**VEN 115 (Raisin and Table Grape Production)**
**Review of Mineral Nutrition of grapevines and Fertilization Guidelines for California Vineyards**

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## Background

Commonly observed grapevine deficiencies in California include those associated with nitrogen, potassium, zinc and boron (Christensen et al., 1978). Less common deficiencies include those of iron, magnesium and manganese. Lastly, toxic effects of nitrogen, chloride and boron have been observed in California vineyards. The major decision to be made in a vineyard fertilization management program is determining whether to fertilize? Many locations in the San Joaquin Valley and elsewhere in California have ground water pollution problems (Harter et al., 2012). The pollutants include, among others, nitrates. In addition, nitrogen management in agro-ecosystems can affect the production of nitrous oxide ($N_2O$), a greenhouse gas (GHG). Therefore, a vineyard N fertilization program should try to minimize the leaching of mineral nutrients below the root zone and the production of GHGs. Once the decision to fertilize has been made the amount and when to apply the fertilizer must be determined. Fertilizers can be costly, and one can become more cost efficient if educated decisions regarding vineyard fertilizations are made.

## Assessing vineyard/vine mineral nutrient status

There are various means to determine the need to fertilize grapevines. The observation of foliar and/or fruit mineral nutrient deficiencies on vines can be used. Unfortunately, these symptoms could indicate that the deficiency may already have caused a reduction in yield. Some grape producing countries use soil analysis to establish the need to fertilize a vineyard. However, it has been concluded that soil analysis for the determination of N, K (potassium), Mg (magnesium) and Zn (zinc) fertilization requirements in California is of no value (Christensen and Peacock, 2000). Those authors do conclude that soil and water analysis can be used to determine B (boron) toxicity levels.

Vine tissue analysis has long been used in California to assess the nutrient status of grapevines (Cook and Kishaba, 1956) and considered to be very reliable (Kliewer, 1991). The organ most often sampled on grapevines is the petiole; however, many growers may also sample the leaf blade. Generally, the petiole and blade will be analyzed separately and not as a single unit. To compare tissue analysis results from one year to the next it is advantageous to collect the samples at the same phenological growth stage each season. The sampling of petioles will occur most commonly at bloom. A second sampling date chosen by some will be at veraison (berry softening). The petioles (or blades) used for the sample at bloom will be taken opposite a cluster along the shoot, although, petioles from fully-expanded, mature leaves may also be used. The petioles sampled at veraison will be obtained from leaves that are considered mature (fully expanded) and probably on the exterior of the canopy. Research conducted in California has shown that the analysis of the fruit at harvest and canes at pruning could also be used to assess the nutrient status of grapevines (Kliewer, 1991). The most common forms of nitrogen analyzed in petioles are nitrate-N and total N while that for leaf blades is total N. The N analysis of fruit at harvest would include total N, the amino acid arginine, ammonia and total amino acids. Ammonia and total amino acids measured in the must have been referred to collectively as yeast assimilable nitrogen concentration or YANC. Lastly, the forms of N analyzed in canes would be total N and arginine.

Critical values of bloom-time petiole nitrate-N have been established for Thompson Seedless grapevines in California (Christensen et al., 1978). It is assumed that a nitrate-N value less than 350 ppm (dry weight basis) is deficient, 350 to 500 ppm questionable and 500 to 1200 ppm adequate. Values over 2,000 are excessive. Adequate values of total N for petioles at bloom range from 0.5 to 3.0%, depending upon the country where those values were developed and cultivar (Kliewer, 1991). There is a linear correlation between bloom-time petiole nitrate-N and total N as shown in Figure 1 and data from Christensen et al. (1994) and Iandolino and Williams (2014). The percent total N in leaf blades and petioles will decrease as the season progresses; both decrease as a function of thermal time or degree-days (Williams, 1987; unpublished data). Therefore, the time of leaf blade or petiole sampling will dictate the value obtained. Critical values of petiole K for Thompson Seedless in California are as follows: less than 1.0% is deficient, 1.0 to 1.5 % is questionable and over 1.5% is adequate. A bloom-time petiole K value of 0.8% or greater appeared to be adequate for Chardonnay and Cabernet Sauvignon, on different rootstocks (Williams, 2000). Values for other mineral nutrients have been determined for Thompson Seedless and can be found in Christensen, et al. (1978) and Christensen and Peacock (2000). These critical values also appear to be adequate for other cultivars and in different vineyard situations.

It has been observed that bloom-time petiole nitrate values will differ from year to year, cultivar to cultivar (Christensen et al., 1994) and whether the vines are on their own-roots or on rootstocks. Therefore, many feel that the critical values established for Thompson Seedless grapevines may not be appropriate in other vineyard situations. For example, the table grape cultivars Perlette and Flame Seedless will generally have lower values of petiole nitrate-N values at bloom than Thompson Seedless when grown at the same location and soil type (Table 1). The values in Table 1 also demonstrate yearly variation in petiole nitrate-N values. The cultivars used to obtain that data never showed any foliar N deficiency symptoms. Irrigation type (drip vs. furrow irrigation) and whether the vines had been irrigated prior to the sample date also will influence petiole nitrate-N values when sampled at bloom. It was demonstrated that drip irrigated Thompson Seedless vines generally had lower petiole nitrate-N values (mean of four years was 345 ppm) than furrow irrigated vines (mean was 1176 ppm) and that non-irrigated vines also had lower petiole nitrate-N values than irrigated vines (Williams, 2015).

A study was conducted to determine if time of day or leaf location would influence petiole nitrate values of Thompson Seedless at bloom (Table 2). The highest nitrate-N values were for leaves collected at 4 pm and for leaves exposed to direct sunlight. At veraison, only leaf location had a significant effect on petiole nitrate-N (Table 3). Petioles from leaves in the shade had significantly greater nitrate-N than leaves in direct sunlight at veraison. Nitrate-N of Chardonnay petioles collected at bloom was not significantly affected by either time of day or leaf location (Table 4) while that of Cabernet Sauvignon was only affected by leaf location (Table 5).

Petioles were collected from Perlette and Flame Seedless grapevines grown in the Coachella Valley at bloom, veraison and harvest in 2002. Petioles were sampled on a diurnal basis for both cultivars at bloom. At bloom, a composite of leaves exposed to direct sunlight and growing in the shade were used, they were not separated into sun and shade petioles. Petioles of both cultivars more than doubled their dry weight when measured between bloom and veraison and gained another 17% between veraison and harvest (Table 6). This may be the primary reason that the concentration of mineral nutrients within petioles decreases during the growing season (i.e. a dilution effect). Time of day significantly affected petiole nitrate-N of Perlette and nitrate-N and K of Flame Seedless at bloom (Table 7). Petiole nitrate-N was greatest at the 4 pm sampling time for both cultivars while K was greatest at midday for Flame Seedless.

During the Spring of 2002, clusters were counted on vines that were part of the fertilizer treatments imposed in the Thompson Seedless, Chardonnay and Cabernet Sauvignon vineyards prior to bloom in 2001. Cluster numbers of Thompson Seedless grapevines receiving either 50 or 100 lbs N per acre were significantly greater than vines receiving no applied N (Table 8). Petiole nitrate-N for the non-fertilized vines was less than 65 ppm while those of the fertilized vines were greater than 2400 ppm. The fertilizer treatments imposed in 2001 in the Cabernet vineyard had no effects on return fruitfulness in 2002 (Table 9). The non-irrigated vines in the Chardonnay vineyard had the lowest number of clusters, probably due to a lack of adequate water during the 2001 growing season.

Several generalizations can be drawn regarding factors influencing the nutrient values of petioles. 1.) The type of leaf chosen to sample, whether it is in the sun, shade or opposite the cluster, can influence the values of nitrate-N and K. Sunlit leaves at bloom generally had higher values of petiole nitrate-N than either shaded leaves or leaves opposite the cluster. At veraison and prior to harvest, shaded leaves had greater values of petiole nitrate-N and K than sunlit leaves. 2.) Irrigation amount (when comparisons between an Irrigated and Non-irrigated treatment were made) influenced petiole nitrate-N and K late in the growing season. The irrigated treatment generally had lower values of nitrate-N and K when compared to the non-irrigated treatment. It is unknown whether the water status of the vine is responsible for this effect. 3.) The three cultivars (Chardonnay, Cabernet Sauvignon and Thompson Seedless) used in a study (starting in

2001) generally responded to the treatments and sampling differences similarly. 4.) Values of bloom petiole nitrate-N below 100 ppm in 2001 were associated with fewer cluster numbers in 2002. The number of clusters on vines with petiole nitrate-N values above 100 ppm was not different from the fertilized vines.

A study was conducted in California by the author to determine if rootstock affected the fertilizer use efficiency of Chardonnay and Cabernet Sauvignon scions. In that study, bloom-time petiole nitrate values were correlated with the N in the fruit at harvest, leaves at the end of the season (as they fell from the vine) and canes when the vines were pruned. The results indicated that the concentration of N generally increases in the fruit, leaves and canes as petiole nitrate-N increased from a low of 50 ppm to approximately 200 ppm (Figure 2). As the nitrate-N values at bloom in the petioles increased from 200 ppm to 10,000 ppm there was no further increase in the percent total N in the fruit, leaves or canes. These results indicate that a critical value of approximately 200-ppm (dry wt. basis) or less in the petioles at bloom may be sufficient under most vineyard conditions. The 200-ppm nitrate-N value, found in this study, may explain why the low values of nitrate-N in some cultivars and/or cultivar-rootstock combinations don't express deficiency symptoms at the "less than adequate" values originally established for Thompson Seedless. Therefore, establishing new critical values of nitrate-N for each cultivar and/or rootstock used may not be necessary. In support of these findings, a study by Spayd et al. (1993) found that yield of White Riesling increased almost five-fold when petiole nitrate-N values increased from 7 to approximately 200 ppm and then leveled off after that.

**Nitrogen and potassium requirements of grapevines and nutrient reserves**

Mineral nutrient budgets (i.e. the amount of nutrients the vine needs for proper growth and development) have been established for numerous cultivars in studies around the world. It was determined that mature Thompson Seedless grapevines needed approximately 39 kg N/ha (~ 35 lbs. N/acre) for the leaves, 11 kg N/ha (10.7 lbs. N/acre) for the stems (main axis of the shoot) and 34 kg N/ha (~ 30 lbs. N/acre) for the fruit (Williams, 1987). The vineyard density was 1120 vines per hectare (454 vines/acre, 8 x 12-foot vine and row spacing, respectively) and the trellis system was a 0.45 m crossarm. It was subsequently determined that the amount of N contained in the roots and trunks of 4, 5 and 6-year-old Thompson Seedless vines ranged from 36 to 50 kg N/ha (32 to 44 lbs. N/acre) (Williams, 2017) while that amount in the trunk and roots of 28-year-old vines ranged from 109 to 138 kg N/ha (97 to 123 lbs. N/acre) (Williams, 2014). While N reserves can be used to support the current season's growth of shoots beginning after bloom, studies I've conducted indicate that those reserve pools are refilled either by harvest or shortly thereafter (Williams, 2017). In summary, approximately 80 kg N/ha (72 lbs. N/acre) was needed to support the growth of the current season's above-ground growth and N reserve replenishment in the roots and trunk of Thompson Seedless.

The total N (found in the fruit at harvest, leaves as they fell from the vine and prunings) in a VSP trained Cabernet Sauvignon vineyard was 52 kg N/ha (46 lbs./acre) (Iandolino and Williams, 2014) while that in other wine grape vineyards using a VSP trellis system varied from 24 to 65 kg N/ha (21 - 58 lbs. N/acre) (Williams, 2000). The amount of N in the roots and trunk at harvest of 10-year-old, dry-farmed Cabernet Sauvignon was only 28 kg N/ha (25 lbs. N/acre) while that in the leaves, stems and clusters at harvest was 26 kg N/ha (23 lbs. N/acre) (Williams and Biscay, 1991). The canopy was a sprawl and vine density 1120/ha (454 vines/acre) in that study. Chenin blanc vines planted to a 2.44 x 2.44 m (8 x 8 ft.) spacing contained 196 kg N/ha (175 lbs. N/acre) in the roots, trunk and cordons at harvest and 168 kg N/ha (150 lbs. N/acre) in the leaves, stems and clusters (Mullins et al., 1992). Therefore, differences in N per unit land area are primarily a function of differences in vine density and final yield. The greatest N amounts were associated with closer row spacings (or higher density) and greater yields.

It has been determined that Thompson Seedless leaves contained greater than 22 kg N/ha (~ 19 lbs. N/acre) after they fell from the vine and the canes at pruning contained approximately 17 kg N/ha (~ 15 lbs. N/acre) (Williams, 2014; 2017). These values are comparable to other studies conducted on Thompson Seedless and indicate that there is considerable N in both the leaves and canes of a vine and that when they are incorporated into the soil would contribute to the soil's organic matter and the availability of N in subsequent years. Williams (2015) found that approximately 5% of the N in fallen leaves was taken up the following year by the vines. About 2% of the N in the prunings was taken up the following year.

The amount of K needed for growth of grapevines also has been determined. In the same vineyard used above to develop a N budget for Thompson Seedless grapevines, a K budget was developed (Williams et al., 1987). Leaves, stems and fruit needed approximately 13, 29 and 50 kg K/ha (~ 11, 26 and 44 lbs. K/acre), respectively, during the growing season. The amount of K in the leaves and canes at the end of the season were equivalent to 9 and 12 kg K/ha (8 and 11 lbs. K/acre). The amount of K found in the fruit at harvest, leaves as they fell from the vine and canes at pruning for two wine grape cultivars, on different rootstocks and at various locations ranged from 25 to 67 kg K/ha (22 - 60 lbs. K/acre) per year across a three-year period (Williams, 2000). Differences in K per unit land area were due to the same factors as discussed in a previous paragraph for N.

**Determination of N fertilizer amounts**

Once the decision has been made to fertilize the vineyard, the appropriate amount of fertilizer should be applied. The above discussion illustrates that there can be significant variation in the requirements of N and K per vineyard. This is due to differences in row spacings, trellis types, yield and overall growth of individual vines. Much of the N and K in the leaves and canes are returned to the soil for future use. Therefore, a better way in determining the fertilizer demands of a vineyard, especially for a maintenance fertilizer program, would be to calculate the amount of that nutrient removed in the fruit at harvest. Based upon several different studies it was determined that the average amount of N, P, K, Ca and Mg in one ton of grapes at harvest was approximately 1.5, 0.3, 2.5, 0.5 and 0.1 kg, respectively (Mullins et al., 1992). The amount of N in one ton of Chardonnay and Cabernet Sauvignon grapes on different rootstocks in California ranged from 0.98 to 1.58 kg (1.96 to 3.26 lbs. per ton) while that for K ranged from 1.8 to 2.9 kg (3.6 to 5.8 lbs. per ton) (Williams, 2000). Thus, if 10 tons of grapes were harvested per acre, the average amount of N and K removed would be equivalent to 30 lbs. of N and 50 lbs. of K using the mean values of N and K per ton (3 and 5 lbs. N and K) of fruit, respectively. This would be the base amount of these two nutrients that one would want to replace with fertilizers.

The next requirement for determining the amount of fertilizer one needs is to estimate the efficiency with which the fertilizer is acquired by the vine. The author has conducted several N fertilizer use efficiency ($RE_N$) trials in the San Joaquin Valley and in the coastal areas of California. These studies utilized fertilizers labeled with a non-radioactive isotope of N ($^{15}N$). As expected, $RE_N$ in a Thompson Seedless vineyard was more efficient under drip irrigation than furrow (surface) irrigation. The $RE_N$ (defined as the amount of $^{15}N$ found in the vine divided by the $^{15}N$ applied) was greater than 40% for the drip treatment compared to approximately 12% for the furrow irrigated treatment (Williams, 2015). The $RE_N$ for the drip treatment was similar regardless whether the vines were fertilized with a single application (28 kg N per ha; [25 lbs N per acre]) at berry set or whether the vines were given 3.1 kg N per ha (2.76 lbs N per acre) every two weeks for a 20-week period. The $RE_N$ increased to greater than 50% when the treated vines were harvested the following year, indicating that the N fertilizer was present in the soil profile the second year after application. The availability of N fertilizer the second year may have been due to the fact the vineyard had a hard pan at an average depth of 1.5 m below the surface of the soil. Therefore, the N fertilizer would not have been leached below the root zone after the winter rainfall.

The second $RE_N$ study was conducted to determine the effect of rootstock on N uptake by Chardonnay and Cabernet Sauvignon grapevines grown in the Napa and Salinas Valleys and at a vineyard in Paso Robles, along the central coast of California. The vines were drip irrigated at 100% of estimated vineyard ET ($ET_c$) and the labeled fertilizer was applied at berry set. Under the conditions of the study, rootstock had little effect on FUE at any of the four vineyard sites (Williams, 2000). As with my irrigation studies in these vineyards, the use of a VSP trellis system could have minimized any effect rootstock had on the vegetative growth of the vines. Therefore, the growth of all scions on the different rootstocks was similar as the vines were hedged to maintain shape. The $RE_N$ varied considerably from one location to another. The greatest $RE_N$ (approximately 15%) was obtained in the vineyard with the lowest bloom-time petiole nitrate-N values. The low $RE_N$ in this study, compared with that of Thompson Seedless in the San Joaquin Valley, may indicate the inherent fertility of the soils at these vineyard sites. Other studies have shown that soil type will affect $RE_N$ within a vineyard. It was found that the $RE_N$ of a N fertilizer was greater on a sandy soil compared to a heavier soil (Conradie, 1986). The study by Conradie (1986), in addition to a study by Iandolino and Williams (2014) also proved that the timing of application affects $RE_N$. Lastly, the $RE_N$ of vines irrigated at 50% of full ET was double that of vines irrigated at 100% of $ET_c$ (Williams, 2000). This differs from what Iandolino and Williams (2014) found.

Using the information from the preceding paragraphs one would calculate the amount of N removed from the vineyard in the harvested grapes and then divide that number by the $RE_N$ to obtain the amount of fertilizer to apply. Therefore, if one removed

30 kg of N per ha (26 lbs N per acre) in the fruit and the $RE_N$ was 50% (or 0.5) then one would need to apply 60 kg N per ha (52 lbs N per acre). The same type of calculation would be used to determine fertilizer amounts for the other macronutrients such as potassium and magnesium. From a practical standpoint, the author believes in a non-deficient vineyard (i.e. tissue analysis does not indicate a deficiency) the actual amount of N or K applied in a maintenance program should only be the amount of that nutrient removed in the fruit without taking into consideration $RE_N$. This is due to the uncertainty in obtaining reliable estimates of $RE_N$ for different mineral nutrients. It should be pointed out that very high $RE_N$ values can be obtained. Treeby and Wheatley (2006) reported that the $RE_N$ of 50-year-old Sultana grapevines in Australia was 70% while Williams (2014) found that the $RE_N$ of 28-year-old, N deficient Thompson Seedless (mean bloom-time petiole $NO_3$-N 94 ppm) was 100%. The above illustrates that $RE_N$ can vary due to numerous factors including several different vineyard management techniques and soil type.

**Kinds of fertilizers**

The choice of N fertilizers for raisin vineyards in California can be based mostly upon cost (Christensen and Peacock, 2000). The same may apply for table grape and wine grape vineyards. The nitrate form of N allows the fertilizer to be available to the vines shortly after an application while the ammonium and urea forms require their transformation to nitrate in the soil profile. The liquid forms of N fertilizers are gaining in popularity due to their ease of handling and application via drip irrigation (fertigation). Many raisin and table grape growers will use farm manure as a source of N, with its application occurring during the dormant portion of the growing season. Lastly, the acidification potential of N fertilizers should be considered in a management program particularly in acid soils. This characteristic of N fertilizers has been outlined by Christensen and Peacock (2000).

It has been concluded that one form of K fertilizer offers no advantage over the other forms (Christensen and Peacock, 2000). Thus, cost may play also role in determining which kind to use in California and whether is to be used in a fertigation program. For vineyards with Mg deficiencies the choice of a fertilizer would probably be magnesium sulfate. The two micronutrients most commonly needed in California vineyards are zinc and boron. Foliar and soil applications of the two fertilizers have been used in California (Christensen et al., 1978). Soil applications of Zn are more effective under drip than furrow irrigation. Research has shown that neutral- or basic-Zn products are the most effective Zn fertilizers (Christensen and Peacock, 2000).

**Timing of fertilization events**

Nitrogen and potassium are required by grapevines throughout their growth cycle. It has been shown that the major sink (the organ that requires the most of an individual mineral nutrient) for N is the leaves while the fruit is the major sink for K (Williams, 1987; 2014, 2015, 2017; Williams et al., 1987; Williams and Biscay, 1991). Generally, one half to two-thirds of the vine's annual requirement for N is between budbreak and several weeks after berry set. This is the period when the canopy is formed by the vine. Much of the remaining third of the vine's annual requirement of N goes to the fruit after berry set. A portion of the N requirements of a grapevine could be derived from N reserves in the roots and other permanent structures of the vine. Anywhere from 15 to 25% of the N in the current season's above ground growth may come from those reserves (Williams, 2017). If the vineyard is fertigated, one could apply the approximate amount of N needed by the vine on a weekly or bi-weekly schedule. Conversely, one could apply ½ the total N fertilizer to be applied for the season four weeks after budbreak and the other half applied shortly after berry set. This method has proved to be highly efficient if one does not over-irrigate the vineyard. It is not recommended that large amounts of an N fertilizer be applied at bloom since it may decrease the number of flowers that set. A few table grape growers want high values of petiole nitrate-N at bloom as they contend a high vine nitrogen status at that time assists in thinning the grape clusters (i.e. decreases berry set). The author does not recommend a N fertilizer application post-harvest, which is contrary to what others may recommend (Christensen and Peacock, 2000; Peacock et al., 1989). This is due to the finding that the $RE_N$ of a post-harvest application of N fertilizer was only 25% that of an N fertilizer applied during the growing season (Williams, 2014). Also, the N that remains in the soil from such an application could be leached during the dormant portion of the growing season.

The uptake of K by the vine is generally a linear function of vine dry biomass accumulation and/or water use throughout the course of the growing season (L.E. Williams, unpublished data). This is due to the linear relationship between vine water use and the production of vine biomass during that time frame. It also indicates that the K within the vine is derived mostly from sources in the soil and very little remobilization of K from the permanent structures of the vine. This is unlike N where some of the current season's demand for N may be obtained from N reserves in the roots and trunk of the vine. These results would indicate that the timing of an application of a K fertilizer could occur at anytime throughout the growing season, especially if one used fertigation and applied a K fertilizer every year. However, it is recommended that vineyards deficient in K should receive a slug application of a K fertilizer during fall or winter such that precipitation can move the fertilizer into the root zone (Christensen and Peacock, 2000).

Both Zn and B deficiencies affect yields by reducing berry set and the formation of berries that fail to develop. A foliar application of a Zn fertilizer before or at anthesis (bloom) can be used. The application could coincide with a "stretch" or "bloom" application of $GA_3$ in seedless table grape vineyards where it may be used. A B fertilizer can be applied via a soil broadcast, soil spray, or foliar application or in the drip system. The B fertilizer can be applied at any time.

The use of phosphorus (P), iron (Fe), manganese (Mn) and calcium (Ca) fertilizers and the appropriate time of their application have received little attention in California due to the low acreage where such deficiencies may occur. In many instances, only a small portion of the vineyard may express deficiency symptoms for such mineral nutrients as Fe and Mn. In those cases, a spot application of the fertilizer is sufficient. The expansion of new vineyards in the foothills of the Sierra Nevada Mountains and Pacific coast mountain ranges has occurred in areas with low soil pH. This has required the application of P fertilizers to those vineyards.

In addition of the application of the above-mentioned fertilizers, many table grape growers in California apply various foliar applications in order to enhance berry quality. Those foliar applications may contain urea, P, K, Ca, Fe, B, Mn and possibly organic material. These foliar fertilizers will be applied in conjunction with fungicides and/or $GA_3$ applications. There has been little research to date in California on the effectiveness of these products.

**Effects of vineyard fertilization on vegetative and reproductive growth**

It is desirable to apply fertilizers in order to correct mineral nutrient deficiencies in the vineyard. The application of a N fertilizer in a deficient situation will increase vine growth and productivity. For wine grape vineyards the addition of a N fertilizer may minimize "stuck" or "sluggish" fermentations at the winery. However, many studies in California have demonstrated that the application of a N fertilizer in a non-deficient situation will have no effect on growth or productivity. In addition, the application of too much N may stimulate vegetative growth resulting in the shading of buds, reducing fruitfulness and lowering yields. For wine grapes, juice and/or wine pH may be a function of the K concentration. The application of too much K fertilizer may therefore decrease wine quality. The above comments would indicate the importance of being able to reliably assess vine nutrient status prior to the application of any vineyard fertilizer.

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Table 1. The effects of cultivar and year on petiole nitrate-N when sampled at bloom. The petioles were sampled from opposite a cluster when the individual cultivar was at approximately 70% bloom. The values are expressed on a dry weight basis. Data was not collected for Thompson Seedless in 1993.

| Cultivar | Year: 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|
| | nitrate N (ppm) | | | |
| Flame Seedless | 74 | 274 | 187 | 926 |
| Perlette | 66 | 215 | 49 | 703 |
| Ruby Seedless | 132 | 949 | 1088 | 1029 |
| Thompson Seedless | 316 | 1244 | 787 | ----- |

Table 2. The effects of time of day and location of leaves on nitrate-N of Thompson Seedless petioles sampled at bloom in 2001. Vines had been fertilized with 100 lbs of N per acre (112 kg N/ha) prior to bloom. Nitrate-N is expressed in ppm (dry weight basis). There was no significant interaction between time of day and location. Leaf blades were exposed to direct sunlight (sun), shaded (shade) or located opposite a cluster at the time of sample.

| Time of Day | Location of Leaves: Sun | Shade | Opposite Cluster | Ave. Effect of Time of Day |
|---|---|---|---|---|
| 0800 h | 3746 | 3358 | 3313 | 3506 b |
| 1200 h | 4008 | 3103 | 3392 | 3501 b |
| 1600 h | 4341 | 3571 | 3816 | 3910 a |
| Ave. Eff. Loc. | 4065 a | 3344 b | 3507 b | |

Table 3. The effects of time of day and petiole location of leaves on nitrate-N of Thompson Seedless petioles sampled at veraison in 2001. Vines had been fertilized with 100 lbs of N per acre (112 kg N/ha) prior to bloom. Nitrate-N is expressed in ppm (dry weight basis). There was no significant interaction between time of day and location. Leaf blades were exposed to direct sunlight (sun) or shaded (shade - located opposite a cluster) at the time of sample.

| Time of Day | Location of Leaves: Sun | Shade | Ave. Effect of Time of Day |
|---|---|---|---|
| 0800 h | 638 | 1568 | 1103 |
| 1200 h | 980 | 1206 | 1093 |
| 1600 h | 865 | 1444 | 1154 |
| Ave. Eff. Loc. | 827 b | 1406 a | |

Table 4. The effects of time of day and petiole location of leaves on nitrate-N of Chardonnay petioles sampled at bloom in 2001. Vines had been fertilized with 80 lbs of N per acre (90 kg N/ha) prior to bloom. Nitrate-N is expressed in ppm (dry weight basis). There was no significant interaction between time of day and location. Leaf blades were exposed to direct sunlight (sun), shaded (shade) or located opposite a cluster at the time of sample.

| | Location of Leaves | | | Ave. Effect of |
|---|---|---|---|---|
| Time of Day | Sun | Shade | Opposite Cluster | Time of Day |
| 0800 h | 1847 | 2411 | 1935 | 2064 |
| 1200 h | 2121 | 2395 | 1893 | 2136 |
| 1600 h | 1970 | 2348 | 2135 | 2151 |
| Ave. Eff. Loc. | 1979 | 2384 | 1988 | |

Table 5. The effects of time of day and petiole location of leaves on nitrate-N of Cabernet Sauvignon petioles sampled at bloom in 2001. The vineyard was located near Oakville in Napa Valley. The vines had not been fertilized but they had been irrigated prior to bloom. Nitrate-N is expressed in ppm (dry weight basis). There was no significant interaction between time of day and location. Leaf blades were exposed to direct sunlight (sun), shaded (shade) or located opposite a cluster at the time of sample.

| | Location of Leaves | | | Ave. Effect of |
|---|---|---|---|---|
| Time of Day | Sun | Shade | Opposite Cluster | Time of Day |
| 0800 h | 371 | 429 | 184 | 328 |
| 1200 h | 358 | 392 | 194 | 315 |
| 1600 h | 312 | 435 | 235 | 327 |
| Ave. Eff. Loc. | 347 ab | 419 a | 204 b | |

Table 6. Dry weight of petioles sampled at bloom, veraison and harvest of Perlette and Flame Seedless grapevines grown in the Coachella Valley. Samples were collected during the 2002-growing season. Samples collected at bloom were a composite (50/50) of leaves exposed to direct sunlight and leaves in the shade. Petioles at bloom also were collected at three times during the day (0800, 1200 and 1600 hours).

| | | ------- Bloom (3/21) ------- | | | Veraison (5/6) | | Harvest (6/16) | |
|---|---|---|---|---|---|---|---|---|
| Cultivar | Replicate | 0800 h | 1200 h | 1600 h | Sun | Shade | Sun | Shade |
| | | ------------------------------ ($g\ 75\ petioles^{-1}$) ------------------------------ | | | | | | |
| Perlette | I | 9.0 | 8.1 | 7.7 | 16.5 | 18.0 | 19.5 | 19.1 |
| | II | 8.3 | 8.9 | 7.2 | 19.8 | 18.3 | 20.5 | 22.6 |
| | III | 8.0 | 7.7 | 7.7 | 18.6 | 16.8 | 23.2 | 22.3 |
| | IV | 7.7 | 7.7 | 6.9 | 19.5 | 17.0 | 24.1 | 20.6 |
| Flame | I | 8.4 | 7.5 | 7.1 | 15.6 | 16.4 | 18.4 | 17.6 |
| | II | 8.0 | 7.5 | 7.8 | 14.7 | 15.5 | 17.7 | 18.2 |
| | III | 8.0 | 7.5 | 7.2 | 15.0 | 14.7 | 17.7 | 17.0 |
| | IV | 8.0 | 7.7 | 7.8 | 15.5 | 15.0 | 17.6 | 17.3 |

Table 7. The effect of time of day on nitrate-N of Perlette and nitrate-N and K of Flame Seedless petioles sampled at bloom, March 21, 2002, in the Coachella Valley. Values of nitrate-N are expressed in ppm (dry weight basis) and K in percent (dry weight basis). Means in a column followed by a different letter are significantly different at $P < 0.05$.

| | Perlette | -------------- Flame Seedless -------------- | |
|---|---|---|---|
| Time of Day | Nitrate-N | Nitrate-N | K |
| 0800 h | 890 b | 825 b | 2.51 b |
| 1200 h | 985 ab | 968 ab | 2.74 a |
| 1600 h | 1083 a | 1025 a | 2.65 ab |

Table 8. Bloom petiole nitrate-N and total N from 2001 and shoot and cluster number per four vines of Thompson Seedless in 2002. Treatments included vines that in 2001 received no applied water before bloom nor were fertilized, vines that had been irrigated prior to bloom but were not fertilized and vines that were irrigated prior to bloom and were fertilized with either 50 or 100 lbs of N per acre (56 or 112 kg N/ha, respectively) before bloom. Means within a column followed by a different letter are significantly different at $P < 0.05$.

| Treatment in 2001 | Bloom 2001 Nitrate-N | Bloom 2001 Total N | Shoot # 2002 | Cluster # 2002 |
|---|---|---|---|---|
| | (ppm dry wt.) | (% dry wt.) | (# 4 vines$^{-1}$) | (# 4 vines$^{-1}$) |
| No Irr./No N | 64 | 0.72 | 365 | 159 b |
| Irrigated/No N | 42 | 0.70 | 333 | 157 b |
| Irrigated/50 lbs | 2450 | 1.33 | 359 | 200 a |
| Irrigated/100 lbs | 2804 | 1.39 | 380 | 215 a |

Table 9. Bloom petiole nitrate-N and total N from 2001 and cluster number per six vines of Chardonnay (grown in Carneros) and Cabernet Sauvignon (grown near Oakville in Napa Valley). Treatments included vines that were not irrigated prior to bloom, vines irrigated prior to bloom in 2001 and vines irrigated prior to bloom and fertilized with either no or 80 lbs of N per acre (90 kg N/ha), prior to bloom.

| Treatment in 2001 | Bloom 2001 Nitrate-N | Bloom 2001 Total N | Cluster # 2002 |
|---|---|---|---|
| | (ppm dry wt.) | (% dry wt.) | (# 6vines$^{-1}$) |
| <u>Chardonnay</u> | | | |
| No Irr./No N | 262 | 0.94 | 123 |
| Irrigated/No N | 152 | 1.02 | 171 |
| Irrigated/80 lbs | 1979 | 1.32 | 151 |
| <u>Cabernet Sauvignon</u> | | | |
| No Irr./No N | 145 | 0.73 | 144 |
| Irrigated/No N | 299 | 0.76 | 142 |
| Irrigated/40 lbs | -- | -- | 148 |
| Irrigated/80 lbs | 3215 | 1.30 | 144 |

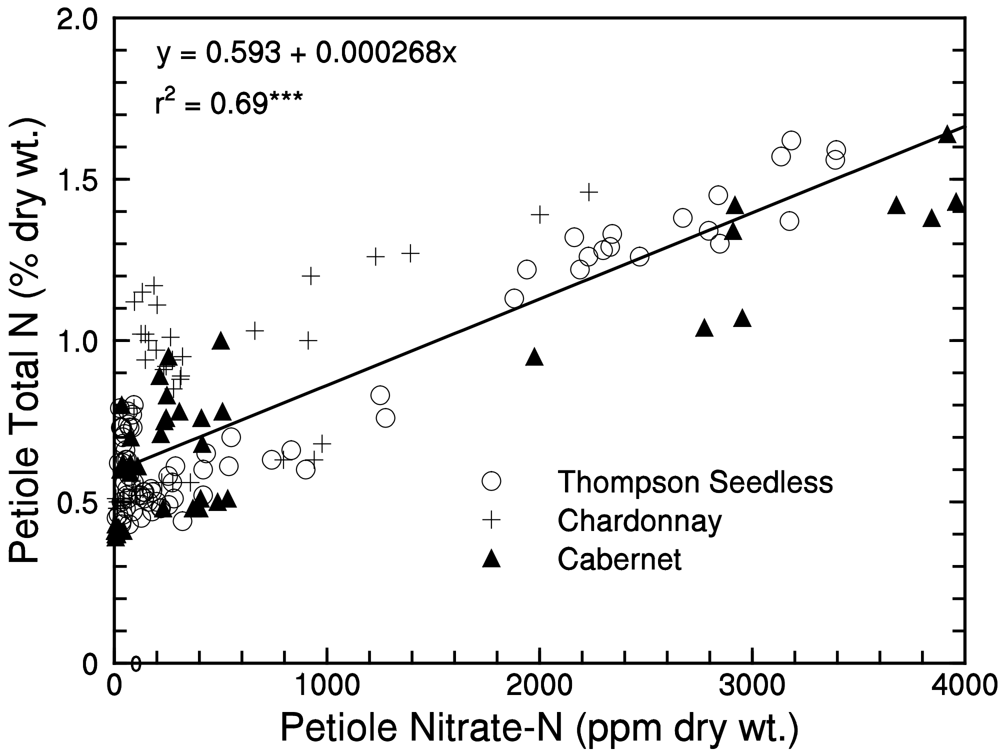


Figure 1. The relationship between nitrate-N and total N measured in petioles at bloom for three grapevine cultivars. Data is taken from Williams (2000).

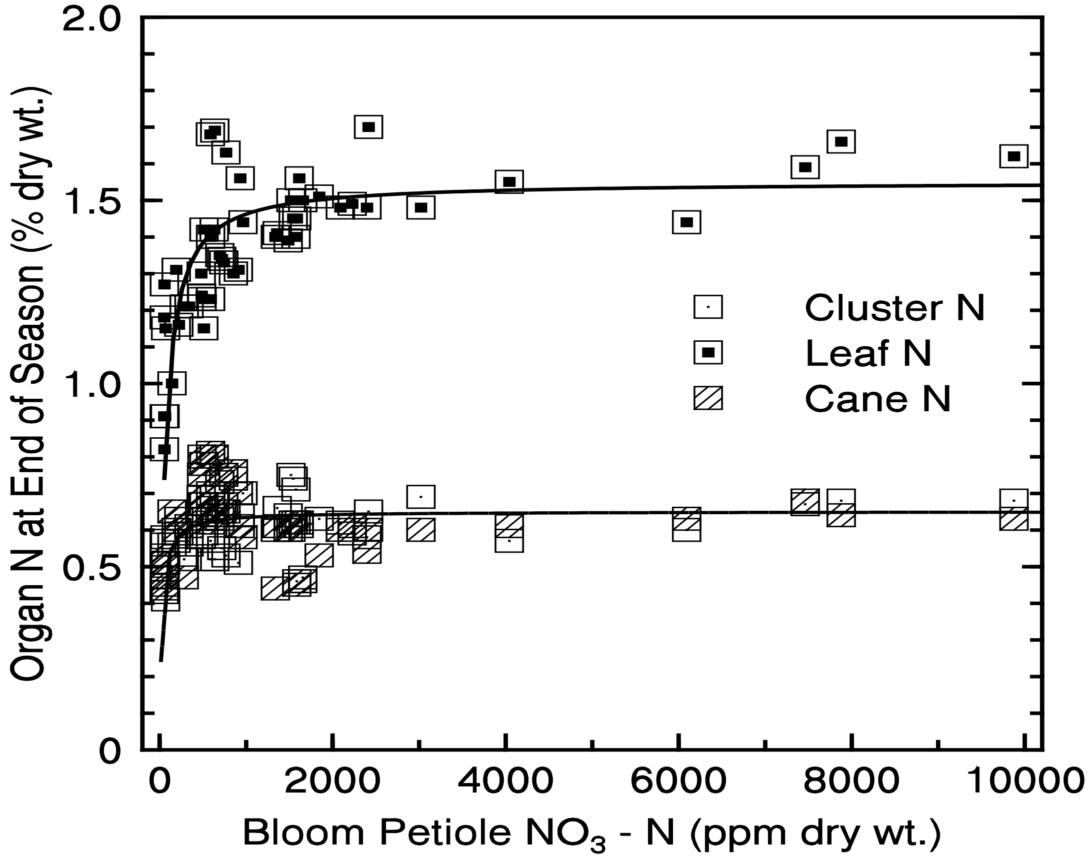


Figure 2. The relationship between petiole nitrate nitrogen ($NO_3$ – N) at bloom and the concentration of N in clusters at harvest, leaves as they fell from the vine and stems of shoots (canes) at pruning. Data were collected in two Cabernet Sauvignon and two Chardonnay vineyards in Napa and along the central coast of California. Vines had been grafted onto different rootstocks at each location.