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To the Viticulture Consortium-Eastern Grants Program and NY Wine/Grape Foundation

Title: Nitrogen uptake, partitioning and utilization of Concord grapevines

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Introduction

Concord growers must achieve and sustain high yields of quality fruit with environmentally sound practices to remain competitive in both domestic and international markets. Producing high yields of quality fruit requires optimal vine nutrition, especially for nitrogen. This is because the natural supply of soil N often does not provide enough N to produce a vine that is big enough to intercept sufficient sunlight for a high yield. However, available nitrogen is highly leachable. Too much nitrogen fertilization not only causes excessive vegetative growth that predispose the vine to freezing injury and disease problems but also increases the chances of nitrate leaching into the environment.

To optimize nitrogen use in Concord production, the N demand-supply relationship throughout the season must be understood first. In general, grapevines have a high demand for nitrogen from two weeks before bloom to veraison to support rapid shoot growth, leaf area development and berry growth. On the supply side, there are three sources. First is reserve nitrogen that has accumulated in the vine from the previous growing seasons. This source of nitrogen is readily available for initial shoot growth and further development of flowers during spring. The second source is the natural N supply from the soil mineralization process. The capacity of this source depends on soil organic matter, soil temperature, and soil moisture conditions. The third is fertilizer nitrogen applied to the soil or to the foliage. Effective N management also requires a good understanding of N uptake, partitioning and utilization, which provides the basis for targeting N fertilization to the vine needs while improving fertilizer use efficiency. Although work has been done on vinifera grapes in California and South Africa, the annual N requirement of mature Concord vines and the contribution from each of the three sources and N uptake efficiency, partitioning and utilization under New York soil and climate conditions remain unknown.

We have taken an approach of combining whole-vine destructive harvesting with the use of ^{15}N labeled fertilizer to study the demand-supply relationship, and uptake, partitioning and utilization of nitrogen in Concord vines under NY climate and soil conditions.

Objectives

The overall objectives are to determine nitrogen requirements, the contribution of each of the three supply sources to the total vine N economy, and fertilizer N uptake, partitioning and utilization with an ultimate goal to sustain high yields of quality fruit while improving nitrogen use efficiency in Concord vineyards. The specific objectives are to determine:

1. Nitrogen accumulation patterns in different organs of mature 'Concord' vines over the entire growing season and fertilizer N uptake and contribution to vine N economy.
2. Timing of nitrogen fertilizer application on fertilizer nitrogen uptake.
3. The N requirement for new growth (shoots, leaves and fruit) and the contribution of reserve N, natural soil N supply, and fertilizer N in field-grown mature vines throughout the growing season;
4. Effects of N supply before and after veraison on vine growth, yield, and contribution of current uptake to the total N economy of 'Concord' vines.
5. Effects of N supply on berry growth and the dependence of both root and foliar uptake of fertilizer N during the postharvest period on vine N status at harvest.

Procedures

1. Determine nitrogen supply-demand relationship, uptake and partitioning, and N use efficiency under NY climate and soil conditions

Use of isotopically-labeled ^{15}N fertilizer and sequential destructive harvesting of whole vines were employed to determine supply-demand relationships, contribution of fertilizer nitrogen to the overall nitrogen economy, and nitrogen uptake efficiency of field-grown mature 'Concord' vines.

The total amount of N in the vine during dormancy was assessed in April of 2003 before budbreak by destructively harvesting of 5 mature vines. At budbreak, ^{15}N-enriched ammonium nitrate were used at a rate of 50 lbs/acre to provide the only source of fertilizer N. Five entire mature Concord vines were excavated at each of 8 physiologically important stages over a full year, i.e. budbreak, 10-inch shoots, bloom, 15 and 30 days after bloom, veraison, harvest, and dormancy. Each vine was divided into thin and coarse roots, shank and trunk, cordons, canes, shoots, leaves and fruit. The samples were oven-dried for dry weight, and then ground for total N and ^{15}N analyses in each organ type. Based on the dry weight of each organ type, the concentrations of total N, seasonal patterns of N accumulation were determined. Fertilizer N uptake pattern, uptake efficiency, partitioning pattern, and contribution of fertilizer N to total vine N economy were calculated according to the amount of N derived from fertilizer in each organ type.

2. Timing of nitrogen fertilizer application on nitrogen uptake

A total 20 mature Concord vines were divided into 4 groups with 5 vines each. Each group received the same 50 lbs actual nitrogen as ^{15}N-ammonium nitrate at budbreak, 2 weeks before bloom, two weeks after bloom or a split equally between two weeks before and after bloom in 2005. At fruit harvest, the entire vines were excavated and each vine was partitioned into thin and coarse roots, shank and trunk, cordons, canes, shoots, leaves and fruit. The samples were oven-dried for dry weight, and then ground for total N and ^{15}N analyses in each organ type. Total nitrogen fertilizer uptake was calculated based on dry weight, nitrogen content and ^{15}N content.

3. Determine the N requirement for new growth (shoots, leaves and fruit) and the contribution of reserve N, natural soil N supply, and fertilizer N in field-grown mature vines

A total of 36 uniform, mature vines were selected and divided into two groups: group A and group B with 18 vines in each group. During the spring of 2003, group A received ^{15}N-enriched ammonium nitrate at a rate of 50 lb N/acre, while group B received regular ammonium nitrate at the same rate. All the vines were pruned to 100 nodes. After leaf fall in November 2003, 3 vines from group A were excavated to determine ^{15}N abundance and this was used to calculate the contribution of reserve N to new growth in 2004. At budbreak in 2004, group A received regular N supply at 50 lb/acre while group B received ^{15}N-enriched ammonium nitrate at

the same rate. At 10 inch shoot, bloom, 30 days after bloom, veraison and harvest, the new growth of 3 vines each from group A and group B were destructively sampled to determine dry weight, concentrations of total N and ^{15}N. The N requirement of the new growth and the contribution from reserve N, natural supply of N from soil, and fertilizer N were determined.

4. Determine the effect of N supply before and after veraison on vine growth, yield, and contribution of current uptake to the total N economy of Concord vines.

Concord grapevines require large amounts of N during the two periods of high demand: from two weeks before bloom to end of shoot growth and from veraison to harvest. The contribution of N absorbed during each of the two periods has not been studied with Concord, yet this information is important for optimizing N fertilization. Use of potted Concord vines in sand culture and ^{15}N-labeled fertilizer allowed us to quantify the contribution of N absorbed during a specific period to the total vine N economy.

Three-year-old own-rooted Concord vines grown in 38-liter containers in sand received one of the following 4 treatments: (1) normal N supply before veraison and normal N supply from veraison to harvest; (2) low N supply before veraison and normal N supply from veraison to harvest; (3) Normal N supply before veraison and low N supply from veraison to harvest; (4) low N supply before veraison and low N supply from veraison to harvest. For each treatment, a total of 10 vines were used: 5 vines received regular N supply before veraison and ^{15}N-labeled N supply from veraison to harvest while the other 5 vines received ^{15}N-labelled N supply before veraison and regular N supply from veraison to harvest. Each vine received 2 liters of 10 mM (normal) or 2.5 mM (low) N supply twice weekly for the N treatments. At the time of switching N supply between regular and ^{15}N-labeled N, pots were thoroughly washed with water. At fruit harvest, the whole vine were excavated and each were divided into fruit, shoots and leaves, one-year old canes, two-year-old canes and roots. All the samples were oven-dried and ground for total N and ^{15}N analysis. Effects of N supply on vine growth and fruiting and the contribution of N supply during each period were determined.

5. Determine the effect of N supply on berry growth and fruit quality and the dependence of both root and foliar uptake of fertilizer N during the postharvest period on vine N status.

The objectives of this experiment were (1) to understand how nitrogen supply throughout the growing season affects berry growth, veraison, yield and quality; and (2) to determine how vine N status at harvest affects both root and foliar uptake of nitrogen for storage.

Four-year-old own-rooted 'Concord' vines grown in 38-liter containers in sand received 2.5 mM, 12.5 mM or 25 mM N supply from two weeks before bloom to harvest. Shoot growth, leaf area development, and berry growth were monitored at regular intervals throughout the growing season. Berry samples were taken at regular intervals to measure berry weight, soluble sugars and organic acids. Veraison time was recorded for each N treatment. At harvest, one set of vines from each N treatment were destructively sampled to determine total dry weight, total leaf area and total nitrogen. Nitrogen concentrations and free amino acid concentrations in both leaves and roots were measured to indicate vine N status at harvesting. The remaining vines in each N treatment were divided into 3 groups. Group A received no nitrogen from harvest to leaf fall; group B received one spray of 2% foliar ^{15}N-enriched urea; and group C received one soil application of 10 mM N from ^{15}N-enriched ammonium nitrate. All the vines were netted and fallen leaves were collected during leaf senescence process. After leaf fall, the whole vines were excavated. All the vine parts were separated and oven-dried to measure total dry weight, total nitrogen and ^{15}N. The total uptake of ^{15}N-fertilizer and uptake rate were calculated and related back to vine N status at harvesting.

Results and Discussions

1. *Nitrogen accumulation, fertilizer nitrogen uptake and partitioning, and N use efficiency under NY climate and soil conditions*

Total dry matter and total N in mature Concord vines did not change significantly from budbreak to bloom (Fig. 1A and 1B). Starting from bloom, both total dry matter and total N increased as the season progressed. Total dry matter reached its maximum at harvest whereas total vine N reached its maximum at veraison with no further increase from veraison to harvest. After leaf fall and pruning, both total dry matter and total vine N returned to essentially the same level as the vine had at budbreak (Fig. 1A, 1B). The total N lost in harvested fruit, fallen leaves and prunings was approximately 40 g/vine, which is equivalent to 50 lb per acre.

Uptake of fertilizer N was low between budbreak and 10 inch shoot growth, indicating reserve N was the primary source for the new growth during this period (Fig. 1C). Fertilizer uptake increased from 10 inch shoots to bloom. At bloom, uptake of fertilizer N contributed about 7% to the total vine N (Fig. 1D). Uptake of fertilizer N continued to increase until veraison, reaching a maximum of 9 gram nitrogen per vine, which corresponds to a fertilizer uptake efficiency of approximately 25%. At harvest, fertilizer nitrogen contributed about 11% to the total vine N.

Dry weight of shoots and leaves increased slowly from budbreak to 10 inch shoots, then very rapidly until 30 days after bloom, followed by a slow rise from veraison to harvest (Fig. 2A). Dry weight of fruit increased almost linearly from 2 weeks after bloom to harvest.

Total N in shoots and leaves increased rapidly from 10 inch shoots to 30 days after boom whereas total N in fruit increased almost linearly from bloom to veraison (Fig. 2B). Both total nitrogen in shoots and leaves and that in fruit reached their maxima at veraison, with a slight decrease observed at harvest (Fig. 2B). Fertilizer N in shoots and leaves and that in fruit showed a similar pattern as their total N. The contribution of fertilizer N to shoots and leaves and fruit increased from budbreak to bloom, then remained at approximately 15% from bloom to harvest (Fig. 2D).

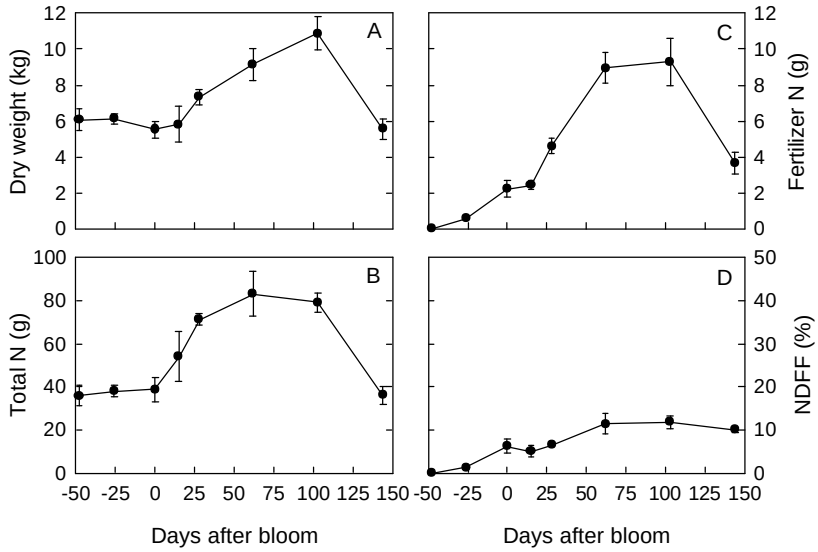


Fig. 1. Total vine dry weight (A), total vine N (B), uptake of fertilizer N (C), and contribution of fertilizer N to total vine N (D) of mature Concord vines fertilized with 50 lb N as ^{15}N-enriched ammonium nitrate at budbreak. NDFF: nitrogen derived from fertilizer

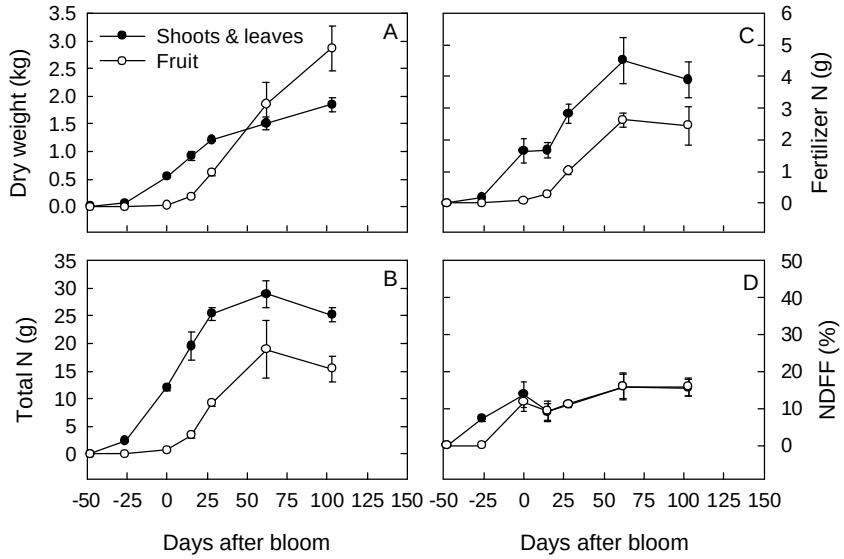


Fig. 2. Dry weight (A), total N (B), fertilizer N (C) in shoots and leaves and fruit and contribution of fertilizer N to total N in shoots and leaves and fruit (D) of mature Concord vines fertilized with 50 lb N as ^{15}N-enriched ammonium nitrate at budbreak.

2. Effect of timing of nitrogen fertilizer application on nitrogen uptake

The total uptake of fertilizer nitrogen and fertilizer nitrogen uptake efficiency by mature Concord vines from the time of N application to fruit harvest increased as the application time was delayed from budbreak to 2 weeks after bloom (Table 1). Split application between 2 weeks before and after bloom appears to have similar total uptake as the application at 2 weeks before bloom. The N uptake efficiency in this experiment was lower than in Experiment 1. We think this overall low nitrogen uptake efficiency is due to the very dry conditions in the 2005 growing season.

Table 1. Effect of timing of N fertilizer application on total uptake and uptake efficiency of mature Concord vines. Vines were excavated at fruit harvest.

Timing of application	*Total uptake (g N/vine)*	*Uptake efficiency (%)*
Budbreak	3.65 ± 0.41	9.74 ± 1.08
2 wks before bloom	5.33 ± 0.12	14.21 ± 0.31
Split application	5.33 ± 0.51	14.20 ± 1.37
2 wks after bloom	6.05 ± 0.48	16.12 ± 1.28

3. Determine the N requirement for new growth (shoots, leaves and fruit) and the contribution of reserve N, natural soil N supply, and fertilizer N in field-grown mature vines

Total dry matter of new growth (leaves, shoots and fruit) of mature Concord vines increased linearly from two weeks before bloom to harvest (Fig. 3A). Dry weight of shoots and leaves increased rapidly from 2 weeks before bloom to veraison, then leveled off from veraison to harvest; dry matter of fruit increased curvilinearly from bloom to harvest (Fig 3A). At harvest, more dry matter was in fruit than in leaves and shoots combined. N concentration in leaves,

shoots and fruit all decreased from 2 weeks before bloom to harvest, with leaves having the highest N concentration and shoots the lowest (Fig. 3C).

Total N in new growth (leaves, shoots and fruit) increased from 2 weeks before bloom to veraison, with no further increase from veraison to harvest (Fig 3B). Total N in shoots and leaves increased rapidly from 10 inch shoots to 30 days after boom, then leveled off whereas total N in fruit increased almost linearly from bloom to harvest (Fig. 3B).

The percent contribution of reserve N to the new growth (leaves, shoots and fruit) was the highest at the beginning of the season, then decreased to about 40% at harvest (Fig. 3D); The percent contribution of natural N supply from soil and fertilizer N showed similar trends. Both increased rapidly from two weeks before bloom to bloom, then slowly increased from bloom to harvest. At harvest, fertilizer N contributed about 20% to the total N in the new growth whereas the contribution from the natural supply of soil N was about 40%. No significant difference was found in the percent contribution of each N source (reserve N, soil N or fertilizer N) between leaves, shoots and fruit (Data not shown)

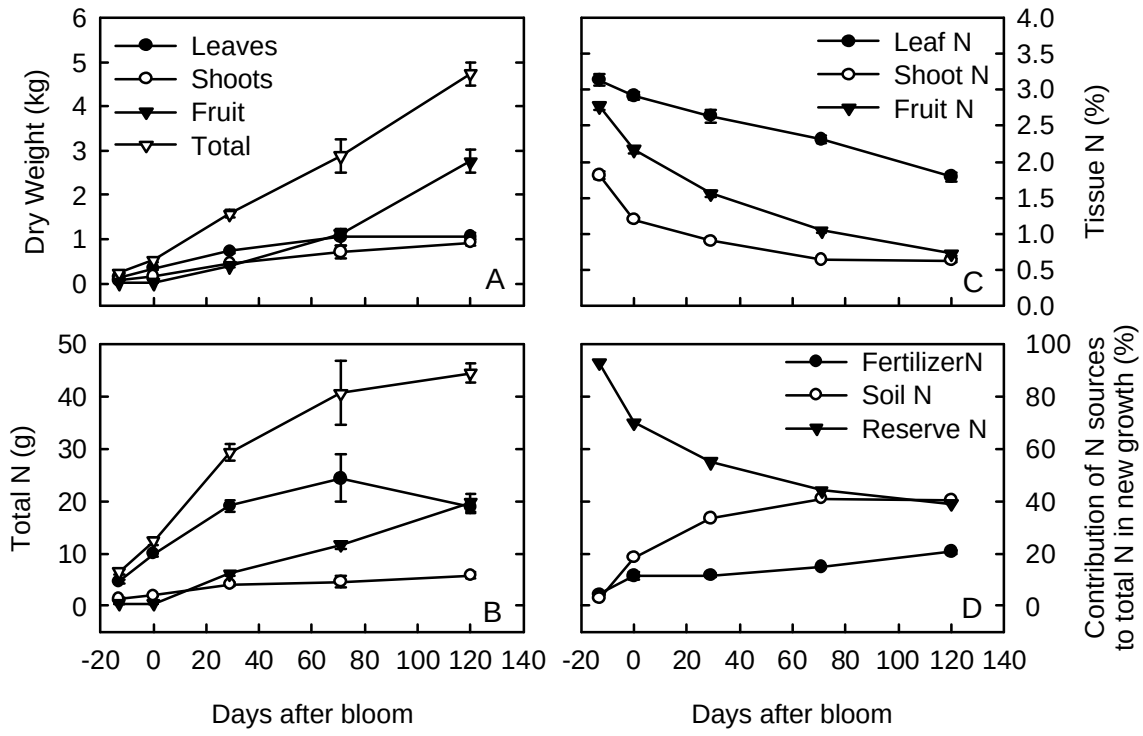


Fig 3. Dry weight of new growth (A), total N in new growth (B), tissue N concentration (C), and contribution of three N sources to total N in new growth (D) of mature Concord vines fertilized with 50 lb N as ^{15}N-enriched ammonium nitrate at budbreak.

4. *Effects of N supply before and after veraison on vine growth, yield, and contribution of current N uptake to the total N economy of Concord vines.*

Vines supplied with low N before veraison had significantly lower shoot growth, total leaf area and total dry matter compared with those grown under normal N supply (Fig. 4A, B). Changing nitrogen supply after veraison did not affect total shoot growth, total leaf area or total dry matter.

Total fruit yield and berry size were significantly lower in vines supplied with low N before veraison than in vines grown under normal N supply (Fig. 4C, D). Fruit soluble solid content was about 1 brix lower in the vines supplied with low N before veraison (Data not shown). Altering N supply after verasion did not significantly affect fruit yield or fruit soluble solids (Data not shown).

Total vine nitrogen at harvest was lowest in vines supplied with low N before and after veraison and highest in vines grown under normal N supply for the entire season; vines supplied with normal N before veraison and low N after veraison have high total N than the vines supplied with low N before veraison and normal N after veraison (Fig. 5)

Less nitrogen was partitioned to leaves and fruit whereas more nitrogen was partitioned to roots in vines supplied with low N before veraison compared with those receiving normal N supply (Fig. 6). Changing N supply after veraison did not significantly alter nitrogen partitioning. Partitioning of dry matter to leaves, fruit and roots showed similar patterns as that of nitrogen (Fig. 6). Compared with nitrogen partitioning, however, leaves accounted for a much lower proportion of the total vine dry matter whereas fruit have a much higher proportion of the dry matter (Fig. 6A, 6B).

Uptake of fertilizer nitrogen depends on the timing and level of N supply (Fig 7). For the same period (before or after veraison), vines supplied with low N took up less fertilizer N than those supplied with normal N. For vines that were supplied with either low or normal N level during the entire season (both before and after veraison), uptake from the pre-veraison period was more than the post-veraison period. The contribution of fertilizer nitrogen to the total vine economy showed similar trends as uptake of fertilizer N.

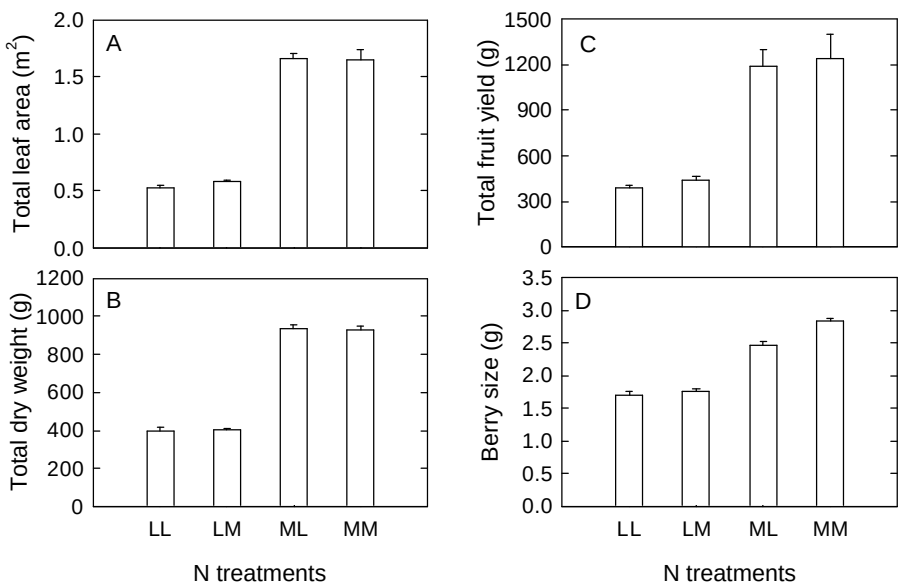
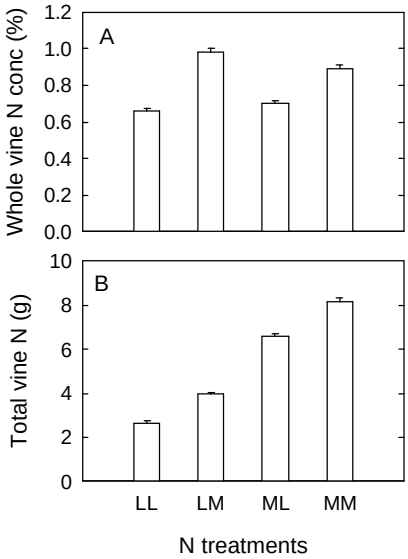


Fig. 4. Total leaf area (A), total dry weight (B), total fruit yield (C) and average berry weight (D) of Concord vine at harvest in response to N supply before and after veraison. L: Low N supply; M: Normal N supply.



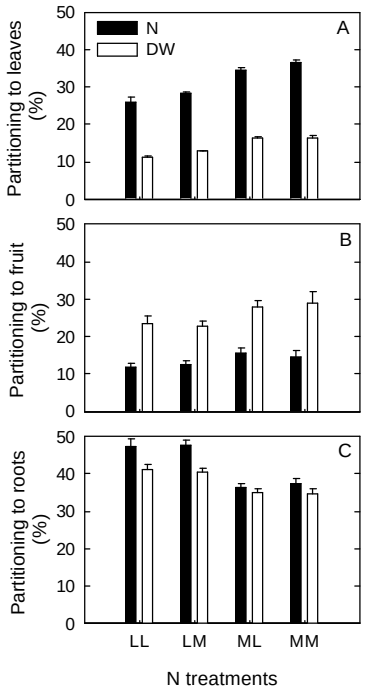


Fig. 5 (Left). Average vine N concentration (A) and total vine N and dry matter (B) at harvest in response to N supply before and after veraison. L: Low N supply; M: Normal N supply.

Fig. 6 (Right). Partitioning of nitrogen and dry matter to leaves (A), fruit (B), and roots (C) at harvest in response to N supply before and after veraison. L: Low N supply; M: Normal N supply.

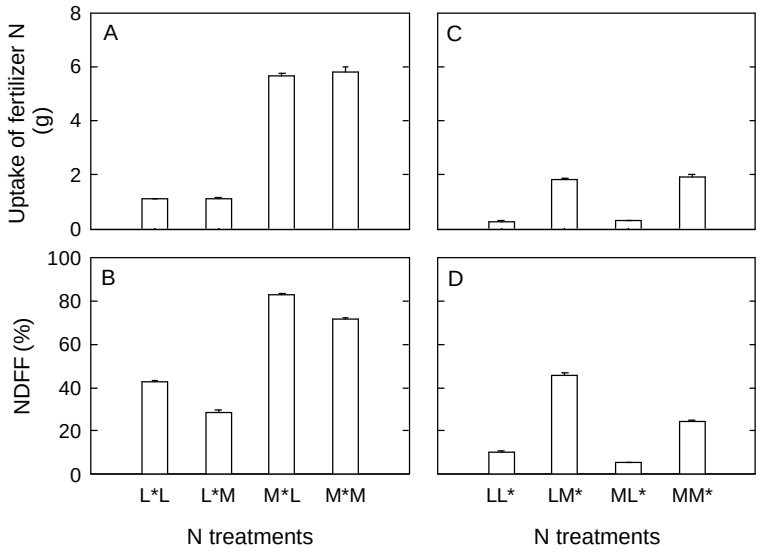


Fig. 7. Uptake of fertilizer N (A, C) and contribution of fertilizer N to total vines N (B, D) in response to N supply before and after veraison. L: Low N supply; M: normal N supply. Asterisk indicates the period during which ^{15}N-enriched ammonium nitrate was supplied.

5. Effects of N supply on berry growth and the dependence of both root and foliar uptake of fertilizer N during the postharvest period on vine N status.

Vines in the low N treatment had significantly lower shoot growth (data not shown), total leaf area and total fruit yield compared with those grown under the medium or high N supply (Fig. 8). Fruit growth was significantly lower in the low N treatment than in the medium or high N treatment throughout the berry growth period (Fig 9). Veraison was delayed for 6 days in the low N vines compared with those grown under medium or high N supply. At harvest, average berry weight of the low N vines was about half of that in the medium or high N vines. Fruit soluble solid content was about 1.5 brix lower in the low N vines compared with the medium or high N vines (data not shown). Berry carbohydrates and organic acids are still being analyzed.

At fruit harvest, leaf N concentration and concentrations of free amino acids were lower in the low N vines than in the medium or high N vines (Fig 10A). Uptake rate of ^{15}N-urea sprayed onto the foliage was significantly higher in the low N vines than the high N vines (Fig 10B). It was interesting to note that vines in the medium N treatment had a similar uptake rate of ^{15}N-urea as the low N vines. On a whole vine basis, low N vines had a lower total uptake of ^{15}N-urea than medium or high N vines due to its much smaller total leaf area. It appears that vine supplied with a medium N level benefited most from foliar urea spray after harvest.

Root N concentration at fruit harvest was significantly lower in the vines supplied with low N compared with those supplied with medium or high N (Fig 11A). Concentrations of total free amino acids in roots showed a similar trend as root N concentration (Fig 11B). Rate of root N uptake from ^{15}N-ammonium nitrate decreased as N supply during the pre-harvest period increased (Fig 11C). Total root uptake of N from ^{15}N-ammonium nitrate by the medium N vines was the highest (Fig 11D).

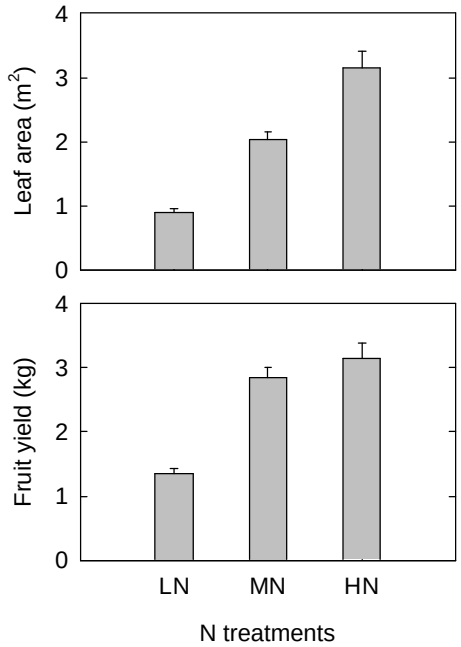


Fig. 8. Total leaf area (A) and total fruit yield (B) of Concord vines at fruit harvest in response to N supply during the growing season.

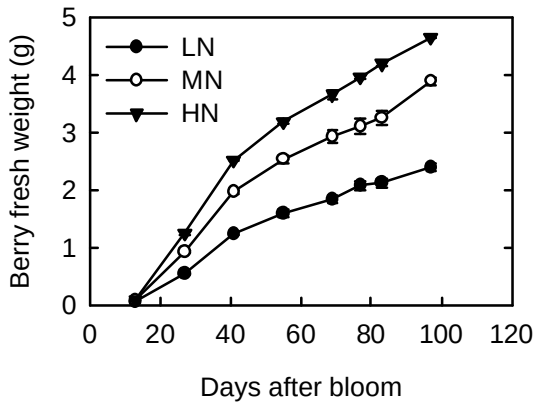


Fig 9. Berry growth from 2 weeks after bloom to harvest in response to N supply.

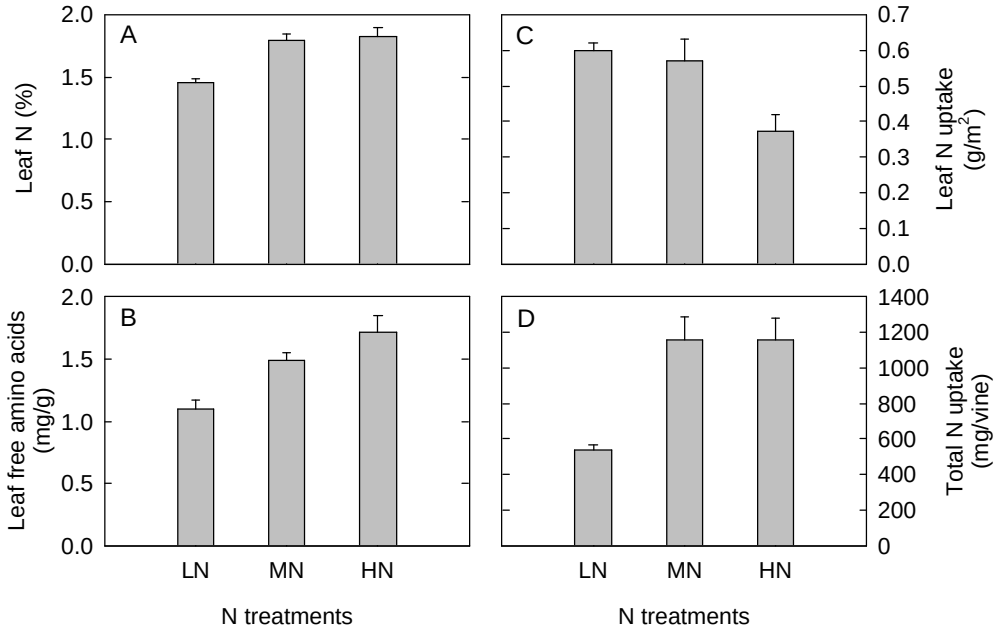


Fig. 10. Leaf N concentration at fruit harvest (A), leaf free amino acid concentration at fruit harvest (B), rate of leaf N uptake from foliar-applied ^{15}N-urea (C), and total N uptake from foliar ^{15}N-urea application (D) in response to N supply during the pre-harvest period.

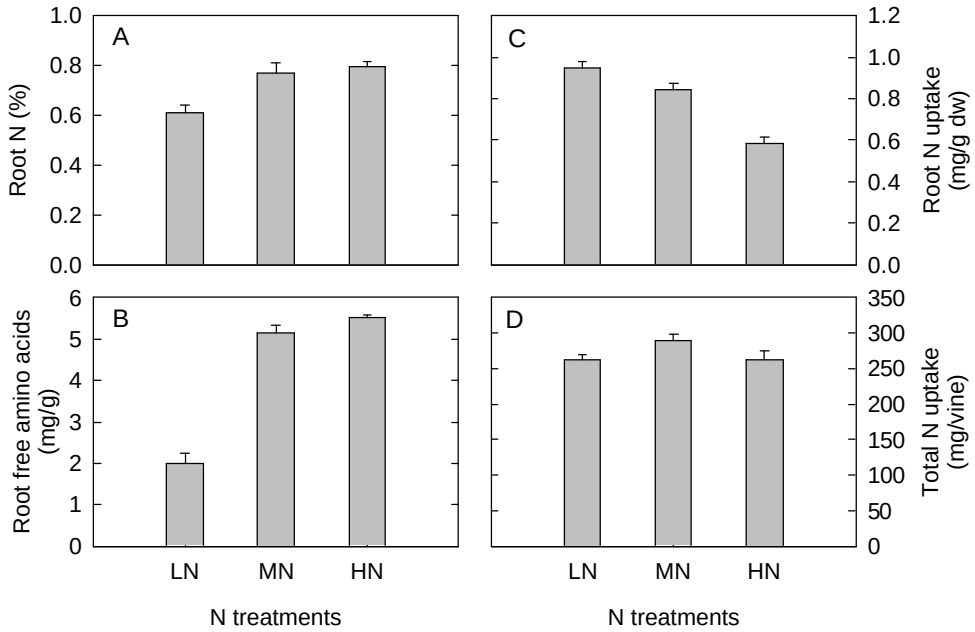


Fig 11. Root N concentration at fruit harvest (A), root free amino acid concentration at fruit harvest (B), rate of root N uptake from soil-applied ^{15}N-ammonium nitrate (C), and total N uptake from ^{15}N-ammonium nitrate (D) in response to N supply during the pre-harvest period.

Summary

Mature Concord vines maintained a relatively constant total dry weight and total nitrogen during dormancy from one year to the next after pruning. The net increase of total vine nitrogen from budbreak to fruit harvest or the net loss of nitrogen due to harvesting, leaf fall and pruning was approximately 50 lbs per acre. The most rapid accumulation of total dry matter and total nitrogen occurred from bloom to harvest and from bloom to veraison, respectively. Of the three N sources (reserve N, natural supply of soil N, and fertilizer N) to new growth, reserve N and natural N supply from soil each provided approximately 40% of the N required for the new growth. Reserve N served as the primary N source during the early part of vine growth (from budbreak to shortly after bloom) whereas natural N supply from soil played an important role from shortly after bloom to veraison. Supplying 50 lbs of actual nitrogen (in the form of ammonium nitrate) at budbreak contributed about 20% of the total N requirement of the new growth for the entire season.

When 50 lbs nitrogen was applied at budbreak, there was very limited uptake of fertilizer nitrogen between budbreak and 10 inch shoot growth. Fertilizer nitrogen uptake increased from 10 inch shoots to bloom, but the most rapid uptake of nitrogen fertilizer was from shortly after bloom to veraison. The accumulative fertilizer nitrogen taken up by the vine at fruit harvest was 9 gram nitrogen per vine (equivalent to 12 lbs N per acre), which gives a fertilizer uptake efficiency of approximately 25% and contributes about 25% to the net vine nitrogen demand from budbreak to fruit harvest. From budbreak to a couple weeks after bloom, the later fertilizer N is applied, the higher the nitrogen uptake efficiency is.

Satisfying the vine demand for nitrogen from 2 weeks before bloom to veraison is critical for shoot growth, leaf area development and fruit growth. When vines were grown under low N

supply before veraison, increasing nitrogen supply after veraison did not significantly increase total leaf area, total yield or fruit quality although it may have improved vine reserve nitrogen status. Fertilizer nitrogen applied during the pre-veraison period contributed more to shoots and leaves and fruit than nitrogen applied during the post-veraison period.

Low N supply from 2 weeks before bloom to veraison significantly decreased vine growth and berry development, delayed veraison, and decreased final berry size. Both foliar and root N uptake after fruit harvest were dependent on vine N status, with low N vines being more efficient in taking up N from foliar urea or soil applied ammonium nitrate than high N vines. On a whole vine basis, however, vines grown under a medium N supply during the pre-harvest period appeared to benefit most in terms of total N uptake from either foliar urea application or soil N application.

Extension accomplishments

The findings of this project were presented at Lake Erie Grape Growers Meeting by Bates in 2005, at the Finger Lakes Grape Growers Convention by Cheng and Bates in 2006, at Orchard and Vineyard Nutrition Workshop at Northwest Michigan Horticultural Research Station by Cheng in 2005, and at many other extension meetings by Martinson and Walter-Peterson throughout New York and the Northeast. Cheng and Bates have been scheduled to present the findings of this project at a series of nutrition workshops organized by National Grapes in New York, Michigan, Pennsylvania and Ohio in the spring of 2007. This information has also been disseminated to Concord growers in Lake Erie region via newsletters.

Acknowledgement

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