Completed

Fertilizer Use Efficiency and Influence of Rootstocks on Uptake and Accumulation of Nutrients in Wine Grapes Grown in the Coastal Valleys of California

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OBJECTIVES:

1. Quantify total uptake of nitrogen and potassium in Chardonnay and Cabernet Sauvignon scions grafted onto various rootstocks at different locations.

2. Use ^{15}N labeled fertilizer to determine fertilizer use efficiency of premium wine grapes on different rootstocks grown in the coastal valleys of California.

3. Compare the efficiency of N fertilizer uptake and total N and K uptake by the various scion/rootstock combinations with other means to determine vine nutritional status (i.e. petiole analysis at bloom and veraison and cluster N and K analysis at harvest).

4. Develop fertilization recommendations for premium wine grapes grown in the coastal regions of California.

EXECUTIVE SUMMARY:

There are approximately 284,000 ha of grapevines grown in California with 42% of that acreage devoted to wine grape production. Presently, the most rapidly growing segment of the wine industry is the sale of premium wine. The majority of grapes used to produce premium wine are grown in the coastal valleys of California. Unfortunately, a large portion of the vineyards in those areas are having to be replanted on rootstocks resistant to Phylloxera, a root feeding louse. Most of the fertilization recommendations for grapevines in California were developed for vines growing in the San Joaquin Valley on their own roots. Thus, there is an

urgent need to develop fertilization recommendations for premium wine grape cultivars grown on different rootstocks in the coastal areas of California.

The primary fertilizer used in California vineyards is nitrogen. Therefore, the timing and amounts of N fertilizer application are critical in optimizing its uptake to avoid leaching below the root zone and possible ground water contamination. The only direct way to measure fertilizer use efficiency is with the use of ^{15}N labeled N fertilizer. ^{15}N is a non-radioactive isotope of N and can be quantitatively measured in plant tissue. The proposed research was designed to determine fertilizer use efficiency using ^{15}N labeled fertilizer in four different vineyards (two Chardonnay and two Cabernet Sauvignon vineyards) growing on different rootstocks, and at different locations in California. In addition, nitrogen and potassium budgets were to be determined on those vines and compared to more conventional means (petiole analysis at bloom time) to determine vine nutritional status.

At berry set in the 1997 growing season ^{15}N labeled fertilizer was applied to six, individual vine replicates for each rootstock at all locations subsequent to berry set (from two to four weeks after anthesis or bloom). The amount of N applied per vine was determined by estimating yield at each site and the corresponding amount of nitrogen that would be removed in the fruit at harvest. This ranged from the equivalent of 30 to 45 kg N/ha, depending upon location. Petioles were collected in 1997 at 30 to 80% of full bloom, prior to when the fertilizer was applied and then again at bloom in 1998. Yields at each location were measured when the sugar in the fruit indicated that particular vineyard would be harvested within one week. The fruit was returned to the Kearney Ag Center and subsequently dried. Leaves on the experimental vines were collected prior to the anticipated date they would have naturally fallen from the vine and taken to the Kearney Ag Center to be dried. All leaves remaining on the vines at each location were removed the second week of December both years. All leaves of each vine were dried and weighed. The dried leaves were subsampled and the remainder were taken back to each vineyard and placed beneath each respective vine replicate. Data vines were generally pruned in December or January both years, fresh weights taken and subsamples of each collected. The subsamples were taken to the Kearney Ag Center, dried and weighed.

As of this date (1 May 1999), all vine material from both years has been dried, weighed, subsampled and ground to a fine powder. The ground samples were sent to a laboratory with the equipment to determine atom percent ^{15}N and percent N (dry weight basis). Total fertilizer N taken up by each vine was determined by multiplying atom percent ^{15}N by total dry biomass (the sum of each vine's cluster, leaf and cane dry weight). In addition, each vine organ was analyzed for potassium at the DANR Laboratory in Davis (1997 data only, the 1998 K data has yet to be determined). This will allow me to calculate both N and K budgets at each vineyard site.

WORK DESCRIPTION:

Task 1: Second growing season (1998)

Subtasks:

1.1:

Petioles were collected for each vineyard/scion/rootstock combination during bloom. Petioles were sampled June 4, 1998, in the Chardonnay vineyards located in the Carneros region of Napa Valley and in Monterey County, June 12 in the Cabernet Sauvignon vineyard located near Paso Robles and June 11 in the Cabernet Sauvignon vineyard located near Oakville in Napa Valley. Three, 75 petiole samples per scion/rootstock combination were taken from vines surrounding the ^{15}N fertilized vine and two approximately 50 petiole samples were taken from the ^{15}N fertilized vines. Both fresh and dry weights were taken of each sample. The dried samples were ground to a fine powder and sent to a commercial laboratory for analysis.

1.2:

Fruit of the data vines were harvested at Carneros, Oakville, Monterey, and Paso Robles on 28 September, 28 September, 21 September, and 9 October 1998, respectively. Fresh weights were taken in the field and the fruit was then transported to the Kearney Ag Center where the clusters were dried. Yields across all scion/rootstock combinations at Carneros, Monterey, Paso Robles and Oakville in 1998 were equivalent to 17.7, 9.61, 16.1 and 16.0 tonnes per hectare, respectively.

1.3:

Senescing leaves were removed from the data vines at each location beginning shortly after fruit harvest, transported back to the Kearney Ag Center and dried. It was anticipated that the leaves removed weekly were about to naturally fall from the vine. This procedure was used instead of placing bird netting around data vines. All leaves remaining on the vines the second week of December were removed and dried. Leaves from each vine replicate on the different harvest dates were combined and total leaf dry weight determined. Subsequently, leaves from each vine were subsampled and ground. The remaining leaves were then taken back to each respective vine and placed on the ground beneath each replicate. This was accomplished when the vines were pruned.

1.4:

During December 1998, and January 1999, data vines were pruned. Fresh pruning weights were taken and then subsampled. The subsamples were transported back to the Kearney Ag Center, fresh weights taken and then dried. The prunings left in the vineyard were cut into short pieces and then distributed on the ground around each vine replicate. It was

decided not to collect trunk and root tissue as many of the vines at the time of pruning at this procedure might be too harmful to these small vines.

1.5:

All dried material was ground to a fine powder during the months of November and December 1998 and January 1999.

1.6:

All ^{15}N labeled vine parts were sent to a commercial laboratory the last week of January 1999 to determine the amount of total N and ^{15}N in each organ for data collected during the 1998 growing season. Data collected in 1997 were analyzed in February of 1998. Potassium for the 1997 growing season was analyzed during the Fall of 1998 while potassium for the organs collected in 1998 will be analyzed shortly.

1.7:

This task was completed in March of 1999.

1.8:

This task was not completed until May of 1999.

RESULTS:

All vines used in this study were irrigated at estimated full ET. Evaporative demand (potential ET; ET_o) was obtained from CIMIS weather stations located within a few kilometers of each experimental vineyard. The crop coefficient (k_c) used at each location was developed at the Carneros site. The amount to irrigate at 100% of estimated vine ET was calculated as following:

$$ET_c = ET_o \times k_c$$

The amount of water vines were irrigated with depended upon the date irrigations commenced, vine density and the evaporative demand at each location. The amount of water applied to the data vines throughout the growing season at the Carneros, Monterey, Paso Robles and Oakville sites were 1257, 1353, 1478 and 465 liters (332, 358, 391 and248 gallons) per vine, respectively. These amounts were equivalent to 387, 291, 265, and 248 mm (15.2, 11.5, 10.4 and 9.8 inches), respectively.

Petioles opposite the lowest cluster on a shoot were sampled during bloom in 1997 and 1998 and analyzed for nitrate nitrogen and total nitrogen (Table 1). The samples collected in 1997 were taken prior to the application of the labeled fertilizer. The values for both nitrate and total N varied greatly from one location to another and somewhat less so for rootstocks at a

particular location. Values in 1997 ranged from a low of approximately 60 ppm nitrate at the Oakville site to 4,000 to almost 10,000 ppm at Paso Robles. Total N in the petioles appeared to be a function of cultivar and not a function of petiole nitrate levels. Petiole analyses in 1998 were either lower or higher than the previous year, depending upon location. All values for petiole total N in 1998 were very similar across rootstocks and location.

The concentration of N in the leaves, stems (main axis of the shoot) and clusters was measured in 1997 at three of the four locations (Table 2). This will be used to determine total N in the vine at the time the fertilizer was applied. Organ N concentrations at the three sites somewhat reflected the petiole nitrate concentrations (i.e. Oakville had low petiole nitrate concentrations and low N concentration in those organs while Paso Robles was just the opposite). The amount of N found in the clusters at harvest, leaves as they fell from the vine and pruning canes was determined for all scion/rootstock combinations at each site (Table 3). Total N per hectare in those organs was greater in 1997 than in 1998, the exceptions being several of the rootstocks at the Paso Robles site. The decrease in total N per hectare was due to the fact that yields were lower in 1997 than 1998, especially at the Gonzales site. Lower yields in 1998 were a general phenomenon in vineyards throughout the State of California. The amount of N per tonne of fruit at harvest was lowest for vines at the Oakville site and highest at the Paso Robles site in 1997 (Table 4). Paso Robles still had the highest amount of N per tonne of fruit in 1998 but the amount of N in the fruit at Oakville was similar to those at Carneros and Gonzales.

The relationship between the concentration of N in clusters, leaves and stems (or pruning canes) at berry set and at the end of the growing season and bloom-time petiole nitrate concentration was determined in 1997 (Figures 1 and 2). The low petiole nitrate concentration at Oakville was associated with low concentrations of N in the clusters, leaves and stems (or pruning canes) whether those were measured at berry set (Figure 1) or at the end of the season (Figure 2). Once petiole nitrate levels were 500 ppm or greater the N concentrations in those organs leveled off. I also examined the relationship between N concentration at berry set and those measured in the same organs at the end of the season (Figure 3). The relationships between leaves and stems harvested at berry set and at the end of the season were significantly ($P \leq 0.05$) correlated with one another. Lastly, the relationship between leaf N concentration at either berry set or at the end of the season were highly correlated with cluster N concentration at harvest (Figure 4).

Potassium was measured in the petioles at bloom time and clusters, leaves and pruning canes at the end of the season in 1997 (Table 5). The same will be done for the tissue collected in 1998. The range in petiole K varied to a lesser degree from location to location and among rootstocks at a particular location than did petiole nitrate concentrations. The concentration of K in clusters, leaves and pruning canes among locations and rootstocks varied even less than the K in the petioles. There appeared to be large differences in total K in the fruit and the entire vine (sum of fruit, leaves and pruning canes) among the rootstocks. Most of the differences among the scion/rootstock combinations at a given location were due to differences in yield. Differences among locations was due mainly to differences in planting density (i.e. planting density at Carneros, Gonzales, Oakville and Paso Robles was 3086, 2240, 5348 and 1792 vines per hectare, respectively). As bloom time petiole K increased the concentration of K in the

clusters also increased (Figure 5). There was no correlation between petiole K and the K found in the leaves and pruning canes at the end of the season.

Ammonium nitrate (NH_3NO_3), with 5 atom % excess ^{15}N, was the N fertilizer utilized in this study. Both N atoms were labeled with ^{15}N. The amount of N fertilizer given to each vine was based upon an estimated yield at each location and subsequent removal of N from the vineyard in the fruit at harvest. The amount of ammonium nitrate given to each vine at Carneros, Monterey, Paso Robles and Oakville in 1997 was approximately 34, 57, 48 and 17 g per vine. The difference in the amount per vine at each location was due to differences in estimated yield and vine density. The amount of actual N applied was 12 (37), 20 (45), 17 (30) and 6 (32) g per vine (kg per ha) at Carneros, Monterey, Paso Robles and Oakville, respectively. The fertilizer was dissolved in water and placed beneath an emitter while the vines were being irrigated. This procedure took place from two to four weeks after full bloom (after berry set).

Fertilizer use efficiency (FUE) (ratio of applied ^{15} N to ^{15} N taken up by the vine) was calculated for all scion/rootstock /location combinations. There were little differences among rootstocks at a given location in 1997 (Table 6). This was anticipated as all rootstocks were culturally treated the same (i.e. vertical trellis system, shoot positioned, hedged at a certain height and drip irrigated according to best estimates of vine water requirements). All fertilizer applications were such that the nitrogen was applied directly beneath an emitter while irrigating. There were somewhat larger differences in FUE among locations. Fertilizer use efficiency, when averaged across rootstocks, was 10.3, 3.81, 3.45 and 11.5% at the Carneros, Gonzales, Paso Robles and Oakville sites, respectively. There are several explanations for the differences among sites. The extremely high petiole nitrated levels in 1997 at the Paso Robles vineyard may indicate an abundance of soil nitrogen at that site thus diluting the uptake of fertilizer N. At the Gonzales site, the cooperator applied a NPK fertilizer without my knowledge again diluting the ^{15}N fertilizer applied at berry set. The higher FUE at the Carneros and Oakville sites may have been due to the fact that neither vineyard had been fertilized since planting. In addition, the Oakville vineyard had very low petiole nitrate levels when sampled at bloom (an average of 60 ppm). The amount of ^{15}N fertilizer found in the clusters, leaves and pruning canes in 1998 was also very low and differed little among rootstocks at a given location (Table 6). The greatest uptake of the labeled fertilizer over the two-year period occurred at the Carneros and Oakville locations.

The distribution of ^{15}N fertilizer among the clusters, leaves and pruning canes was determined from the 1997 data set (Table 7). As expected, the clusters contained the highest proportion of labeled fertilizer followed by the leaves and pruning canes.

DISCUSSION AND CONCLUSIONS:

This study has quantified the uptake of nitrogen and potassium as a function of scion, rootstock and location for two growing seasons. As has been found in other studies on

grapevines, the clusters are the major sinks for both nitrogen and potassium. Over the two growing seasons the amount of N found in the clusters at harvest, leaves as they fell from the vine and the pruning canes ranged from a low of 23.7 to a high of 64.5 kg N per hectare. The actual amount of N removed from the vineyards (by harvesting the fruit) ranged from 23 to 38 kg N per hectare (approximately 1.0 to 1.5 kg N per tonne of fruit). The amount of potassium removed from the vineyards via fruit harvest in 1997 ranged from 31 to 72 kg K per hectare. The amount of K found in one tonne of fruit ranged from 2 to 3 kg.

Both location and rootstock had an effect on bloom time petiole analysis for nitrate, total N and percent K as others have found. In fact, there was a tremendous effect of rootstock and location on petiole nitrate nitrogen. The current recommendation for adequate levels of nitrate in the petioles at bloom, for Thompson Seedless grapevines, is between 500 and 1200 ppm nitrate. The data presented in Figures 1 and 2 indicate that when bloom time petiole nitrate levels were below 500 ppm, the concentration of nitrogen in the clusters, leaves and stems (or canes) was lower than when the levels were greater than 500 ppm. However, the concentration of nitrogen in those same organs did not increase as bloom time petiole nitrogen increased from 500 to 10,000 ppm. This data would indicate that the values of petiole nitrate nitrogen established for Thompson Seedless also might be valid for other cultivars and rootstocks. It is unknown at this time whether a reduction below 500 ppm had a negative impact on vine productivity at Oakville.

It is interesting to point out that petiole nitrate N at Oakville increased dramatically in 1998 compared to 1997 even for vines that were not fertilized the previous year. This demonstrates that climatic factors may greatly influence petiole nutrient values. The 1997 Spring was very dry (and those vines had not been irrigated prior to taking petiole samples that year) while 1998 had a very wet Spring (soil water content was very high at the time petioles were sampled then). It should also be pointed out that the vineyard in Paso Robles was irrigated in 1997 prior to taking petioles for analysis while in 1998 the vineyard had not been irrigated prior to bloom. In that situation, the irrigation may have caused the high petiole values in 1997 while not irrigating the vines in 1998 resulted in lowered petiole nitrate values. Growers should be made aware that irrigation starting date; amount and frequency may impact petiole sample values.

I also found good correlation between organ tissue N concentration at berry set and the same organ's N concentration at the end of the season, and the concentration of N in the leaves and the fruit at harvest using the 1997 data set. Similar correlations will be made on data collected in 1998 and for data collecting during the growing season in 1999. These relationships would also indicate that any of the above organs, sampled either during the growing-season or during dormancy (pruning canes) could also be useful in determining vine nutrient status when used in conjunction with petiole analysis.

The data collected to date would indicate that the efficiency of N fertilizer utilization by the various rootstocks differs only slightly. It is often assumed by many in the grape industry that rootstocks with greater petiole nutrients (such as higher nitrate levels) are more efficient than rootstocks that generally have lower values. The data collected in this study would indicate that not to be the case. The small differences among the rootstocks at any one location

may be due to how the rootstock affected vine growth and that the growth then drove the uptake of the N fertilizer. It appears that vines with a larger crop load used more N and K.

The above fertilizer use efficiencies seem quite low compared to a FUE of approximately 40% the PI found on Thompson Seedless grapevines grown in the San Joaquin Valley. It should be pointed out that the FUEs presented in this summary were based upon N found in the fruit, leaves and pruning canes while those on Thompson Seedless also analyzed the root system, trunk and fruiting wood. Those three organs contained approximately 40% of the total ^{15}N labeled fertilizer taken up by the vines in that study. It was anticipated that the labeled fertilizer in the trunk, cordons and root systems of the vines used in this study would be remobilized and found in the in the clusters, leaves and pruning canes in 1998 and 1999. The data found in Table 6 indicates that only a small fraction of ^{15}N was found in those organs in 1998. Possible reasons for the differences between the Thompson Seedless study and this one are: 1.) the vineyard site in the Thompson study had a hardpan at a depth of 1.0 m, this would have prevented any leaching of the fertilizer below the root zone, 2.) vines in this study were irrigated at estimated full ET, which may have leached the fertilizer below the rooting zone and 3.) other reasons for the low FUE at the Gonzales and Paso Robles have been explained above in the **Results** section. In support of reason 2, an additional treatment was established at Carneros where vines were irrigated at 50% of estimated full ET and fertilized with a combination of potassium nitrate and ammonium sulfate labeled with ^{15}N (left over from my Thompson study). The FUE was twice (approximately 23%) that of the full ET treatment (unpublished data).

PROJECT EVALUATION:

None.

OUTREACH ACTIVITIES SUMMARY:

1/19/99 "Research update on Irrigation and Nitrogen trials on Cabernet Sauvignon grafted onto three different rootstocks at the Robert Mondavi Oakville vineyard", Monthly meeting of the North Coast Viticulture Research Group, Mondavi Winery, Oakville, CA. 30 participants, vineyard managers from Sonoma and Napa Counties.

1/21/99 "Fertilizer use efficiency and influence of rootstocks on uptake and nutrient accumulation in wine grapes", 1999 California Plant and Soil Conference, Visalia, CA. 60 participants, growers, PCA's, vineyard managers

Table 1. Bloom-time petiole nitrate and total N concentrations in 1997 and 1998. Each value is the mean of four, 100 petiole samples.

Location	Rootstock	$NO_3 - N$ (ppm)		Total N (% dry wt)	
		1997	1998	1997	1998
Carneros	5C	911	590	1.50	1.09
	110R	718	340	1.69	1.16
Gonzales	5C	768	486	1.06	0.81
	110R	638	481	0.66	0.83
	Freedom	587	695	0.91	0.84
Oakville	5C	68	1655	2.63	1.09
	110R	56	1338	2.60	1.01
	3309	52	1586	2.47	0.98
Paso Robles	5C	6191	1359	2.64	1.06
	110R	4042	964	2.76	1.30
	Freedom	9876	1485	3.34	1.04
	140Ru	7462	1418	2.64	1.26
	1103P	7878	1575	2.84	1.20

Table 2. The concentration of N in the leaves, stems and clusters on the date the ^{15}N fertilizer was applied in 1997. Data were not collected at the Gonzales site. Each value is the mean of three individual vine replicates.

Location	Rootstock	Leaves	Stems	Clusters
		----------% dry wt.----------		
Carneros	5C	3.33	1.48	2.80
	110R	3.89	1.32	3.15
Oakville	5C	2.64	0.43	1.30
	110R	2.82	0.43	1.34
	3309	2.62	0.43	1.02
Paso Robles	5C	3.34	1.17	1.49
	110R	3.89	0.78	1.95
	Freedom	3.66	0.81	2.36
	140Ru	4.24	0.83	1.83
	1103P	3.58	0.84	1.84

Table 3. Total N in the leaves, stems (prunings), and clusters at the end of the 1997 and 1998 growing seasons. Each value is the mean of six individual vine replicates.

Location	Rootstock	Total N (kg ha^{-1}) 1997	Total N (kg ha^{-1}) 1998
Carneros	5C	52.8	40.2
	110R	64.5	45.0
Gonzales	5C	44.4	26.5
	110R	51.6	29.3
	Freedom	45.5	23.7
Oakville	5C	55.6	45.4
	110R	42.8	44.4
	3309	35.8	38.9
Paso Robles	5C	38.7	40.9
	110R	35.8	47.8
	Freedom	47.7	41.3
	140Ru	47.5	52.8
	1103P	48.6	47.5

Table 4. The total amount of N in the fruit at harvest, leaves as they fell from the vines and prunings taken during the winter and N per tonne of fruit at the four vineyard locations. Each value is the mean (averaged across rootstocks) at each location for each year.

Location	Total N (clusters, leaves & prunings) (kg ha^{-1})		Total N (kg tonne^{-1} fruit)	
	1997	1998	1997	1998
Carneros	58.7	42.6	1.34	1.25
Gonzales	47.2	26.5	1.24	1.28
Oakville	44.7	42.9	0.98	1.24
Paso Robles	43.7	46.1	1.58	1.51

Table 5. Yield, percent K of petioles (sampled at bloom) clusters, leaves and prunings, and total K in the fruit at harvest and combined with that found in the leaves and prunings at the end of the 1997 growing season as a function of cultivar, rootstock and location.

				% K				Total K	
Location	Cultivar	Rootstock	Yield	Petiole	Fruit	Leaves	Prunings	Fruit	Vine[1]
			(t/ha)	(% dry wt.)				(kg/ha)	
Carneros	Chardonnay	5C	21.6	1.24	0.81	0.01	0.64	42.8	63.3
		110R	28.0	0.98	0.92	1.37	0.77	63.4	91.7
Gonzales	Chardonnay	5C	23.0	1.11	0.67	0.72	0.41	40.8	47.6
		110R	25.2	1.35	0.70	0.87	0.54	48.4	59.2
		Freedom	22.1	1.29	0.65	0.67	0.41	41.7	49.0
Oakville	Cabernet	5C	25.4	2.34	1.17	0.86	0.60	71.6	92.8
		110R	19.8	2.37	1.21	1.21	0.62	59.2	80.8
		3309C	16.5	2.31	1.15	0.88	0.57	48.2	63.8
Paso Robles	Cabernet	5C	14.7	3.04	1.00	0.90	0.46	38.0	47.6
		110R	11.3	1.70	1.03	1.20	0.52	31.6	45.8
		Freedom	13.7	2.98	1.08	1.06	0.47	39.7	54.6
		140Ru	11.6	2.20	1.13	1.33	0.58	35.8	56.8
		1103P	14.4	2.39	1.19	1.14	0.51	46.7	62.9

[1] Total K per vine is the sum of K found in the fruit, leaves and pruning canes.

Table 6. The relationship between the amount of ^{15}N labeled fertilizer found in each rootstock/scion combination and the amount of ^{15}N fertilizer applied at berry set in 1997 at the end of the growing seasons in 1997, 1998 and total percentage after two years.

			^{15}N in vine/^{15}N applied		
Location	Cultivar	Rootstock	1997	1998	1997 & 1998
			(%)		
Carneros	Chardonnay	5C	9.7	1.1	10.5
		110R	11.1	1.2	12.3
Gonzales	Chardonnay	5C	4.0	0.6	4.4
		110R	4.3	0.5	4.8
		Freedom	4.0	0.4	4.4
Oakville	Cabernet	5C	10.4	1.5	11.9
		110R	11.2	2.1	13.3
		3309C	11.5	2.1	13.6
Paso Robles	Cabernet	5C	2.1	1.2	3.3
		110R	3.2	1.8	5.0
		Freedom	6.1	1.7	7.8
		140Ru	3.5	1.6	5.1
		1103P	4.8	2.2	6.0

Table 7. The distribution of the ^{15}N labeled fertilizer among the leaves, clusters and canes at pruning as a function of vineyard location in 1997. Values are the means of all rootstocks at each site $\pm$ SD (except Carneros).

	----------Distribution of ^{15}N Label (% of total ^{15}N)----------		
Location	Clusters	Leaves	Canes
Carneros	65	25	10
Gonzales	71 ± 4	22 ± 4	7 ± 1
Oakville	55 ± 3	30 ± 3	15 ± 1
Paso Robles	48 ± 6	36 ± 4	16 ± 3

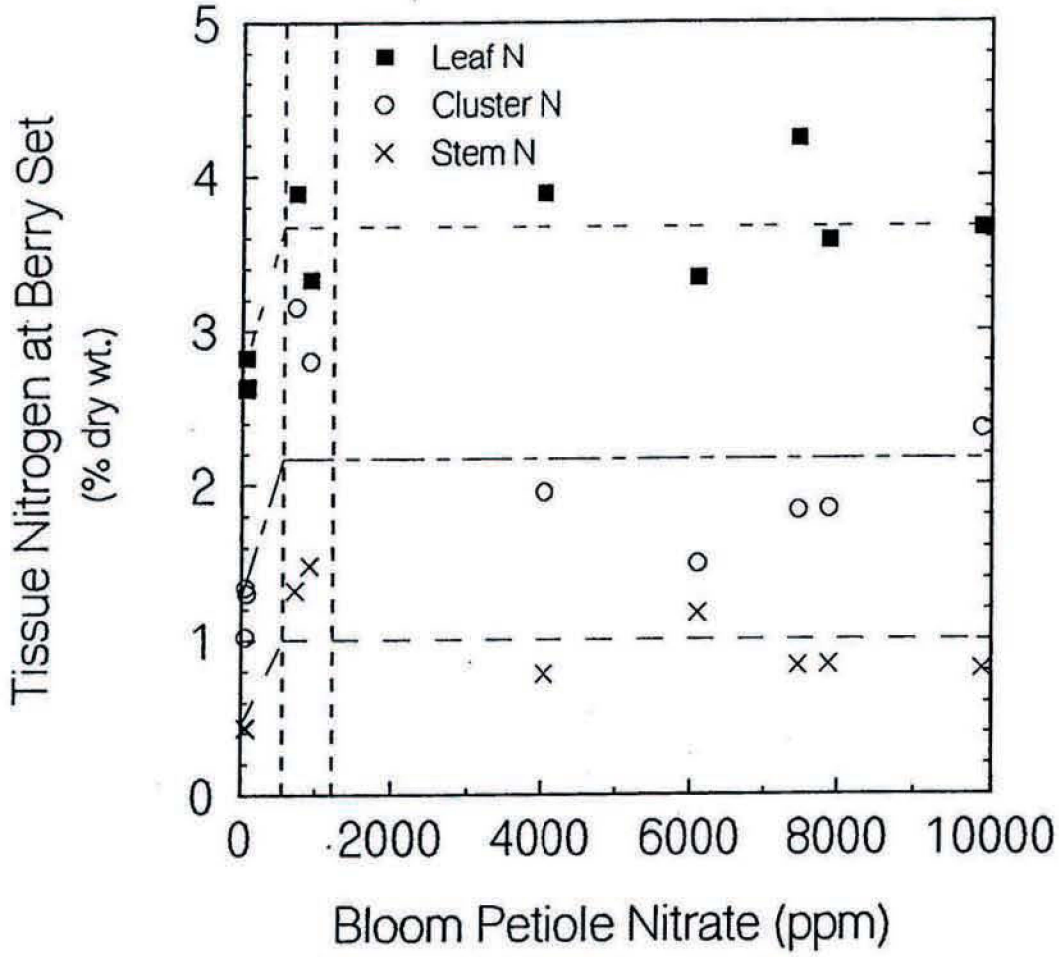

Figure 1. The relationship between petiole nitrate nitrogen determined at bloom and organ nitrogen concentration at berry set. Data were collected in 1997. The two vertical lines (at 500 and 1200 ppm petiole nitrate) represent the "adequate" bloom time petiole nitrate levels for Thompson Seedless grapevines. Each data point represents the values obtained from petiole analysis and vine harvests for individual rootstock/scion combinations at three of the experimental vineyard locations.

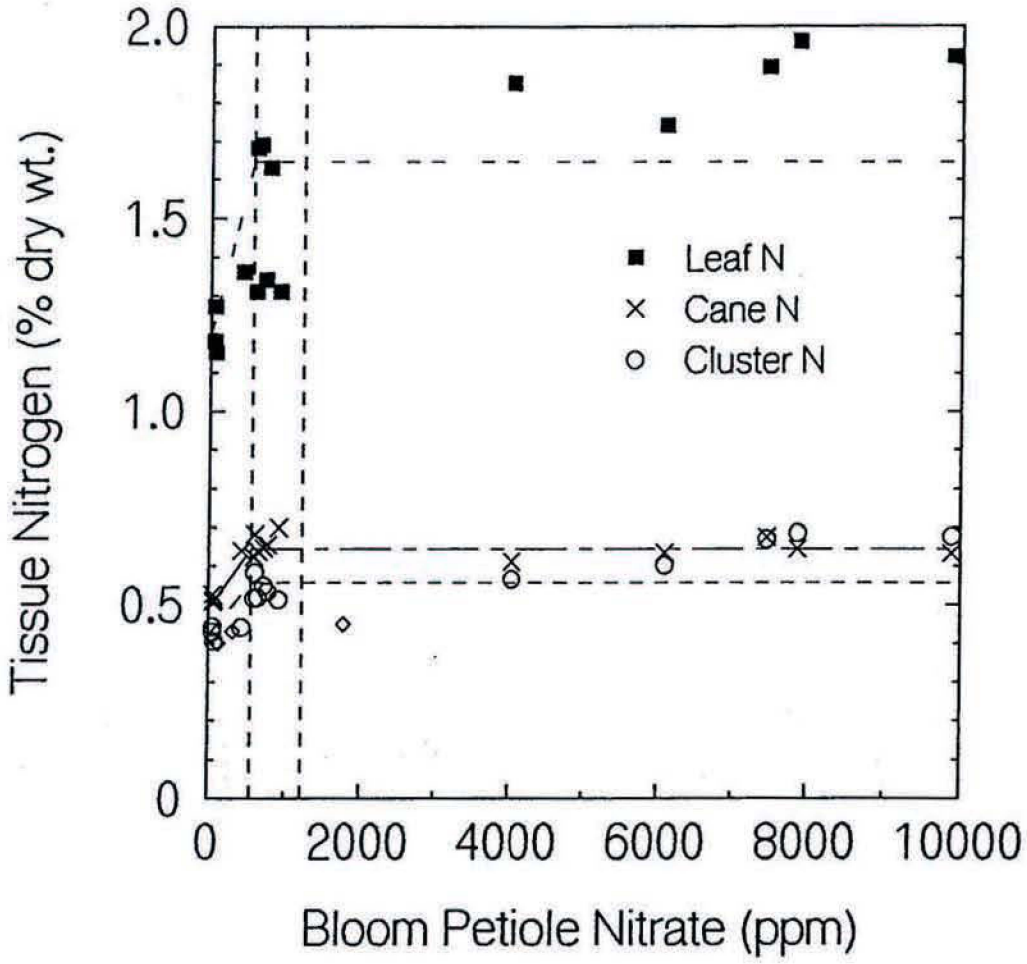

Figure 2. The relationship between petiole nitrate nitrogen determined at bloom and organ nitrogen concentration for clusters at harvest, leaves as they fell from the vine and pruning canes collected during the dormant portion of the season. Each data point represents the values from petiole analysis and organ harvests for individual rootstock/scion combination at all of the experimental vineyard locations. Other information as found in Figure 1.

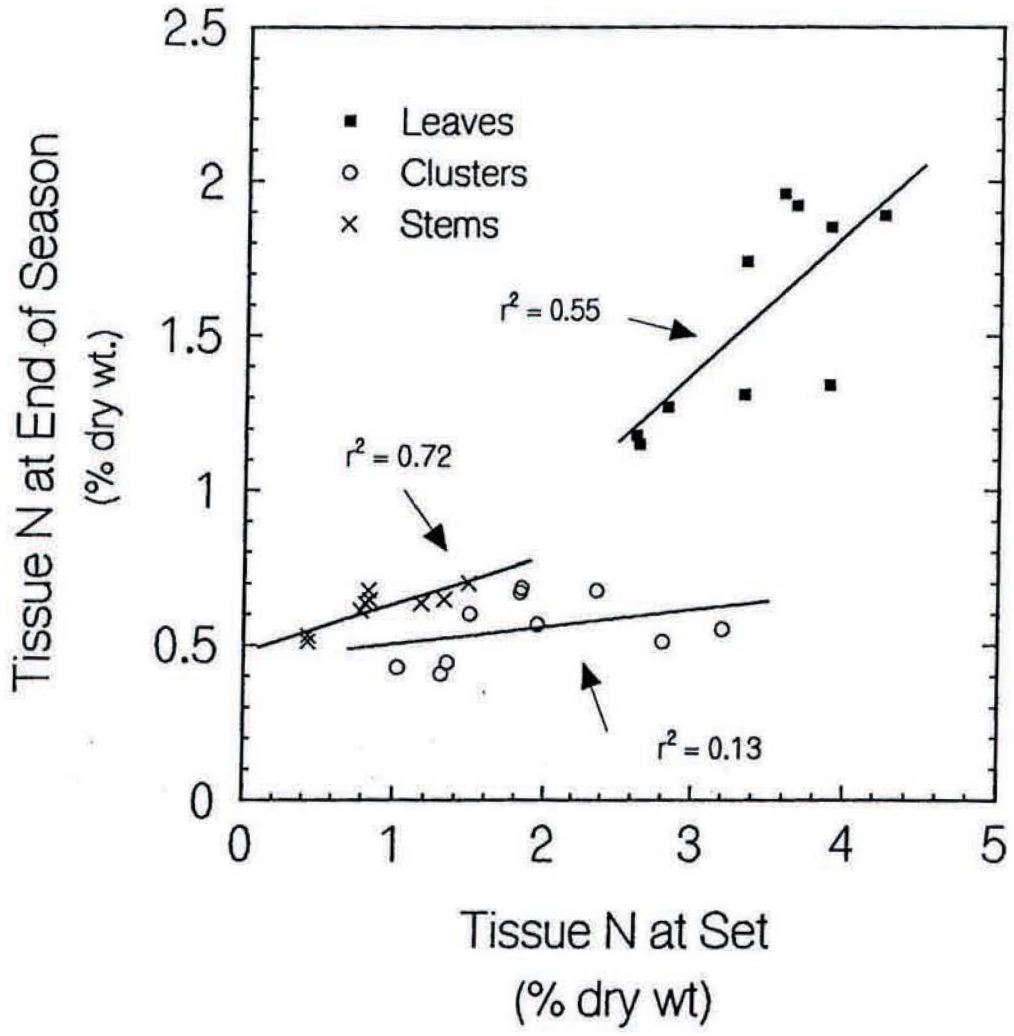

Figure 3. The relationship between organ nitrogen concentration determined at berry set and those organs harvested at the end of the growing season. Other information as found in Figures 1 and 2.

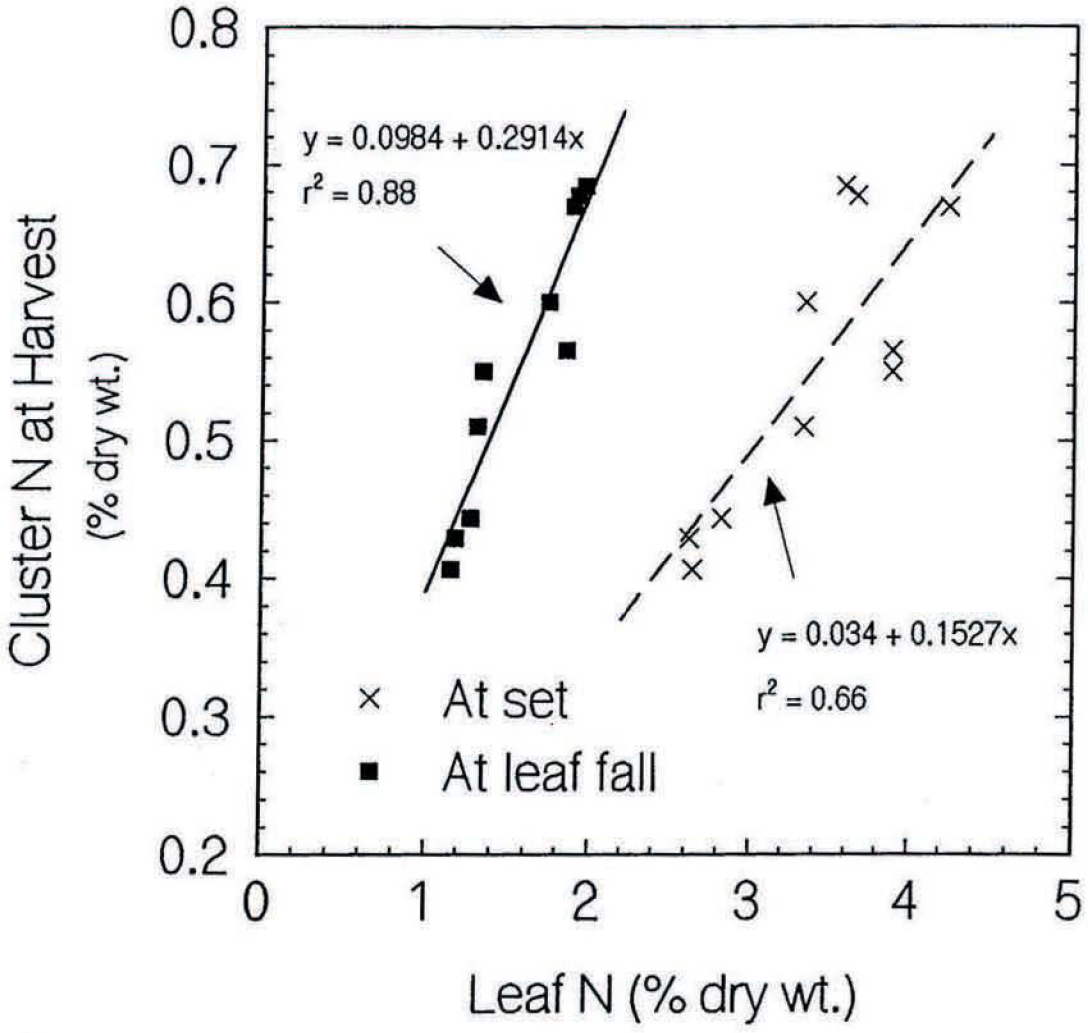

Figure 4. The relationship between leaf tissue nitrogen concentration (determined at berry set and leaf fall) and cluster nitrogen concentration at fruit harvest in 1997. Each data point represents the values obtained for individual rootstock/scion combinations at three of the experimental vineyard locations.

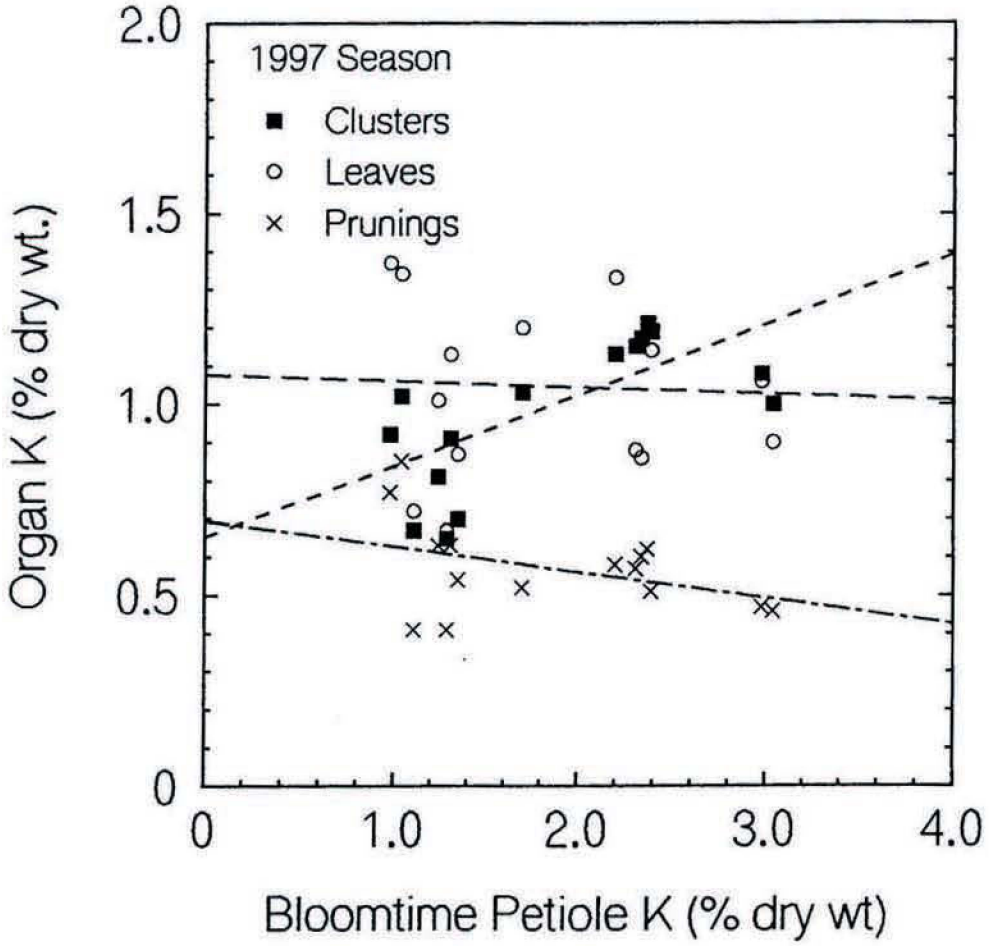

Figure 5. The relationship between bloom time petiole K concentration and the K concentration in the fruit at harvest, leaves as they fell from the vine and pruning canes collected during the dormant portion of the growing season. Data represent rootstock/scion combination at all of the experimental vineyards. The equation for the relationship between petiole K and cluster K is: $y = 0.635 + 0.185x$; $r^2 = 0.46$.