NITROGEN REQUIREMENTS OF TABLE GRAPE CULTIVARS GROWN IN THE SAN JOAQUIN VALLEY OF CALIFORNIA

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Abstract:

Context and purpose of the study - Ground water in the interior valleys of California is contaminated with nitrates derived from agricultural activities, primarily the over fertilization of crops. Agriculture is now mandated by the State of California to monitor all possible nitrogen (N) inputs into agro-ecosystems and only apply N amounts that meet a crop's demand. The best estimate of N required for the current season's growth of shoots and fruit in raisin, table and wine grape vineyards in the San Joaquin Valley is approximately 70 to 80 kg N ha^{-1} (values derived from Thompson Seedless and several wine grape cultivars). The table grape industry continues to develop new cultivars and replanting vineyards using open-gable trellis systems which will produce greater vegetative biomass and fruit yields. One objective of this study was to determine the N budget of several established and newer table grape cultivars trained to overhead trellises, grown in the San Joaquin Valley.

Materials and Methods – Flame Seedless, Scarlet Royal, Crimson Seedless, Princess, Sheegene-21 and Autumn King grapevines grown at eight commercial vineyards within 30 km of the KARE Center were used in the study. N fertilizer was applied in three of the vineyards, the amount being that removed in the fruit at harvest and twice that. The control vines received no applied N. Petioles were collected at bloom and veraison to assess vine N status. Shoots and clusters were removed from data vines in each vineyard at bloom, veraison and fruit harvest, biomass and N concentrations determined and N budgets developed in each vineyard.

Results - Petiole nitrate-N at bloom and veraison were significantly correlated with petiole ammonia-N and total N measured at the same stage and total N in the leaves, stems and fruit at bloom, veraison and harvest. Values of petiole nitrate-N below 200 ppm (dry weight basis) at bloom in the current season resulted in fewer clusters produced by the vines the following year. Yield of Flame Seedless, Scarlet Royal and Crimson Seedless averaged across treatments and years was 55, 67 and 53 t/ha, respectively. The amount of N per ton of fruit ranged from 0.98 to 1.85 kg. The amount of N accumulated by vines at harvest in the leaves, stems and clusters ranged from 131 to 210 kg/ha. The amount of N in the fruit (kg/t) was dependent upon location and somewhat correlated with petiole analyses at bloom and veraison.The amount of N to produce a crop was a function of location, row spacing and supply of N from the irrigation water and soil profile. The N required by the vines in these table grape vineyards were much greater than earlier estimates.

Key words: table grapes, N nutrition, N budget

1. Introduction

Over fertilization of agricultural crops in the San Joaquin and Salinas Valleys of California is partly responsible for nitrate contamination of ground water (Harter et al., 2012). When nitrogen is applied to crops but not removed at harvest, lost via air emissions or runoff, it is leached from the root zone into the groundwater and therefore the main source of nitrate contamination; representing 96% of the total. Nitrogen intentionally or incidentally applied to crops includes inorganic fertilizers (54%), animal manure

(33%), N in the irrigation water (8%), atmospheric deposition (3%) and wastewater treatment and food processing facility effluent and associated solids (2%) (Harter et al., 2012).

Most table grapes in California are grown in the southern San Joaquin Valley counties of Kern, Tulare and Fresno. Grapevines in the San Joaquin Valley are grown on their own roots or grafted to nematode-resistant rootstocks. Vineyards planted since the 1990s are commonly drip-irrigated and supported with various types of overhead and gable trellises that are much larger than the typical table grape trellis used in the past. Modern trellis systems separate the fruiting zone from the foliage and increase the interception of sunlight. The later may allow for potentially greater productivity and increases total biomass production by the vines which should increase the demand for N and K.

The nutrient requirements of grapevines are low compared to many annual crops (Williams, 1987; Williams and Matthews, 1990). The greatest demand for N by the vine is during the initial growth of the shoots from budbreak until flowering with a second large demand for the clusters after berry set (Williams, 1987; Williams and Biscay, 1991). The largest demand for potassium (K) by the vine is during fruit growth (Williams and Smith, 1991). The fertilizer use efficiency (FUE) (nitrogen used by the vine compared to that applied) is greater for drip irrigated vines than those that are flood/furrow irrigated (Williams, 2015). It was also demonstrated in that study, that a single application of N fertilizer was just as efficient as multiple applications throughout the growing season. Irrigation type can also influence vine nutrient requirements (Araujo et al., 1995). Drip irrigated vines will use more K than furrow irrigated vines while drip irrigated vines will use less N than furrow irrigated vines.

Improved N management practices across commodities would assist in minimizing nitrate leaching into the groundwater. There are several such practices one could use. Tissue analysis (petioles, shoots and roots at anthesis, veraison and harvest) has been used to determine critical mineral nutrient value/concentration for grapevines in the San Joaquin Valley and elsewhere (Christensen and Peacock 2000; Kliewer, 1991; Peacock et al., 1989). Reliable critical values across cultivars and rootstocks would assist in applying a fertilizer only when necessary (Christensen et al., 1994; Iandolino and Williams, 2014).

The purpose of this study was to determine the N budget of modern table grape vineyards and how different N treatments affect the vines' mineral nutrient budgets. The Flame Seedless (Selma) study is a continuation from 2016, in which various amounts of N were applied in either of two split applications (or "slug" treatment), where ½ the total amount was applied one month after budbreak and the second half after berry set, or more numerous "spoon fed" applications in which the total amount of N to be applied is split into ten equal amounts, each applied every two weeks over a twenty period (1/10 the total at each application).

2. Materials and Methods

Six *Vitis vinifera* L. table grape cultivars (Autumn King, Crimson Seedless, Flame Seedless, Princess, Scarlet Royal and Sheegene 21) were used in the study. One of the Flame Seedless vineyards, a Princess vineyard and an Autumn King vineyard were located west of Traver, CA, while the Sheegene 21 vineyard was located northwest of Laton and near Parlier, CA. An additional Flame Seedless vineyard and Autumn King vineyard were located near Selma.

An open gable trellis system was used in all vineyards. The Flame Seedless (Traver), Princess, Sheegene 21 and Autumn King (Traver) vineyards were planted with vine and row spacings of 1.83 and 3.05 m, respectively. The Flame Seedless vineyard near Selma was planted with vine and row spacings of 1.83 and 3.66 m, respectively. The Flame Seedless, Sheegene 21 and Princess vines were trained to quadrilateral cordons and spur pruned. The Autumn King (Traver) vines were pruned to a combination of canes and spurs on quadrilateral cordons while the Autumn King (Selma) vines were head-trained and cane pruned. The vineyards were drip irrigated according to the cooperator's irrigation schedule although the Flame Seedless (Traver) vineyard~~s~~ was also flood irrigated at various times during the growing season. Water meters were installed within the drip lines in both Flame Seedless vineyards and the Autumn King vineyard (Selma) (two per vineyard) to measure applied water amounts. During the growing season, the irrigation water in the

Flame Seedless and Autumn King vineyards (Selma) was analyzed numerous times to quantify nitrate concentrations.

The N fertilizer treatments imposed during 2017 in the Flame Seedless (Selma) vineyard were similar to those in 2016. The treatments were 3 different N amounts: 1.) a control (no applied N fertilizer), 2.) '1.0X' or 'X' treatment – the amount of N applied to replace that removed in the fruit at harvest the previous growing season and 3.) a '2.5X' treatment or 2.5 times the amount of N removed in the fruit at harvest the previous year. The N fertilizer was applied at two frequencies: a slug treatment in which ½ the fertilizer was applied one month after budbreak and the other half applied after berry set or multiple applications in which 1/10 of the fertilizer was applied every two weeks across twenty weeks beginning one month after budbreak. The fertilizer used was calcium nitrate and ammonium sulfate applied in equal amounts of actual N for the slug treatments. Calcium nitrate and ammonium sulfate were applied on alternate application dates for the multiple application treatment. The amount of N applied to the 'X' treatment was 27.1 g N/vine (equivalent to 40.4 kg N/ha) while that applied to the '2.5X' treatment was 67.8 g N/vine (equivalent to 101 kg N/ha). The experiment was designed as a split block with the main plot (fertilizer amount) and the subplot application frequency. Blocks were imposed across 6 contiguous rows with a minimum of 2, border vines separating the plots. Data were collected from 4 of the vines (three middle vines plus one/half of vines 1 and 5) within each treatment plot.

Calculation of N budgets

Leaf and stem biomass were estimated at bloom, veraison and harvest to develop N and K budgets in all vineyards and budgets in the Flame Seedless (Selma) vineyard as a function of N fertilizer treatments. Dry biomass was estimated by taking 5 individual shoot samples, randomly collected within a treatment plot, measuring shoot length and removing the leaves and clusters from the stems. Leaf and stem fresh weight of all 5 shoots were measured, then subsampled and dried. Early in the growing season the number of shoots per vine were determined and subsequent multiplied by the value of an individual stem's dry biomass.

Cluster dry biomass was determined at bloom and veraison by randomly sampling 4 or 5 clusters from taking the shots that were sampled. An average of their dry biomass was obtained through the determination of an average of the individual clusters dry weight. All clusters were counted at harvest and the total number per vine recorded. Mean cluster dry weight at bloom and veraison was multiplied by the total number of clusters per vine at harvest to estimate fruit dry biomass at those times. On each fruit harvest date, all clusters (packed clusters plus cull fruit) were weighed and summed to determine total fruit fresh biomass. On the first fruit harvest date clusters were subsampled, fresh weight determined and those clusters then dried to estimate total dry fruit biomass.

The amount of N per vine was calculated as the product of the N concentration (g TN 100 g^{-1} dry weight) of leaves (TN_{lh}), stems (TN_{sh}) and clusters (TN_{fh}) and the estimated dry biomass of leaves and stems and actual dry biomass of clusters (Tb_{fh}) per vine. Estimated stem biomass (Tb_{sh}) on each date was calculated by multiplying average stem dry weight by the number of shoots per vine. Leaf and cluster biomass were estimated as given in the previous paragraph. Total N per vine on each harvest date (phenological stage) was calculatedas follows: $TN = (Tb_{lh} x TN_{lh} + Tb_{sh} \text{ x } TN_{sh} + Tb_{fh} x TN_{fh}) \text{ x } 0.01$

Determiningvinenutritionalstatus

Petioles were sampled at bloom and veraison. They were screened for total N, nitrate-N, ammonium-N and K. The N and K nutritional data from the petioles collected at bloom were compared with the N and K nutritional values of petioles at veraison. The N and K nutritional data collected from both petioles sampling dates were compared with N concentration in leaves, stems and clusters when collected at bloom and veraison, respectively. Regression analyses were used to compare N and K concentrations in all the three organs examined with N and K values in the petioles.

Sample preparation/analysis

Leaves and stems were dried in a forced air oven at 60°C until no further decrease in weights measured. The clusters collected at the bloom stage underwent the same procedure, while those at the veraison and harvest were dried at 45°C until no further decrease in weight was recorded. Dried leaves and stems were subsampled, ground to a fine powder with a Cyclone or Wiley mill and analyzed for total N and K at Delavalle Laboratories, Fresno, CA. Cluster samples picked at the veraison and harvest stage were subsampled after drying and ground with a motor and pestle in liquid nitrogen.

3. Results:

Applied water amounts in the Flame Seedless (Selma) vineyard from the beginning of irrigation to subsequent to harvest was 3,527 L/vine (equivalent to 541 mm, [6.7 m^2/vine]). The average NO_3-N measured in the irrigation water across those dates was 2.03 mg/L. Therefore, the amount of N in the irrigation water across the above dates was equivalent to 7.16 g of N per vine (10.7 kg N/ha).

The N status in several other vineyards was determined by analyzing petioles at bloom and veraison. Sheegene-21 (Laton) had the lowest petiole values of NO_3-N and NH_4-N both at bloom and veraison compared to vines in the other commercial vineyards (Table 1). The NO_3-N for Sheegene-21 was 285 ppm at bloom and 120 ppm at the veraison while the levels of NO_3-N ranged from 1194 to 2380 ppm at bloom and from 849 to 1815 ppm at veraison in the other vineyards. Sheegene-21 also had the lowest total N values at bloom (1.16%) and veraison (0.48%) while those in the other vineyards ranged from 1.40 to 1.76 % at bloom and 0.75 to 1.04% at veraison. It should be pointed that no N fertilizer was applied to any of the vineyards as far as I know.

Total N in the leaves, stems and clusters of vines at the Flame Seedless (Traver) vineyard decreased as the growing season progressed (Table 2). The N concentration in the leaves ranged from 3.86% at bloom to 2.46% at harvest, the stems from 1.55% at bloom to 0.78% at harvest and the clusters varied from 2.71% at bloom to 1.03% at harvest. Nitrogen fertilizer amount had significant effects on the N concentration of the leaves, stems and clusters at almost all growth stages (bloom, veraison and harvest) in Flame Seedless (Selma) vineyard (Table 3). The 2.5 X treatment generally had the greatest value at each growth stage. There were significant interactions between N fertilizer amount and timing of application on the N concentration in the leaves at bloom and veraison and in the clusters on all three sample dates.

Total dry biomass (sum of leaves, stems and clusters) of the Flame Seedless (Selma) vines was significantly affected by N fertilizer amount at bloom, veraison and harvest (data not shown). The 2.5 X treatment had the greatest dry biomass on all three dates. Dry biomass of the 1.0 X treatment was greater than the 0 control at veraison and harvest. However, the applied N fertilizer treatments had no significant effect on the number of clusters at harvest or harvestable crop, though total fruit weight of the 2.5 X treatments was significantly greater than that of the 0 controls (data not shown).

Total N of the Flame Seedless (Selma) tissue (sum of leaves, stems and clusters) collected at bloom, veraison (data not shown for both dates) and harvest was significantly affected by the N fertilizer treatments (Table 4). The values of the 1.0 X and 2.5 X treatments were almost double compared to the 0 control. This increase in N amount was due to a combination of greater dry biomass and N concentration.

Yield of Flame Seedless (Selma) in 2017 ranged from 15 to 26 t/ha while the amount of N in the fruit per unit area ranged from 8 to 21 kg N/ha (Table 5). The N amount found in the fruit at harvest ranged from 0.5 to 0.8 kg N/t. The total vine N in the leaves, stems and clusters ranged from 55 to 118 kg N/ha. Yields of other table grape cultivars used in the study across years varied from 43 to 70 t/ha while the N amount in the fruit per unit area ranged from 55 to 110 kg N/ha. The amount of N per ton of fruit ranged from 1 to 1.6 kg while total vine N in the leaves, stems and clusters ranged from 134 kg N/ha for Crimson Seedless to 192 kg N/ha for Autumn King (Table 6).

4. Discussion

Except for the Sheegene-21 (Laton) vineyard, the other commercial vineyard sites listed in Table 1, would not have needed N fertilizer based upon critical NO_3-N values measured in the petioles at bloom (Christensen et al., 1978; Christensen and Peacock, 2000; Kliewer, 1991). Conversely, petiole NO_3-N values at bloom and veraison of vines in all the N treatments imposed at the Flame Seedless (Selma) site would be considered deficient in N based upon the references in the preceding sentence (data not shown). Since the critical value of petiole NO_3-N at bloom was 350 ppm, the Sheegene-21 (Laton) vineyard would also be considered deficient and in need of a N fertilizer.

The sufficient value of total N (% dry wt.) in the petiole at bloom is > 0.6 (Kliewer, 1991). Based upon this value, all the commercial vineyards listed in Table 1 would not need to be fertilized with N, including the Sheegene-21 (Laton) vineyard. Total N in the petioles of Flame Seedless (Selma) vines ranged from 0.42% to 0.55% (bloom and veraison) and all treatments would be considered deficient. The optimum values of total N in leaf blades range from 1.5 to 3.0% (Kliewer, 1991). Leaf % N values from the Flame Seedless (Traver) vineyard would indicate the N status to be sufficient. Those values from the Flame Seedless (Selma) vineyard would be marginally sufficient.

Total vine dry biomass almost doubled at the Flame Seedless (Selma) studycomparing the non-fertilized treatment to the 2.5 X treatment at harvest despite little differences in petiole NO_3-N at bloom or veraison among treatments. Iandolino and Williams (2014) also reported very low values of petiole NO_3-N among treatments with the same trend in biomass production, but only an increase of about 40%. While, applied N at the Selma Flame Seedless vineyard significantly increased the number of clusters early in the growing season and the total biomass throughout the growing season and berry weight at harvest compared to the '0 control' they had no significant effect on the number of clusters at harvest. This may have been due to the fact that cluster removal by hand commonly takes place in table grape vineyards to thin the crop and increase fruit quality. Perhaps this is the reason harvestable fruit amount was not significantly affected by the N application treatments.

Based upon the above paragraph one may conclude that the NO_3-N concentration in the petioles at bloom may not have been a true reflection of the N status of all treatments at the Selma Flame Seedless vineyard. It has been demonstrated that grape yield increases sharply as a function of bloom petiole NO_3-N values starting at values less than 10 ppm, dry weight basis (Kliewer, 1991; Spayd et al., 1993). Therefore, small increases in bloom petiole NO_3-N values in extremely N deficient vineyards may have a large effect on vine growth, yield and vine N uptake as found in this vineyard and elsewhere (Iandolino and Williams, 2014).

A comparison of the % total N in the leaves, stems and clusters of the two Flame Seedless vineyards, Selma and Traver, indicated that the values are higher in the Traver vineyard for each vine organ at every growth stage. The Flame Seedless (Traver) data, where no N fertilizers had been applied, are even greater when compared with vines fertilized with N at the Selma Flame Seedless vineyard. This may be due to higher values of N in the irrigation water and vineyard soil. The mean NO_3-N of the irrigation water for the Traver Flame Seedless vineyard in 2014 and 2015 was 12.8 and 7.8 mg/L respectively, while that for the Selma Flame Seedless vineyard was 1.97 and 2.03 mg/L in 2016 and 2017 respectively. The amount of actual N applied with the irrigation water to the Traver Flame Seedless vineyard in 2015 was equivalent to 66 kg N/ha. The amount of N in the irrigation water applied to the Selma Flame Seedless vineyard in 2016 and 2017 was equivalent to 14.4 and 10.7 kg N/ha, respectively. In addition, the concentration of NO_3-N and NH_4-N in the soil at the Traver vineyard averaged 6.2 and 1.4 mg/kg soil, respectively, while those at the Selma vineyard were much less. Therefore, the contribution of N from various sources should be considered when determining fertilizer needs. In addition, petiole bloom and veraison NO_3-N, NH_4-N and total N from vines in the Flame Seedless (Traver) vineyard reflected the contribution of other sources of N tothevine N status.

The amount of N per ton of fruit in the commercial table grape vineyards (Table 6) is similar to the average reported in the literature of 1.46 kg N/t (Mullins et al. 1992). The Flame Seedless (Selma) fruit N values were lower when compared with the Flame Seedless (Traver) vines even for the treatment plots that received the 2.5 X dosage of N fertilizer. Furthermore, the amount of N per ton of fruit was lower than that considered "low" (0.90 kg N/t) in the literature (Mullins et al. 1992). The amount of N required for the growth of the current season's shoots and fruit ranges from 27 to 120 kg N/ha (Williams 1987, Williams and Biscay 1991, Williams and Smith 1991, Araujo et al. 1995, Iandolino and Williams 2014). Comparing that data with the vineyards of this study, the Flame Seedless located near Selma had values that ranged from55 to 118 kg N/ha. The amount of N needed to produce a crop in the Flame Seedless (Traver) vineyard (188 kg/ha) was much greater than the range reported above. The higher N requirements of the Flame Seedless (Traver) vineyard may be due to the fact that an over-head gable trellis system will create more vegetative biomass and therefore support a greater crop level. Both increased vegetative biomass and fruit yield require increased amounts of N. In addition, the Flame Seedless (Traver) vineyard had a row spacing of 3.05 m as opposed to a more common row spacing of 3.66 m found in older table grape vineyards and at the Flame Seedless (Selma) vineyard. A vineyard with a 3.05 m row spacing will have 20% more vines per ha than a vineyard with a 3.66 m row spacing (assuming vine spacings are similar) and therefore the possibility of producing greater yields.

5. Acknowledgements

The study was supported by the California Table Grape Commission and the California Department of Food and Agriculture Fertilizer Research Program.

6. Literature cited

Araujo F., Williams L.E., Matthews M.A., 1995. A comparative study of young 'Thompson Seedless' grapevines under drip and furrow irrigation: II. Growth, water use efficiency and nitrogen partitioning. Scientia Horticulturae. 60:251-265.

Christensen L.P., Kasimatis A.N., Jensen F.L., 1978. Grapevine Nutrition and Fertilization in the San Joaquin. DANR Publication 4087, Univ. California, Oakland, CA. 40 pp.

Christensen L.P, Bianchi M.L., Peacock W.L., Hirschfelt D.J., 1994. Effect of nitrogen fertilizer timing and rate on inorganic nitrogen status, fruit composition and yield of grapevines. American Journal of Enology and Viticulture 45,377-387.

Christensen L.P., Peacock WL. 2000. Mineral nutrition and fertilization. In: Raisin Production Manual. L.P. Christensen (ed). pp. 102-114. DANR Publications, Univ. California, Oakland, CA.

Harter T., Lund J.R, et al., 2012. Addressing Nitrate in California's Drinking Water, With A Focus on Tulare Lake Basin and Salinas Valley Groundwater, Report for the State Water Resources Control Board Report to the Legislature, Center for Watershed Sciences, University of California, Davis, 87p.

Iandolino A.B., Williams L.E., 2014. Recovery of ^{15}N labeled fertilizer by *Vitis vinifera* L., cv. Cabernet Sauvignon: Effects of N fertilizer and applied water amounts. American Journal of Enology and Viticulture 65 :189-196.

Kliewer W.M., 1991. Methods for determining the nitrogen status of vineyards. In: J.M. Rantz (ed.), Proc. Inter. Symp. On Nitrogen in Grapes and Wine, Seattle, WA., 18-19 June 1991. American Society of Enology and Viticulture. Davis, CA. pp. 133-147.

Mullins M.G., Bouquet A., Williams L.E., 1992. Biology of the grapevine. Cambridge University Press, Cambridge, U.K., 231pp.

Peacock W.L., Christensen L.P., Broadbent F.E., 1989. Uptake, storage and utilization of soil-applied nitrogen by Thompson Seedless as affected by time of application. American Journal of Enology and Viticulture40:16-20.

Spayd S.E., Wample R.L., Stevens, R.G., Evans R.G., Kawakami A.K., 1993. Nitrogen Fertilization of While Riesling in Washington: Effect on Petiole nutrient concentration, yield, yield components and vegetative growth. American Journal of Enology and Viticulture44, 378-386.

Williams L.E., 1987. Growth of 'Thompson Seedless' grapevines: II. Nitrogen distribution. Journal of the American Society for Horticultural Science, 112, 330-333.

Williams L.E., 2015. Recovery of ^{15}N-labeled fertilizer by Thompson Seedless grapevines: Effects of N fertilizer type and irrigation method. American Journal of Enology and Viticulture 66, 509-516.

Williams L.E., Biscay P.J., 1991. Partitioning and dry weight, nitrogen and potassium in Cabernet Sauvignon grapevines from anthesis until harvest. American Journal of Enology and Viticulture 42, 113-117.

Williams L.E., Matthews M.A., 1990. Grapevine. IN: Irrigation of Agricultural Crops, ASA Monograph #30. B.A. Stewart and D.R. Nielsen (eds.). ASA-CSSA-SSSA, Madison, WI. pp. 1019-1055.

Williams L.E., Smith R.J., 1991. The effect of rootstock on the partitioning of dry weight, nitrogen and potassium and root distribution of Cabernet Sauvignon grapevines. American Journal of Enology and Viticulture 42, 118-122.

Table 1. The concentrations (dry weight basis) of nitrate N, ammonia N and total N of Sheegene 21 (Laton - L), Sheegene 21 (Parlier – P), Flame Seedless, Princess and Autumn King (all three at Traver) measured in the petioles at bloom and veraison in **2017**. The potassium concentration in the petioles is also given. No N treatments were imposed. Each value is the mean of 6 replicates ± SD except for the Flame Seedless data where n = 30.

Cultivar	**NO_3-N**	**NH_4-N**	**Total N**	**K**
Bloom	----------------- (ppm) -----------------		------------------ (%) -----------------	
Sheegene-21 (L)	285 ± 106	686 ± 87	1.16 ± 0.07	2.09 ± 0.20
Sheegene-21 (P)	1473 ± 194	1011 ± 295	1.40 ± 0.07	3.08 ± 0.19
Flame Seedless	1194 ± 191	1871 ± 304	1.76 ± 0.15	1.57 ± 0.17
Princess	2182 ± 296	1125 ± 77	1.58 ± 0.07	4.17 ± 0.27
Autumn King	2380 ± 815	1663 ± 883	1.47 ± 0.34	3.53 ± 0.46
Veraison				
Sheegene-21 (L)	120 ± 43	124 ± 19	0.48 ± 0.02	2.26 ± 0.14
Sheegene-21 (P)	1815 ± 355	200 ± 23	0.78 ± 0.06	3.35 ± 0.46
Flame Seedless	1062 ± 230	1009 ± 320	1.04 ± 0.10	1.01 ± 0.12
Princess	849 ± 297	361 ± 76	0.75 ± 0.07	3.08 ± 0.27
Autumn King	1160 ± 240	397 ± 25	0.81 ± 0.11	3.70 ± 0.13

Table 2. The concentrations of total N in the leaves, stems and clusters of **Flame Seedless** (Traver) as a function of growth stage in **2017.** No N treatments were imposed in this vineyard. Each value is the mean of 6 replicates.

		------------------------- Organ -------------------------		
Cultivar	Growth Stage	Leaves	Stems	Clusters
		-------------- Total N (% dry weight) ---------------		
Flame Seedless	Bloom	3.86	1.55	2.71
	Veraison	2.71	0.87	0.88
	Harvest	2.46	0.78	1.03

Table 3. The effect of fertilizer amount and growth stage (bloom, veraison and harvest) on the concentration of N in leaves, stems and clusters of **Flame Seedless** (Selma) in **2017**. Values within a row not followed by a different letter are not significantly different.

		------------------ Fertilizer Amount ------------------		
Organ	Growth Stage	0	1.0 x	2.5 x
		--------------- Total N (% dry weight) ---------------		
Leaves	Bloom[a]	2.12 c	2.36 b	2.79 a
	Veraison[a]	1.49 c	1.95 b	2.49 a
	Harvest	1.78 b	1.83 b	2.06 a
Stems	Bloom	0.70	0.68	0.80
	Veraison	0.45 b	0.51ab	0.58 a
	Harvest	0.33 b	0.34 b	0.40 a
Clusters	Bloom[a]	1.09 c	1.35 b	1.63 a
	Veraison[a]	0.25 b	0.27 b	0.33 a
	Harvest[a]	0.27	0.35	0.34

[a] There was a significant interaction of N amount and timing.

Table 4. The effect of nitrogen fertilizer amount and timing of fertilizer application on total N of **Flame Seedless** (Selma) tissue (leaves + stems + clusters) collected at harvest in **2017**. Values are grams per vine. There was a significant effect of N applied amount on total N per vine.

Harvest Total-N (g/vine)	------------ Fertilizer Amount ----------------			Ave. Effect
Fertilizer Timing	0	1.0 x	2.5 x	Timing
2 Slug Applications	39.3	59.7	78.9	59.3
10 Applications	37.1	62.3	66.0	55.2
Ave. Effect Amt.	38.2 b	61.0 a	72.5 a	

Table 5. The effect of N treatments on total fruit fresh biomass at harvest, kilograms of N in the fruit at harvest per hectare and per ton of fruit from the **Flame Seedless**(Selma) vineyard in **2017**. Also included is the total N per vine in the leaves, stems and clusters at harvest. Vineyard density is 1492 vines/ha (vine x row = 1.83 x 3.66 m).

Flame Seedless	------------------ Fruit metrics -------------------				Total Vine
Selma	kg/vine	t/ha	kg N/ha	kg N/ton	kg N/ha
0-s	10.3	15.4	7.6	0.49	58.6
0-ma	13.3	19.8	8.9	0.51	55.4
x-s	11.8	17.6	11.9	0.63	89.1
x-ma	17.3	25.8	12.8	0.65	93.0
2.5x-s	12.6	18.8	20.7	0.80	117.7
2.5x-ma	16.2	24.2	10.9	0.45	98.5

Table 6. Mean values across years on total fruit fresh biomass at harvest, kilograms of N in the fruit at harvest per hectare and per ton of fruit for 6 table grape cultivars. Also included is the total N per vine in the leaves, stems and clusters at harvest across several years. Vineyard density is 1792 vines/ha (vine x row = 1.83 x 3.05 m) for all vineyards except the Crimson Seedless vineyard where density is 1120 vines/ha (vine x row = 2.44 x 3.66 m).

Cultivar	------------------- Fruit metrics --------------------				Total Vine
(Years)	kg/vine	t/ha	kg N/ha	kg N/ton	kg N/ha
Flame Seedless					
(2014-16)	32.9	58.8	88.4	1.50	186.1
Scarlet Royal					
(2014-16)	37.5	67.2	70.0	1.06	208.4
Crimson Seedless					
(2014-16)	51.2	57.4	55.7	0.97	134.0
Princess					
(2015-16)	32.2	57.7	77.9	1.35	188.1
Autumn King					
(2015-16)	39.1	70.1	110.2	1.57	192.0
Sheegene-21					
(2016-17)	23.9	42.8	54.6	1.28	177.4