the aggregates, thereby influencing the water and nutrient reservoir for vine growth. Vines commonly have a low bulk density and strength allowing roots to grow without restriction.

In contrast, soils with poor structure have a high proportion of small pores and high bulk density and strength which results in restricted air, water, root and nutrient movement.

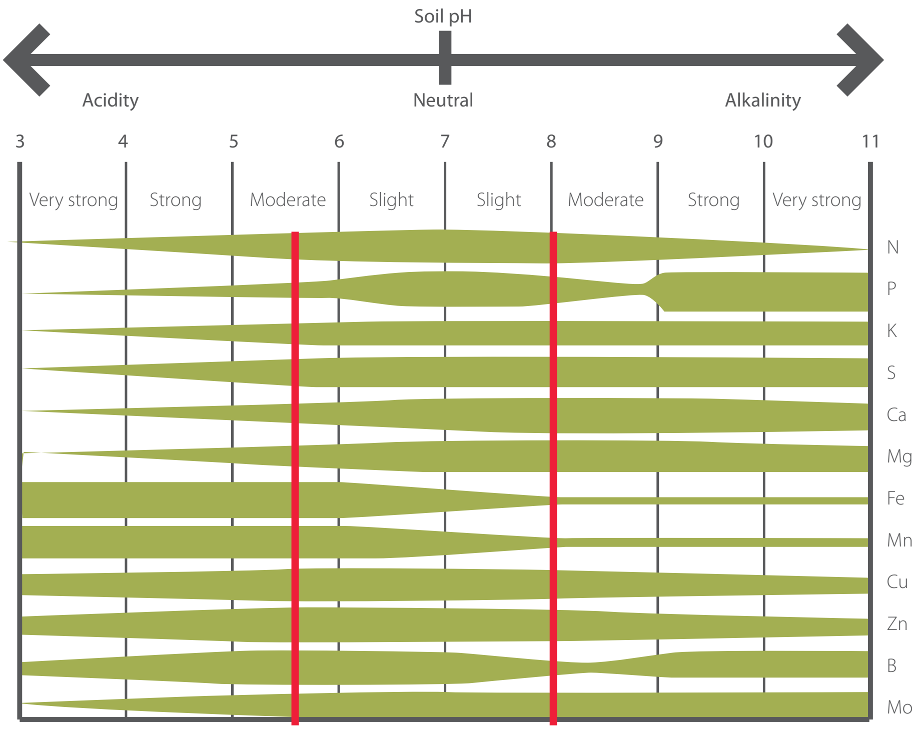
Vines growing in such conditions may exhibit a number of deficiency symptoms associated with poor nutrient uptake.

The slaking of aggregates and the dispersion of clay is generally synonymous of structural degradation and in some cases can be improved through the use of gypsum and a change in soil management practices.

For information on how to assess slaking and dispersive behaviour in soils and whether they are likely to be responsive to gypsum, refer to the fact sheet available at: **www.gwrdc.com.au/wp-content/uploads/2012/09/2011-FS-Managing-Soil-Structure.pdf**.

A key chemical component of soil in relation to nutrient availability to grapevines is pH. Each nutrient responds differently to changes in soil pH, with the optimum range (measured in water) for nutrient uptake being between 5.5 and 8.

Figure 1 The effect of soil pH on the availability of nutrients to grapevines (Longbottom 2009). The optimum pH range (measured in water) for nutrient uptake is between 5.5 and 8



Soils with a pH>8 (alkaline) can cause the following nutrients to become poorly available for vine uptake:

- P, Fe, Mn, Zn, Cu and B because they form insoluble compounds; and
- Ca and Mg because Na takes their place on the surface of colloids.

Alkaline soils may therefore be sodic due to the abundance of Na and may also produce ammonia gas as a result of volatilisation of ammonium nitrogen.

Soils with a pH<5.5 (acidic) can cause the following nutrients to become poorly available for vine uptake:

- P and Mo because they form insoluble compounds; and
- Ca and Mg because they are displaced by Al and H.

In strongly acidic soils (pH<5), Al and Mg may become freely available to vines at toxic levels. Soil acidity can also increase the uptake of heavy metals such as Cu and lead (Pb) and decrease the population of micro-organisms.

Soils with a pH<5.5 (acidic) can cause the following nutrients to become poorly available for vine uptake: P and Mo because they form insoluble compounds, and Ca and Mg because they are displaced by aluminium (Al) and hydrogen (H).

In strongly acidic soils (pH<5), Al and Mg may become freely available to vines at toxic levels.

The routine measurement of soil pH and the application of lime to ameliorate acidic soils are important vineyard activities. The best time to apply lime is prior to planting a vineyard since it can be ripped into the soil at depth. In established vineyards, a surface application with some form of incorporation is generally the only option. The requirement for lime can vary with soil texture and the buffering capacity of the soil. Soil tests should be used to determine an appropriate rate.

The following guidelines for selecting and applying lime should be observed:

- Lime is available in various pure forms and mixtures. Calcium carbonate (ground limestone, agricultural lime and shell lime) is often the cheapest but least reactive form. Calcium hydroxide (slaked or hydrated lime) is more reactive but also more expensive. Calcium oxide (burnt lime, quicklime) is the most reactive and must be stored dry.
- Lime particles need to be as fine as possible (i.e. <2 mm).
- It is best to apply lime in small amounts frequently until the target pH is achieved. As a guide, sands and loamy sands require 1–2 t/ha of lime to raise the pH of the soil by one pH unit, sandy loams require 2.5–3.5 t/ha and loams and sandy clay loams require 3.5–4 t/ha. Higher rates are required for treating soil deeper than 20 cm.
- Be aware that the application of lime may result in a decrease in the availability of one or more of the following nutrients; Mn, Zn, Cu and Fe.
- The neutralising value and cartage/spreading costs need to be assessed to select an effective, economic product.

For more information on measuring soil pH and the use of lime refer to the fact sheets available at: **www.gwrdc.com.au/wp-content/uploads/2012/09/2006-FS-Measuring-Soil-pH.pdf** and **www.gwrdc.com.au/wp-content/uploads/2012/09/2006-FS-Liming.pdf**.

High pH soils are much less common and can be managed by use of acidifying fertilisers.

Cation exchange capacity (CEC) is a measure of the soil's ability to attract/hold positively charged nutrient cations. It is an important soil property influencing soil structural stability, nutrient availability, soil pH and the soil's reaction to fertilisers and other ameliorants. The CEC of a soil varies according to both the percentage and mineralogy of clay it contains, the amount of organic matter present and the pH.

The most commonly occurring clay in WA soils is kaolinite which has a CEC of about 10 meq /100 g. Other clays such as illite and smectite have CEC's ranging from 25 to 100 meq /100 g. Organic matter has a high CEC ranging from 250 to 400 meq/100 g (Purdie 1998). Because a higher CEC usually indicates that more clay and organic matter is present (i.e. greater potential soil fertility), high CEC soils are also likely to have a greater water holding capacity than low CEC soils.

Soils with a low CEC have a low resistance to changes in soil chemistry that are caused by land use, and as such, are more likely to develop deficiencies in K, Mg and other cations than soils with a high CEC. Sandy soils and acid soils often have a low CEC.

Nutrient cycling is the core function associated with soil chemical fertility. Organic nutrient compounds found in soils are rarely in a form readily available for vine uptake and need to be converted into available forms through mineralisation.

The community of organisms that live in healthy soils (i.e. the soil biota, which include bacteria, fungi, protozoa, nematodes, mites, earthworms and arthropods) are a key part of this process. As these organisms feed on organic matter, decomposing the complex carbon (C) compounds and deriving energy for their growth, the elements of the organic matter are mineralised.

Nutrient cycling is the core function associated with soil chemical fertility. Organic nutrient compounds found in soils are rarely in a form readily available for vine uptake and need to be converted into available forms through mineralisation.

The proportion of each element (mainly C, N, P, S) released in mineral form varies with the composition of the organic compounds being decomposed and the demands of the microbial population for each element.

Vine roots growing in deep sand.

5. CHARACTERISTICS OF VARIOUS SOIL TYPES IN RELATION TO NUTRIENT AVAILABILITY

5.1 SANDY SOILS

Sandy soils have many large pores making water movement and drainage more rapid. This often results in the leaching (i.e. loss) of mobile nutrients such as nitrate (e.g. between 30–60% of N inputs can be lost to the environment, Whitehead 1995). Where sands are water-repellent, water movement is slow and nutrient availability at depth is usually poor. Generally, these soils have low levels of organic matter which gives them a low fertility status. Sandy soils retain a low amount of water for vine use which can make irrigation scheduling and nutrient application via fertigation difficult. The CEC of sandy soils is generally low.

5.2 LOAMS

Loams usually retain sufficient water for vine use and drain readily. They generally contain sufficient nutrients for vine growth and reproduction and are considered to be naturally fertile soils.

Deep gradational loam.

5.3 CLAYS

Clays have many small pores, thus water movement and drainage is slow. This can result in the development of topsoil structural problems such as hard-setting/crusting, and also prone to water logging which can limit new root growth. Even though the CEC of clay soils is generally high, nutrient deficiencies can occur as a result of clay particles binding certain nutrients (especially K) to their surface, thereby rendering them unavailable to the vine.

Hard-setting and crusting soil which limits the infiltration of water.

Quantitative and qualitative information on vine and soil nutrient status is essential in order to make informed management decisions about fertiliser requirements.

6. WATER AND NUTRIENT MOBILITY

Only a nutrient in the soil solution is immediately available to a vine, therefore, the uptake of nutrients is generally less in dry soils compared to wet soils.

Grapevines, like all vascular plants, have a vascular system composed of xylem and phloem cells which transport water, sugar, hormones and nutrients. Water moves uni-directionally within xylem vessels transporting dissolved nutrients which are absorbed from the soil solution surrounding the roots. Nutrients move upward from the roots through the trunk to the shoots, leaves and fruit as part of the transpiration stream.

In contrast, phloem vessels transport nutrients and other solutes throughout the vine. The mobility of a certain nutrient relates to its ability to move multi-directionally within these phloem vessels.

Some nutrients (N, P, K, Mg) are highly mobile and can be relocated as and when they are needed by the vine. Other nutrients have either low mobility (Mn, Ca, B, Fe) or are considered to be variably mobile (Zn, S, Mo, Cu) and cannot therefore be easily relocated within the vine.

7. QUANTITATIVE AND QUALITATIVE ASSESSMENT OF VINE NUTRIENT STATUS

Assessing vine nutrient status is crucial as this information provides an important tool for making fertiliser decisions in the vineyard. Importantly, the outcome is affected by both temporal and spatial variability. Vine nutrient status is temporally variable because it changes over the course of a day and throughout the season in response to phenological development and external influences such as the availability and quality of water, atmospheric temperature and vine productivity.

Spatial variability can be managed through the identification of discrete 'zones' within the vineyard which perform differently (see section 14). Recognising both forms of variability is important as they determine when and where sampling for nutrient analysis should be conducted, and where and when fertiliser should be applied and how much.

Both quantitative and qualitative assessments are essential when determining the nutrient status of vines. This information should be supported by an evaluation of crop yield and fruit quality in relation to whether production and wine quality expectations are being met.

7.1 QUANTITATIVE ASSESSMENT

There are three parts to the assessment process, including:

- Analytical testing of soil;
- Vine tissue or sap; and
- Irrigation water.

In each case, it is advisable to use the same commercial National Association of Testing Authorities (NATA) or Australasian Soil and Plant Analysis Council (ASPAC)-accredited laboratory since this avoids variation in results which arise from the use of different analytical techniques. In a vineyard that is performing satisfactorily, nutrition monitoring should include soil analysis every 2 to 4 years (linked to tissue analysis where possible), tissue analysis (petiole or leaf blade) every spring during flowering, and irrigation water analysis every year. If vine performance is poor, then the monitoring process should be conducted more frequently.

In addition, monitoring should also include observations of vine health and vigour, with a focus on the colour, size and shape of leaves which provide visual clues to the potential deficiency or toxicity of certain nutrients.

7.2 SOIL ANALYSIS

The analysis of soil sampled from within the vine row and/or mid row area can provide information about the physical, chemical and biological nature of the root zone and the distribution of previously applied fertiliser. The analysis can provide information on what nutrients are in the soil but not how much nutrient is available for vine growth.

Samples should be collected at the same time and at the same location each sampling year (e.g. Autumn before fertilisers are applied). In new vineyard developments, samples should be collected several months prior to planting to allow time for the application of soil amendments if required. For vine row samples, soil should be collected from the edge of the wetted dripper zone. For mid row samples, soil should be collected from across the whole width.

Laboratory analysis is usually conducted on a sub-sample (e.g. 500g) of soil collected from a composite of samples taken across the vineyard in order to account for spatial variation. As the variation in soil properties across the vineyard increases, so should the number of samples collected to ensure that the sub-sample is representative.

For topsoil (0–10 cm) at least 20 individual samples should be obtained. For subsoils (20–60 cm), this number can be halved. It is important when mixing the soil samples to form the composite sample, that the soil is not exposed to external influences (e.g. other soil, dust or fertilisers). The samples should be labelled appropriately (i.e. name, vineyard/block identification, depth interval and date). For more information refer to the fact sheet available at: **www.gwrdc.com.au/wp-content/uploads/2012/09/2006-FS-Taking-Soil-Samples.pdf**.

Soil sample collected using an auger.

7.3 TISSUE ANALYSIS

Tissue analysis is a useful tool to quantify the nutrient status because the vine integrates the variability in the soil explored by its roots. A well-defined phenological growth stage, time of day and position on the vine is required to standardise the sampling strategy since the nutrient flux within the vine is variable.

Shoot with tendrils, leaf blades and petioles.

7.4 COLLECTING SAMPLES FOR PETIOLE (LEAF STALK) ANALYSIS

Samples should be collected in the early morning when leaf turgor is optimal, and also during flowering when 80% of the calyptas (caps) have been shed from the flowers (i.e. E-L growth stage 25).

Petioles should be collected from opposite the most basal bunch on a shoot. Analysis of leaf blades has also been used to monitor vine nutrient status, however, petioles are generally considered to be more responsive to change in nutrient status than blades and have become the industry standard.

About 100 to 200 petioles are required to provide sufficient tissue for laboratory analysis. Samples should once again be representative of the vines within the vineyard block and each sample should be from vines of the same variety, rootstock, age and vigour as well as management practice. Commercial sampling and analysis kits are available from agricultural/horticultural suppliers. For more information refer to the fact sheet available at: **www.gwrdc.com.au/webdata/resources/factSheet/21PetioleAnalysis.pdf**.

Petioles should be collected from opposite the most basal bunch on a shoot. Analysis of leaf blades has also been used to monitor vine nutrient status. However, petioles are generally considered to be more responsive to change in nutrient status than blades and have become the industry standard.

7.5 SOIL VS TISSUE ANALYSIS

Soil analysis is not the preferred analytical method on an annual basis for a number of reasons that include:

- Soil nutrient concentrations are determined using various chemical extractants and each extractant can give a different result;
- Soil analyses may not necessarily relate to the ability of vine roots to extract a certain nutrient from the soil solution, it is difficult to take a soil sample which represents the complexity of the root zone in relation to both nutrient and root distribution; and
- It is difficult to convert a soil test result into a fertiliser or amendment recommendation. A combination of soil and tissue analysis should be used to decide whether there is need to apply nutrients (especially N, P and K) to a vineyard.

7.6 SAP ANALYSIS

While technology is available to conduct rapid xylem sap analysis of various nutrients, to date there is limited data available for interpreting the results for grapevines. There are currently two methodologies available; Merckoquant test strips, and a variety of meters (e.g. Cardy, Horiba).

Merckoquant test strips are suitable for the semi-quantitative detection of ions and inorganic and organic substances. They can be used in the field and provide a quick summary of the concentration of substances in the expressed sap solution.

The meters are also field-based devices and are capable of providing quantitative measurements of nitrate and potassium in the expressed sap solution.

7.7 SOIL WATER ANALYSIS

The concentration of nutrients in the soil water environment of the root zone can be directly measured using ceramic tip samplers. These are inserted into the soil at various depths in representative areas of the vineyard. At a minimum, samplers should be placed both within the root zone and below the root zone to detect any nutrient leaching.

After an irrigation event following the application of fertilisers to the soil, the water within each sampler can be analysed using test strips or metres to estimate how much of the fertiliser applied moved past the root zone and therefore wasted. Note that the samplers generally do not work in heavy clay soils.

7.8 WATER ANALYSIS

The quality of water used for the application of nutrients either through the irrigation system (fertigation) or via a spray (foliar) is important to test annually. Poor water quality can lead to a reduction in the effectiveness of any fertilisers applied because of compound reactions and/or blockages.

Water quality may also directly affect vine nutrient status, especially when it is sourced from reclaimed and/or winery effluent water. About 200 ml of water from each source is required for laboratory analysis. Refer to Table 2 for guidelines on interpreting water sample results.

Table 2 Guidelines for interpreting water quality results when irrigating grapevines (adapted from Nicholas 2004)

Property	No problem	Minor problem	Severe problem
pH	6.0–8.5		
Electrical conductivity (dS/m)	0–2	2–3	>3
Sodium Adsorption Ratio	<6	6–9	>9
Calcium Carbonate Saturation Index	>-0.5–<0.5	<-0.5–>0.5	
Boron (mg/L or ppm)	0–1	1–3	>3
Sodium (mg/L or ppm)	<460		
Chloride (mg/L or ppm)	<140	140–530	>530
Iron (mg/L or ppm)			0.1–1.5

Irrigation water is commonly delivered via drip line systems.

Phosphorus deficiency.

Potassium deficiency.

Manganese deficiency.

7.9 QUALITATIVE ASSESSMENT

Visual deficiency symptoms vary between nutrients and the extent of the lack of supply. The difference between sites where deficiency symptoms first appear is related to remobilisation and the mobility of the various nutrients. Severe deficiencies appear on leaves of all ages. Deficiencies often result in foliar symptoms and vine growth and reproductive issues (Table 3).

An excess supply of nutrients can cause toxicity problems, resulting in foliar symptoms, tissue damage (necrosis), stunted vine growth and possibly death. Both the effect of deficiency and toxicity only become visible with severity, because micro-nutrients having a smaller range between the two extremes than the macro-nutrients. Note that once the symptom is detectable, the damage has already been done.

For photographs of typical deficiency and toxicity symptoms, refer to the following references: Robinson (1992), Magarey *et al.* (1999), Nicholas (2004), Longbottom (2009).

Table 3 Visual deficiencies in grapevines (adapted from Magarey *et al.* 1999, White 2009)

Nutrient	Expression of symptoms
Nitrogen	Overall reduction in growth. Leaves become uniformly light-green or yellow.
Potassium	Starts as yellowing (white varieties) or bronze-reddening (red varieties) of older leaf margins. As the deficiency worsens, leaf margins become necrotic and curl upwards and interveinal chlorosis develops. Berry set can be poor.
Calcium	Shoot tips become stunted and may die.
Magnesium	Bright yellow (white varieties) or red (red varieties) wedge-shaped areas extend inwards between the veins on older leaves. When severe, necrosis extends inwards from the leaf margins.
Phosphorus	Vines may have stunted shoots and fruitfulness is likely to be poor. Early in the season there is a bronze/red colouration between the main veins in older leaves.
Sulphur	Symptoms are often similar to N deficiency (i.e. leaves become uniformly yellow, including the veins). Rare in vineyards where S sprays are used.
Boron	Shoot tip death and short inter-nodes, resulting in shoots with a zigzag appearance. Yellow mottling between the veins of older leaves. Edges of leaves may have small-red-brown spots. Fruit set is often poor and bunches often have 'hen and chicken' berries.
Iron	Young leaves show interveinal chlorosis. When severe, leaves are likely to be very pale with necrotic blotches. Shoots are likely to be stunted in their growth.
Manganese	Older leaves have a yellow mottle colour between the veins.
Zinc	Short internodes, resulting in shoots with a zigzag appearance. Shoot tips have small upward curling leaves. Mottled, light-coloured interveinal colouring on leaves. Small, poorly developed bunches with 'hen and chicken' berries.
Copper	Short internodes and shoot tips often die. Leaves are likely to be small, yellow and distorted. Rare in vineyards where Cu sprays are used.
Molybdenum	Necrosis of leaf margins. Poor fruit set and stunted shoot growth.

8. BALANCING NUTRIENT INPUTS AND OUTPUTS

The key to the long-term viability of a vineyard is ensuring nutrient inputs at least balance nutrient outputs via the harvested fruit, prunings (if removed), cover crop (particularly if grazed by sheep) and losses through erosion, nitrate leaching, denitrification, volatilisation of ammonia or the slow conversion of soluble P to insoluble forms.

The amount of nutrient exported from a vineyard varies from site to site and year to year depending on crop yield, variety, rootstock, vine health and performance and management practice. Table 4 shows approximate amounts of macro-nutrients exported annually from a vineyard both in terms of fruit and pasture.

Table 4 Typical amounts of major nutrients exported annually from vineyards
Figures for fruit are based on Glendinning (2000) and figures for sheep are based on personal communication with M. Staines (Department of Agriculture and Food, Western Australia)

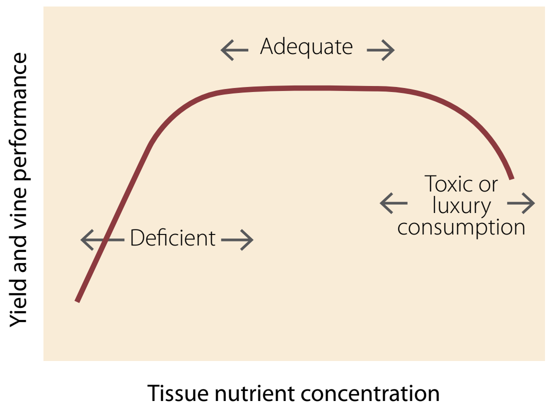
Nutrient	Nutrient export through fruit (kg/t)	Nutrient export through sheep# (kg/ha)
Nitrogen	1.5	2.02
Phosphorus	0.3	0.84
Potassium	3.1	0.25
Sulphur	0.1	NA
Calcium	0.5	1.54
Magnesium	0.1	0.06

based on the assumption of 10 sheep per hectare grazing for 140 days growing at a modest rate of 100 g/head/day. NA = data not available.

The amount of nutrient required for maintaining vine productivity is generally greater than the amount lost through removal because the efficiency of vine uptake and use is less than 100%. While micro-nutrient loss is lower (g/tonne of fruit) than macro-nutrient loss (kg/tonne of fruit), it can still have an impact over time.

Most biological systems are characterised by non-linear relationships between causes and effects. A good knowledge of the nature of the relationship between an input and the resulting response is required in order to make quantitative predictions about vine responses to fertiliser inputs. Figure 2 shows the non-linear response of crop yield and vine performance to tissue nutrient level.

Figure 2 A generalised relationship between tissue nutrient concentration and vine yield and performance (Iland *et al.* 2011)



8.1 INTERPRETING VINE TISSUE RESULTS

Results from tissue analyses compared with standards (guidelines) which place each nutrient into a particular classification (e.g. deficient, marginal, adequate, high or toxic) which then allows semi-quantitative conclusions to be made regarding vine nutrient status and vineyard fertiliser requirements. The results are expressed on a dry weight basis and usually presented as a %, mg/kg or ppm.

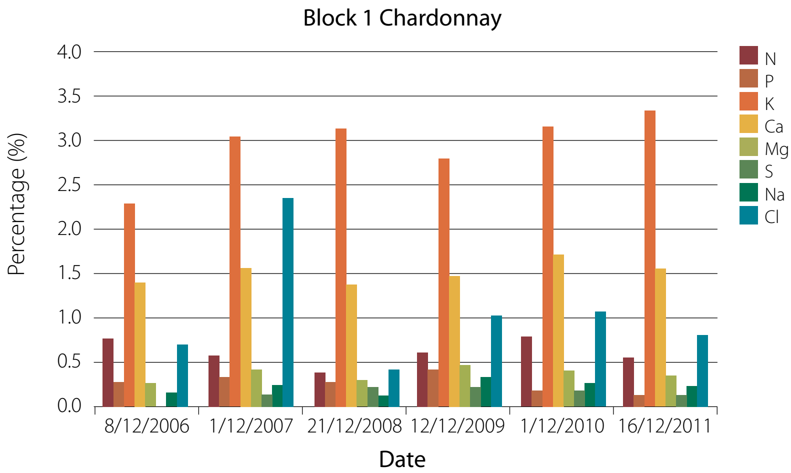
The petiole standards shown in Table 5 are the best available at the present time and were initially developed from data acquired in California and later modified following survey work in South Australia and Western Australia. These are generally regarded as being appropriate for commercial, high yielding (8–15+ t/ha), irrigated vineyards and are aimed at maintaining 'adequate' levels. They are not necessarily appropriate for lower yielding (4–8 t/ha), irrigated or dry-grown vineyards.

These standards are also not appropriate for all grapevine varieties or rootstocks as they do not consider the effect of nutrient status on berry composition, wine style or quality. Standards which relate to wine style and quality should be developed with the associated winery.

Table 5 Guidelines for interpreting petiole results (adapted from Robinson *et al.* 1997, Goldspink and Howes 2001)

Nutrient	Deficient	Marginal	Adequate	High	Toxic
Nitrogen (%)	<0.7		0.8–1.1	>1.2	
Nitrate nitrogen (mg/kg)	<340	340–499	500–1500	1500–2500	>2500
Phosphorus (%)	<0.15	0.15–0.24	0.25–0.50	>0.50	
Potassium (%)	<1.0	1.0–1.3	1.3–3.0	>3.0	
Calcium (%)	<1.0		1.2–2.5		
Magnesium (%)	<0.30	0.30–0.39	>0.40		
Sodium (%)			0.1–0.3	0.4–0.5	>0.5
Chloride (%)			<1.0	1.0–1.5	>1.5
Zinc (mg/kg)	<15	15–26	>26		
Manganese (mg/kg)	<20	20–29	30–60		>500
Iron (mg/kg)		7	70		
Copper (mg/kg)	<3	3–6	>6		
Boron (mg/kg)	<25	25–30	31–70	71–100	>100

Figure 3 An example of tracking (benchmarking) annual petiole results (expressed as %) for a range of nutrients



It is critical to be wary of 'general' standards and consideration must always be given to vine health, productivity and fruit quality when planning fertiliser requirements. Benchmarking nutrient levels over time on a block basis is an advisable strategy; an example is given in Figure 3.

9. FERTILISER PRODUCTS AND SELECTION CRITERIA

Fertilisers can be considered as organic or inorganic materials of either natural or synthetic origin. If they are required in a vineyard, then the type and nature of the material needs to be considered as part of the selection process as they can influence the way in which the vineyard can be managed (e.g. conventionally, organically or biodynamically) and how the product can be applied (e.g. broadcast, foliar or through the irrigation system).

Fertiliser products can be categorised into two main groups:

- Chemically synthesised inorganic fertilisers which are generally manufactured using raw materials sourced from non-renewable resources (e.g. mines, fossil fuels). They include the widely-used and commercially available products used in forms of agriculture (e.g. urea, ammonium nitrate and ammonium sulphate as sources of N, superphosphate, mono-and di-ammonium phosphate as sources of P, and potassium chloride, nitrate and sulphate as sources of K).
- Organic fertilisers which include materials from naturally occurring mineral deposits (e.g. powdered rock phosphate), plants (e.g. wood ash, compost, grape marc, leguminous cover crops) and animals (guano, manure, fish emulsion, worm castings).

In addition, there are a number of products sold as soil amendments (e.g. lime, gypsum, and dolomite), soil conditioners (e.g. seaweed/kelp, compost tea, humic substances) and enzymatic activators or bio-fertilisers/inoculants. The latter category refers to a range of products which contain living microorganisms. They add nutrients to a soil through the natural process of N-fixation, solubilising P and stimulating plant growth through the synthesis of growth-promoting substances.

By utilising the mid-row as a nutrient source, the cost of cover cropping and fertiliser input can be reduced while soil and vine health are simultaneously enhanced.

Maintaining legumes within the cover crop mix or within the rotation should extend the period of time between fertiliser applications.

9.1 SYNTHETIC INORGANIC FERTILISERS

There are numerous products available which vary in nutrient concentration, solubility, effect on and within the soil and price.

Examples of some commonly-used high analysis products are shown in Table 6. Note that nutrient concentrations vary slightly between manufacturers.

Table 6 Macro-nutrient content and characteristics of some high analysis, synthetic fertiliser products (adapted from Goldspink and Howes 2001)

Product	%N	% P	% K	Ca	Mg	S	Characteristics
Urea	46						Very soluble, high loss through volatilisation, easily leached, acidifying, inexpensive per unit of N.
Ammonium sulphate	21					24	Soluble, some loss through volatilisation, strongly acidifying, medium risk of loss through leaching, low N availability at low soil temperatures.
Ammonium nitrate	34						Soluble, some loss through volatilisation, acidifying, nitrate easily leached, expensive per unit of N.
Calcium nitrate	15.5			19			Soluble, alkalising, nitrate easily leached, expensive per unit of N.
Mono-ammonium phosphate	11	22					Very soluble, strongly acidifying, slow to leach, ammonium N helps in uptake of P.
Di-ammonium phosphate	18	20					Very soluble, acidifying, slow to leach, ammonium N helps in uptake of P.
Single superphosphate		9		22		10.5	Produced from rock phosphate, high in readily-available P, non-acidifying, very slow to leach.
Double superphosphate		17.5				3.5	Produced from rock phosphate, high in readily-available P, non-acidifying, very slow to leach.
Muriate of potash			49.8				Very soluble, non-acidifying, not to be used on saline soil, cheap per unit of K.
Sulphate of potash			41.5			18	Soluble, non-acidifying, slow to leach, expensive per unit of K.
Potassium nitrate	13		38				Very soluble, alkalising, slow movement of K, nitrate easily leached, expensive per unit of K.
Magnesium sulphate					20	27	Very soluble, non-acidifying.

In order to determine value for money and the best strategy of use, it is important to know the following information about any fertiliser product:

- The nutrient(s) it contains and how much of each,
- The form of the nutrient, including its solubility and effect on soil pH,
- The manner and speed in which the nutrient becomes available to the vine and;
- The way each nutrient behaves on the soil surface and within the soil profile.

Most of this information is available on the labels of product containers as well as from chemical registration authorities and suppliers.

For example, consider the following scenario when deciding which N-based fertiliser to use. Based on the following price of $305/t for urea, $440/t for ammonium nitrate and $75/110L drum of calcium nitrate, the cost of N/kg is 66c for urea, $1.29 for ammonium nitrate and $5.11 for calcium nitrate. Therefore, urea is the best value for money but the most acidifying and easily lost through leaching and volatilisation.

Note that certain fertiliser products (particularly those which are synthetic) are not permitted to be used in vineyards under organic or biodynamic management systems. Certifying organisations (e.g. National Association for Sustainable Agriculture Australia) can provide this information.

Pelletised manure.

9.2 ORGANIC FERTILISERS

Organic systems, and the use of natural organic fertilisers, tend to concentrate on encouraging natural nutrient cycling in the presence of active soil biology. As such, organic viticulture becomes skills-based rather than product-based and as a result requires greater observation and engagement. The products tend to be more variable in their nutrient composition, bulkier to transport and apply, and often more expensive to purchase and use than high analysis synthetic products.

Compost.

An important feature of natural organic fertiliser products is that the nutrients they contain must be broken down into inorganic forms through mineralisation before they become available to plants. Hence, it can be difficult to have the appropriate nutrients in a readily available form at the right growth stage for vine use. A common observation is that vine response is often slower compared to using high analysis synthetic products. However, there are many potential benefits of using such products, including:

- Provision of moderate amounts of nutrients and organic carbon;
- Assistance in minimising or eliminating soil acidity through a more natural system of nutrient cycling;
- Liberation of inherent fertility through an active microbial population; and
- Improved physical and chemical soil properties.

Table 7 shows some commonly used organic fertiliser products. For further information on the composition of a range of organic fertilisers and amendments, refer to Goldspink and Howes (2001) and Quilty and Cattle (2011).

Table 7 Characteristics of some commonly-used natural N, P, K fertiliser products (adapted from Jenkins 2004)

Product type	% N	% P	% K	Comments
Rock phosphate	0.2	11–16	1	Slow/medium release of P. Requires humic acid.
Blood and bone	4.7	4.5	5	Non-acidifying, N availability influenced by soil temperature.
Poultry manure	3–6	1–2	1–2	Slightly acidifying, nutrient content variable, slow release of nutrients, best to incorporate to avoid loss of N.
Cow manure	2–4	0.3–0.7	1–3	Slightly acidifying, nutrient content variable, slow release of nutrients, best to incorporate to avoid loss of N.
Fresh grape marc	1.5–2	0.3	1.3–2	Slightly acidifying, cheap if using own product, needs to be composted before use.
Mineral-based commercial blends	6.1–12.1	2.7–3.2	6.2–10.2	Slow release of nutrients.
Compost	0.8–1.3	0.2–1.3	0.2–0.4	Slow release of nutrients.
Fish emulsion	2.1–6.6	0.5–0.8	0.6–1.2	Slow release of nutrients.

As a guideline to costs when using such products, a number of organic fertiliser/amendment product types used in Australian agriculture (not specifically viticulture) are listed in Table 8.

The recommended application rates and estimated costs are shown for each product in its solid and liquid form. Application rates and costs vary considerably between suppliers and manufacturers. Expert advice should be sought to determine whether such products should be used in a vineyard situation and if so, at what rates.

Table 8 A selection of organic fertilisers/amendments manufactured in Australia for agronomic use with the range of recommended application rates and estimated costs.
Information drawn from suppliers and manufacturers published on the internet in 2011. (Adapted from Quilty and Cattle 2011).

Product type	Application rate	Estimated cost ($)
Composts		
Pelletised	0.075–5 t/ha	100–500/t
Non-pelletised	0.5–30 t/ha	7–800/t
Vermicasts		
Liquids	10–100 L/ha	1–20/L
Solids	2–50 t/ha	250–1000/t
Humic substances		
Liquids	1–30 L/ha	4–25/L
Solids	0.025–1 t/ha	40–800/t
Meat, blood and bone meal		
Liquids	1–30 L/ha	10–30/L
Solids	0.1–1.2 t/ha	800–1200/t
Fish hydrolysate		
Liquid	2–60 L/ha	15–25/L
Seaweed extract		
Liquid	0.5–20 L/ha	10–30/L
Bio-inoculants		
Liquid	1–20 L/ha	10–75/L

10. FERTILISER APPLICATION METHODS

The fertiliser application method adopted depends on the behaviour of the nutrient. For example, fertilisers need to be soluble if they are to be used as foliar sprays or when fertigating.

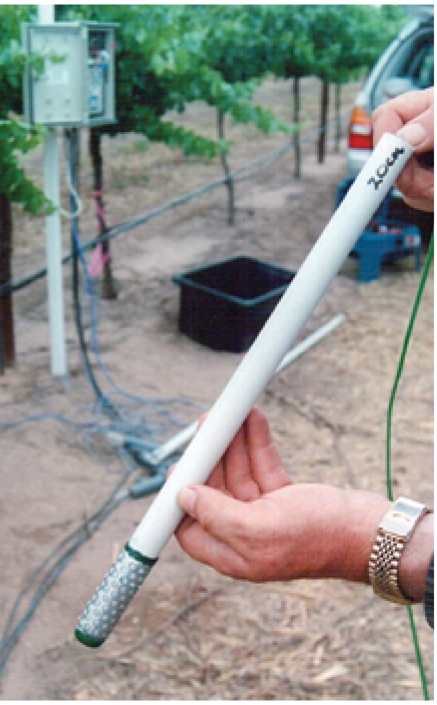
The following are the various ways nutrients are typically applied in a vineyard:

- Broadcast across the whole vineyard area (e.g. N and P),
- Banded on the soil surface along the vine row (e.g. P and K),
- Placed below the soil (15–30 cm) by ripping (e.g. N, P, K),
- Placed below the soil (10–15 mm) through shallow cultivation (e.g. P for cover crops),
- Dissolved in irrigation water 'fertigation' (e.g. N, K),
- Applied as foliar sprays to the canopy, often in chelate form or with surfactants for better uptake (e.g. N, Mg, Zn, Mn) and;
- Applied as cover crops, mulches, composts and manures.

Some products, particularly those containing micro-nutrients, are more suited to application as foliar sprays rather than by broadcasting, banding, incorporation or irrigating. Some macro-nutrients (e.g. N, K, Mg) can also be applied in this way.

So-called 'complete' foliar fertilisers are commercially available and can be used to correct both macro and micro nutrient deficiencies. When selecting these products it is beneficial to compare concentrations in a spray-tank since it is often cheaper to use products containing only the nutrients known to be deficient. Chelated forms generally release nutrients for longer. Product compatibility should always be checked before mixing with fungicides as some foliar fertiliser products are not compatible.

When applying fertilisers, there is a need to consider the vine growth cycle, soil variability and water status, product characteristics and costs, application method, and vineyard management philosophy and practices.



Installing a gypsum block to measure soil water tension.

11. TIMING OF FERTILISER APPLICATION

Fertilisers should be applied to young vines often and in small quantity until their root systems have filled the available soil volume. Nutrients will be lost if fertilisers are placed where small root systems cannot access them, and through leaching if irrigated beyond the maximum root depth.

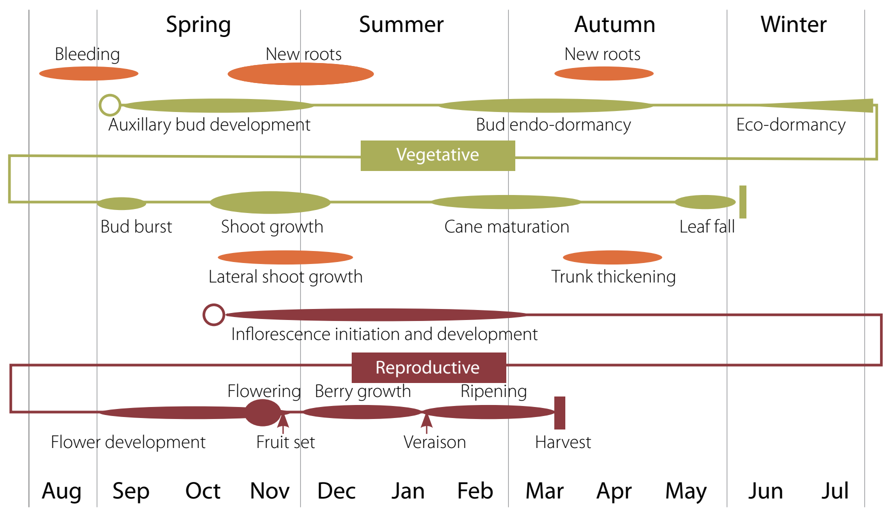
Fertiliser requirements for mature vines are considerably less because of their more extensive root systems. A number of factors determine when in the growing season nutrients should be applied.

11.1 VINE GROWTH STAGE

In order to manage the timing of fertiliser inputs, it is important to consider the annual growth phases of the grapevine (Figure 4) and to relate this to changing nutritional needs during the season.

For example, the uptake of nutrients is greater during the main flushes of root growth which generally occur between flowering and veraison and again after harvest.

Figure 4 Seasonal growth phases of the grapevine (adapted from Pearce and Coombe 2004)



11.2 SOIL WATER UPTAKE AND AVAILABILITY

Since nutrients are moved through the vine in solution, the water status of the soil and vine are important considerations when applying fertilisers to the vineyard. Soil moisture monitoring using sensors is therefore an important aspect of soil management.

Vine water uptake (and therefore nutrient uptake) is low very early in the season when the leaf area is small. Similarly, it is low towards the end of the season when leaves senesce and fall.

Applying nutrients at these times of year is unlikely to be cost effective as they may not be utilised by the vines, however, late season nutrient storage is important to support early spring growth in the following season. If there are deficiency symptoms, then post-harvest applications are likely to be beneficial.

11.3 NUTRIENT MOBILITY

Mobile nutrients are readily leached from the soil by rainfall and irrigation. Therefore, to avoid nutrient loss in this way, mobile nutrients applied via fertigation should not be applied early in an irrigation cycle.

11.4 FERTILISER PRODUCT

There is often a greater lag time between application and nutrient availability when using organic fertiliser products compared with synthetic inorganic products.

11.5 BIODYNAMIC CERTIFICATION REQUIREMENTS

Certain nutrients have to be applied according to the lunar cycle when vineyards are managed biodynamically.

12. QUANTITATIVE ASSESSMENT OF SOIL HEALTH

Since the overall health status of a soil cannot be measured directly, its assessment relies on a number of soil measurements (or indicators).

For example, the Cornell University soil health program (**http://soilhealth.cals.cornell.edu/**) uses a suite of 12 biological, chemical and physical parameters (Table 9). The resulting soil health test report allows growers to benchmark their practices against other growers to improve soil health. In Australia the 'Healthy soil for sustainable farms' program (**www.soilhealthknowledge.com.au/**), and the 'Water and Vine' program technical booklet also contain information on which soil attributes should be tested in relation to determining the overall health status of the soil.

Installing a fertiliser leachate collection device.

A number of soil measurements (indicators) can be used to assess the current health status of a soil, thereby allowing management-induced changes to be quantified.

Table 9 Soil health indicator tests and associated functional processes included in the Cornell Soil Health Test (adapted from Schindelbeck and van Es 2011)

Soil parameter / indicator	Soil functional processes
Physical	
Soil texture and stone content	All
Aggregate stability	Aeration, infiltration, shallow rooting, crusting
Soil strength (penetrometer)	Rooting
Available water capacity	Plant-available water retention
Chemical	
pH	Toxicity, nutrient availability
Extractable phosphorus (P)	P availability, environmental loss
Extractable potassium (K)	K availability
Minor element content	Micro-nutrient availability, elemental imbalances, toxicity
Biological	
Organic matter content	Energy/carbon storage, water and nutrient retention
Active carbon content	Organic material to support biological functions
Potentially mineralisable nitrogen (N)	Ability to supply N
Root health rating	Soil-borne pest pressure

Organic matter levels should be optimised in order to enhance the capacity of soil organisms to mineralise nutrients into plant-available forms.

This can be achieved by utilising mid-row cover crops, under vine mulches, composts and minimising tillage.

Grass and legume cover crops.

The C : N ratio of organic residues is variable; a C : N ratio of >20:1 stimulates immobilisation causing N to be unavailable for vine use while a C:N ratio of <20:1 has the opposite effect.

13. MANAGEMENT PRACTICES TO ENHANCE SOIL NUTRITION AND HEALTH

13.1 COVER CROPS

Where cover crops can be grown successfully, the utilisation of the mid-row area can become a direct source of nutrients for vines providing the roots extend laterally into the area. The mid-row can also be an indirect source of nutrients when material that has been slashed is side-thrown into the vine row.

In high rainfall and fertile soil regions, certain cover crops may be able to supply vines with sufficient N for their annual growth. However, as rainfall decreases and soils become lighter with less organic matter, cover crops are unlikely to be able to supply sufficient N for normal growth.

Non-legume cover crops (e.g. grasses and cereals) contain about 1.5% N while legumes (e.g. vetches, clovers, medics, beans and peas) contain about 2.5% N (Penfold 2003). If N is required quickly, then legume-based cover crops should provide more N and will breakdown faster.

For example, a cereal crop producing 5 t/ha will contain about 75 kg/ha N. The equivalent for a legume crop will be 125 kg/ha N. If this material is then transferred from the mid-row to the under vine area through slashing, the equivalent of 150 kg/ha N and 250 kg/ha N respectively will be applied (assuming that the under vine area is half the area of the mid-row). However, only a proportion of this N is immediately available to the vine. Approximately 20% will be available in the first year and of the remainder, some will be lost as volatile ammonia, and much of the rest will be tied up in the soil organic matter and become slowly available as it is mineralised by soil microbes.

A cultivated soil generally has a lower organic matter level than a non-cultivated soil because more of the organic matter is exposed to decomposing organisms.

In addition, cultivated soils are at greater risk of soil and nutrient loss through water and wind erosion. Mowing, rolling and/or herbicide spraying are therefore the preferred options for controlling cover crop and weed growth in vineyards to enhance soil nutrition and health.

13.2 MULCHES, COMPOSTS AND MANURES

Mulches are products (organic or inorganic) which are suitable for placing on the soil surface. The benefits of mulching with organic materials (e.g. straw, cover crop slashings and wood chippings) include soil moisture retention and weed suppression, soil temperature regulation, and organic matter level increase and earthworm activity. Inorganic mulches (e.g. plastic, glass particles and stone) do not provide additional organic matter to the soil.

Composts are products that are generated from the controlled microbiological transformation of organic materials under aerobic and thermophilic conditions. The variation in water, nutrient and salt content as well as in nutrient release characteristics are often the medium of choice for most organic growers as they provide a source of nutrition as well as contributing soil-conditioning benefits through the provision of carbon and microbial activity.

Composts can be applied to the topsoil or subsoil and have been shown to improve organic carbon levels, soil water holding capacity, CEC, microbial biomass activity, and available N and P content.

Importantly, when using compost in vineyards, the carbon to nitrogen (C:N) ratio should be <20:1 and needs to be both stable and mature. For more information refer to the Compost for Soils website: **www.compostforsoils.com.au**.

Livestock manures may be composted or un-composted and can be applied to the topsoil and subsoil. Like composts they vary in composition and nutrient release characteristics. In the raw form, the nutrient content of most manures do not meet the requirement of plants.

Uncomposted manures also have the potential to become an environmental and human health issue as they are likely to contain pathogens.

There are advantages and disadvantages associated with each product. When using them, growers should be aware of the following:

- Vineyard risks. These include those associated with nutrient loading (e.g. vine vigour and fruit quality), as well as frost, fire and pests;
- Quality assurance. Suppliers should comply with current standards (AS4454-2012) which require materials to be free from weed seeds and plant pathogens, as well as being stable. Suppliers should also provide a specification sheet detailing a typical analysis of their product. There is an increasing trend for growers and wineries to produce their own materials cost-effectively using garden, wood and paper waste, grape marc and manure;
- Application rate and grade. The thickness and width of any applied product will determine how beneficial it is likely to be. When using compost as mulch, it should be banded 0.5 m wide and 50–75 cm deep beneath the vines;
- Nitrogen drawdown can occur when there is a lot of woody material in the compost or a high proportion of easily degradable carbon components without adequate N in the substrate. This can result in N deficiency symptoms in vines as soil microbes compete with plants for nitrate reserves in the soil while breaking down the raw material;
- Product breakdown. As organic N is broken down by bacterial action, the nitrate form is released for vine use. The rate of breakdown is dependent on factors such as the nature of the product, soil temperature and water content, but it is possible for 5–15% of the organic N to be broken down in the first year; and
- Fruit specification. Consider end-use specifications and keep in mind that the use of such products may influence vegetative growth and fruit composition. Only use appropriate amounts on soils that require improvements in soil health.

13.3 MYCORRHIZAL FUNGI

Mycorrhizal fungi (fungus root) form associations between themselves and the host-plant which are mutually beneficial. The fungi receive carbohydrates (derived from photosynthesis) from the host plant root system and in return, nutrients are passed back into the plant roots from the soil.

When a plant becomes colonised, the majority of the absorbing area of the root system becomes fungal hyphae. Fungal hyphae are thinner than roots or root hairs and are able to penetrate the smallest of pores and fissures in the soil profiled. Mycorrhizas therefore extend the volume of soil explored by the plant, a characteristic that is especially important for the uptake of P which does not move in the soil solution unlike N. Trace elements such as Cu and Zn behave in a similar way to P in soil and roots must explore the soil in order to access them.

Straw applied undervine.

Side-thrown mid row cover crop.

Composted mulch applied undervine.

Vineyard management practices need to focus on strategies to improve soil health and in particular the topsoil. Strategies which increase the organic matter content and mycorrhizal fungi populations will increase the efficiency by which vines access and uptake water and nutrients.

All vineyards are variable. High resolution spatial information on soil attributes and vine performance allows growers to move away from the 'one-size-fits all' approach to vineyard management.

Economic benefits have been realised by adopting a 'targeted' rather than a 'uniform' management approach.

Grapevines have a relatively coarse root system compared to annual crops and it has been shown that they benefit from the symbiotic relationship with mycorrhizal fungi, and in particular arbuscular mycorrhizas (AM). These grow into the root cells producing branched structures (arbuscules) inside the cell wall. In addition to improved efficiency in the uptake of water and nutrients, other reported benefits include an increased tolerance to drought, salinity and heavy metals and improved soil structure through a greater aggregation of soil particles (Zady 2010). These benefits appear to be more pronounced in soils with low organic matter (Baumgartner 2005).

The most practical method of managing soil mycorrhizal populations is through the preservation of the topsoil. Soil conditions such as acidity and salinity have been shown to have an adverse effect on mycorrhisas. Practices such as tillage have also been shown to result in their destruction within vineyards.

Therefore, reduced cultivation and the use of cover crops are recommended practices which help to preserve the topsoil through reduced disturbance and the accumulation of organic matter.

It is also now possible to inoculate the soil with mycorrhizal populations. A number of companies produce beneficial microbes and selected mycorrhizal fungi commercially which can be applied directly as a soil drench or as a seed/fertiliser coating.

The presence of mycorrhizal associations can be determined by examining young root tissue under a microscope.

14. TARGETED MANAGEMENT CAN PROVIDE ECONOMIC BENEFITS

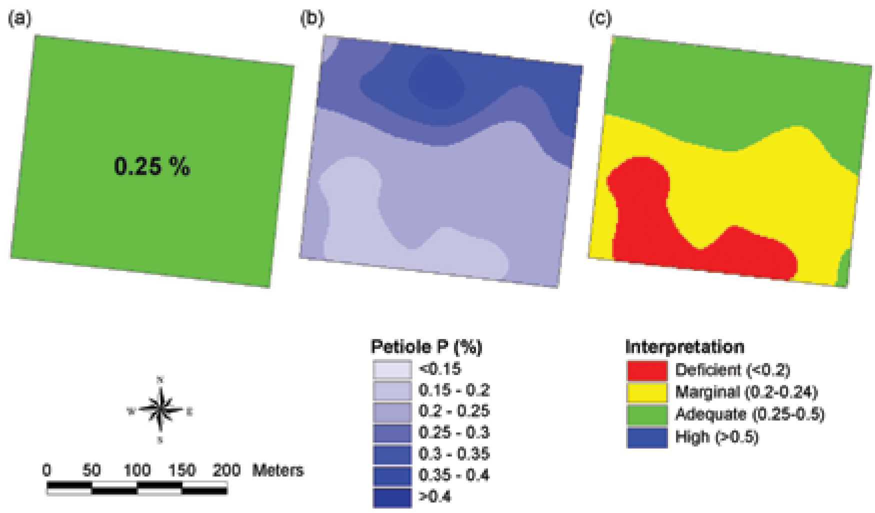
Numerous examples are available which demonstrate the economic benefits of using high resolution spatial information to adopt a 'targeted' approach rather than a 'uniform' approach to vineyard management (Proffitt *et al.* 2006). These benefits have been realised through either improved outputs (crop yield and fruit quality) and/or reduced inputs.

'On-the-go' sensors, coupled with global positioning systems (GPS) and geographic information systems (GIS) offer a powerful new way of carrying out vineyard management activities, when they are required, based on soil health attributes and vine requirements. Remote and proximal sensing technologies provide information on the spatial variation in canopy size and health, yield monitors mounted to harvesters provide information on the spatial variation in crop yield, and soil sensors mounted to vehicles provide information on the spatial variation in soil characteristics.

In addition, the use of accurate (± 2 cm) GPS information in three dimensions (longitude and latitude coordinates and height) allows three-dimensional elevation models to be created. The use of such high resolution data enables the grower to make more informed decisions about soil and vine attributes and consequently, where in the landscape to apply inputs such as water, fertilisers, soil amendments, mulch, and sprays.

In addition, the data allows the grower to make more informed decisions about where to perform vineyard activities such as sampling, soil and canopy management practices and harvesting. The following example provides an insight into the spatial variability in vine nutrient status and how such information should improve productivity, as well as either maintaining or reducing nutrient input costs. However, in this case the cost of extra analysis should be balanced against the potential value of the more precise information.

Figure 5 Petiole phosphorus (P) at flowering in a 7.3 ha Cabernet Sauvignon vineyard.
Refer to the text for further explanation (Proffitt *et al.* 2006).



'On-the-go' soil sensing using an EM38.

Figure 5a was produced using the results obtained when applying the standard approach to tissue sampling (e.g. petioles) across a vineyard block. The bulk sample was analysed to give a single index of the P status of vines (i.e. 0.25%) which was assessed as being 'adequate'. In producing Figure 5b, petioles were collected from vines within different areas of the vineyard block and analysed separately. The location of the vines was recorded using a GPS. When the results were interpreted, the results indicated that the P status of vines was sub-optimal, with many being deficient in this nutrient (Figure 5c).

15. CLIMATE CHANGE AND WHAT IT MEANS FOR VINE NUTRITION

Model simulations indicate that climatic conditions are changing in Western Australia and will continue to do so, resulting in higher average temperatures and rates of evaporation, reduced rainfall and runoff with greater seasonal variability, and more frequent extreme weather events.

A change in climatic conditions is likely to have implications with respect to nutrient availability and uptake, and the timing and need for fertilisers in the vineyard.

With respect to vine nutrition, changes in temperature and evaporation are likely to affect the availability of soil water to the vines as well as the internal mechanisms of water movement through the vine. Heavier and more frequent rainfall events could increase the incidence of water logging, leaching and erosion causing unfavourable conditions for nutrient uptake as well as a loss of nutrients from the soil.

This in turn is likely to directly affect the ability of vines to extract nutrients from the soil and therefore nutrient mobility within the vine. Monitoring soil water content and improving soil health through better management practices will therefore become increasingly important.

Earlier budburst and a shorter growing season will increase the rate of vine development, and hence the timing and need for nutrients. Symptoms of nutrient deficiency are likely to appear earlier and hence the response time for remedial action will need to occur quicker.

Given that input costs (e.g. fertilisers and labour) are also likely to increase with time, the use of diagnostic tools and spatial information will therefore become increasingly important in order to remove the guesswork when managing vineyard nutrition.

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