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# A Database and Guideline Approach for Table Grape Nutrients

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## ABSTRACT

Nutrient management has been a concern for table grape growers for several years. Using soil analysis and recommendations as a guideline has had little or no effect on yield in various assessments. A guideline model linked to a database, known as the Table Grape Nutrition Management Model (TGNMM) has been developed for application of nutrition management advised to improve the table grape industry in Zanjan province, Iran, which is one of the main grape-producing areas in Iran. This practical model monitors the grapevine nutrient status, using the soil and tissue analysis (STA), provides further refinement of the fertilizer programme, and determines mineral deficiencies and excesses. TGNMM considers the total mineral flux within the grapevine ecosystem and derives a budget of the amount of main nutrients requirement for grape. The data for generation of TGNMM were collected from the same set of experimental vines during the period of 2002-2005.

**Keywords:** fertilizer recommendation, grapevine ecosystem, nutrition advice, yield predicted
**Abbreviations: AON-FM**, almond orchard N-fertilization model; **CM**, computer modeling; **D**, deficient concentration; **DFM**, dynamic fertilizer model; **DRIS**, diagnostic recommendation integrated system; **FEM**, fertilizer evaluation model; **FR**, fertilizer recommendation; **MUE**, mineral use efficiency; **O**, optimum concentration; **STA**, soil and tissues analysis; **TC**, toxic concentration; **TGNMM**, table grape nutrition management model

## INTRODUCTION

The competitive nature of the table grape market mandates production of high quality fruit with optimum yield. A well-balanced nutrient management in the vineyard plays an extremely important role in the success of any table grape operation. Growth and fruit yield of seedless grape 'Beidaneh Qermez' drastically declines in the grapevines due to leaf chlorosis, in Zanjan province, which is one of the main grape production areas in Iran (Amiri and Fallahi 2007). There are several fertilizer recommendations available for vineyards, many of which are specific to a certain region and thus, would not apply to the Zanjan climate (Chelvan *et al*. 1984; Gutierrez *et al.* 1985; Bravdo and Hepner 1987; Bell and Robson 1999; Conradie and Myburgh 2000). While it was suggested that growers do regular soil tests and apply fertilizers based on soil test recommendations to maintain soil fertility, many growers are of the general opinion that "more is better". This approach leads to an excessive accumulation of some nutrients resulting in harmful effects on the plant and impacts the ecology and environment, contributing to ground and surface water pollution (Amiri 2004). Applications of nutrients, as estimated just based on crop removal and without regards to soil and tissue analyses is not advised (Goh and Haynes 1983; Conradie and Myburgh 2000; Shange 2006).

Soil and tissue analysis together with the previous season's yield and quality is strongly recommended for more precise nutrient management (Fallahi *et at.* 1985; Smolarz and Mercik 1997). In this process, it is initially necessary to correctly determine the yield-limiting impact of a given nutrient (Davee *et al.* 1986). There are many factors which can be measured quantitatively to determine the nutrient programme (Mengel and Kirkby 1987; Marschner 1995). This programme can be considered as a database or a nutrient model (Buwalda and Smith 1988; Brown and Zhang 2005). Modeling has become a principle tool for integrated analysis management system and for yield prediction (Allen and Stamper 1978; Gutierrez *et al.* 1985). Most grape growth models were constructed by engineering or demographic approaches (Gutierrez *et al.* 1985; Wermelinger *et al.* 1990). Submission of an effective model to show the plant nutritional status has been the target of many studies in plant nutrition (Goh and Haynes 1983; Buwalda and Smith 1988; DeJong *et al.* 1996; Greenwood *et al*. 1996; Greenwood and Karpinets 1997; Brown and Zhang 2005). Current methods include the soil and tissues analysis (STA) (Fallahi *et al*. 1988). The STA method is based on the assumption that chemical extracts simulate the root system acquisition of soil nutrients in a comparable manner. But to generate a fertilizer recommendation (FR) for an individual vineyard, the study of a complete description of the mineral dynamics through the grapevine ecosystem is very crucial. Any grape nutrition model must lead to the development of an advisor model, which describes nutrient fluxes within the vineyard ecosystem from which a fertilizer requirement is derived (Buwalda and Smith 1988). This fertilizer budget must take into consideration uptake, efficiency of recovery, cycling within the graveyard, and any previous nutrient disorders.

### Computer modeling

Progress has already been made in computer modeling (CM) of some fruit crop growth, but this will need to be considerably expanded to include nutritional management modules. For example, some models on mineral uptake, mineral partitioning and growth of fruit trees (Allen and Stamper 1978; Habib *et al.* 1989; DeJong *et al.* 1996; Diamond *et al*. 1998; Rodriguez-Lovelle and Gaudillére 2002) are based on the assumption that nutrients are not limiting. To adequately encompass the whole growing system, such models will need to be considerably expanded to nutritional modules. A dynamics model of mineral supply within grapevine ecosystem was reported (Amiri 2004), but we are a

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**Table 1** List some different models available were designed to predicate nutrients requirements in different fruits.

| Model name | Fruit | Predication | Reference |
|---|---|---|---|
| GNM | grape cv. 'Beidaneh Qermez' | nutrient requirements | Amiri 2004 |
| MM | kiwifruit | annual fertilizer requirements | Buwalda and Smith 1988 |
| DMl | arable cropping | K fertilizer on crop growth | Greenwood and Karpinets 1997 |
| DFM | grape | growth and development | Gutierrez *et al.* 1985 |
| AON-FM | almond 'Non Pariel' | N requirement | Brown and Zhang 2005 |
| FEM | sweet cherry 'Napoleon' | mineral limitations | Davee *et al.* 1986 |
| | apple 'Starkspur G. Delicious' | mineral requirements | Fallahi *et a.* 1985 |
| | apple 'Fuji' | nutrient requirements | Diamond *et al.* 1998 |

**Table 2** Soil minerals contents and chemical properties of grapevine in Zanjan province, Iran, during experiment (2002-2005).

| Years | CEC[a] (meq) | OC[b] (%) | pH ($H_2O$) | EC[c] (mS) | $NO_3^-$ μ g/g | $NH_4^+$ μ g/g | P (%) | Ca (%) | Mg (%) | K (ppm) | Fe (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2002 | 6.4 | 1.3 | 7.4 | 2.2 | 35 | 11 | 1.8 | 2.1 | 0.5 | 450 | 21 |
| 2003 | 7.2 | 1.6 | 7.3 | 2.4 | 37 | 17 | 2.2 | 2.3 | 0.6 | 519 | 26 |
| 2004 | 7.1 | 1.4 | 7.6 | 3.2 | 39 | 15 | 1.9 | 2.5 | 0.8 | 620 | 41 |
| 2005 | 7.8 | 1.7 | 7.4 | 2.3 | 41 | 18 | 2.3 | 2.2 | 0.5 | 485 | 36 |

[a] CEC = cation exchange capacity in meq100g$^{-1}$ soil; [b] OC organic carbon (%); [c] EC=electrical conductivity in *mS*cm$^{-1}$.

**Table 3** Plant analysis data (macro and micro elements in DW) of grape "Beidaneh Qermez" in leaf petiole in Zanjan province, Iran during experiment (202-2005).

| Years | N (%) | P (%) | K (%) | Mg (%) | Ca (%) | S (%) | Fe (ppm) | Mn (ppm) | Cu (ppm) | Zn (ppm) | B (ppm) | Mo (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2002 | 0.90 (D) | 0.22 (C) | 2.1 (C) | 0.31 (C) | 2.5 (N) | 0.45 (N) | 100 (N) | 100 (N) | 15 (N) | 40 (N) | 20 (N) | - |
| 2003 | 1.9 (O) | 0.27 (O) | 2.6 (N) | 0.36 (O) | 2.3 (N) | 0.40(O) | 120 (O) | 150 (O) | 13 (N) | 30 (O) | 30 (O) | 0.3 (O) |
| 2004 | 1.1 (D) | 0.12 (D) | 1.8 (D) | 0.20 (D) | 1.8 (D) | 0.18(D) | 60 (D) | 130 (O) | 8 (D) | 12 (D) | 15 (D) | 0.2 (O) |
| 2005 | 2.6 (T) | 1.20 (T) | 3.0 (O) | 0.34 (O) | 1.5 (D) | 0.42 (N) | 108 (N) | 110 (N) | 18 (O) | 380 (T) | 90 (T) | 0.04 (D) |

N = concentration; O = optimum concentration; D = deficient concentration associated with leaf symptoms and lower yield; T = toxic concentration associated with leaf symptoms; C = critical concentration.

long way from a complete dynamics model of whole agro-ecosystems, which include both crop growth and soil fertility and it can form a key element in any sustainability of our agro-ecosystems (Zhang *et al.* 2002). There are a number of fertilizer models that have been developed for specific crops, regions and uses (**Table 1**).

Although the objective of a fertilizer model is to estimate the levels of optimum nutrient demand, and to increase accuracy in the nutritional diagnosis (Beaufils 1973; Conradie 1992; Diamond *et al*. 1998), there is not yet a clear definition for the best recommendation (Davee *et al.* 1986; Smith *et al.* 1986). The simulation of each nutrient demand must be based on the following reasons: (a) adequate nutrients are indispensable to maintain healthy plant growth and high yield production, which influences grapevine ecosystem; (b) the surplus to requirements of nutrients has implications for grape growth. The nutrient unbalanced indexes were obtained through the sum of values in module. The sample with the least nutrient unbalanced indexes was considered the ideal sample for their nutrient concentrations, and its values were used to create an artificial database and determining which critical values would be more consistent when compared to the DRIS evaluations (Chelvan *et al.* 1984).

## MATERIALS AND METHODS

### Site selection and data collection

All data of the STA were collected on *Vitis vinifera* cv. 'Beidaneh Qermez', which occupies the maximum area under grape cultivation in Zanjan province, over four growth seasons (2002 to 2005). However, its cultivation is less profitable (due to lower yield), even though it is a popular red seedless table grape with a firm, crispy texture and sweet, neutral taste. The region is semiarid with no summer rain, and the average annual temperature in the region is about 13°C; average maximum temperature, 30°C (in July); average minimum temperature, 7°C (in January); average annual rainfall 300-400 mm (rain is uncommon from May to October). Annual total chilling hours (≤7.2°C) is about 850 with summer relative humidity of about 40%. **Table 2** shows the soil mineral content and chemical properties of the investigated grapevine in the province of Zanjan, Iran and **Table 3** shows plant analysis data (macro- and microelements in DW) of grape 'Beidaneh Qermez' in leaf petioles during the experiment. Since fluctuation of mineral concentrations in leaf petioles (leaves opposite of cluster) was less in cv. 'Beidaneh Qermez'whose leaf petiole is large and thick, compared to the leaf blade (Robinson *et al.* 1978; Amiri and Fallahi 2007).

Deviations of nutrient concentrations from their optimum norms (Conradie and Saayman 1989a, 1989b; Conradie and Myburgh 2000), for vegetative growth, yield or quality, were recorded. The method was intended to evaluate isolated deficiency or excess values, by considering the overall nutritional balance. The STA was a fundamental step for better accuracy of this method (Robinson *et al.* 1978).

### Preferred nutrient forms

All nutrients were applied in plant-available forms according to TGNMM (**Table 5**). For example, since K is much more readily absorbed in chloride form, it was not applied as chloride (because low N soil and high soil pH), therefore, it was used in sulphate form. All fertilizers, including N, were broadcast over the entire vineyard floor by bud-burst in spring to maximize cluster numbers (on the bases of TGNMM or Table Grape Nutrition Management Model).

## MODEL STRUCTURE

The general structure of TGNMM is based on Buwalda and Smith (1988) and Amiri (2004). This is shown schematically in **Fig. 1**. Initially, TGNMM was considered as the total amount of mineral uptake by grape roots, which is indicated as a function of current shoot growth and yield (Amiri 2004). The quantity of nutrients (fertilizer) required to maintain the soil nutrient pool at equilibrium is related to the total nutrient uptake by grape roots, after considering the efficiency of mineral recovery (fertilizer) by the grape and contribution of minerals from non-fertilizer sources (atmospheric) (**Fig. 1**). As total annual biomass production within the whole plant is usually linearly related to the total yield, in TGNMM, the contribution of minerals in the annual harvest yield, as well as mineral composition in the tissue were considered. The nutrient demand by grapevine (for the current season vegetative,

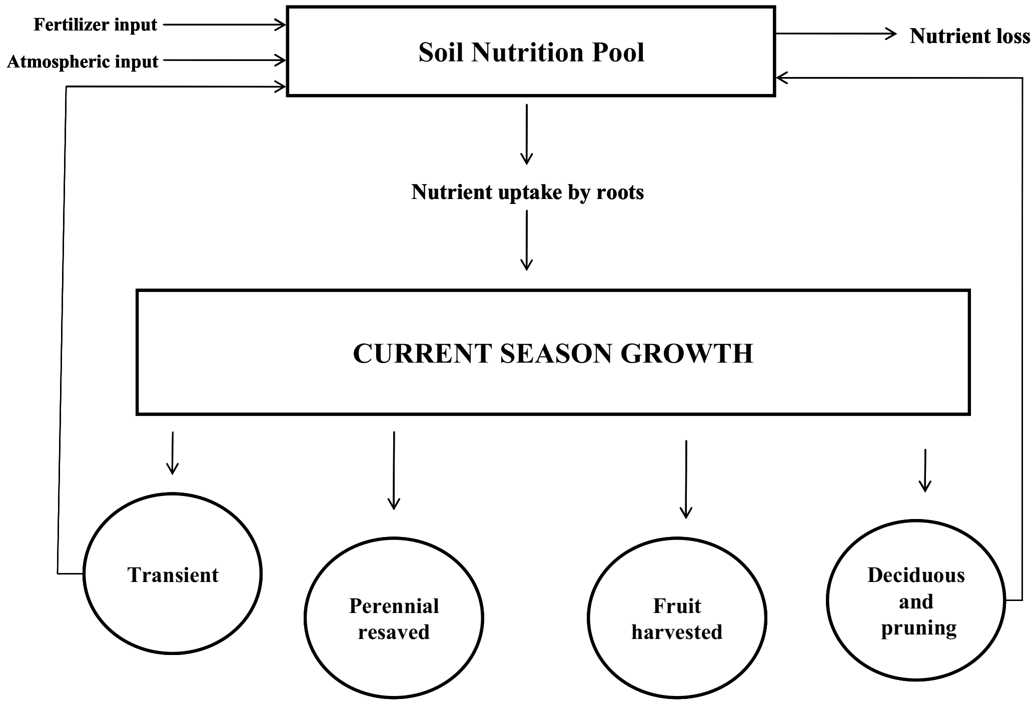


**Fig. 1** General schematic of directional mineral flows within the grapevine ecosystem.

**Table 4** Nitrogen inputs and status for grapevine "Beidaneh Qermez" was grown in a commercial 15 year-old vineyard receiving advice via the GNMM in Zanjan province, Iran (2002 – 2005).

| Samples | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|
| Fruit yield (t/ha) | 15 | 25 | 21 | 14 |
| N-fertilizer (Kg/ha) | | | | |
| Base | 0 | 120 | 130 | 140 |
| Correction[a] | 170 | 150 | 210 | 160 |
| Leaf N (g/100 g) | 0.90 | 1.9 | 1.1 | 2.6 |
| N-status | deficient | optimum | deficient | toxic |

[a] TGNMM database recommendation.

**Table 5** Nutrient inputs (average fertilizer use kg ha$^{-1}$ yr$^{-1}$) and recoveries for a 15 year-old grapevine 'Beidaneh Qermez' producing an average of 20 t ha$^{-1}$ yr$^{-1}$ of fruit yield in Zanjan province, Iran.

| | N | $P_2O_5$ | $K_2O$ | MgO |
|---|---|---|---|---|
| Fertilizer inputs | 180 | 130 | 260 | 80 |
| Cycling [(a)] | 79 | 19 | 40 | 10 |
| Atmospheric [(b)] | 29 | 0.5 | 12 | 7 |
| Total | 288 | 149 | 312 | 97 |
| Uptake | 129 | 39 | 219 | 35 |
| % Recovery | 45 | 26 | 70 | 36 |

[a] includes nutrients in summer (shoots) and winter prunings (canes) and return into ground.
[b] estimated nutrients from N fixed by permanent legumes cover plants and rains in the orchard sward.

nutrient reserves in the plant, and yield) and total supply have been calculated (**Tables 4, 5**). This latter variable can be used as a single measure for describing annual nutrient uptake within a specific grapevine, by assuming stability in the soil mineral pool and the nutrient status of the vines. For detection of any mineral deficiency or mineral excesses, the results of analyses of leaf (petiole) samples can be used (Davee *et al.* 1986; Shange 2006). The fertilizer recommendation is based on direct assessment of the mineral status of the grapevine (petiole samples). Annual monitoring with tissue and soil analyses indicates trends away or towards the target mineral status (Fallahi *et al.* 1988), and is the basis for a permanent fertilizer programme (**Table 4**).

Increase in growth and mineral utilization was computed per day degree above the development threshold of 10°C (Winkler *et al.* 1974). Simulated growth (vegetative and reproductive) per plant increased with fertilizer application until the end of September (end of growth season). The fertilizer recommendations for each specific grapevine during dormancy season (autumn-winter), so depends on an estimate of the potential fruit yield (cane number, bud density, vine background) and hence total biomass production (current season growth). Annual "vine monitoring" for describing the yield component and hence identifying its key limitations normally provides flower bud density data. Yield estimations were based on other parameters, such as the main pervious yields; fertilizer recommendations can be modified to correct mineral disorders that may be detected by leaf analysis. Fertilizer advice, based on previous season yield, soil and tissue (petiole) sample analyses, can be modified to correct mineral disorders (deficit or surplus). TGNMM does not consider the details of mineral dynamics and transformations within the soil (e.g. solubility, mobility, availability, leaching, interaction, and precipitation of minerals); rather leaf analyses primarily use the plant as an "integrator".

## Application

Practical application of TGNMM depends on rapid and convenient access to relevant data such as soil feature of grapevine (soil fertility) yield parameters (flower buds number, bunches number and weight), nutrient management background, pervious yield. Plant monitoring data (e.g. pervious and current season yields, yield parameters), soil and tissue analyses are central to this recommendation. TGNMM can be used in dormancy season (winter) with a specific fertilizer recommendation, by identifying the petiole sample analysis and any mineral unbalances. Any mineral disorders led in emergence recommendations for corrective fertilizer applications, while other minor deviations from the ideal nutrient status led to adjustments to the fertilizer programme (**Tables 2, 3** and **4**). The lack of an objective approach led to much inconsistency and the proliferation of some disorders. For example, to performance under simulated N deficiency condition and to assess the influence of varied soil N levels on grapevine growth, N fertilizer recommendation generated by TGNMM causes correction the nutrient status of the grapevine to within the ideal range and accordingly ensured that nutrient was no longer a major yield-limiting factor (**Table 3**).

Similarly to some other models that describe growth aspects and fertilizer use efficiency and estimate of fruit yield (Brown and Zhang 2005). Generalized estimates of the efficiency of fertilizer recovery are initially used in every grapevine, for example in different degree soil fertility and nutrient content in the vine. The generalized estimates may be refined as grapevine-specific information on mineral recovery is accumulated.

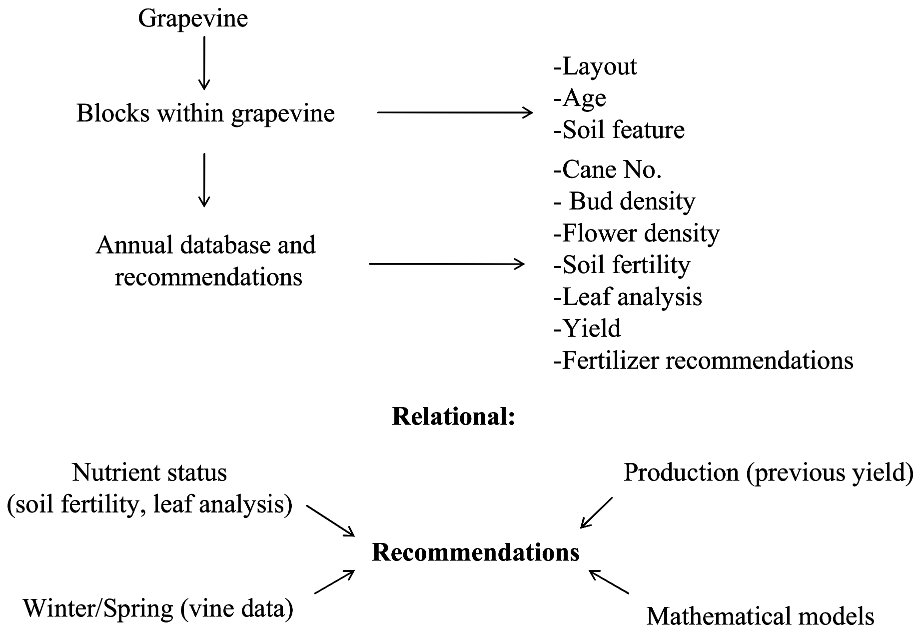


**Fig. 2** Illustration of hierarchical and relation components of grapevine fertilizer management.

The main operation of TGNMM commences in the dormancy season (winter) with a fertilizer recommendation. As already mentioned "vine monitoring" data (e.g. cane number, cane length, bud density and historical leaf mineral analysis) and soil fertility are very crucial to this fertilizer recommendation (**Fig. 2**). In the middle of spring a leaf sample is analyzed and any nutrient imbalances are identified. A major disorder results in immediate recommendation for corrective fertilizer applications, while a minor mineral disorder results in adjustments to the fertilizer programme for the next season. TGNMM generates a corrective fertilizer recommendation and a fertilizer recommendation for each season, based on cane number and bud density. For example, leaf analysis in spring 2002 showed the N- status is not sufficient. Consequently, corrective fertilizer application was necessary. The N-fertilizer recommendations restored the nutrition status of the grapevine to within desirable range for next season growth (2003). The yield for this grapevine in each season was very close to that predicted during the pervious winter.

A carefully managed fertilizer program by applying TGNMM has many benefits. Response to applied nutrients that lead to higher yields and more profit is an obvious one. Tools and information available to help growers reach yield and profit goals include soil and tissue testing, field history, and recently emerging site-specific management techniques. Grape quality is also enhanced through fertilization. Nutrient programs that provide balanced nutrition and minimize stress as the crop develops and matures support high yield and quality, resulting in improved profit potential. Grape reproductive growth (Skinner and Matthews 1989) and its quality are affected directly and indirectly by fertilization (Amiri and Fallahi 2007). Direct benefits relate to the function of essential nutrients in the plant itself and how they affect crop growth. Indirect effects include factors beyond direct nutritional benefits such as how a plant resists disease and insect pressures. Both direct and indirect effects can have major impacts on ultimate crop quality.

## RESULTS AND DISCUSSION

TGNMM is modeled by simulating soil and tissue analysis (STA), vegetative and reproductive (yield) interception (Williams and Biscay 1991). This model can be used to perform relative comparisons of soils, vine growth, and nutrient management and to estimate field yields with reasonable accuracy (Edwards *et al.* 1994). In TGNMM, the specified growth stage under almost ideal growing conditions, assuming adequate nutrients. Nutrient uptake is calculated and taken into account in the simulation. The vine's annual nutrient demands are calculated as the difference between current nutrient content and nutrient content in the previous season under the specified growing conditions (Amiri 2004). Grape nutrient demands can be converted to fertilizer requirements on an annual basis. Since there are many natural and commercial fertilizer formulations, including organic fertilizers and compost, the model simply generates specific nutrient demand, without specifying a particular formulation.

Undoubtedly, TGNMM fits in well to a closed loop situation where nutrients are recycled within the vineyard. For commercial vineyards, however, there is a major loss of nutrients to the vineyard system in the harvested yield. The amount of nutrients removed depends upon yield and nutrient composition of the particular cultivar. Within the vineyard itself, nutrients in pruning and leaves can be recycled *in situ* if pruning is mulched and if leaves decompose under the vines and are not blown by the wind to areas around windbreaks. On a much longer time scale nutrients within the woody canes can be recycled if mulched when the vineyard is removed (**Table 3**). It can be monitored information on the linkages between soil nutritional status and vine performance. Further, being a perennial plant with storage organs that have temporally variable nutrient contents, soil test interpretations in relation to a final predicted yield, as in annual cropping, is associated with high levels of uncertainty (Conradie and Saayman 1989a, 1989b). Grapevine fertility, like other perennial plants, is best managed through the use of TGNMM. It is important to sample the correct plant part for a given stage of growth, and to list this information on the sample information forms, to insure that we make a correct interpretation of the data. A current soil sample plus information on the recent fertilizer applications, weather conditions, and other cultural practices greatly improves Spectrum's ability to interpret the analytical results (Beaufils 1973; Chelvan *et al.* 1984; Smith *et al.* 1986). This provides us with better information from plant analysis.

The concept of "critical tissues" has been proposed for grape and is defined as those plant tissues that are accurate indicators of the fertility needs of the plant and have a strong relationship with yields (Conradie and Myburgh 2000). Critical tissues are tissues that are used in tissue analysis. Tissue analysis came about as a result of the ineffectiveness of soil analysis for some cases in determining tissue concentrations and predicting plant response (Bertamini and Nadunchezhian 2005). Critical tissues have been identified for the petiole opposite the first bunch in grape (Robinson *et al.* 1978). This tissue has been found to be a more accurate indicator of the fertility status of the grape at various growth stages, and even have been used in tissue nutrient diagnostics to predict plant response to fertilizer (Davee *et al*. 1986). Critical tissues provide site specific assessments of tissue nutrient status that cannot be attained by soil tests (Conradie and Saayman 1989a, 1989b) and establish relationships between nutrient concentrations of critical tissue(s), mineral concentrations in soil, and yield. Critical tissues varied for each mineral studied while relationships revealed tissue N concentration was related to yield. Therefore, identification of critical tissues at different growth stages could serve as a tool to determine plant nutrient health and be used to determine if nutrient concentrations in the tissues are sufficient for optimal yields. The relationships between soil concentration, tissue concentration, and yield would provide valuable information to grape growers allowing them to calibrate soil nutrient status during the growing season to attain adequate tissue nutrient concentrations for better yield quantity and quality.

## CONCLUSION

TGNMM maintains the optimal tissue nutrient levels to maximize yields and to minimize negative effects of excess nutrients. It can be applied for fertilizer recommendations of grape industry and for many temperate fruit production. This database model is according to a calculated budgetary analysis of mineral dynamics through the vineyard ecosystem, which it is a considerable different from traditional methods of fertilizer management. In the course of the construction of this model, one faces the need to make some certain factors estimation of the “demand” for different proposes. The database can be used also to determine yield limiting factor by examine components of yield enables relationships between fruit yield and factors such as plant mineral status (critical tissues), crop load (associated with the relationships between vegetative and reproductive weight) for individual grapevines. Critical tissues were identified at all growth stages. However, each element has a specific critical tissue at each growth stage that needs to be utilized for plant analysis.

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