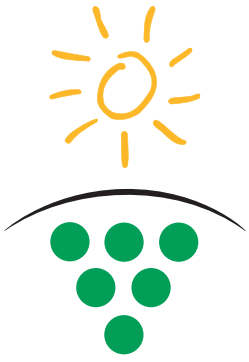
Grapevine Nutrition Literature Review

March 2006



Cooperative
Research Centre
for
Viticulture

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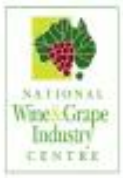

Acknowledgements

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Acknowledgements are made to Murray Valley Winegrowers' Inc for the opportunity to compile this winegrape literature review. It is hoped that the information contained within will be useful to winegrape growers' in the Murray Valley.

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Executive Summary

Nutrition is a key component of vineyard management. Nutrition has the potential to influence various factors in vine production that include fruit set, fruit quality and the quality of the end product. Nutrition of any crop including wine grapes is not simplistic, factors such as vineyard variability need to be considered. The need to consider factors such as rootstock, soil type, irrigation type etc means that a “one fits all program” is not possible. To develop a suitable nutrient plan on a block-by-block, variety-by-variety basis, growers’ need to have an understanding of the nutrients that they are applying in the vineyard and management history.

Part one of this report details information of nutrient deficiencies and toxicities, nutrient roles in plants, nutrient effects on growth, fruit set, yield, fruit quality and the quality of the end product. Nutrients covered in this section include nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Zinc (Zn), Manganese (Mn), Iron (Fe), Copper (Cu), Boron (B) and Molybdenum (Mo).

Part two of this reports details information regarding the advances in fertiliser application technology from broadcasting field grade fertiliser on the ground in the vineyard to methods of fertigation where fertiliser is applied from a central point using technical grade fertiliser through the irrigation system. While the industry has experienced advances in this type of technology little scientific information is available.

Part three of this report details information regarding plant nutrient analysis methods. Plant nutrient analysis is a key tool used to determine plant nutrient status with results providing important information for the development of nutrient plans. Australia currently uses petiole sampling as the main method for determining grapevine nutrient status. Standards for this method were adapted from a technique used in California, which has been modified to suit Australian conditions. Petiole analysis standards however were developed using relatively low yielding vines and there are questions regarding whether the analysis method and standards are suitable for present conditions.

Introduction

Yandilla Park was approached by Murray Valley Winegrowers' Inc to compile a winegrape nutrition literature review. The following components were requested:
Topic 1 - Investigation of both macro and micronutrients indicating the following items:
Application timing,
What effect it had on the grapevine, fruit quality or wine quality
Brief summary of the literature most relevant to warm climate of the Murray Valley.
Topic 2 - Fertigation technology versus broadcast technology.
Topic 3 - Comparison of methods to measure plant nutritional status.

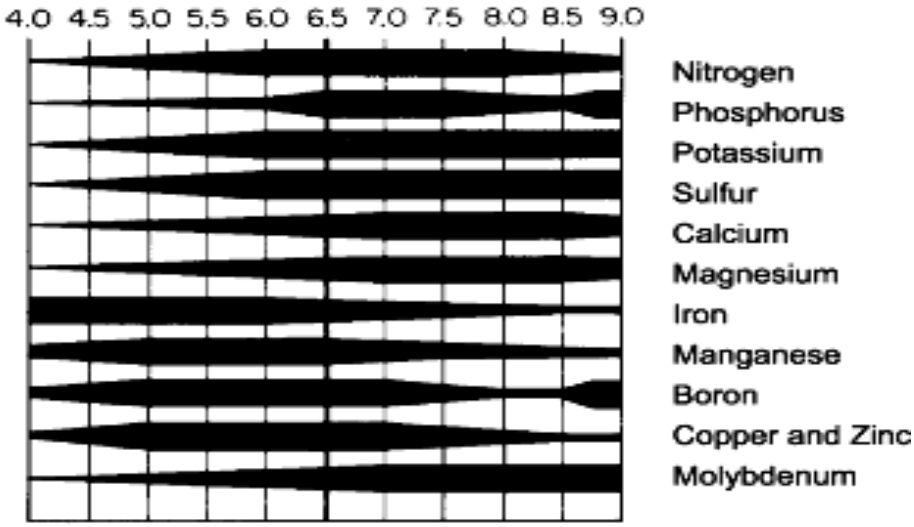
The information gathered has been compiled in to the following report.

Nutrition is a critical management tool for winegrape growers. The use of nutrition in the vineyard can influence fruit set, fruit quality and the quality of the end product. Nutrition in the vineyard is often determined on a vineyard-to-vineyard basis due to vineyard variation, though much can be learnt and applied from basic knowledge of site-specific soils (e.g. texture, pH, etc.), the role of specific nutrients in the plant, variety and rootstock characteristics.

Many publications previously have indicated the role of the different nutrients within the plant. Such as calcium's involvement in the strengthening of plant cell walls providing structure or potassium involvement in the turgor of cells. The role of nutrients in the plant is the key information in developing a balanced nutrition plan for a vineyard; however it is not the only information required to produce suitable and sustainable results.

Nutrients can be present in a number of different forms, however plants generally prefer one form over another, e.g. nitrate and ammonium are both forms of nitrogen however generally nitrate is more available to the plant than ammonium. The availability of nutrients is often determined by the soil properties and nutrient interactions. Microbial populations in the soil can help to convert nutrient to plant available forms for absorption. Soil pH affects the availability of the nutrients to the plant as

can be seen from the table below. For example if you have a soil with a pH of 8 limiting nutrients would possibly include Iron and Boron.



Grapevine variety and rootstocks also contribute to nutrients required. Listed below is the level of vigour of the different rootstocks. Vigorous rootstocks such as Ramsey are more capable of finding the necessary nutrients from the surrounding soil environment. Indicating that it does not require as much nutrient as say Schwarzmann. The application of nitrogen at the same rate as Schwarzmann would result in vines on Ramsey to have excess vigorous, shading, decrease grape quality and the potential to affect bud development for the next season.

Rootstock	Vigour	Vegetative cycle
101-14	M-L	Short
Schwarzmann	M-L	Short
3309	M-L	Medium
S04	M	Medium
5C Teleki	M	Medium
5BB Kober	M-H	Medium
110 Richter	M	Very long
1103 Paulsen	M-H	Long
99 Richter	M-H	Medium
140 Ruggeri	H-M	Very long
K51-32	M-H	Long
K51-40	M-H	Long
Ramsey	H-M	Very long
Nicholas (1997)		

Topic 1 – Investigation in to Macro and Micro Nutrients

Nitrogen

Nitrogen (N) is one of the major nutrients required by plants for sufficient growth. Nitrate (NO_3^-) and ammonium (NH_4^+) are the major forms of N that are absorbed by plants. Generally the nitrate form is available for immediate uptake but is readily leach out of the soil profile. Ammonium is taken up more slowly and is converted to the nitrate form through nitrification. When N is applied in insufficient or excessive amounts it can cause negative effects in plant production and productivity.

In *Vitis spp* deficiency symptoms include pale green to yellow leaves. Older leaves usually show signs of N deficiency before younger leaves. N is highly mobile in the plant and will move from the older leaves to the younger leaves in times of low N availability. Petiole and rachis stems can turn pink or red. Excessive symptoms include dark green leaves, increased growth, increased internode length, prolonged growth and leaf blades may become long, thick and cupped (Pearson and Goheen, 1988).

Toxicity symptoms are not always observed as described above as was shown by Bell *et al.* (1999) in their investigation into the reproductive capacity of Cabernet Sauvignon / own roots in Western Australia. Bell *et al.* (1999) showed a reduction in berry size and vegetative growth when an application rate of 740.8 Kg N / Ha was applied. Increases in shoot growth and yield were noted at lower application rates (92.6 kg N / Ha and 185.2 kg / Ha). These results indicate that there can be varied responses to the over application of N.

The increase in vegetative growth as result of N application is a well recognised vine response and has been recorded in various N research Zerihun *et al.* (2002), Conradie (2001), Keller *et al.* (1998), Keller *et al.* (2001[b]) and Ahlawat and Yamdagni (1988[a]), yet Martín *et al.* (2004) has noticed no change in vegetative growth as a result of N application. Increases in N application has resulted in increases in shoot growth, pruning weights, leaf area / vine, lateral shoot length and trunk girth.

An increase in crop yield in response to N application has also been recorded in various N research as an increase in berry size and fruit set Bell *et al.* (1999), Conradie (2001), Keller *et al.* (2001[a]),

Keller *et al.* (1998) and Ahalwat (1988[b]). Unlike the previous research Martín *et al.* (2004) has noted no change in yield and berry size as a response to N application under the condition of their trial. Martín *et al.* (2004) work included the application of 0, 50 and 200 g / vine of N on 'Tempranillo' / 110-Richter.

Bell *et al.* (1999) also demonstrated an increase in N concentration in the petiole analysis as a result of N application. The increase in petiole analysis was noticed up to an N application rate of 185.2 Kg N / Ha. Delgado *et al.* (2004), Conradie (2001) and Wolf *et al.* (1983) have all reported an increase in N concentration in the petiole as a result of N application, indicating that there is a positive response in petiole N concentration to the application of N.

The incidence of inflorescence and stem necrosis as well as the occurrence of bunch rot (*Botrytis cinerea*) has been shown to be influence by the application of N. A decrease in inflorescence necrosis from the application of N has been noted by Keller *et al.* (2001[a]) and Keller *et al.* (1998). Keller *et al.* (2001[a]) also reported an increase in stem necrosis and bunch rot from the application of N, which was supported by Christensen *et al.* (1994) in work on the application of N in French Colombard and Grenache. This demonstrates that the application of N is not just linked to quality and growth parameters of the vine but can also influence the development of disease and physiological disorders.

The chlorophyll content of leaves is another parameter that can be influenced by the application of N, Keller *et al.* (2001[b]) showed an increase in leaf chlorophyll content as a result of the N applications. The degradation of chlorophyll was delayed as a result of N application as well as a delay in leaf senescence. Leaf gas exchange also increased as a result, improving photosynthetic activity. Keller *et al.* (1998) also reported a delay in leaf senescence as a result of N application

The biomass distribution of the vine can be influenced by the application of N. Zerihun *et al.* (2002) reported that on Cabernet Sauvignon graftlings biomass distribution amongst vine organs was altered as a result of N application. Increasing N concentration decreased allocation to the roots dependent on the stock-scion interaction. The same distribution of biomass in vine organs was also documented by Rodriguez-Lovelle *et al.* (2002). They also noted that when another sink (Fruit) is introduced into

the system the alterations in the biomass distribution was not seen. An understanding of the way that N can influence biomass distribution can help producers manage their vines vegetative growth.

The application of N can also influence and interact with the absorption and role of other nutrients. Wolf *et al.* (1983) has noted these interactions in their study of the affects of four different Nitrogen concentrations on Seyvel Blanc. Tissue analysis has shown that increasing N concentration has increased phosphorous (P) and iron (Fe) levels while decreasing calcium (Ca) and magnesium (Mg) concentrations. A decrease in P concentration was noted by Bell *et al.* (1999) as a result of N application in their study of the reproductive and vegetative capacity of Cabernet Sauvignon.

The visual symptoms of toxicities and deficiencies are well recognised in the industry, but the effects of N rates and timing is not as widely recognised. Conradie (1980) investigated the seasonal uptake of N by Chenin blanc / 99R in sand culture. His investigation revealed two distinct periods of N absorption, the first slowly starting after budburst through to veraison and the second after harvest till the end of natural leaf fall. The second N adsorption peak accounted for 34% of the vine total seasonal requirements. During the season the partitioning of N within the grapevine was also investigated showing the accumulation of N in the crop, leaf, pruning and permeate parts being 35.8%, 31.4%, 14.4% and 18.7% receptively. From the data collected, Conradie (1980) calculated the expected crop removals for Chenin blanc / 99R at 2.1 kg N / tonne based on leaf and pruning material being retained in the nutrient cycle. Graph 1 shows the N content of the vine parts through the season.

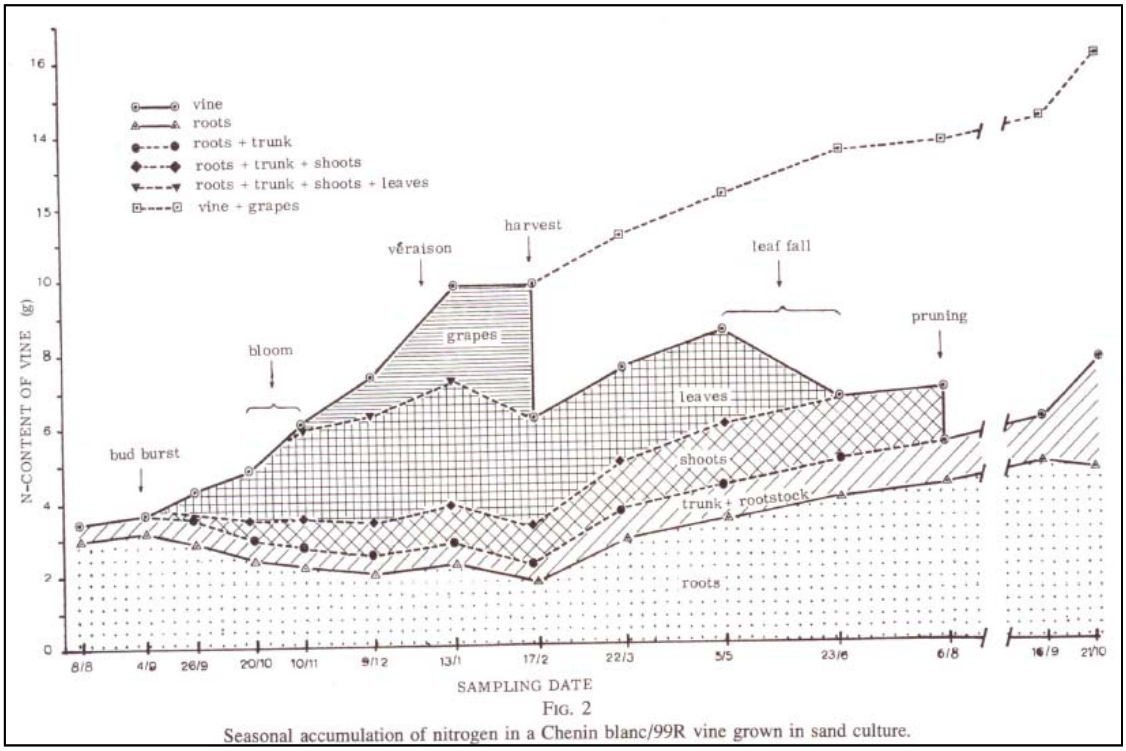
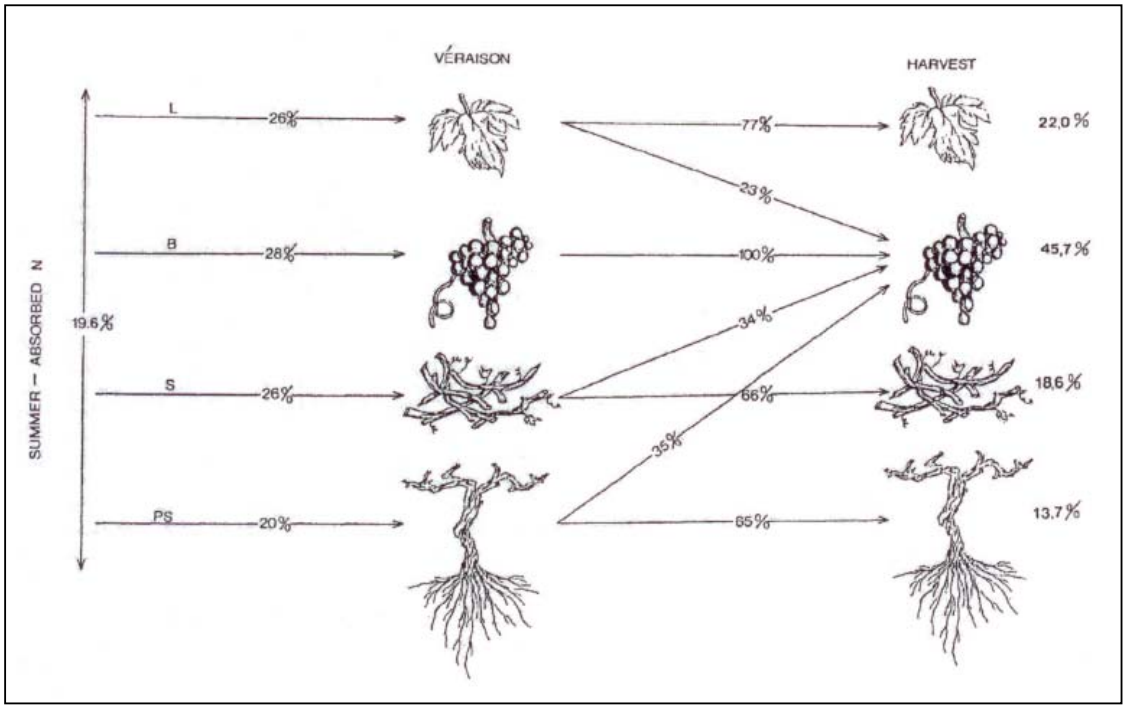


FIG. 2
Seasonal accumulation of nitrogen in a Chenin blanc/99R vine grown in sand culture.

Graph 1. Season accumulation of N. Conradie (1980)

The periods of uptake are useful but the translocation and distribution of applied N also needs be understood in both periods. The translocation and distribution of N applied in early summer (post flowering) for Chenin blanc / 99R grown in sand culture was studied by Conradie (1991). The study included the use of isotope 15 labelled N (^{15}N) over a 25-day period from the end of rapid shoot growth (berries at 8mm), vines were sampled over a 10 month period and all parts of the plant was split up and analysed. At the time of veraison the labelled N accounted for 22% of the N present in the vine with the major proportion (52%) being present in the vegetative growth, and the remainder in bunches (28%) and permanent parts (20%). Over the harvest period till dormancy the distribution of N within the vine is altered and relocated to the permanent structures where labelled N made up 6% of the total N in the vine with 78% being located in the roots and 22% in the permanent structures. Conradie (1991) noted that the allocation of summer applied N was similar to the allocation of spring (budburst) applied N within the vine. Summer and spring absorbed N was also used in similar amounts by the vine from veraison onwards. Graph 2 illustrates the translocation and distribution of summer applied N



Graph 2. Translocation and distribution of summer applied N. Conradie (1991)

Conradie (1992[c]) also investigated the utilisation of ^{15}N applied during the previous post-harvest period, on Chenin blac / 99-Richter. Conradie study suggest that 60% of the vines N reserve at the start of budburst comes from N absorbed during the post-harvest period and one quarter of the N reserves in the vine is utilised by the end of flowering, but by the end of harvest 50% of the N reserve present at budburst has been used.

Generally the industry has three main timings of N application: budburst, post flowering and post harvest. Data collected by Christensen *et al.*, (1994) during trial work on the effects of timing and rate of N application supports these timings. The quantity of N to apply during these times is harder to understand but the data from Conradie (1980), Conradie (1991) and Conradie (1992[c]) sheds some light on the subject. The measurement of 60% of vines N reserves at the start of budburst coming from the post harvest application (Conradie, 1992[c]) indicates the importance of a post harvest N program. Christensen *et al.* (1994) also noted that the post harvest N application was as effective as the budburst application in increasing NO^3-N concentration in the petiole at flowering.

Wine quality parameters can also be influenced by the application of N. Delgado *et al.* (2004) investigated the effects of N application on *Tempranillo* /110-Richter. An increased anthocyanin levels was seen at moderate N (50g N / vine) application rate while at higher rates a decrease in soluble solid was noticed. Increases in anthocyanin levels at moderate N (50g N / vine) application and a reduction in soluble solids was also seen by Martín *et al.* (2004) Conradie (2001), Christensen *et al.* (1994), Ahalwat (1988[b]), Ruhl *et al.* (1992) and Keller *et al.* (1998). Ahalwat (1988[b]) noted that the reduction in soluble solids could be a result of growth dilution caused by excessive growth as a result of N application.

Ruhl *et al.* (1992) assessed the affects of N application on other juice composition parameters of Riesling, Chardonnay and Cabernet Sauvignon grown in different regions (Sunraysia, Coonawarra and Mornington Peninsula). The investigation revealed that the N application in Chardonnay significantly increased juice pH, citrate and malate while lowering chloride concentration. In Riesling an increase in juice pH and malate was seen, while in Cabernet Sauvignon it increased pH, potassium concentration, citrate, malate and tartrate significantly. The results suggested that the increases in juice pH would result in a poorer quality end product. Ahalwat (1988[b]) reported a decrease in juice pH as a result of N application, which contradicts previous findings.

Further effect of N application can be seen in work conducted by Treeby *et al.* (2000). Amino N and phenolic composition was improved as a result of N application irrespective of rootstocks used in the trial, Ramsey, Teleki 56 and Schwarzmann were the rootstocks used. Generally autumn applied N reduced colour scores, while any N supplied to Ramsey reduce colour. No N or N during summer resulted in the highest colour score for Teleki 56 and Schwarzmann. Taste panel assessment suggested that summer N application negatively affected wine quality of Ramsey, while the autumn application timing affected the Schwarzmann rootstock. Taste panel assessment of Teleki 56 was unaffected by N application timing. Conradie (1992[c]), Christensen *et al.* (1994) and Treeby *et al.* (2000) have presented data on the influence of Autumn applied N indicate the influence that post harvest N can have on crop performance and quality.

Like Treeby *et al.* (2000), Rodriguez-Lovelle *et al.* (2002) has shown that N is needed to develop favourable amino acids. Rodriguez-Lovelle *et al.* (2002) have shown that even when N is limited

from flowering to veraison, then applied in adequate amount through veraison a favourable amino acid profile can be reached. This indicates that the N status of the vine needs to be considered when considering the quantity and timings of N application.

Phosphorous (P)

Phosphorous is the second most limiting nutrient to plants and is absorbed by plants as both a monovalent ($H_2PO_4^-$) and divalent (HPO_4^{2-}) phosphate ion. The availability of the phosphate ion is affected by the pH of the soil, with a pH less then 7 resulting in the monovalent phosphate ions being available and a pH above 7 resulting in the divalent phosphate ion being available. The monovalent ion is the primary phosphorous form adsorbed by plants (Salisbury and Ross, 1992).

Generally in plants deficiency symptoms include stunted growth, dark green foliage, older leaves may become dark brown as they die and a delay in fruit maturity has also been observed. Excessive P application can increase root growth reducing the root to shoot ratio. P is mobile in the plants and is essential to photosynthesis, respiration and many metabolic processes (Salisbury and Ross, 1992). In *Vitis spp* P deficiency include small dark green leaves and a delay in fruit maturity. Toxicity symptoms include zinc and iron deficiency as P acts as an antagonist (Pearson and Goheen, 1988) reducing the amount of these nutrients absorbed.

As expected the first response of P application should be seen through the increase in P concentration in the petiole analysis. Smolarz and Marcik (1997) have reported this in their long-term study of varied P application rates, Heaseler *et al.* (1980) and Conradie and Saayman (1989[b]) are other authors that have reported the same response.

Smolarz and Marcik (1997) also reported in their long-term study of varied P application rates that the absence of P resulted in a reduction of berry size, although the textbook deficiency symptoms were not seen indicating the effects of P deficiency can start before textbook symptoms are visible. A reduction in berry weight was also reported by Skinner and Matthews (1989) when they studied the reproductive development of grapes under limited P conditions.

Skinner and Matthews (1989) study also showed that deficiency are seen in reproductive tissue before vegetative growth and withholding P at any stage during the vegetative cycle decreased berry numbers, berry weights, bunch weights and the number of bunches / vine. Heaseler *et al.* (1980) study showed an increase in yield, bunches per vine, bunch weight, vigour and fruitfulness as a result of P application. Increases in vigour has also been reported by Grant & Matthews (1996[a]) as a result of P application

Interaction can occur between nutrients as Heaseler *et al.* (1980) has shown in their study where the application of P decreased calcium (Ca) and zinc (Zn) concentrations in the petiole analysis. Skinner and Matthews (1990) investigation showed a synergist interaction between P and magnesium (Mg), through the monitored of the magnesium concentration in the roots and xylem sap of vines. The application of P increased the translocation of magnesium from the roots to the shoots of P deficient vines. Further interactions have been noticed by Conradie and Saayman (1989[b]), where increases in N, Ca and Mg concentration and a decrease in potassium (K) was documented. The increase in Ca concentration is contrary to previous finings.

As a result of increased magnesium concentration in the petiole Skinner and Matthews (1990) have reported an increase in leaf photosynthetic rate from 0.7 to greater than 1.0 nm CO_2 cm^{-2} sec^{-1}, which in turn is improving the productivity of the vine as a result of increased photosynthetic activity and vine performance.

Like N the understanding of the uptake of P by vines is one of the keys to determining the nutrient requirements of the vine. Conradie (1981) examined the timing of P uptake in order to determine the best timings for fertiliser application throughout the season. Results from his experiment of Chenin blanc grafted to 99R grown in a sand culture indicated that prior to budburst the vine does not actively extract P from the soil and 82.1% of total P in the vine was located in the roots. Vines begin to actively take up P 22 days after budburst, with root reserves still supplying a lot of the P required by new shoots. P uptake rapidly increased in the period to veraison with little coming from root reserves. In the 35 day preceding veraison some P starts to be diverted to roots for reserves. The content of P in the vine from veraison to harvest remained relatively even, though the concentration of P increase in bunches and decreases in the shoots. At the time of harvest vine P levels were the

highest in bunches (34.1%) followed by leaves (27.3%), roots (19.2%), shoots (13.9%) and the trunk (5.4%). Following harvest for approximately 33 days P uptake resumed with root storage levels increasing. In the 44 days preceding leaf drop P uptake increases, increasing levels in the leaves, roots, shoots and the trunk. By the completion of pruning the roots once again contained 81.1% of the vine's P. Over the season 1,875 mg P was absorbed per vine with 641 mg removed by the crop. This work shows two distinct absorption periods for P during the season, with the 1st 22 days after budburst to veraison and 2nd from harvest to leaf drop with maximum uptake in the 44days proceeding leaf fall. Graph 3 illustrates the P content in the vine through the season.

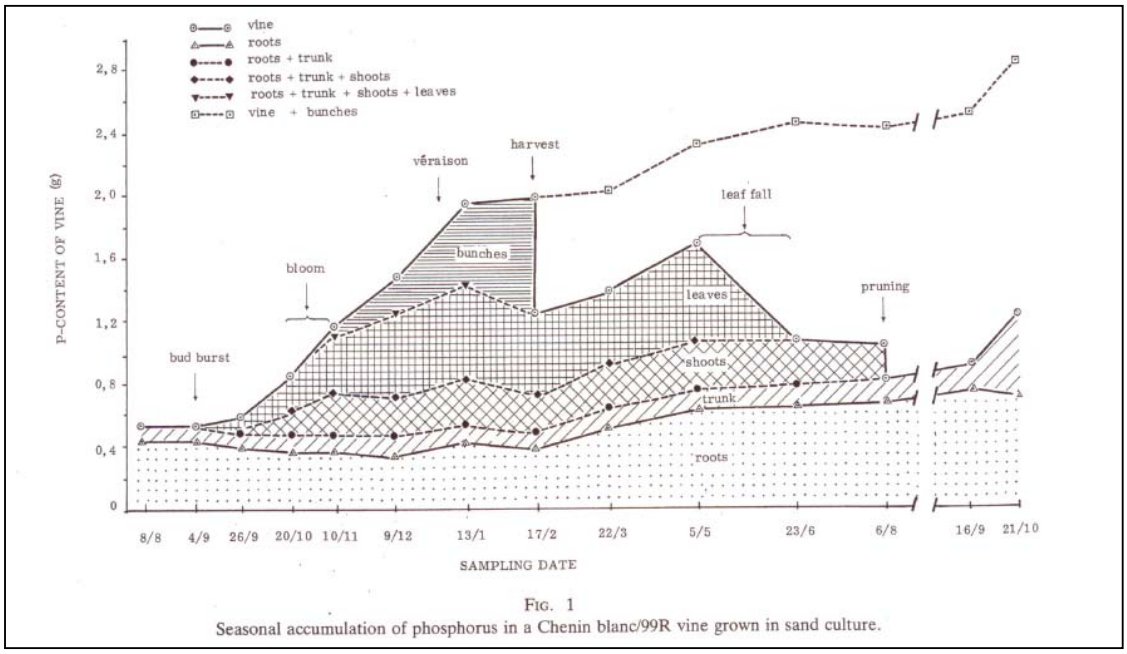


FIG. 1
Seasonal accumulation of phosphorus in a Chenin blanc/99R vine grown in sand culture.

Graph 3. Season accumulation of P. Conradie (1981)

The ability of rootstocks to take up all nutrients differ and Grant & Matthews (1996[a]) have investigated the effects of P on four different rootstocks: Freedom, Aramon Rupestris Ganzin no.1(AxR#1), Rupestris St George, 110 Richter (110R). The rootstock data illustrated that vines on Freedom remained vigorous despite the amount of P applied, vines on St George were greatly inhibited by the lack of P. 110R produced the lowest growth in the P treatment but it was least affected by a lack of P. Vines on AxR#1 were intermediately inhibited by a lack of P. This indicates that Freedom and 110R maybe more suited to low P soils as well as indicating that rootstocks react differently to P limitations and application.

In a later study Grant & Matthews (1996[b]) studied root system characteristics, P uptake and P partitioning in Chenin blanc on Freedom and St George rootstocks. Results demonstrated the importance of P to root growth with root length, volume and surface area being significantly lower when P was limited. P extraction from the soil was higher in the Freedom rootstock despite the P treatment, which is probably due to the significantly higher root area ratio recorded in this rootstock. P partitioning was found to be significant between rootstocks with St George storing more P in the petiole confirming variability between different rootstocks and the need for individual P programs based on rootstocks.

During an examination of the long-term effects of P fertilisation Conradie *et al.* (1989[a]) determined the P removal by seven year old Chenin blanc / Jacquez. P removal was calculated at 0.22kg P / tonne of fruit harvested based on the treatments of the trial and on a production figure of 11 tonnes / Ha. Under the conditions of the trial P application at 9kg / Ha increased crop yield by 5.84% and shoot mass by 12.9 %. P applied at 18kg / Ha showed no significant increase. The author suggested that 9kg P/ Ha was adequate for quality production under the conditions of the trial.

Potassium (K)

Potassium (K) is mobile in the plant and generally older mature leaves show up deficient symptoms first. Potassium is an activator of enzymes that are essential for photosynthesis and respiration as well as enzymes that produce starch and proteins (Bhandal and Malik, 1988). K is also involved in the osmotic potential of cells as well as the turgor of the guard cells that open and close stomata (Salisbury and Ross, 1992).

In *Vitis spp* symptoms vary with leaf age, in young leaves a lightened colour appears in areas and a few necrotic spots can occur along the leaf margin. During dry weather necrotic areas develop between the interveinal tissue, leaf margins can dry and roll. Leaves can also become distorted and ruffled. Older leaves can become violet brown to dark brown. Deficiencies are more common in dry climates (Pearson and Goheen, 1988).

Smolarz and Marcik (1997) observed strong K deficiency symptoms in study of the long-term (since 1923) effects of different fertiliser application on two grape cultivars – Aurora and Schuyler. The

treatments included different rates of fertiliser application including various nutrients. K was applied at 0 and 100 kg / Ha as potassium chloride.

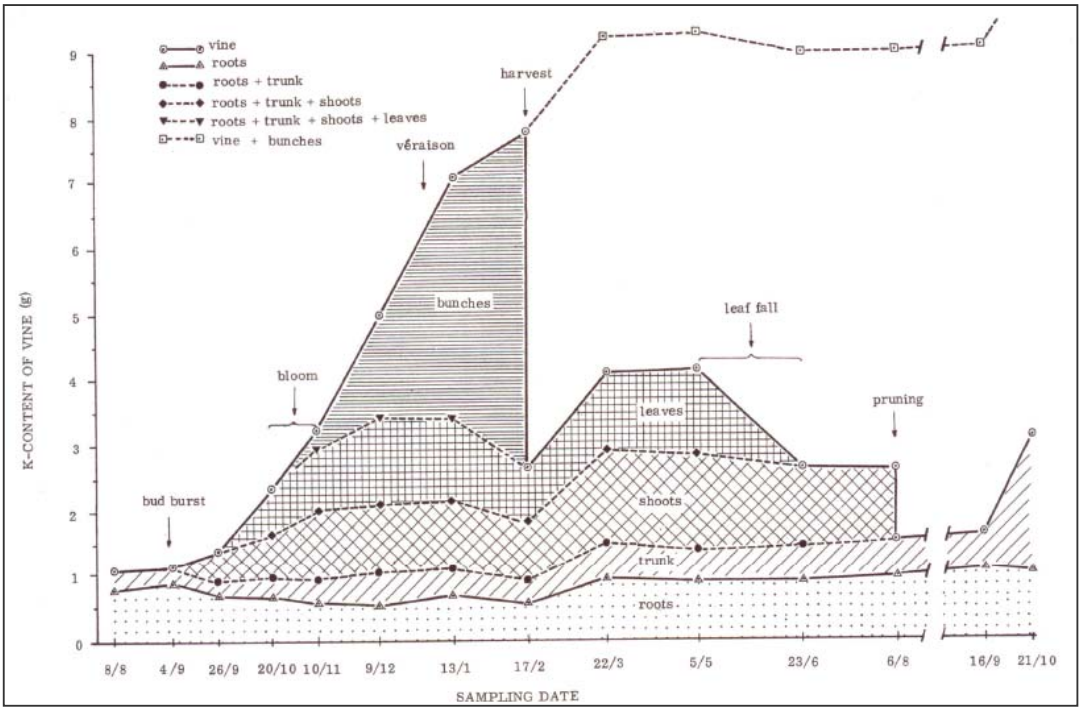
Morris and Cawthon (1982) explored the effects of K on Concord / own roots and noted that the application of K increased the K concentration in the petiole analysis. Other authors including Wolf *et al.* (1983), Garcia *et al. (*1999), Morris *et al.* (1980), Delgado *et al.* (2004), Poni *et al.* (2003) and Cline and Bradt (1980) have all noted an increase in the petiole, blade or grape analysis as a result of K application.

Morris and Cawthon (1982) showed a decreased in Ca and Mg concentrations as a result of K application, indicating interactions between K and the other nutrients. Wolf *et al.* (1983) findings also showed a reduction in N and Mg levels in the blade analysis to increasing K concentrations; while at moderate concentrations (117-235 mg / L) an increase in Ca was seen. The increase in the Ca concentration is opposing to Morris and Cawthon (1982) findings, suggesting that the level of K determines the interaction between K and Ca.

Garcia *et al. (*1999) investigated the interaction between K and Ca and the effects of their ratios on the nutrition of grapevine grown hydroponically. Cultivar Négrette clone 456 / 101.14 M.G. clone 3 (*Vitis riparia* X *Vitis rupestris*) was grown hydroponically with four nutrient solutions. An antagonism reaction between K and Ca was observed indicating that the addition of Ca can inhibit the uptake of K. This and previous authors investigations indicate that potassium and calcium are antagonistic when the other element is available in higher concentrations. An antagonism was also observed with K and Mg, as the addition of K decreased the concentration of Mg in the plant in the same manner as reported by Morris and Cawthon (1982) and Wolf *et al.* (1983). Morris *et al.* (1980) also observed a reduction in the concentration of Ca and Mg as a result of K application, their study also showed a reduction in manganese (Mn) concentration in the petioles.

Knowledge of the deficiency symptoms and the effects of K application on nutrition analysis (Petiole and Blade sampling) are not the key points in understanding the nutritional need of grapevine, an understanding of nutrients uptake, rootstocks and the effects of K on growth, yield and quality need to be considered in determining an adequate K program.

Conradie (1981) looked at the seasonal uptake of K in Chenin blanc on 99R. His findings found that the K content of the vine did not change significantly during the first 22 days after budburst. After this time K uptake increased till the end of rapid shoot elongation (74 days). In the period from the end of flowering till veraison (64 days) the vine accumulated 49% of its yearly K requirements. Between veraison and harvest K uptake decreases and at this time the K partitioning in the vine was as follows bunches (66.1%), trunk (4.7%), roots (6.9%), shoots (11.7%) and leaves (10.7%). A second peak of K accumulation occurred in the 33 days following harvest but it did not extend beyond this point. During the season the vine accumulated 7,937 mg K of which 5,147 mg K being removed by the crop and 488 mg K being retained by the permanent parts of the vine, the reminder was lost and recycled during leaf fall. Graph 7 illustrates the K content and distribution in the vine through the season.



Graph 7. Season accumulation K. Conradie (1981)

Distribution of K in Cabernet Sauvignon / 5C was studied by Williams and Biscay (1991), where whole vines were analysed, including samples of leaves, trunk, roots and fruit from flowering to the end of fruit maturity. Their analysis showed that there was no change in root K concentration over the fruit growth period but levels decreased over the same period for leaves stems and bunches.

During the fruit development periods K concentration in the bunches increased while a decrease was seen in the canes, leaves and stems. 77% of the K concentration increase in the bunches can be explained by the decrease of K in the canes, leaves and stems if all the K is remobilised. This is unlikely as at leaf fall the leaves still contain considerable amounts of K. At harvest bunches contained 31% of the total K contained in the vine, which is considerably less than what was found by the Conradie (1981). This study showed that K remobilisation did not occur until one month before fruit maturity and the main remobilisation occurred from the stems. The plant must have taken up the remainder, which was the author's conclusion.

Both previous authors have shown that berries accumulate K during the veraison period, Freeman and Kliewer (1983) have showed that berries of Carignane have two distinct rapid K accumulation periods. The first being up to 10 ^{o} Brix (5.5 Baume) and then the second starts once the berries have reached 17 ^{o} Brix (9.4 Baume) till the end of ripening.

Table 1. Rootstock varieties and their origin according to Stirling (1976), Galet (1979) and Alleweldt (1987)

Genotypes all belong to the genus *Vitis*

Name	Origin
Rupestris du Lot [Rupestris St George] (Rup)	*V. rupestris*
1103 Paulsen (1103P)	*V. berlandieri* Rességuier No. 2 x *V. rupestris* du Lot
140 Ruggeri (140R)	*V. berlandieri* Rességuier No. 2 x *V. rupestris* du Lot
110 Richter (110R)	*V. berlandieri* Rességuier No. 2 x *V. rupestri* Martin
Kober 5BB (5BB)	*V. berlandieri* x *V. riparia*
SO4 (SO4)	*V. berlandieri* x *V. riparia*
Millardet et de Grasset 420A (420)	*V. berlandieri* x *V. riparia*
Schwarzmann (Schw)	*V. riparia* x *V. rupestris*
Millardet et de Grasset 101–14 (101)	*V. riparia* x *V. rupestris*
3309 Couderc (3309)	*V. riparia* tomentosa x *V. rupestris*
1202 Couderc (1202)	*V. vinifera* x *V. rupestris*
1616 Couderc (1616)	*V. solonis* x *V. riparia*
1613 Couderc (1613)	*V. solonis* x *V.* (*Labrusca* x *Riparia* x *Vinifera*)
Ramsey (Salt Creek) (Ram)	*V. champinii*
Dog Ridge (Dog R)	*V. champinii*
K51–40 (51–40)	*V. champinii* x *V. rupestris*
K51–32 (51–32)	*V. champinii* x *V. rupestris*
Freedom (Free)	1613 Couderc x Dog Ridge

Graph 4. Rootstocks and their origin. Ruhl (1989)

Rootstock plays a key role in nutrient uptake and understanding the role that they play is needed when determining nutrient requirements. Ruhl (1989) studied the uptake and distribution of K by

rootstocks. Rootstocks used in the study can be seen in the Graph 4. Rootstocks Freedom and Dog Ridge showed high K concentration in their petioles while 110R and 140R had low K concentration. The author outlined that grapevines generally accumulate higher concentration of K in their shoots than in their roots, but there was an exception to the rule found in the study as 1103 Paulsen and 140 Ruggeri accumulated high concentration of K in their roots.

In 1994 Brancadoro *et al.* examined the role that rootstock had on K content of grapevines during the vegetative period. The study included 20 different rootstocks:

S04	125 AA,	140 RU,	16-16,
Casmo 2	161-49,	93-5,	5004-846,
420A	1103P,	41B,	44-53M,
420 cl1	1447P,	1202,	106-8,
Kober 5BB,	779 P,	143 A,	554-5

TABLE 2 Leaf and must potassium levels in Croatina cultivar as influenced by the rootstock. Average data 1987-1990.

Rootstock	K at fruit-set (% D.W.)	K at veraison (%D.W.)	Must K (g/l)
Own root	1,36 bc	1,46 b	0,81 bc
SO 4	1,56 b	1,90 a	0,92 a
Cosmo 2	1,24 c	1,28 bc	0,77 cd
420 A	0,95 c	0,95 c	0,69 d
420 A cl1	1,14 c	1,25 bc	0,73 cd
K 5BB	1,28bc	1,41 b	0,77 c
125 AA	1,23 c	1,30 bc	0,74 cd
161-49	1,24 c	1,23 bc	0,71 cd
1103 P	1,13 c	1,18 bc	0,76 cd
1447 P	1,26 bc	1,12 bc	0,76 cd
779 P	1,24 c	1,20 bc	0,73 cd
140 Ru	0,99 c	0,88 c	0,64 d
93-5	1,48 bc	1,52 ab	0,85 b
41 B	1,39 bc	1,43 b	0,81 bc
1202	0,96 c	1,09 bc	0,69 d
143 A	1,54 bc	1,37 bc	0,85 b
16-16	1,28 bc	1,32 bc	0,90 ab
5004-846	1,31 bc	1,53 ab	0,77 c
44-53 C	2,05 a	1,70 ab	0,79 bc
106-8	1,24 bc	1,33 bc	0,75 cd
554-5	1,26 bc	1,00 bc	0,71 d

* means followed by the same letter are not statistically different p=5%.

Graph 5. Average leaf and must K concentrations. Brancadoro *et al. (1994)*

Significant differences were obtained in K concentration between rootstocks. 44-53 and SO4 had the highest K concentration while 140Ru, 420A and 1202C had the lowest. Graph 5 illustrated the concentration differences amongst the rootstocks. Data presented by Ruhl (1989) and Brancadoro *et al.* (1994) also showed the difference in K uptake between different rootstocks, showing why nutritionally rootstock need to be treated differently based on there abilities to take up and accumulate nutrients.

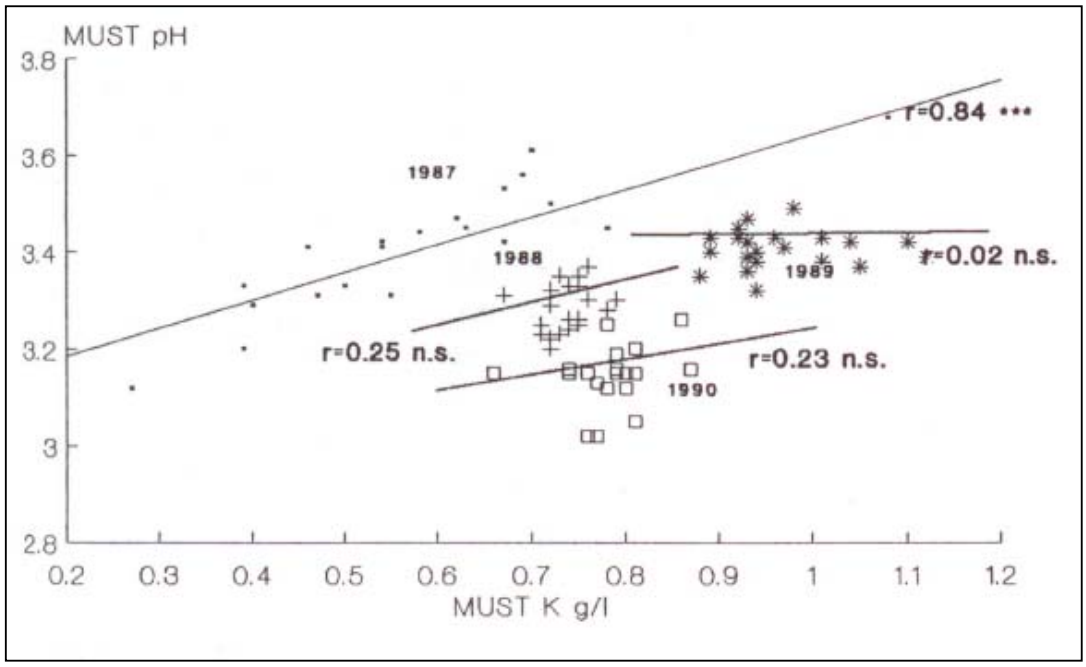
Unlike Ruhl (1989) and Brancadoro *et al.* (1994) investigation, Williams and Smith (1991) found that the rootstocks that they investigated showed no significant difference in the K concentration in the parts of the vine between the different rootstocks in the condition of the trial, indicating that the rootstocks used have simular K accumulation characteristic and can be generally treated the same in terms of K nutrition. Aramon Rupestris Ganzin No1 (AXR 1), Rupestris St George (St George) and 5C Teleki (5C) were used in the investigation.

The application of K can result in increased vine growth increasing pruning weights, dry mass, shoots / vine, leaves / vine and trunk girth, as noted by Morris and Cawthon (1982), Wolf *et al.* (1983) and Conradie *et al.* (1989[a]). Smolarz and Marcik (1997) reported that the lack of K over a number of years decrease shoot growth considerable in their long-term nutrition study. A reduction of growth was also observed by Wolf *et al.* (1983) but they noted it as a result of excessive application of K causing the element to becoming toxic. Ahalwat *et al.* (1988[a]) also noted a similar response but it was noted that the response may have been caused by the use of potassium chloride.

As well as a reduction in growth Smolarz and Marcik (1997) also showed that a lack of K resulted in a decrease in crop yield and fruit weight. Conradie *et al.* (1989[a]) showed a significant increase in yield at an application rate of 45kg K / Ha while Poni *et al.* (2003). reported no change in yield, bunches / vine or berry weight as a result of K application. Ahalwat *et al.* (1988a) also reported no change in yield but did state that there was a reduction in bunch weights as concentrations of K increased yet it did not affect vine yield. Ahalwat *et al.* (1988a) suggested that the decrease in bunch weight might have been the effect of toxicity caused by the use of Muriate of Potash (Potassium Chloride), indicating that fertiliser selection is important to vine performance.

The source of K was investigated by Cline and Bradt (1980) on Concord / own roots. K was applied as Potassium Sulphate, Potassium Nitrate and Potassium Chloride. Potassium Sulphate and Muriate of Potash was just as effective in increasing leaf K levels, potassium nitrate did not have the same response. The use of Muriate of Potash resulted in no adverse effects to wine quality and no toxic effect was detected from its use, which differs from Ahalwat *el al* (1988) findings.

Ruhl (1989) noted that the concentration of K in the vines petioles was related to pH of grape juice as high K concentration in the petiole resulted in reduced acidity that can result in reduced wine quality. Brancadoro *et al.* (1994), Morris and Cawthon (1982), Morris *et al.* (1980), Conradie *et al.* (1989[b]), Delgado *et al.* (2004) and Dundon *et al.* (1984) have all reported a reduction in acidity as a result of K application. Brancadoro *et al.* (1994) took the relationship one step further and found a correlation between K concentrations in the petiole and must with the pH of the must. The relationship between must pH and K concentration is illustrated in Graph 6.



Graph 6. Correlation between must pH and K concentration

In their investigation into the interaction between K and Ca Garcia *et al.* (1999) concluded that the addition of lime on acid soils might depress the effects of K uptake, favouring more acidic wines, improving wine quality off these soils.

A reduction in the acidity is not the only quality parameter that has been noted to be influenced by the application of K, soluble solids, maturity and anthocyanins levels are all influenced by K. A reduction in colour intensity, and uneven berry ripening was noted by Morris *et al.* (1980). Delgado *et al.* (2004) illustrated an increase in the anthocyanin levels at an application rate of 60 and 120 g K / vine with an increase of 23% and 40% respectively.

Ahalwat *et al.* (1988a) showed that the soluble solids increased with increasing applications of K with the highest level recorded at a application of 300 g K / vine, this result differs from Delgado *et al.* 2004 and Dundon *et al.* (1984) findings, which showed no change in soluble solid concentrations.

Climate is also another dynamic factor that needs to be considered. Dundon *et al.* (1984) investigated the affects of K fertiliser over four years on the must and wine of Shiraz grapevines grown in a cool climate (Eden Valley) and hot irrigated vineyard (Waikerie). Each site included a control (0 g K / Vine) and treatment (1.62 g K / vine) with the K applied as potassium sulphate, except in the second season when muriate of potash was applied. In Waikerie, soil analysis indicated that with the use of potassium sulphate after 5 months the K was evenly distribute through the soil profile and within 12 month the K had been leached out of the root zone, the use of muriate of potash resulted in higher K values in the root zone after 12 months but also resulted in a high soil salinity. Results differed in Eden Valley, 12 month after the K application the concentration in the soil was still higher than the control, showing that K movement through the profile was slow in the cool climate. The use of muriate of potash also gave higher K concentration in the soil as well as soil salinity. Waikerie's petiole analysis indicated that there was no significant change in K concentration over the control when potassium sulphate was applied, but the use of muriate of potash increased K Cl, and Na concentrations, in Eden Valley no change was observed.

Calcium (Ca)

Calcium (Ca) is taken up by plants as a divalent ion, which cannot be taken up and translocated in the phloem cell of the plant. Given this deficiency symptoms occur in the young parts of the plant where it is used in cell division. Generally deficiency symptoms include twisted and deformed tissues at the growing tips (Salisbury and Ross, 1992).

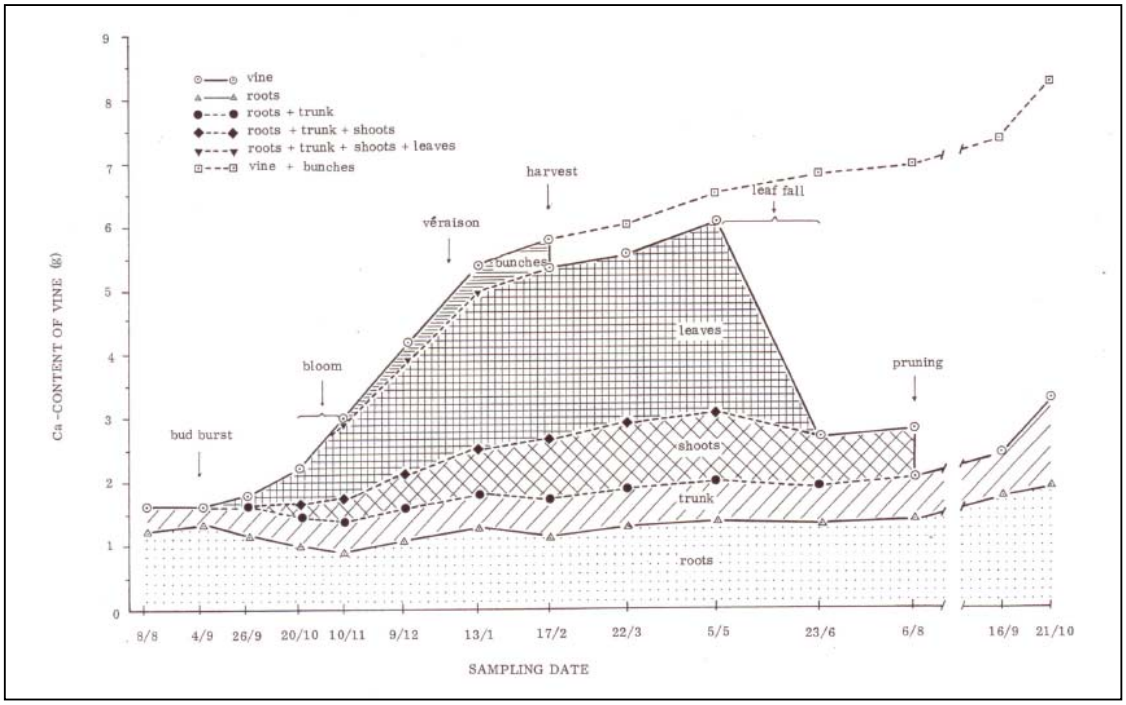
In *Vitis spp* deficiency symptoms are uncommon but can occur in strongly acidic soils, below pH 4.5. Deficiency symptoms start as a narrow necrotic border at the leaf margin that moves in steps towards the petiole attachment. Dark brown pimples may also appear up to 1 mm in diameter, on the primary bark of the internode. The growing bunches can also dry up from the tip resembling severe stem necrosis. (Pearson and Goheen, 1988).

Garcia *et al*. (1999) investigated the effects of Ca and K ratios on the nutrition of grapevine grown hydroponically. Cultivar Négrette clone 456 / 101.14 M.G. clone 3 (*Vitis riparia* X *Vitis rupestris*) was grown in four nutrient solutions including a low K and normal Ca, high K and low Ca and a enriched stock solution with Ca. The Ca concentration in the laminae and the petiole increased with the application of Ca but it was noticed that the increase in Ca content in the plant was dependent on the K concentration. A Ca-Mg antagonism was observed in this investigation.

In the previous section the interaction between Ca and K was also seen by Morris and Cawthon (1982) and Morris *et al.* (1980). Wolf *et al.* (1983) found the opposite to Garcia *et al.* (1999), with results that indicated that the application of K increased Ca concentration. Even though some of the findings are contrary to each other they do indicate that there is an interaction between the two elements and any nutrient programs need to consider these interactions.

Just like other nutrients the key to understanding Ca nutrition is to understand its uptake. Seasonal uptake of Ca has been studied by Conradie (1981) on Chenin blanc / 99R. The study showed that little Ca was accumulated by the vine prior to budburst nor in the 22 days after budburst, though Ca reserves decreased in the roots as new growth accumulated Ca in this period. In this same period Ca levels in the bark were noted to have doubled and continued to increase over the subsequent 45 days as Ca accumulation continued to increase in the vine. Between flowering and veraison 2,398 mg of Ca was absorbed by the vine, which accounted for nearly half the vines yearly consumption. Between veraison and harvest bunches accumulated no Ca but the vine does slowly take up Ca for other parts of the vine. At harvest Ca levels were as follows: bunches (7.7%), leaves (46.4%), roots (19.8%), shoots (16.7%) and the trunk (9.4%). Ca accumulation was insignificant after harvest, however in the 44 days proceeding leaf drop Ca uptake increased significantly. During leaf drop Ca levels increased in the leaves and decreased in the shoots, with 54% of total vine Ca being lost

through the leaves. During the season the vine accumulated 5, 242 mg Ca, with 442 mg Ca removed by the crop and 370 mg Ca retained by the permanent vine parts. The active accumulation periods for Ca during the season are three weeks after budburst till veraison and in the six weeks before leaf fall. Graph 8 illustrates the Ca content in the vine through the season.



Graph 8. Seasonal accumulation of Ca. Conradie (1981)

Cabanne & Doneche (2003) have taken the accumulation of Ca in the berry one step further by examined the accumulation and redistribution of Ca during the development of the grape berry. Their study was conducted on Sauvignon blanc, Semillon, Merlot and Cabernet Sauvignon grown in Bordeaux France. Results indicated Ca content increased in the berry from flowering till veraison as noted by the previous author, after veraison Ca that had been previously building up in the flesh and pericarp of the berries were diverted to the developing seed and skin, showing that parts of the vines still has a need for Ca even though Ca is not been actively taken up.

Magnesium (Mg)

Like Ca, plants take up Mg as a divalent ion, generally deficiency symptoms can be seen as interveinal chlorosis of older leaves. Mg is an essential component of chlorophyll as well as the

functional ability of ATP in many reactions. It is also responsible for the activation of many enzymes in photosynthesis, respiration and the formation of DNA and RNA (Salisbury and Ross, 1992). Deficiencies normally occur in light, acid soils with low Mg content, sandy soil with high K concentration and calcareous soils may also promote deficiencies. High use of ammonium and potassium fertilisers can also cause problems (Pearson and Goheen, 1988).

In *Vitis spp* deficiency symptoms can basically take two different forms, early in the season it form an interveinal chlorosis and later it shows as interveinal yellowing. Late in the season deficiencies normally occur in the basal leaves, the first signs of deficiency will normally appear just before flowering as small brown-green spots near the margin and in the interveinal tissue of young leaves (Pearson and Goheen, 1988).

Wolf *el al.* (1983) investigating the affect of Mg concentrations on Seyvel Blanc. Results showed that growth and dry mass data increased with increasing Mg concentration up to 150 mg / L, then plateaued out. Wolf *el al.* (1983) also noted that increasing Mg concentrations increased Mg concentrations in the blade analysis.

Májer (2004) investigated the application of Mg through ground and foliar application. The trial was conducted in an area where deficiency symptoms have been seen over the past several years. Data suggested that the ground application increased harvest yield while the foliar treatment did not. However increases in crop yield and berry weight through the application of foliar sprays has been noted by Usha and Singh (2002) at a 0.2% concentration sprayed at two timings (pre flowering and fruit set).

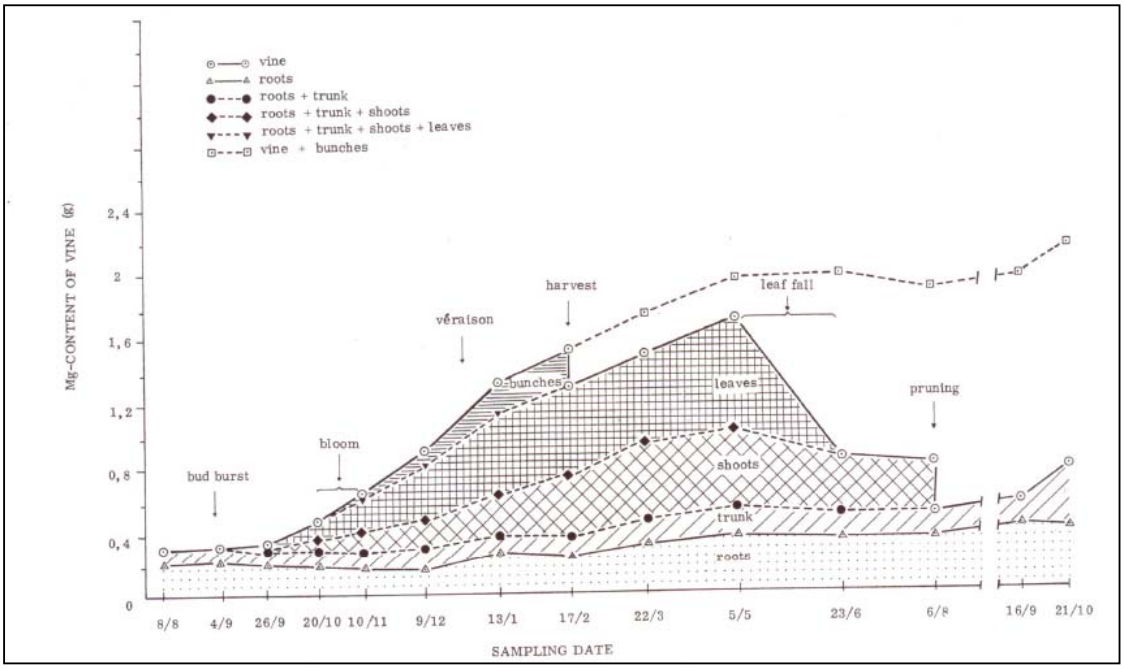
In 1985 Dabas and Jindal also studied the effects of Mg sprays at a 0.1 % application rate. A significant increased in fruitful buds, increase in berry set and a reduction in inflorescence dryness was observed. The author indicated that the application improve pollen germination and viability, improving fruit set.

Interaction between nutrients has been documented previously by research. Morris & Cowthan (1989), Garcia *et al.* (1982) and Morris *et al.* (1980) have all documented that increasing K

concentration reduce Mg concentration in the vine. Wolf *et al.* (1983) have also noticed an interaction between the two elements. Their study showed a decrease in K concentration as a result of increasing Mg concentration, indicating that there is a strong interaction between the two elements. An interaction between N and Mg was also observed; N decreased the Mg concentration in the vine.

Increases in Mg concentration in the vine has been seen by Conradie and Saayman (1989) as a response to P application. Skinner and Matthews (1990) investigated the application of P on the translocation of Mg from the roots to the shoots. Skinner and Matthews (1990) data indicate that an increase in Mg was observed as a result of the P application, when P was limited less Mg was found in the xylem sap of vines. This indicates that P is important in the translocation of Mg to shoots.

The uptake of Mg was studied by Conradie (1981), which showed that Mg uptake was not significant in the 22 days prior to budburst nor the 27 days following budburst in Chenin blanc / 99R. Mg uptake began to increase in the time period surrounding flowering, which was translocated mostly into new growth. Mg absorption continued to increase from flowering to veraison with Mg reserves increasing in the roots, shoots and leaves. The berries absorbed little Mg during this time. From veraison to harvest, Mg absorption continued but at a slower rate. At harvest Mg levels were as follows: bunches (15.4%), leaves (36.8%), roots (15.1%), shoots (26.2%) and trunk (6.4%). After harvest vines accumulated a significant amount of Mg, which was stored in the roots, shoots and woody components of the trunk. Mg accumulation continued to leaf fall with most being stored in the roots and leaves. No Mg was actively absorbed during leaf drop. A total of 1,568 mg Mg was accumulation per vine during the season, with 234 mg Mg removed by the crop and 195 mg Mg retained by the permanent vine parts. Mg accumulation is relatively steady across the season therefore timing for Mg application could occur from just prior to flowering till leaf drop. Graph 9 illustrates the Mg content in the vine through the season.



Graph 9. Seasonal Mg accumulation. Conradie (1981)

Like other nutrient the type of rootstock can influence the uptake of Mg. Garcia *et al.* (2001) examined the effect of three different rootstocks (101-14, 3309 C, SO 4) on the extraction of Mg. Results indicated that vines grafted to 3309 C had the highest Mg concentration followed by 101-14 and SO 4. Again showing like previous nutrients that the rootstocks need to be considered in the development of a nutrition program.

The effect of Mg application on grape juice composition in Riesling, Chardonnay and Cabernet Sauvignon grown in different regions (Sunraysia, Coonawarra and Mornigton Peninsula) was investigated by Ruhl *et al.* (1992). In Chardonnay the Mg application significantly reduced the pH of the juice by 0.02 units, while in the other varieties no change was observed. Májer (2004) also reported no change in acidity due to the application of Mg.

Zinc (Zn)

Zn is taken up as a divalent ion, deficiency symptoms result in a reduction in growth of young tissues, which can cause small leaves and internodes. Interveinal chlorosis can also occur in many plants. Zn is involved in the production and functioning of many enzymes as well as many growth

hormones (Salisbury and Ross, 1992). Zn may become deficient in sandy soils, high pH soils, soils with high P content and were the topsoil has been removed (Pearson and Goheen, 1988).

In *Vitis spp* deficiency symptoms occur as small leaf blades with small petiolar sinuses and sharp teeth. One half of the leaf blade can become larger than the other and the interveinal areas can turn light green to yellow in a mosaic pattern. In red cultivars it can become red to black. Leaf veins can become clear with narrow boarders of green, more advanced symptoms include chlorotic areas that can become necrotic (Pearson and Goheen, 1988).

Some of the above deficiency symptoms were observed by Volschenk *et al.* (1996) when they looked at the effects of different Zn levels on the growth of grapevines. One year old Muscat d' Alexandrie / 140 Ruggeri and 110 Richter were used grown in a Pyrex canning flask filled with a complete nutrient solution plus altered Zn concentrations. The deficiency symptoms were seen at concentration below 0.025 mg Zn / dm^3, indicating that vine will become Zn deficient below this concentration. Increasing Zn concentrations resulted in increased fresh and dry mass, increased photosynthetic activity and Zn concentration in the plant. 140 Ruggeri illustrated an increase in leaf area and internode length as the Zn concentrations increased.

The preferred method to apply Zn in the winegrape industry has been through the application of foliar sprays and generally not through fertigation or solid fertiliser application. Volschenk *et al.* (1999) looked at the assimilation and translocation of Zn applied to the apical leaves, basal leaves and the roots of Muscut d' Alexandria / 140 Ruggeri and 110 Richter. Plants were grown in pyrex canning flask filled with a complete nutrient solution minus Zn, the root treatment included Zn in the complete nutrient solution. The results showed that 80% of the Zn applied to the apical leaves remained there, application to the basal levels resulted in more translocation of Zn to other permanent parts of the plant. Root uptake of Zn was greater but only 20% of the Zn taken up was translocated to other parts of the vine, results can be seen in graph 10.

Christensen (1980) investigated the effects of Zn foliar sprays on grapevines (Thompson seedless, Petite Sirah and Muscat of Alexandria). Zn was applied before the end of leaf drop and as a weekly application starting three weeks before flowering through to two weeks post flowering. Zn was

applied as Zinc Sulphate (36% Zn) at 0.76 kg / 100L and a Zinc Sulphate compound (DelMo-Z (50% Zn)) at 0.48kg / 100L, the active Zn concentration for both products was 0.24 kg Zn / 100L. The data suggested that Zn is best applied from 2 weeks pre flowering through to fruit set, no mention was made about differences in results due to the chemical used.

TABLE 2. Translocation of ^{65}Zn to plant parts (% of total amount assimilated).

Plantparts	Position of application/Rootstock					
	Roots		Apical leaves		Basal leaves	
	140 Ruggeri	110 Richter	140 Ruggeri	110 Richter	140 Ruggeri	110 Richter
Apical leaf blades	1.07	0.70	55.38	68.10	5.52	12.15
Apical leaf petioles	0.44	0.43	6.62	8.29	10.23	2.35
Apical wood	6.11	4.82	12.80	16.81	2.85	16.69
Basal leaf blades	0.35	0.20	5.95	2.29	39.73	29.21
Basal leaf petioles	0.25	0.14	12.89	2.02	17.02	21.96
Basal wood	8.74	5.08	1.91	1.76	11.80	11.08
Roots	83.04	87.92	3.95	0.72	9.81	6.56

Graph 10. Allocation of Zn application roots, apical and basal leaves. Volschenk *et al.* (1999)

The best time to apply foliar application is a question that always gets asked and Christensen (1980) furthered his previous work and tested night versus day application of Zn and found that under the conditions there was no noticeable difference between the treatment timings but did note that both sprays increased berry weight, crop yield and reduced brix.

A common question is what is the best form of Zn to foliar to apply? Christensen and Jensen (1978), investigated the response of Thompson seedless to two different Zn compounds (zinc sulphate-50% Zn) and Zn-EDTA chelate (14.2% Zn)). A dilute (1169 L / Ha) and concentrated (234 L / Ha) spray was applied for each compound, Zn Sulphate was applied at 2.2 and 4.4 kg / ha, Zn-EDTA was applied at 3.9 and 7.8 kg / Ha and there was a control with no treatments, giving nine treatments. The Zn sprays were applied 2- 2.5 weeks before full flowering. Results indicated that the dilute spray improved Zn uptake regardless of the compound. Application of Zn-EDTA when applied at the same Zn concentration per Ha as zinc sulphate increased the Zn concentration in the plant but using Zn sulphate at a higher rate counteracted the increase seen. This indicates that the chelated Zn is more

efficiently taken up by vines. Shoot tip analysis showed that the effect of the Zn application was diminished within 20 days after the application, which support Christensen (1980) findings that Zn is best-applied 2 weeks before full bloom to supply Zn during flowering.

As previous noted foliar application is the most widely used method to correct Zn deficiency symptoms. Pire (1987) looked at correcting Zn deficiency by the treatment of pruning wounds. A trial was conducted on Cardinal vines where wounds were painted with three treatments no Zn, Zn as Zinc sulphate (22% Zn) and Zn as Zineb (zinc ethylene-bis-dithiocarbamate, 23% Zn). Zn sulphate and Zineb was applied as a 150 grams / L solution. The treatments increased yields by increasing bunch weights, increase pruning weights and levels of Zn in the petiole. Zinc sulphate was the most effective compound in the trial, showing that other methods can be used to correct deficiency symptoms.

Manganese (Mn)

Mn exists as three different ionic states (Mn^{2+}, Mn^{3+}, and Mn^{4+}) as well as in a chelated form, yet like other ion it is taken up as a divalent ion (Mn^{2+}). In plants deficiency symptoms are seen as interveinal chlorosis of younger and older leaves. Mn itself is known to be important in the photosynthetic split of water and also as an activator of many enzymes (Salisbury and Ross, 1992).

In *Vitis spp* deficiency symptoms as in other plants is seen as interveinal chlorosis that have a mosaic like arrangement. Generally symptoms are more severe on sun-exposed leaves and advanced conditions can affect the growth of berries and shoots, it may also delay veraison. Deficiency symptoms are more likely to occur on alkaline, sandy soils high in organic matter or on limey soils that are deficient in Mn (Pearson and Goheen, 1988).

Iron (Fe)

Iron is an essential component of a number of proteins and enzymes as well as acting as a proton carrier during photosynthesis and respiration. Deficiency symptoms have been called iron chlorosis, lime chorisis and lime-induced chlorosis. Deficiencies normally occur during times of cool wet weather when iron movement in the soil is very slow. Symptoms are normally found in soils that

have relative high lime (Ca) content (Pearson and Goheen, 1988). Symptoms are seen, as pronounced interveinal chlorosis that can even be white in colour (Salisbury and Ross, 1992). Fruit set can also be affected by Fe deficiency (Pearson and Goheen, 1988).

Bertamini and Nandunchezhian (2005) studied the response of Pinot noir to iron deficiency. Leaves were classified for the study as Fe deficient and Fe sufficient based on chlorophyll concentration in the leaf, below 10 nmol chlorophyll / cm^2 (deficient) and above 30 nmol chlorophyll / cm^2 (sufficient). Results showed that Fe deficiency decreases vegetative growth, affected membrane integrity, decreased leaf CO_2 exchange and photosynthetic efficiency, reduced leaf area and dry matter accumulation, as well as resulting in increased fruit abscission or drop.

Although it is easy to see the visual symptoms of Fe deficiency, it is relative hard to alleviate the problem in calcareous soils where it normally occurs. Foliar sprays are relative ineffective as the ion is relatively immobile in the plant. The method of applying Sulphuric acid to the soil to alleviate the problem of Iron chlorosis was investigated by Nikolic *et al*. (1998). The trial was conducted on Riesling / Kober 5 BB grown in 5 kg of potted soil with a pH of 8, 30% calcium carbonate ($CaCO_3$) and 9 mg Fe / kg dry soil. Plants were grown in a controlled growth chamber and the treatments of 10 and 20 ml (equivalent to 6000L and 12000L / Ha respectively) of 1:4 Sulphuric acid solutions was applied once. Soil was maintained at a moist state (60% water holding capacity). The applications resulted in an increase of 65% in Chlorophyll a+b, 53- 55% increase in Fe^{2+} content and a decrease in soil pH. A decrease in the $CaCO_3$ and HCO_3^- (bicarbonate) levels was also seen as a result of the application. The treated plants showed no symptoms of Fe deficiency and results indicated that the lower rate was adequate to alleviate the iron chlorosis problem. The authors illustrated the following reaction (1) as a result of the sulphuric acid application, illustrating that sulphuric acid acts as a proton donor to neutralize bicarbonate in the rhizosphere (reaction (2) and (3)).

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + CO_2 + H_2O \quad (1)$$

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-} \quad (2)$$

$$H^+ + HCO_3^- \rightarrow CO_2 + H_2O \quad (3)$$

In 2004 Chen *et al.* investigated the response of CO_2 assimilation, photosynthetic enzymes and carbohydrates of one year old Concord / own roots from the application of Iron as Fe-EDDHA. The investigation showed that increasing Fe levels increased active Fe levels in the leaf but it did not significantly increase total Fe concentration. The authors explained this as an adaptive mechanism of the plant because sufficient Fe was still being taken up by the vine but it was being deactivated as a result of the high pH in the cell apoplast. Therefore the Fe-EDDHA is more stable at high pH remaining active in the cell apoplast. It was also noted that in the Fe limitation treatment the leaf area and chlorophyll content was reduced. Fe limitation reduced the activity of Rubisco and in turn the CO_2 assimilation and non-structural carbohydrates making them source-limited.

Copper (Cu)

Plants need very small amount of Cu and because of this they are very rarely deficient, but in Australia many soils are Cu deficient (Salisbury and Ross, 1992). Cu can be taken up in both the monovalent and divalent form, the monovalent form is generally only taken up in wet soils were oxygen is limiting. Deficiency symptoms occur as dark green and twisted leaves, the ion is used in several enzymes and proteins involved in oxidation and reduction (Salisbury and Ross, 1992). Generally it is rare to find Cu deficiency in the vineyard. Cu is also known to be involved in the lignification or hardening of canes and shoots.

Boron (B)

Boron is taken up as a boric acid, which is translocated slowly with in the plant. Deficiency symptoms can include a failure of root tips to elongate, inhibition of DNA and RNA synthesis and inhibition of cell division in the shoot apex of young leaves. Boron is also known to be critical in the elongation of the pollen tube (Salisbury and Ross, 1992). The uptake of B is affected by irrigation and under drought stress it can become limited to plants, on the others side high rainfall and intensive irrigation can result in the ion being leached from the profile especially in sand soils (Pearson and Goheen, 1988).

In *Vitis spp* deficiency symptoms can start as early as flowering on the tendrils of the shoot tips, they become dark, knotty bulges and become necrotic, flower clusters can also die. During rapid shoot

elongation the internodes can swell and the pith becomes necrotic. Leaves have short thick petioles sometime with longitudinal lesions. Roots remain short and become thickened; they can also swell and form knots that can break open longitudinally. In the season after the deficiency the buds form B deficient canes will give rise to short, bushy, branched sterile shoots. (Pearson and Goheen, 1988).

Toxicity symptoms affect the above ground parts of the plant, younger leaves can become severely deformed, necrosis tips form on the serrations of older leaves that progress into the interveinal tissue, this can also be seen as spotting in the same manner. Tip growth of the main shoots is decreased in favour of lateral shoots that produce a vine that looks weak and bushy (Pearson and Goheen 1988).

Mahorkar and Patil (1987) investigated the effect of B on growth of three grape cultivars (Thompson seedless, Gulabi and Bangalore Purple). Each cultivar was potted and irrigated with 250ml of a complete solution fortnightly with the exception of B. B was applied at six different levels on a tri-monthly basis. Thompson seedless and Gulabi increased growth up to 0.076 g B / pot but above this level the increase was not seen, stem girth was greatest at 0.03g B / pot in Thompson seedless. Bangalore Purple increased growth up to 0.07 g / pot and decreased growth after that concentration. It was also noted that there was a slight decrease in the Ca content of the petioles as B levels increased.

The effect of B on the growth and mineral composition of Cabernet Sauvignon vines was studied by Downtom and Hawker (1980). Developed rooted cuttings were used for the trial held in gravel, sand and peat moss mixture located in a glasshouse. Plants were watered on a daily basis with a complete solution which varied in B concentration of 0 or 10mg B / L. Results showed that excessive B concentration reduced shoot length, plant dry mass and root mass, while stimulating plant lateral growth. Plant analysis data showed that the B concentrations reduced P concentration in the roots and the blade. A decrease in K concentration in the roots was also seen but an increased K in the blade was observed. Some symptoms of B toxicity were observed in the trial and it was noted that high chloride concentrations decreased the symptoms of B toxicity even with similar blade B levels.

In 1985 Dabas and Jindal studied the effects of B sprays on Thompson seedless. Boric acid was applied at 0.1, 0.2, 0.3 % concentration and water only was applied as a control. Applications were

applied one week before full flowering. The 0.3 % application significantly increased fruitful buds and reduced vegetative buds. Berry set was increased and berry drop was decreased with the applications, 0.1% gave the best results. The author indicated that the application improve pollen germination and viability. A reduction in inflorescence dryness and improved quality was also observed.

Chistensen (1986) (73) examine three different application methods of B on Thompson Seedless. B was applied as a broadcast, berm (weedicide cart) spray and a foliar application. Broadcast and berm spray application were applied in winter and the foliar application was applied just after flowering. The results showed that the berm treatments increased the B levels the most and was the most desirable application methods. It was suggested that small amounts should be applied every season as a maintenance rather that every couple of years. Foliar application can be used as an emergency corrective measure but ultimately a ground application was needed in the trial. The trial was conducted on fine sandy soils with an annual rainfall of 10.48 inches (262mm).

Molybdenum (Mo)

Little is known about Molybdenum (Mo) as it is only used in small amounts by plants and deficiency symptoms are rare. Molybdenum is available in a molybdate (MoO_4^{2-}) and MoS_2 form (Salisbury and Ross, 1992). Mo is known to be involved in *nitrate reductase*, which reduces nitrate ion to a nitrite ion. It is also thought to be involved in the reduction of purines like adenine and also as an oxidase that converts abscisic acid aldehyde to the hormone ABA that is involved in the adaptation of plants to stress.

Generally it has been thought that vine do not require Mo but work conducted by Williams *et al.* (2004) on Merlot vines has shown that the application of Mo can increase yield as a result of increased bunch weight and a reduction in “hen and chicken”(millerandage). An increase in functional seeds and percentage of coloured berries was seen as a result of Mo application. Mo was applied in two foliar applications before flowering at a rate of 118 g Mo / Ha as sodium molybdate, 410-800 L / Ha water. Williams *et al.* (2004) stated that level of Mo in the petiole at flowering of 0.05-0.09 mg / kg was associated with deficient vines.

Longbottom *et al.* (2005) also reported an increase in crop yield as a result of Mo application to Mo deficient Merlot vines, through increased fruit set. Mo was applied at two rates as sodium molybdate at 0.101 g / vine and 0.202 g / vine at two application timings, 10cm shoot length and one week later. The high rate did not improve the response of Mo application

Topic 2 – Fertigation Technology versus Broadcast Technology

Traditionally broadcast fertiliser technology has been used with flood and overhead irrigation, however the development of micro-sprinklers and drip irrigation has provided the opportunity for advances in fertigation as an alternative method for growers to deliver nutrients to the root zone.

Broadcast fertiliser application is defined as the application of solid fertilisers onto the ground surface generally two to three times per year in viticulture. The fertiliser is banded along the vine bank to ensure delivery of nutrients to the root zone. Broadcasting fertiliser generally occurs at times that suit management constraints and not the specific requirements of the plant. This causes the plant to rely heavily on the nutrient holding capacity of the soil.

Currently there are many different ways in which fertigation can be described considering the wide range of techniques and systems that are available. The techniques and systems can differ from slug dosing of fertiliser to continual injection system that can control the pH and electrical conductivity (Ec) of the irrigation water e.g. Martinez Open Hydroponics Technology (MOHT). MOHT applies nutrient to plants based on their physiological demands and production goals.

Generally fertigation can be described as the application of nutrients through the irrigation system using water as a carrier. Smaller amounts of nutrients are applied over a longer period of time, improving the effectiveness of the nutrients being applied and the vines ability to effectively use the nutrients. This decreases the plants reliance on soil properties and improves control of production goals. Some of the main advantages of fertigation include:
Improved uniformity of fertiliser application,
Timely adaptability to plant requirements,
Reduced labour cost and time saving,
Improved fertiliser efficiency,
Ability to chemically and electro chemically balance irrigation water, and
Increased productivity, yield and growth.

Nutrients are taken up as ions that have an electrical charge and not as elements. The chemically and electro – chemically balancing of irrigation water is perhaps the greatest advantage that the use of fertigation can give. It involves the balancing of the different charged ions and also the ratios between them. A correctly balance fertiliser solution can give further improvements in nutrient uptake, fertiliser efficiency and production. An improvement in production generally comes from improved energy usage within the plant, because less energy is used to acquire nutrients from the soil medium. This saved energy than can be used to improve production outcomes.

Equipment requirements separate the two methods of application, with broadcast application requiring a tractor and spreader, while fertigation requires a mixing tank, injection system, pipe work and injection point. Pipe work and tanks need to be selected with the types of chemicals to be used in mind, as many chemicals can be corrosive. The injection systems can vary from suction, pressure differential and pump injection.

Fertiliser selection is different with fertigation using technical grade products that are more soluble with fewer impurities. As a consequence of using technical grade products there is an increase in cost but an improved efficiency compared to field grade products (Conradie & Myburgh, 1999).

Generally fertigation needs a higher level of management skills focusing on application amounts, timings and equipment technology. Fertigation however can make nutrient application easier through the application of nutrients from a central point.

The use of fertigation needs knowledge based around solubility and compatibility of products. The solubility of fertilisers being used needs to be known and is generally given in a weight per volume at a given temperature. This indicates the maximum weight of fertiliser that can be dissolved in a volume of water at that water temperature. The solubilities of fertilisers can be found on the product specification sheets that are available through fertiliser retailers. Solubility of some of the main fertigated fertilisers is shown below (Table 1).

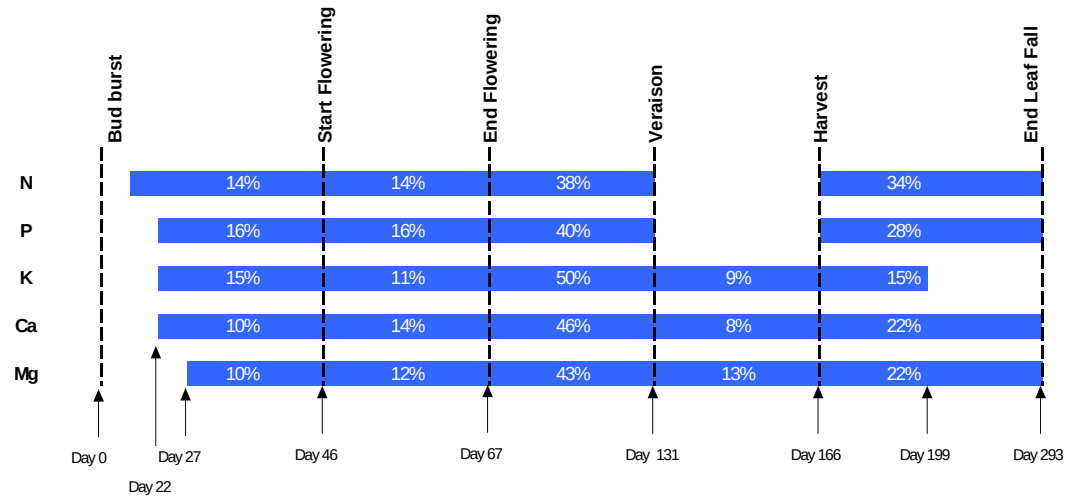
Fertiliser	Solubility grams / Litre @ 20ºC water Temperature
Potassium Sulphate (K_2SO_4)	120
Magnesium Sulphate ($MgSO_4.7H_20$)	330
Potassium Nitrate (KNO_3)	315
Ammonium Nitrate (NH_4NO_3)	1920
Calcium Nitrate (Hydro) ($5(NO_3)_2Ca.\ NH_4NO_3.10H_20$)	2500
Mono Ammonium Phosphate (MAP) ($NH_4H_2PO_4$)	365
Urea ($CO(NH_2)_2$)	1050
Table 1. Solubility of the main ferigated fertilisers	

Solubility considerations can be overcome with the use of liquid fertilisers. Liquids have their advantages and disadvantages. Liquid fertilises can reduce manual handling, mixing times and they are generally easy to handle. In the current supply situations the greatest disadvantage is the cost but growers need to consider the product based on their individual situations.

Compatibility of fertilisers provides essential information when producing mixes for fertigation. Incompatible products when mixed together react with each other and precipitate (solidify) out of the solution leaving a hard to dissolve slurry in the bottom of the tank. One example is the mixing of calcium nitrate with any phosphate based fertilisers like mono ammonium phosphate (MAP), the phosphate reacts with the calcium to form solid calcium phosphate.

After a general understanding of the above considerations, fertigation and nutrition comes down to what quantity of nutrients should be applied and when to apply them? Components of the previous section do shed some light on the question. Work conducted by Conradie (1980) and Conradie (1981) gives us an understanding of the times of nutrient uptake and when the vine will accumulate them, summarized below (Graph 11). This information can be used with fertigation to deliver nutrients to the plant at times when they are required.

Graph 11: Nutrient and proportions of uptake by Chenin Blanc / 99R



Note: P, Post harvest P uptake was slow in the first 33 days after harvest, maximum uptake occurred in the 44 days before leaf fall.
K and Mg, Uptake in the period from veraison till harvest was considerably slow.

Adapted from Conradie (1980) and Conradie (1981)

Fertigation programs concentrate on macronutrients (N, P, K, Ca and Mg) as many of the micronutrients can be efficiently corrected by foliar applications. In considering nitrogen the main timings that are used widely in the industry include budburst, post-flowering and post harvest application, which have been shown by Christensen *et al.*, (1994) (53). The above table also shows similar findings.

Crop removals can be used as guidelines to determine the quantity of nutrients to apply, yet depending on the variety, rootstock, yield, soil type and climate, the requirement of the vine may differ. Recycling of nutrients, leaching and reserves also need to be considered. Nutrients are recycled through leaves, pruning and roots, while the soil and vine may act as reserves. The form of nutrient applied and irrigation practice can alter nutrient efficiency e.g. excess irrigation may leach fertilisers out of the active root zone

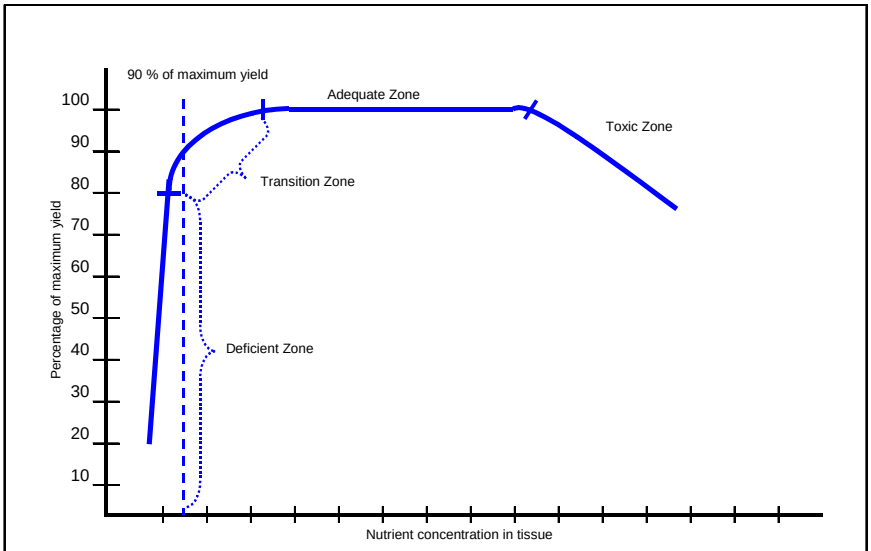
Fertigation has shown to be an efficient method to apply nutrients to grapevines (Bravo & Hepner, 1987), improving crop performance and the effectiveness of products applied. The use of high frequency nutrient applications has the potential to further improve crop performance through

improved nutrient uptake by the plants (Silber *el al.* 2003). The quantity and timing of nutrient application should be considers with the final product and quality in mind.

Topic 3 – Methods to Measure Plant Nutritional Status

The application of nutrients can influence vine performance as demonstrated in part one of this report. Determining the nutrient balance of a vineyard and what nutrients vines require can be very difficult using field assessment alone. Plant nutrient analysis is a technique that was developed to assist in the determination of which nutrients were deficient, optimal or at toxic levels, providing growers with extra information and a tool to optimise vine performance.

Critical nutrient concentrations make the bases of assessing the nutrient status of plants, generally through the relationship between plant nutrients concentration and yield. The relationship shows an ascending, level and descending portions of a curve using yield and nutrient concentration results. The ascending, level and descending portion of the curve can explain deficient, adequate and toxic zones respectively. The critical nutrient concentration refers to the nutrient concentration around 90% of maximum yield (Blair and Sale, 1996). A depiction of the curve can be seen below (Graph. 12).



Graph 12. Relationship between yield and tissue nutrient concentration. Adapted from Blair and Sale (1996)

In 1978 Robinson *et al.* (93) compared three main methods of analysis that were being used, known as the French, South African and the Californian method. The French method included the sampling of the whole leaf (Blade and petiole) at two times of the year; end of flowering and beginning of

veraison. The two sample (flowering and veraison) results are averaged out to give the analysis results.

The South African method used a blade sample taken in January at veraison. The blade was sampled from the first normal sized leaf from the base of the shoot no higher than the 5th node.

Finally the Californian method used a sample of petioles taken from the basal part of the shoot opposite a bunch at flowering. In each case the samples were collected and analysed using a method that included drying, grinding and analysis, for finally comparison with appropriate standards. Robinson *et al.* (1978) concluded that the Californian method gave the best assessment of vineyard nutrient status, however it would need to be modified to reflect Australian conditions.

The Californian method has been widely adopted in Australia and is used as the main assessment of nutritional status and as a key tool in the development of nutritional programs. Originally the Californian standard used in Australia came from work conducted by Cook (1966) and Chritensen *et al.* (1978), based on relative low yielding vines (3.5-4.5 tonnes / acre). The standard was then modified after survey work in South Australia by Robinson *et al.* (1985) from which they proposed some working standards. Continued work by various researchers has lead to the today's standards (Table 3).

Element	Deficient	Marginal	Adequate	High	Toxic or Excessive
As a percentage of dry matter of leaf					
Nitrogen			0.8-1.1		
Phosphorus	Below 0.2	0.2-0.24	0.25-0.5	Above 0.5	
Potassium	Below 1.0	1.0-1.7	1.8-3.0		
Calcium			1.2-2.5		
Magnesium	Below 0.3	0.3-0.3.9	Above 0.40		
Sodium					Above 0.5
Chloride					Above 1.0
As mg/kg (parts per million) dry matter of leaf					
Nitrate - N03	Below 340	340-499	500-1200	Above 1200	
Manganese	Below 20	20-29	30-60		Above 500
Zinc	Below 15	15-25	Above 26		
Copper	Below 3	3-5	6-11		
Boron	Below 25	26-34	35-70	71-100	Above 100
Iron			Above 30		

Table 3. Nutrient standards. Adapted from Reuter and Robinson (1997)

Petiole sampling has been a successful method in the assessment of vineyard nutrient status. In recent times the winegrape industry has advanced considerably in it's management techniques resulting in the ability to increase vine performance and fruit quality. This has caused some doubt amongst viticultural producers about the relevance of the current petiole nutrient standard, which were developed using relative low yielding vines. This view has been documented by Swinburn and Saris (2005) in the report "Results of a Survey to Identify the Issues Relating to Nutrition, Fertiliser Use and Soil Management for the Murray Valley Wine Industry".

The development of new standards has been made difficult due to many considerations of vineyard variability. This includes soil type, rootstock, variety (red versus white), yield, fruit quality, irrigation type and fertigation. These variables will make it difficult to develop new plant nutrient standards for winegrapes. Nutrient analysis however is a critical management tool that the winegrape industry can not afford to loose but it does requires updated standards that consider today's and future production standards.

Sap testing is a recent plant nutrient analysis method that is being used by growers. It involves the testing of the soluble elements in transported in the plant system that are available for metabolism (Crop Tech, 2006[a]). This testing is conducted on a regular basis from weekly or fortnightly sampling during the growing season through to harvest. In grapes a petiole sample is taken from the first fully expanded leaf normally the forth of fifth leaf back from a growing point (Crop Tech, 2006 [b]). The analysis method can be used to monitor plant stress, management and response to fertiliser application. It can detect minor and temporary deficiencies in the plant enabling an accurate diagnostic of the problem and give a timely response (Crop Tech, 2006 [a]). Standards for the analysis are still relatively unclear given the technology is relative new to the viticultural industry, however growers using the technology on a regular basis are able to build up a source of nutritional information specific to their own conditions.

Given the advances in nutrient delivery through fertigation and nutrient uptake data discussed previously, the question of whether petiole analysis is still relevant to Australian condition needs to be asked, is the French, South African or new technology like sap analysis more relevant?

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