Winegrape nutrition and fertiliser application for sustainable production

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In a nutshell

A 'vineyard system' is defined as the grapevines and that part of the soil profile exploited by roots (the 'rootzone').

Nutrients are removed from vineyard systems through losses below the rootzone, and when grapes are harvested and taken away from the vineyard.

The availabilities of mineral nutrients to vine roots are influenced by soil characteristics, soil moisture, the form that the particular mineral nutrient is present as, the vineyards cropping history and how much, when and how fertilisers and soil amendments are applied.

Different fertilisers and soil amendments have different characteristics that influence why, when and how they are used in vineyards.

Qualitative and quantitative assessments of vine nutrient status can used to determine the suitability of vineyard fertiliser/soil amendments programs.

Introduction

Mineral nutrition is a major part of grape production, impacting on all aspects vine growth, berry development and maturation and ultimately juice composition as it relates wine making. Most of the influence of mineral nutrition is on berry composition is indirect, through altered growth and yield level. However, nitrogen application does directly affect the composition of nitrogenous compounds in the must and therefore the fermentation process and the wine produced. Mineral nutrients are divided into macro-nutrients, which are present in plants at concentrations expressed as %, and micro-nutrients, which are present in concentrations expressed as parts per million (ppm) or mg/kg.

Macro-nutrients include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S). Micronutrients include iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B) and molybdenum (Mo). Sodium (Na) and chlorine (Cl), which are often present at % levels in plant tissue, are generally considered to be micronutrients.

Aluminium (Al), selenium (Se), nickel (Ni) and cobalt (Co) are all considered to be essential micronutrients as well, but for the most part don't cause any issues and needn't be considered further. Likewise, silicon (Si), which is considered beneficial and facilitating disease defence mechanism, but not essential, doesn't need to be considered further as well.

The various macro- and micro-nutrients have functions and roles that impact on vine development and grape composition.

Vineyard nutrient balance

A summary of vineyard mineral nutrient dynamics and balance is presented in Figure 1. The mineral nutrient requirements of grapevines vary according to the variety, whether the vines are growing on a rootstock, and on what rootstock that is, vine age and production levels. There is no single 'recipe'.

All mineral nutrients are removed by the crop, but the removal of some, e.g. N and K, is on a much larger scale than the removal of others, e.g. Fe and Mn.

Some nutrients [e.g. N in the nitrate (NO_3^-) form] can be lost below the rootzone by leaching, and can also be lost to the atmosphere by a process known as denitrification.

Most of the biomass (shoots and leaves) produced annually by grapevines remains in the vineyard and releases mineral nutrients back to the soil as it breaks down. The rate of release is dependent on the materials' carbon:nitrogen (C:N) ratios; wood has a high C:N ratio and breaks down slowly (months – years), and leaves have a low C:N ratio and breaks down quickly (weeks – months). The same principal applies to cover crops; oats and rye corn, for example, break down slowly (months), and faba beans breaks down quickly (weeks). Breakdown of organic matter will also be influenced by temperature and moisture, and the degree of contact between the organic matter and the soil.

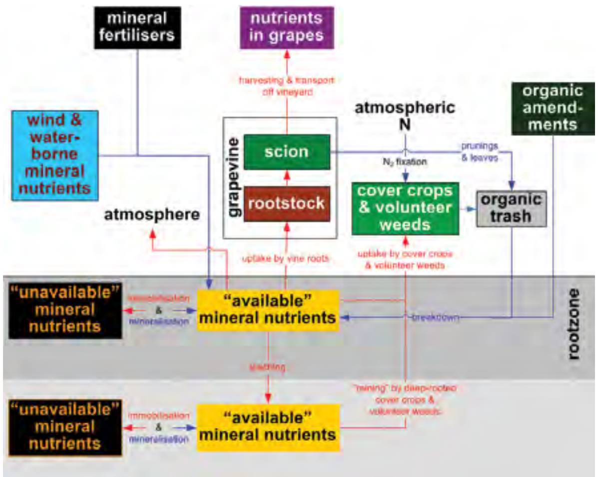

__Figure 1.__ The vineyard mineral nutrient balance (modified from Bauer, 1992).

Immobilisation and mineralisation within the rootzone are two processes working in opposite directions; immobilisation removes nutrients from the available pool, and mineralisation puts them back; this is particularly important for P.

Soil fertility

Mineral nutrients exist in soils in organic and inorganic forms in the soil solution, and bound up in organic matter. Soil fertility simply means the capacity of a soil to keep plant roots well supplied with mineral nutrients in the inorganic form. Mineral nutrients bound up in organic material and in organic forms are not available for uptake by plant roots. Inorganic forms are the major source of mineral nutrients for plants. Crop production on highly fertile (i.e. high levels of mineral nutrients in inorganic form) soils requires little if any supplementary mineral nutrient supply. Crop production on an infertile soil generally requires considerable supplementary mineral nutrient supply. Grapevines are no different.

Soil tests use various chemical extraction methods to estimate the amount of available nutrients; in other words, soil tests 'measure' soil fertility. The results correlate reasonably well with the amounts of nutrients taken up by most annual crops, and hence have some application in estimating the fertiliser needs of annual crops. The correlation is not as strong for perennial crops because of the longer period of nutrient uptake, the greater volume of soil explored and the amount of mineral nutrients stored in the vine or tree from one season to mobilised and used in the next season. Nonetheless, soil tests can be useful in diagnosing poor vine growth and performance, and are useful in the pre-planting phase of a vineyard development.

The characteristics of the rootzone (depth, texture, pH, moisture, aeration and organic matter) have a considerable influence on the processes that govern the actual availability of mineral nutrients to vine roots.

Soil depth and texture are important in determining the soil's ability to hold water and supply water to vine roots. Depth and texture are also important because water brings some mineral nutrients to vine roots and water is needed by soil micro-organisms to grow and breakdown soil organic matter for energy. The mineral nutrients in organic matter and in organic forms must be released and/or mineralised into soluble inorganic forms before they can be absorbed by plant roots. This process is facilitated by micro-organisms as they breakdown organic matter for energy, and they themselves die and decompose. Adequate organic matter is obviously critical here, as is soil temperature, aeration and moisture are also critical here. The upshot is that rates of mineralisation are greater in warm moist free-draining soils with reasonable levels of organic matter compared to dry cold soils with poor drainage and low levels of organic matter.

Mineral nutrient availability is strongly dependent on the soil pH, and this is simply a chemistry issue because inorganic mineral nutrients change form as the pH changes. Optimum soil pH range for grapevines is thought to be around 5.5 to 8.0 (Figure 2). Outside of this range excesses of certain elements and deficiencies of others become important. For example, soil with a pH less than 5.5 is likely to contain an excess of aluminium ions. In contrast, deficiencies of iron, manganese and copper are induced under alkaline soil conditions (pH greater than 8.0). The use of lime-tolerant rootstocks negates this problem to some extent.

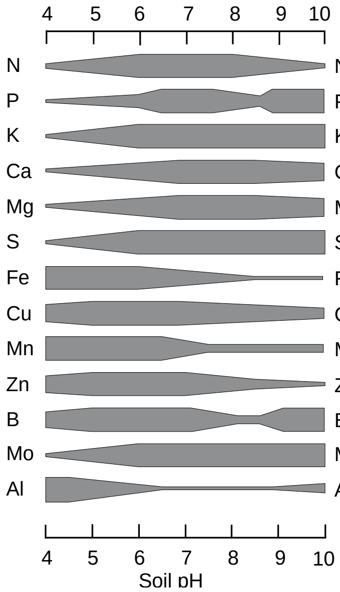

Figure 2. *Relationship between soil pH and nutrient availability (adapted from Lucas and Davies 1961).*

Nutrient function

Nitrogen, Mg and S form part of the chlorophyll, which uses sunlight to convert carbon dioxide (CO_2) and water to produce sugars. Nitrogen and S are components of proteins, which do all the work in the cell. Enzymes, which catalyse metabolic and catabolic reactions, are proteins. Calcium and B perform rolls in plant cell walls, which provide the mechanical strength to hold the inner the thin membrane and cell contents, and giving plants some mechanical strength. Phosphorus is involved in storing and releasing energy, and is a vital structural ingredient of the membrane around each cell. Potassium is involved in carbohydrate metabolism and transport, and the regulation of water movement.

Root growth and the uptake of nutrients from the soil solution require energy from stored or recently assimilated carbohydrates. Macro and micro nutrients are essential for plant growth, because of their roles in metabolic functions and structural components. Nitrogen is one of the most important macro nutrients and the seasonal N accumulation varies between the different vegetative and reproductive parts of the grapevine (Figure 3).

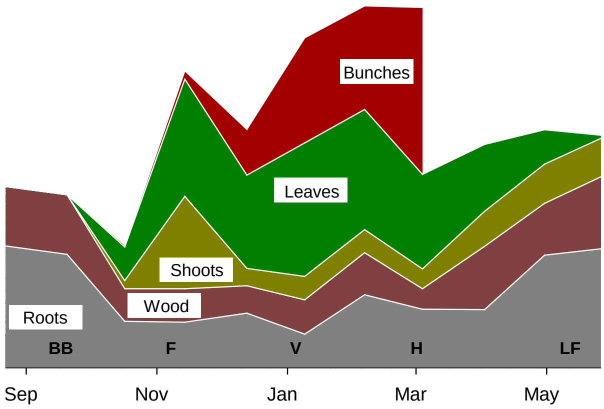

Figure 3*. Seasonal N accumulation (relative) in a 10 year old Shiraz vineyard (Riverina).*

Iron, Mn, Zn and Cu are involved in the CO_2 assimilation process, and in plant defence mechanisms against stress such as heat. Iron and Mo play significant roles in the conversion of NO_3^- into a useable form where it finally ends up in proteins etc.

Several nutrients have an important role in the vegetative and reproductive development of grapevines. Shoot growth in spring is influenced by the availability of N, P and K and micro nutrients. Sufficient supply of B and Cu ensures cane maturation and a good supply of N and Fe avoids premature leaf fall. Nitrogen and P are important for inflorescence initiation and development, while the supply of the micro nutrients Zn, B and Mo are important for fruit set. Berry growth is influenced by N availability after fruit set and K and Mg are important nutrients during the berry ripening process.

The nutrient composition of grapes influences the winemaking process, and the wine produced from these grapes. The supply of the macro nutrients N, P and K alter the must composition, excessive K results in high juice pH and low colour in the ferment and wine. The amounts of nitrogenous compounds present in the must as amino acid and ammonium have a critical role in the fermentation process and the final wine composition. The timing of N application and the seasonal water supply influences amino N concentration in the juice.

Assessing nutrient status

Assessing grapevine nutrient status is important for verifying the assessing whether the vineyard fertiliser is achieving what it is supposed to be doing: ensuring that vine productivity isn't limited by mineral nutrient supply. Both qualitative information (i.e. appearance of the vines vigour-wise and any leaf symptoms) and quantitative information (i.e. nutrient concentrations in a standard tissue sampled at a standard time) are needed. Visual deficiency (or toxicity) symptoms generally are only become apparent after the productivity declines.

Shoot vigour and deficiency or toxicity symptoms on leaves are important indictors of vine nutrient status. Most macro-nutrient deficiency symptoms appear first on the older leaves (except N and S), while most micro-nutrient deficiencies appear on the younger leaves (the exception is Mn) (Table 1). The difference between the occurrences of deficiencies in leaves of different ages relates to the mobility of the nutrient within the vine.

Table 1. *Visual symptoms of nutrient deficiencies in grapevines used to make qualitative assessments of vine nutrient status (adapted from Nicholas 2004).*

	Symptoms (leaf, growth)	Location
Macronutrient		
N	Overall leaf yellowing, growth reduction	all leaves, first youngest leaves
P	Interveinal areas yellow/pale green, growth reduction	Older leaves
K	Leaf curling, interveinal areas/ margin yellow	Older leaves
Mg	Yellow or red leaf interveinal areas/ margin	Older leaves
S	Overall leaf yellowing	Most leaves, first youngest leaves
Micronutrients		
Fe	Interveinal arreas yellow, stunted growth	Young trees
Mn	Interveinal areas pale green	Older/mid-shoot leaves
Cu	Small young leaves, interveinal areas yellow, stunted growth	Young leaves
Zn	Interveinal areas pale green, stunted growth	Young leaves
B	Interveinal areas pale green, stunted shoots, shoot tips die	Young parts

The interpretation of mineral nutrient concentrations in the petioles sampled from leaves from leaves opposite the basal bunch at 50% capfall (EL stage 23) is based on a comparison with nutrient standards that reflect the relationship between mineral nutrient content in petioles at that time and vine performance (Table 2). Other interpretative standards exist for other parts of the vine sampled at other times, but the most robust are the petioles at flowering standards. It is recommended that about 100 petioles are collected from a cross a management unit (i.e. a single variety, a variety on a particular rootstock or an area irrigated from a single valve basal bunches at flowering (50% cap fall) and compare the analytical nutrient results to the recommended standards.

Fertilisers and their application

The seasonal pattern of nutrient demand and uptake by grapevines influences the application timing of most fertiliser. Typically, fertiliser is applied during the main periods of root growth in the spring and autumn. This is particularly relevant to the supply of nitrogenous fertilisers, which shouldn't be supplied until late spring, and the autumn application should be modest to avoid re-stimulating shoot growth and having leaves remain on the vine beyond autumn, but sufficient to allow sufficient uptake and storage of N to support spring growth the following season.

An exception to this generalisation is P supplied as single- or double-strength super phosphate. Phosphate (PO_4^{3-}), which is the form of P taken up by plants, is so sparingly soluble and moves so slowly down the soil profile, that application anytime of the year will have the same effect: small amounts of PO_4^{3-} moving slowly down the profile with each irrigation and significant rainfall event.

The various N, P and K fertilisers available vary in concentration and solubility (and hence speed of nutrient availability) and often contain more than one macro-nutrient. Selection depends upon many factors (e.g. effect on soil pH, suitability for delivery by fertigation, cost per unit nutrient, the need for rapid result where a deficiency is obvious etc.). Ease of spreading is also a consideration, and here inorganic fertilisers have an advantage of organic fertilisers, which tend to be more voluminous and of variable and lower macro-nutrient content. Obviously, applying fertiliser through a drip irrigation system is significantly easier than broadcasting fertiliser, but the higher solubility and purity needed for fertigation comes at a cost. Several alternative fertilisers (e.g. organic and bio-dynamic products) claim a range of nutritional benefits associated with their use, but Australian experience with these materials is limited, and as a consequence there is little information available to assist their use on Australian vineyards.

An important consideration for users of organic fertilisers is that mineral nutrients in those materials need to be released and/or transformed into available forms by the breaking down of the material in the soil. This is not a rapid process for materials with a high C:N ratio, and if conditions aren't conducive to microbial activity in the soil then that breakdown process may be quite prolonged. A material that was being used to correct a chronic N deficiency, for example, would need to have a low C:N ratio to ensure that the N in the material was mineralised reasonably quickly.

Grape growing regions differ in the mineral nutrition issues that are important because soils and climate varies from region to region. For instance, soils with a low pH would need amelioration in the form of lime addition, which improve the availability of several nutrients. However, this measure is most appropriate prior to planting a vineyard. Generally, grape production in Australia can be separated into warm (irrigated) and cool (supplementary irrigation) regions. Warm regions tend to problems with deficiencies of Zn, and Fe to a lesser extent, while deficiencies of B are more likely in cool regions with higher rainfall.

As indicated earlier, there is no 'recipe' to suit all vineyards, and, accordingly, it is difficult to estimate how much fertiliser needs to be applied. As a general rule, provided that irrigation is managed to avoid excessive mineral nutrient loss through run-off or leaching, and pruned canes remain in the vineyard after pruning, the main loss of nutrient from a vineyard will be in the fruit harvested and moved off-site. A reasonable approach and starting point to simply replacing what has been removed, therefore, is to estimate the amount of mineral leaving the vineyard in the grapes given the yield. For example, a tonne of fruit removes about 2 kg N; a yield of 20 t/ha would require a replacement of approximately 40 kg N/ha. That amount of N fertiliser can be the basis of the annual application needed — mindful of the other considerations around timing and not leaching NO_3- down the profile etc. – and can then be adjusted upwards or downwards by conducting plant tissue analysis on petioles collected at flowering and comparing the concentrations of mineral nutrients in the petioles with the standard ranges, as described above. Assessing nutrient (especially N) concentrations in winter spurs is a useful indication of the amount of nutrients in reserve that the vine has available to support spring growth (Table 2).

Table 2. *Recommended adequate ranges of petiole nutrient levels for grapevines at flowering (Robinson et al. 1990) and spur concentrations at dormancy and fruit nutrient content of Chardonnay grapes (Riverina).*

	Macronutrients						Micronutrients				
	N	P	K	Ca	Mg	S	Fe	Mn	B	Zn	Cu
	(% DW)						(mg/kg)				
Petiole concentration	0.9–1.1*	0.25–0.50	1.8–3.0	1.2–2.5	>0.4	–	>30	30–60	35–70	>26	6–11
Spur concentration	0.59	0.08	0.44	0.4	0.13	0.04	95	26	71	22	–
	(kg/t)						(g/t)				
Fruit content	2.13	0.33	3.34	0.33	0.15	0.17	1.2	2.4	13.2	8.3	–

* 0.9 to 1.25% N for vines grafted onto Ramsey.

Conclusions and recommendations

Current best practice is to determine the soil nutrient status before the establishment of a vineyard and supply the necessary nutrients to avoid early poor vine growth. Subsequently, it is recommended to analyse petioles at flowering annually to determine vine nutrient levels and modify fertiliser programs to bring the next season's petiole results into the optimum range. In addition, soil samples should be taken every 2–3 years to assess soil nutrient levels. Maintaining accurate records of yields and petiole and soil sample results is important to pick up trends. This information, together with visual observations of vine growth can greatly assist vineyard nutrient management. Selection of mineral nutrient source (i.e. inorganic vs organic, readily soluble vs sparingly soluble, high analysis vs low analysis, multi-nutrient vs single nutrient) needs to be on the basis of compatibility with the vineyard's production philosophy, the vineyard's delivery system and the response speed needed. The timing and amount of fertiliser applied should be undertaken in accord with vine demand, yield and grape quality targets, mindful of the need to avoid losses through leaching and waterlogging.

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