Final Report to the Eastern Viticulture Consortium
And NY Wine/Grape Foundation

Title – Effects of cultural practices on reserve nitrogen and carbohydrates and their roles in growth and development of Concord vines

Principal Investigators

Lailiang Cheng	Dept. of Horticulture, Cornell, Ithaca
Terence R. Bates	Dept. of Horticultural Sciences, Cornell, Geneva

Cooperators

Alan N. Lakso	Dept. of Horticultural Sciences, Cornell, Geneva
Martin C. Goffinet	Dept. of Horticultural Sciences, Cornell, Geneva
David M. Eissenstat	Dept. of Horticulture, Penn State University

Introductions

Both reserve nitrogen and carbohydrates are essential for vine growth and development in spring. Any environmental factors or cultural practices that alter supply-demand relationships of nitrogen and carbohydrates (cropload, pruning, environmental stress, and diseases and pests, etc.) will likely affect both reserve nitrogen and carbohydrate status of the vine, and consequently influence vine performance the following season. Compared with other grape-growing regions of the world, there is a very short leaf retention period after harvesting the crop (anywhere between a few days to 3 to 4 weeks) in the Northeast. Reserve nitrogen and reserve carbohydrates may become more important for vine performance the following season in the Northeast for two reasons. First, because photosynthesis is limited after harvest vines may not be able to accumulate enough reserve carbohydrates if environmental stresses have reduced carbon supply or demand from a heavy crop has exceeded the supply before harvest. Secondly, rapid drop of temperature or killing frost after harvest may significantly reduce or even stop mobilization of N from leaves back to the plants during leaf senescence and also decrease root activity for nitrogen uptake from the soil, leading to low reserve N status.

Developing a better understanding of how cultural practices affect both reserves and their roles in vine growth and development has important practical implications for improving viticulture practices. If vine growth and fruiting are mainly limited by carbohydrate reserves, cultural practices should be optimized to increase carbohydrate reserves. In contrast, if growth and fruiting are mainly determined by nitrogen reserves, nitrogen management directed at optimizing nitrogen storage would improve vine productivity. Over the last three years, we were focused on how vine growth and development were related to reserve N and carbohydrates using both field-grown vines at the Fredonia Vineyard Lab and the potted vines in sand culture at Cornell Orchards.

Objectives

The overall objectives are to gain a better understanding of how cultural practices affect reserve N and carbohydrates and their roles in vine growth and development, to identify limiting processes, and to design/modify cultural practices to improve productivity and fruit quality. The specific objectives are to determine:

1. effects of cultural practices (cropload, rate and method of nitrogen fertilization) on reserve N and carbohydrate levels and their relationships to growth and fruiting the following year;
2. effects of nitrogen fertigation during the growing season and foliar urea applications in the fall on levels and forms of N and carbohydrate storage and vine growth and fruiting the following year.
3. effects of early defoliation and foliar urea application prior to defoliation on vine N and carbohydrate reserves and vine performance.

Procedures

1. *Effects of cultural practices on reserve N and carbohydrates and vine performance.*

Effects of cropload, soil N fertilization, and foliar urea application on vine reserve nitrogen and carbohydrate status and vine performance the following year were investigated using field-grown mature Concord vines at the Fredonia Vineyard Lab.

(1) Cropload effects

A. Cropload experiment 2001: Dormant vines were hand-pruned and adjusted to 120 nodes/vine in January 2000. At 4 weeks after bloom, 10 vines were defruited by hand to estimate the full potential crop. Then, cropload was adjusted to 0, 25, 50, 75, and 100% of the full potential crop. This experiment consisted of 5 crop levels with 8 replicate vines at each crop level. This resulted in a crop load of 0 to 10.7 tons/acre at harvest in 2000. These vines were pruned to 120 nodes/vine in January 2001 for return crop evaluation.

B. Cropload/foliar urea experiment 2002: The objective was to determine the effect of foliar urea application on vine reserve N and carbohydrate levels and vine performance in relation to cropload. Dormant vines were hand-pruned and adjusted to 120 nodes/vine in January 2001. At 4 weeks after bloom, vines were defruited by hand to create a range of final cropload from 9.5 to 33 lb/vine. After harvesting the crop in the fall of 2001, vines with similar crop were paired. In each pair, one vine was sprayed with 3% urea (25 lb/100 gal at 200 gal/acre) twice (October 1 and 12) while the other served as a control. All the vines were pruned to 120 nodes/vine in January 2002 and their pruning weights were recorded. The 2002 crop was harvested on September 25.

(2) N rate experiment of Concord: Part of a long-term experiment at the Fredonia Lab known as the “West Tier” was adapted for this purpose. Vines have been fertilized at a rate of 0, 50, or 100 lb of nitrogen/acre for over 35 years. These vines had received balanced pruning in the past, but were converted to 100 nodes/vine since January 2001. In 2001, 2002 and 2003 pruning weights and crop yields were recorded.

(3) Foliar urea experiment: Mature own-rooted Concord vines received one of the following four N treatments: (1) no N application as control; (2) foliar urea sprayed twice at weekly intervals after harvesting (46 lb N/acre); (3) soil application of N in the spring (46 lb/acre); and (4) 50/50 split between fall foliar and spring soil application (46lbs/acre). All the vines were pruned to 120 nodes/vine and their pruning weights and crop yields were recorded.

(4) N rate experiment of Niagara vines: Niagara vines (planted in 1996) received 0, 50, 125 or 200 lb of nitrogen in split applications between budbreak and end of bloom.

Each treatment was replicated 4 times in a randomized complete block design. Vines were balance-pruned (20+20) in January 2002 and their pruning weights were recorded.

Representative cane samples were taken from all the above experiments before budbreak for reserve nitrogen and carbohydrate analysis. Tissue samples were frozen at –80C, freeze-dried, and then ground to pass 40 mesh. Nitrogen was determined by the Kjeldahl method. Soluble sugars were extracted with 80% ethanol, and then measured colorimetrically using phenol-sulphuric acid method. Starch was converted to glucose by amyloglucosidase, and then measured by phenol-sulphuric acid method. Total non-structural carbohydrates are the sum of starch and soluble sugars. Vine growth and return crop were evaluated each year to determine the relationship between reserves and vine performance.

2. *Determine the effect of N fertigation and foliar urea application on storage level and forms of nitrogen and carbohydrates and vine performance the following season.*

The objective of this experiment was to use N fertigation during the growing season and foliar urea application in the fall to differentially alter levels of reserve N and carbohydrates, and then determine their roles in vine performance the following season.

One-year-old vines were fertigated with 0, 5, 10, 15, or 20 mM nitrogen by using Hoagland's solution from June 22 to August 17 in 2001. There were 24 vines at each N fertigation concentration. Half of the vines at each N concentration were sprayed with 3% foliar urea twice (September 20 and 29) while the rest served as controls. After natural leaf fall, all the vines were moved to a cold room (2 to 4°C) for storage.

Four vines from each treatment were destructively sampled on March 26, 2002. Each vine was divided into one-year-old cane, shank, and roots. All the samples were frozen at –80 °C, freeze-dried, then ground to pass 40 screen. A composite sample was made for each vine based on its dry matter distribution among different parts to determine the chemical composition of nitrogen and non-structural carbohydrates. Free amino acids and protein amino acids were determined by using a Beckman amino acid analyzer as described in Cheng et al. (2004). Soluble sugars and starch were quantified with a Dionex HPLC (Cheng and Fuchigami, 2002).

The remaining vines were transplanted into an N-free medium in the spring. These vines were further divided into two groups. Starting from budbreak, one group received a 5 mM ^{15}N-ammonium nitrate in Hoagland's solution as the only N source. The other group were not supplied with any nitrogen but received all the other mineral nutrients. Leaf photosynthesis and berry set and development were monitored at regular intervals until fruit harvest. At 30 days after bloom, fruit was harvested and the vines were destructively sampled to determine total shoot growth, leaf area, total vine dry weight, and N content, then related vine performance to reserve levels of N and carbohydrates, and to current supply of nitrogen. For the vines that received ^{15}N-ammonium nitrate, the percentage of N derived from the labeled fertilizer (NDFF%) was calculated as (0.3663- tissue atom % ^{15}N) × 100% / (0.3663- fertilizer atom % ^{15}N).

3. *Determine the effect of early defoliation and foliar urea application prior to the defoliation on vine reserve status and performance.*

This experiment was initiated in the fall of 2002. The idea was that if the reduction in reserve carbohydrates caused by early killing frost were the main cause for the reduced growth in the spring, the defoliated vines would not show improved growth in the spring in response to foliar urea spray before the frost in the previous fall because foliar urea application increases reserve N but reduces reserve carbohydrate levels. In contrast, if reserve N were the limiting factor, vine performance would be improved by foliar urea application prior to frost. So, four treatments were used in this experiment: 1) Control; 2) 3% foliar urea sprayed twice at weekly intervals in mid to late September; 3) Manual leaf removal in early October; and 4) 3% foliar urea sprayed twice in mid to late September, followed by manual leaf removal in early October. Here, manual leaf removal is used to simulate early killing frost. There are 4 replications for each treatment with 3 vines in each plot in a completely randomized design.

One set of vines (4 vines) from each treatment were destructively harvested before budbreak in 2003 for reserve N and carbohydrate analysis. The remaining vines were further divided into two groups. Starting from budbreak, one group received 5 mM ^{15}N-ammonium nitrate in Hoagland's solution twice weekly from two weeks before bloom to 30 days after bloom. The other group were not supplied with any nitrogen but received all the other mineral nutrients from a modified Hoagland's solution. At 30 days after bloom, vines were destructively sampled and total leaf area, new shoot growth, and fruit yield were measured and related back to vine reserve nitrogen and carbohydrate levels.

Results and Discussions

1. Effects of cultural practices on reserve nitrogen and carbohydrates

(1) Effects of cropload

A. Cropload experiment 2001: Over the range of cropload examined, nitrogen and carbohydrate concentrations in cane tissues did not change significantly (Table 1). Both N and carbohydrate concentrations of roots tended to decrease as cropload increased, but only the vines in the two highest cropload treatments had significantly lower N content than those with no crop. When regression analysis was performed, root N content decreased linearly with increasing cropload (R^2 = 0.27, P < 0.01, graph not shown).

Table 1. Effects of cropload on reserve nitrogen and carbohydrates of mature Concord

Cropload 00 (T/acre)	*Cane N (%)*	*Cane CHO (%)*	*Root N (%)*	*Root CHO (%)*	*Periderm (#/vine)*	*Return crop 2001(T/acre)*
0	0.784a	10.94a	1.305a	18.47a	583a	8.66a
5.56±0.56	0.781a	11.40a	1.108ab	18.91a	481a	8.34a
6.07±0.46	0.764a	11.06a	1.121ab	17.12a	499a	7.50a
8.62±0.37	0.771a	10.31a	1.035b	15.92a	475a	7.29a
10.67±0.85	0.759a	11.12a	1.066b	16.10a	488a	8.02a

Cane and root samples were taken on April 4, 2001 before budbreak. Each number is mean of 8 replicates. Different letters indicate significant level at 0.05% by Tukey's studentized range test.

Ripe nodes of periderm tended to be higher in the no crop treatment than all the other treatments (P=0.06). There was no significant difference in return crop in year

2001 among different cropload treatments. This may be related to the overall poor fruit set in year 2001, which may have prevented the vines in the low cropload treatments from reaching a higher return crop.

B. Cropload/foliar urea experiment 2002: Although the cropload of individual vines varied from 9.5 to 30 lb in 2001 in response to cluster thinning, nitrogen content and carbohydrate concentration in cane tissues did not change significantly (Fig. 1). Postharvest foliar urea applications significantly increased N content of cane tissues from 0.827% to 0.913%. There was no significant difference in carbohydrate concentrations between the control and foliar urea treatments (14.58% vs. 14.02%). All the vines in this experiment had a good crop in year 2002 (38.8 lb/vine) regardless of the previous year's cropload and foliar urea applications.

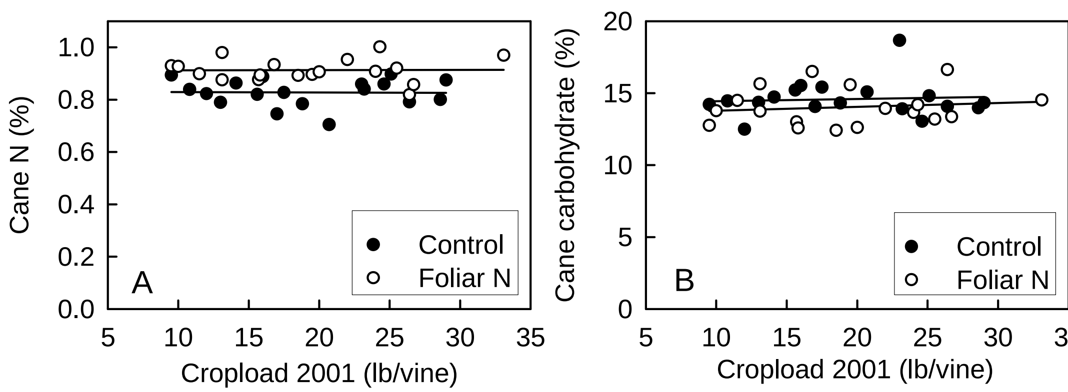


Fig. 1. Concentrations of nitrogen (A) and carbohydrates (B) in cane tissues of mature Concord vines in relation to cropload, as affected by foliar urea application.

(2) N rate experiment of Concord: Soil application of 50 lb nitrogen per acre in spring significantly increased cane reserve nitrogen concentration (Table 2). There was no difference in cane N concentration between 50 lb and 100 lb nitrogen treatments. Soil N application did not affect carbohydrate concentrations in cane tissues. Vine size, as indicated by pruning weight, increased as N rate increased. Therefore, total amount of both reserve nitrogen and carbohydrates was expected to increase with increasing N rate. Crop yield in year 2002 followed a similar pattern as pruning weight in response to N rate (Table 2). Data for reserve N, carbohydrates, vine pruning weight and yield in 2001 and 2003 were not presented as they showed similar trends as that of 2002.

Table 2. Soil N application on Concord reserve N and carbohydrates and yield (2002)

N rate (lb./acre)	*Cane N (%)*	*Cane CH_2O (%)*	*Pruning wt (lb/vine)*	*Crop yield 02 (lb/vine)*
0	0.75a	14.16a	1.52a	18.37a
50	0.83b	14.31a	2.61b	25.36b
100	0.87b	14.40a	2.49b	26.25b

Cane samples for reserve N and carbohydrate analysis were taken on April 11, 2002 before budbreak. Different letters indicate significant level at 0.05% by Tukey's studentized range test.

(3) Foliar urea experiment: Foliar urea applications after harvest significantly increased cane reserve nitrogen concentrations (Table 3, 4, 5). Cane reserve carbohydrate concentration was slightly lower in the foliar urea treatments. No significant difference in pruning weight or yield was observed among the four treatments.

Table 3. Effects of postharvest foliar urea applications on nitrogen and carbohydrate reserves and yield of mature Concord (2001)

*N application method**	*Cane N (%)*	*Cane CH_2O (%)*	*Yield 2001 (Ton/acre)*	*Brix*
Postharvest foliar urea twice	0.853a	9.281a	7.63a	16.9a
50/50 split (foliar urea/soil N)	0.793b	9.648a	8.14a	16.6a
Spring soil N application	0.738c	9.935a	7.45a	17.2a
No N application	0.743c	10.294a	7.59a	17.0a

*Cane samples were taken on April 4, 2001. By then, only foliar N was applied. Different letters indicate significant level at 0.05% by Tukey's studentized range test.

Table 4. Effects of postharvest foliar urea applications on nitrogen and carbohydrate reserves and yield of mature Concord (2002)

N application method	*Cane N (%)*	*Cane CH_2O (%)*	*Pruning wt (lb/vine)*	*Yield 2002 (lb/vine)*
Postharvest foliar urea twice	0.90ab	14.63a	2.35a	32.10a
50/50 split (foliar urea/soil N)	0.91a	15.49ab	2.38a	34.53a
Spring soil N application	0.84ab	15.91ab	2.50a	34.43a
No N application	0.76c	16.21b	2.13a	30.33a

*Cane samples were taken on April 11, 2002. Different letters indicate significant level at 0.05% by Tukey's studentized range test.

Table 5. Effects of postharvest foliar urea applications on nitrogen and carbohydrate reserves and yield of mature Concord (2003)

N application method	*Cane N (%)*	*Cane CH_2O (%)*	*Pruning wt (lb/vine)*	*Yield 2003 (lb/vine)*
Postharvest foliar urea twice	0.82a	10.97a	1.93a	39.78a
50/50 split (foliar urea/soil N)	0.76ab	11.10a	1.85a	40.50a
Spring soil N application	0.67b	11.61a	2.05a	43.70a
No N application	0.66b	11.23b	1.93a	40.25a

*Cane samples were taken on April 10, 2003. Different letters indicate significant level at 0.05% by Tukey's studentized range test.

(4) N rate experiment of Niagara: Compared with Concord, Niagara vines have much higher concentrations of carbohydrates (Table 6). This may be related to its

smaller vine size and earlier harvest, compared with Concords. Nitrogen application rate, ranging from 0 to 200 lb/acre, did not significantly affect cane N content, carbohydrate concentration or pruning weight. All vines had a heavy crop in 2002.

Table 6. N application on Niagara nitrogen and carbohydrate reserves and yield (2002)

N rate (lbN/acre)	*Cane N (%)*	*Cane CH_2O (%)*	*Pruning wt'01 (lb/vine)*	*Yield'02 (lb/vine)*
0	0.742a	21.57a	1.19a	39.65a
50	0.733a	20.20a	1.27a	39.61a
125	0.745a	19.67a	1.16a	40.69a
200	0.786a	19.52a	1.32a	37.16a

Cane samples were taken on April 11, 2002. Different letters indicate significant level at 0.05% by Tukey's studentized range test.

2. Effects of N fertigation and foliar urea application on reserve nitrogen and carbohydrates and vine performance the following season.

N content of the dormant vines increased slightly with increasing N fertigation concentration (Fig. 2A). Foliar urea applications significantly increased reserve N content across all five N fertigation concentrations. Carbohydrate concentration declined with increasing N fertigation concentration (Fig. 2B). Foliar urea applications decreased carbohydrate concentration to a similar level across the N fertigation concentrations.

Both concentrations of free amino acid-N and protein-N remained relatively stable across all the N fertigation concentrations except for a slight increase in the 20 mM N treatment (Fig. 3A). Foliar urea application in the fall increased the concentrations of free amino acid-N and protein-N at each N fertigation concentration. The C/N ratio of free amino acids was approximately 2, which was not affected by N fertigation or foliar urea application (Fig. 3B). In contrast, foliar urea application decreased the C/N ratio of proteins from 3.9 to 3.5 across the range of N fertigation concentrations. Compared with free amino acids, proteins had a much higher C/N ratio at each N level.

The ratio of N in proteins to that of free amino acids decreased curvilinearly from 13.5 to 10 as N supply from fertigation increased from 0 to 20 mM (Fig. 3C). Foliar urea application in the fall decreased the N ratio to about 7 across N fertigation concentrations. This indicates that free amino acids account for a larger proportion of the total N in vines at a higher N level, but proteins remain as the main form of storage nitrogen.

As N supplied from fertigation increased, the carbon in carbohydrates decreased slightly (Fig. 4A) whereas the carbon in proteins and free amino acids remained unchanged except a slight increase at the highest N concentration (Fig. 4B). Foliar urea application in the fall decreased the carbon in carbohydrates, but increased the carbon in proteins and free amino acids across the N fertigation treatments. The sum of carbon in proteins and free amino acids and carbohydrates did not change significantly in response to N fertigation (Fig. 4C). Foliar urea application in the fall slightly decreased the sum of carbon in total proteins and free amino acids and carbohydrates (Fig. 4C). Approximately 60% of the decrease in the carbon from carbohydrates caused by foliar urea application was recovered in proteins and amino acids.

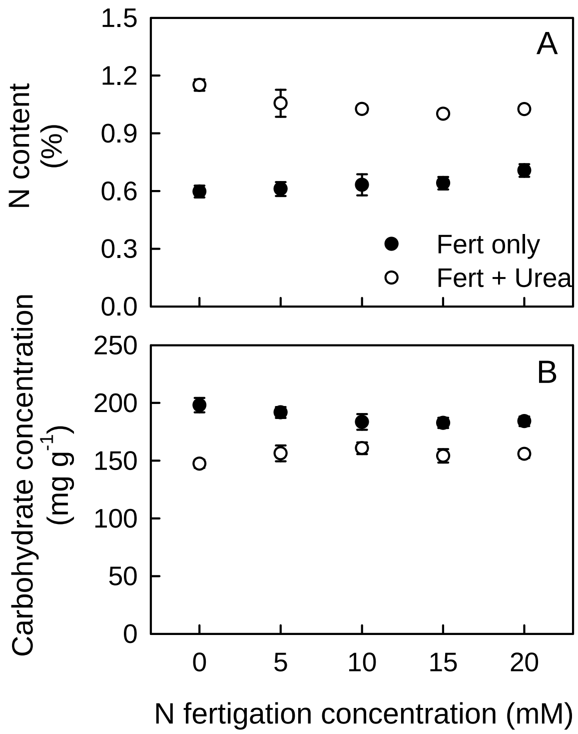
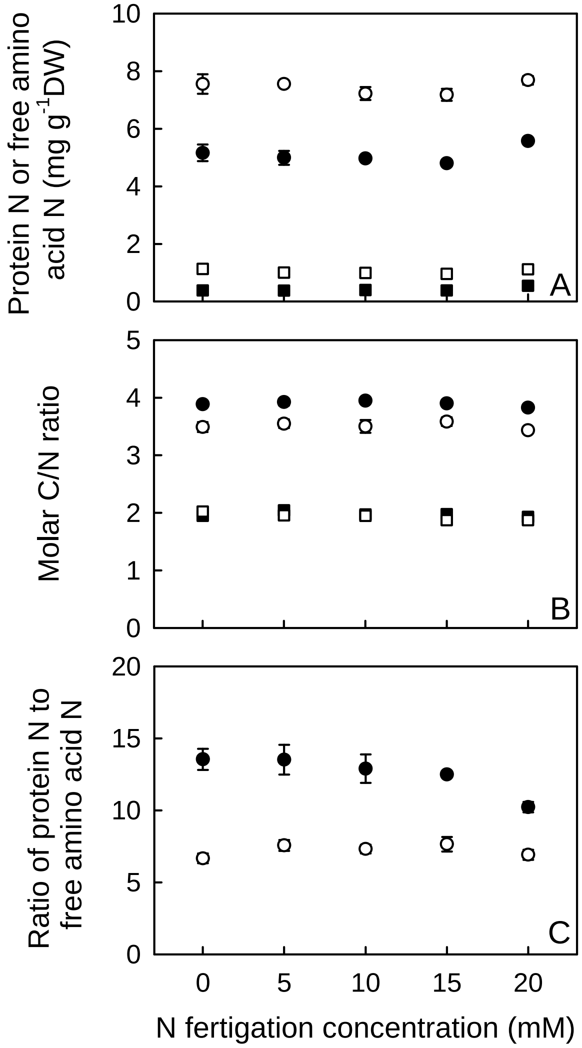


Fig. 2. Concentrations of nitrogen and carbohydrates of Concord vines in response to N fertigation and foliar urea applications.

On a whole vine basis, total amount of N increased with increasing N fertigation concentration (Fig. 5A). Total reserve carbohydrates increased with increasing N fertigation concentration first then leveled off with further rises in N supply from fertigation (Fig. 5B). Foliar urea applications increased total N reserves but decreased total carbohydrate reserves at each given N fertigation level.

Vine vegetative growth and fruiting responded to previous year's nitrogen treatments and current season's nitrogen supply. When no nitrogen was provided during the regrowth period, both vine total leaf area and yield increased with increasing N fertigation concentrations from the previous year (Fig. 6). Vines sprayed with fall foliar urea produced a larger total leaf area and a higher yield at each given N fertigation concentration. This corresponded well with the total N reserves at the beginning of the regrowth period. Providing vines with sufficient nitrogen during the regrowth period significantly increased total leaf area and fruit yield across the previous N fertigation concentrations. Vines with low N reserves responded more to current supply of nitrogen than those with high N reserves in terms of leaf area (Fig. 6A), but responded less in terms of yield (Fig. 6B). Nonetheless, vines sprayed with foliar urea still had a larger leaf area and a higher yield than those that did not receive foliar urea applications at each given N fertigation concentration. Because foliar urea applications did not affect vine dry weight at the end of the first growing season (Data not shown), this means that when vine size was the same, regardless of whether N was supplied during the regrowth period,



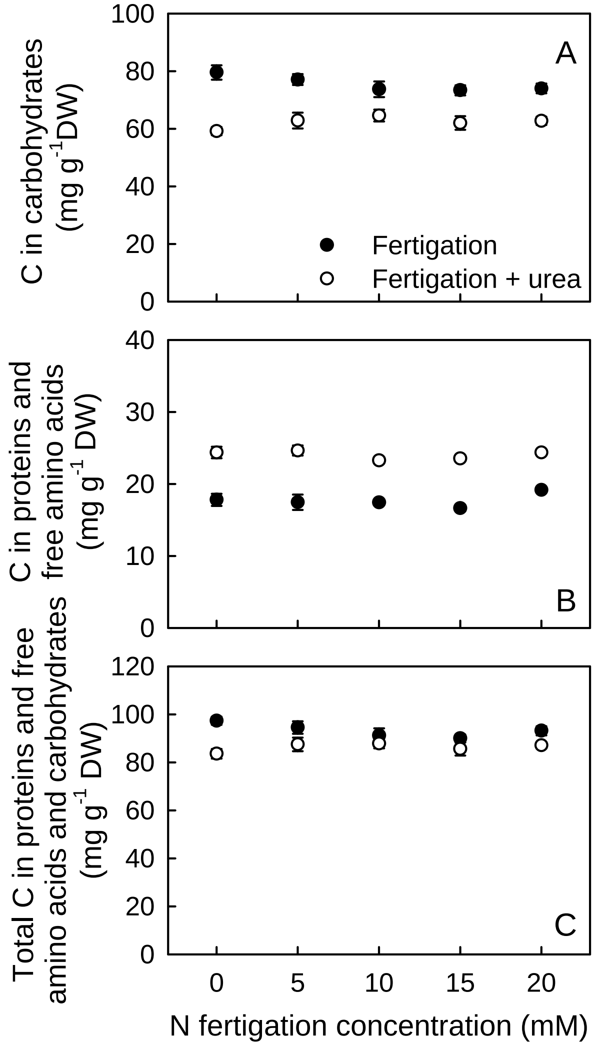
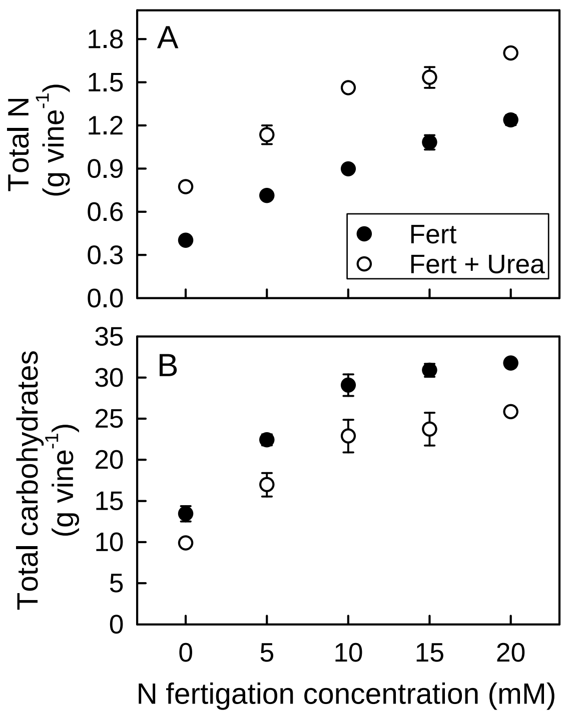


Fig. 3 (Left). Protein N or free amino acid N (A), molar C/N ration of proteins or free amino acids (B) and the ratio of protein N to free amino acid N of Concord vines in response to N fertigation and foliar urea applications. Solid circles or squares represent vines that were only fertigated whereas open circles or squares represent vines that also received foliar urea application. In A and B, circles denote proteins whereas squares are free amino acids.

Fig. 4 (Right). Carbon in total non-structural carbohydrates (A), carbon in proteins and free amino acids (B), and total sum of carbon in proteins and free amino acids and carbohydrates (C) of dormant Concord vines in response to nitrogen fertigation during the growing season and foliar urea application in the fall. Solid circles are vines that were only fertigated whereas open circles are vines that also received fall applications of foliar urea.

vines with higher N reserves but lower carbohydrate reserves had more new leaf growth and higher yields than those with lower N reserves but higher carbohydrate reserves.

The contribution of reserve N to shoot and leaf growth increased as N supply from previous N fertigation increased (Fig. 7A). Foliar urea application the previous fall increased this percentage contribution at each given N fertigation level. The contribution of reserve N to fruit showed a similar trend as that of shoots and leaves, but the actual percentage is much lower in the fruit than in the shoots and leaves (Fig. 7B). This indicates the current season's N supply contributes more to fruit growth than to shoots and leaves, which may explain why providing sufficient N supply during the current season had such a large effect on fruit yield (Fig. 6B).



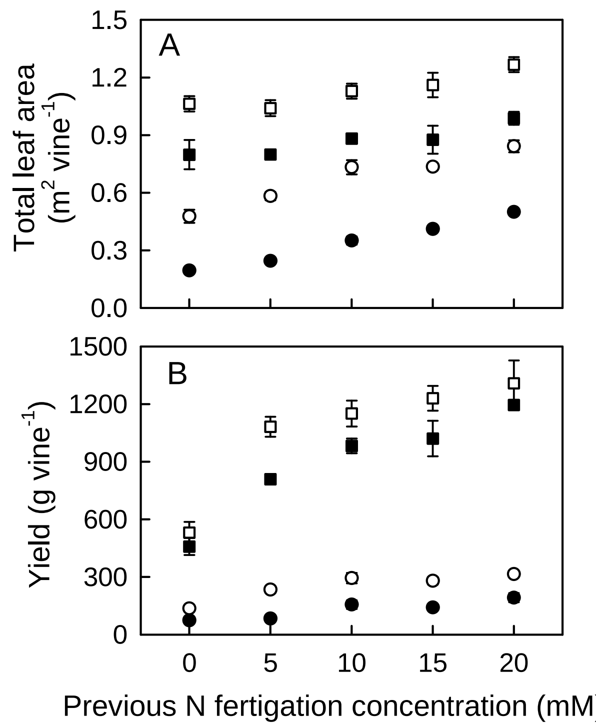


Fig. 5 (Left). Total nitrogen (A) and carbohydrates (B) of Concord vines in response to N fertigation and foliar urea applications.

Fig. 6 (Right). Total leaf area (A) and fruit yield (B) of Concord vines at the end of the regrowth period in relation to N fertigation concentrations and foliar urea applications during the previous year and the current season's nitrogen supply. Circles represent vines that did not receive any nitrogen during the regrowth period whereas squares represent vines that received 10 mM N supply. Solid circles or squares represent vines that were only fertigated whereas open circles or squares denote vines that also received foliar urea application during the previous year.

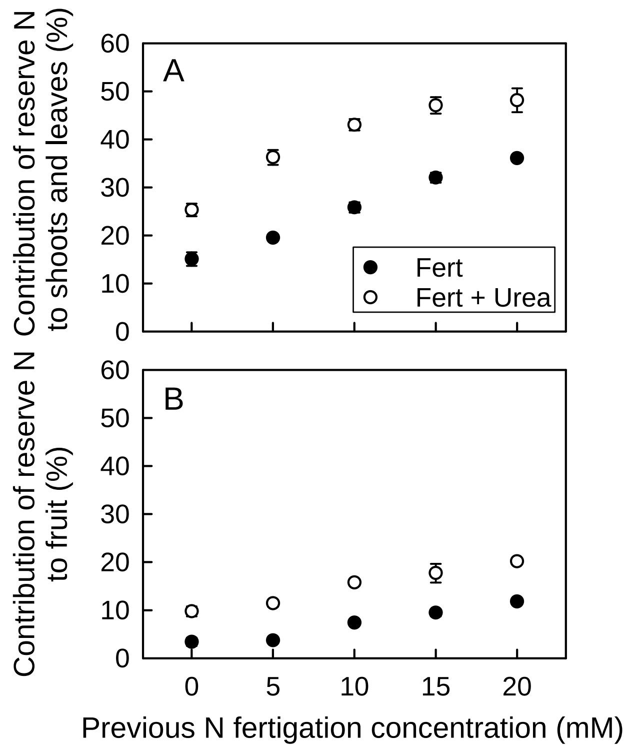


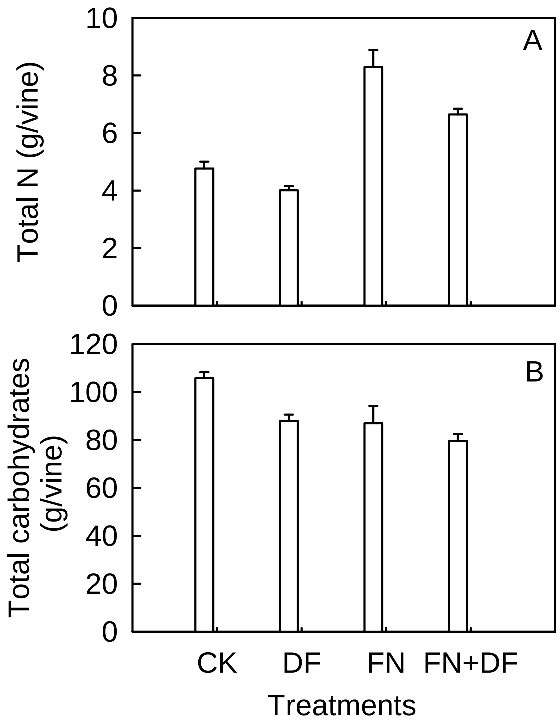
Fig. 7. Contribution of reserve nitrogen to shoots and leaves (A) and fruit (B) in relation to previous year's N fertigation and foliar urea applications.

3. *Effect of early defoliation and foliar urea application prior to the defoliation on reserve nitrogen and carbohydrates and vine performance the following year*

Manual defoliation in the fall significantly decreased both total nitrogen and total carbohydrates in the vine (Fig. 8). Foliar urea application increased the total amount of nitrogen, but decreased the total amount of carbohydrates.

Regardless of whether N was provided or not in the current season, defoliated vines had a smaller total leaf area than non-defoliated vines (Fig. 9A). Vines sprayed with foliar urea the previous fall had a larger leaf area than those that did not receive foliar urea application. Supplying sufficient nitrogen in the current season also significantly increased total leaf area.

When no nitrogen was provided in the current season, defoliated vines had lower fruit yield than the non-defoliated vines (Fig. 9B) and vines sprayed with foliar urea had a higher fruit yield than the ones that did not received foliar urea. Providing sufficient nitrogen the current season significantly increased fruit yield across all the treatment combinations. Vines sprayed with foliar urea still had a higher yield than those that did not receive foliar urea application, but there was no statistical difference in fruit yield between defoliated vines and non-defoliated vines.



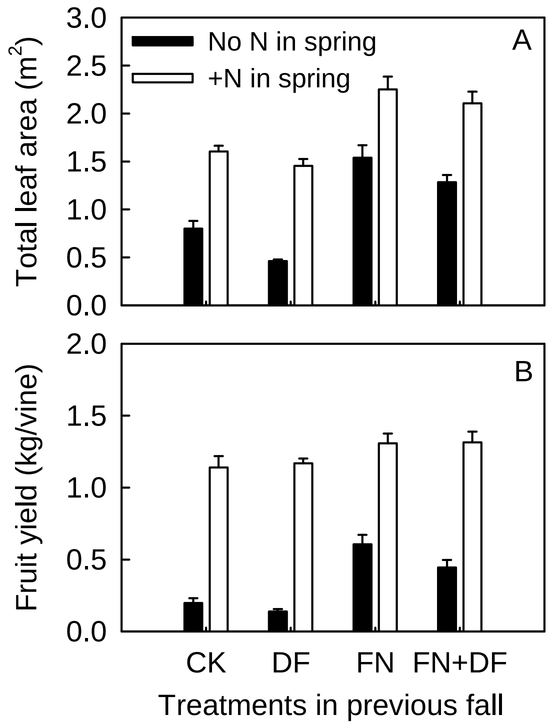


Fig. 8 (Left). Effects of manual defoliation and foliar urea application in the fall on total nitrogen and carbohydrates of 3 year-old Concord vines. CK: Control; DF: manual defoliation; FN: foliar urea application; FN+DF: foliar urea application followed by manual defoliation.

Fig. 9 (Right). Total leaf area (A) and fruit yield (B) of Concord vines at the end of the regrowth period under no N supply (solid bars) or 10 mM N supply (empty bars) in the current season.

These data indicate that (1) regardless of current N supply, both vegetative growth and fruiting are determined by reserve nitrogen not by reserve carbohydrates; and (2) the current season's N supply plays an important role in determining fruit yield.

Summary and Conclusion

Both soil N application in the spring and foliar urea application after harvesting improved reserve N status of field-grown vines. Although vine reserve carbohydrate concentration was not significantly altered by cropload or N applications, cropload or N application may have an indirect effect on its total amount via vine size.

Reserve nitrogen and carbohydrates of potted vines in sand culture responded differentially to N fertigation during active vine growth and foliar N applications in the fall. As N supply from fertigation increased during the growing season, vine growth and N reserves increased, but reserve carbohydrate concentration decreased. Foliar urea application in the fall increased N reserves, but decreased carbohydrate reserves.

Regardless of the current N supply during the spring, vines with higher N reserves but lower carbohydrates reserves had a larger leaf area and a higher yield than those with lower N reserves but higher carbohydrate reserves. Manual defoliation/foliar urea experiment also showed that vines with higher N reserves but lower carbohydrate reserves in the foliar N treatment had a larger leaf area and higher fruit yield than those that did not receive foliar N application. Therefore, we conclude that vine growth and fruiting are mainly determined by nitrogen reserves. There were high concentrations of reserve carbohydrates accumulated in the vines with low reserve nitrogen, but these vines can not make the best use of the reserve carbohydrates to support the new growth unless additional nitrogen was provided. Our results also indicated that current season's N supply plays a very important role in vine growth and development, especially for fruit growth.

Future research is needed (1) to determine the role of current N supply in fruit growth and development; (2) Uptake of nitrogen during the current season and the contribution from each of the three supply sources (reserve N, soil N and fertilizer N) to the vine N economy of mature vines in the field.

References

Cheng, L. and L. H. Fuchigami 2002. Growth of young apple trees in relation to reserve nitrogen and carbohydrates. *Tree Physiology* 22: 1297-1303.

Cheng, L., F. Ma and D. Ranwala. 2004. Nitrogen storage and its interaction with carbohydrates of young apple trees in response to nitrogen supply. *Tree Physiology* 24: 91-98.