Sustainable Viticulture: Optimizing Nitrogen Use In Vineyards

Jamie Hawk[1] and Timothy E. Martinson[2]

[1]Finger Lakes Grape Program, Cornell Cooperative Extension, Penn Yan, NY

[2]Department of Horticultural Sciences, NYSAES, Cornell University, Geneva, NY

Utilizing production practices that minimize environmental impacts will help grape growers reduce risks, improve profitability and stay competitive with other regions. Optimizing nitrogen fertilization programs can improve juice and wine quality while limiting groundwater and surface water contamination from nitrogen leaching and run-off.

Grape and wine production is a high-profile agricultural enterprise. An industry-wide goal to produce grapes, juice, and wine utilizing production practices that minimize environmental impacts, that are economically viable, and at the same time socially responsible, will help growers reduce risks, improve profitability and stay competitive with other regions. To help achieve this goal the New York Sustainable Viticulture Program was established through a cooperative effort between the Finger Lakes Grape Extension Program, Lake Erie Regional Grape Extension Program and Long Island's grape extension program. It is a statewide effort to both document sustainable grape growing practices already in use and promote sustainable practices throughout the industry. The foundation of the program is its grower self-assessment workbook – 140 questions in 8 sections covering the multitude of management decisions faced by New York State grape growers. The workbook serves as a roadmap for evaluating viticultural practices, addressing the diversity of the state's grape growing industry with a broad range of questions. A website dedicated to the program will be launched this winter, which will contain an interactive version of the workbook. Growers will have the ability to create an account and password to complete the workbook on-line at their own pace. One-on-one assistance from Jamie Hawk (Finger Lakes), Edith Byrne (Lake Erie) and Libby Tarleton (Long Island and Hudson Valley) will continue as well.

Complementing the workbook is a newsletter, "*Sustainable Viticulture in the Northeast*," which provides an in-depth examination of the economic, environmental and social implications of specific production practices. Two newsletters have been published thus far, "Optimizing Nitrogen Use in Vineyards" and "Soil and Water Conservation Practices for Vineyards." Future topics will include innovative weed management, reduced risk pesticides, scouting and biofuels, among others. Six bi-monthly newsletters are slated to be published annually.

The potential benefits to participating growers in this program include: 1) Cost-sharing opportunities for financing conservation needs through the Soil and Water Conservation Districts; 2) increased product marketability for grapes and grape products; 3) economic and environmental savings through efficient use of fertilizers and agri-chemicals; and 4) improved neighbor relations and industry reputation.

This article focuses on sustainable nitrogen use in vineyards. Nitrogen is the most commonly applied fertilizer in agriculture. Excess nitrogen contributes to the contamination of both ground and surface waters, leading to potential health risks for humans and environmental degradation of our coastal habitats. Furthermore, the cost of nitrogen fertilizers (tied directly to natural gas prices) is rising. Producing one ton of anhydrous ammonia (from which ammonium nitrate, urea and solution liquid fertilizer are produced) consumes 33,500 cubic feet of natural gas. As natural gas prices rise, nitrogen fertilizer prices rise in parallel. By matching nitrogen supply with vine nitrogen demand and adjusting the rates and timing of supplemental fertilizers, growers can modify nitrogen inputs, often reducing rates without sacrificing yield and quality.

Nitrogen and The Environment

Nitrogen is mobile in the soil, and excess nitrates can contaminate groundwater and wells. Regulatory agencies have set a limit of 10 ppm for nitrate-N in drinking water, though health risks have been found at lower levels. Ingestion of nitrate in drinking water has been linked to reproductive problems and higher cancer risks in adults and an interference with blood oxygen levels in infants.

Problems associated with nitrogen runoff and leaching involve many agricultural, industrial and municipal sources. Although grape production is a relatively small contributor to the overall problem, growers can reduce their impact through careful management and planning. It is the combined effort of individuals making informed decisions about nitrogen use throughout the state that can lead to significant reductions in the nitrogen loading to our environment.

Nitrogen in the Vineyard

Nitrogen gas (N_2) makes up 78% of our atmosphere, yet this form is unavailable to vines. Instead, N_2 is converted to ammonium (NH_4^+) by nitrogen-fixing bacteria. Decomposition of organic matter also releases ammonium to the soil, and soil bacteria further transform ammonium to nitrite (NO_2^-) and nitrate (NO_3^-) ions through a process called nitrification. Nitrate is the most biologically desirable form of nitrogen, though it is susceptible to loss through leaching (via water movement through the soil) and denitrification (to N_2 by bacteria under anaerobic [low oxygen] conditions). Loss of nitrogen to the atmosphere can also occur via volatilization, especially during dry periods following fertilizer application.

Nitrogen in the soil. Nitrogen is supplied naturally in the soils through the breakdown of organic matter (major source) and the weathering of soil minerals (very minor source). The level of available nitrogen is also affected by the cation exchange capacity (CEC) of the soil. Soils carry a net negative ionic charge which attracts and holds positively charged ions (cations: such as NH_4^+, Ca^{2+}, Mg^{2+}, and K^+) in the soil, preventing them from being lost through leaching and maintaining their availability to the vines.

Soil microbes transform the nitrogen compounds in the soil, and their rates of activity are driven by temperature. During the winter months, relatively little decomposition occurs, but as the soils warm in the spring and early summer, microbial activity increases, releasing ammonium from organic matter breakdown and nitrifying the ammonium to nitrate for vine uptake. Moisture conditions also influence soil nitrogen levels. Repeated heavy rainfalls, particularly during spring and early summer when the bulk of nitrogen fertilizers are applied, may promote leaching. During periods of drought, leaching is less common, but vine uptake of nitrogen is diminished unless supplemental irrigation is used.

In strongly acidic soils, aluminum (Al^{3+}) becomes soluble and displaces the essential nutrient cations from the cation exchange sites. Raising the pH back into the optimal range for grape production (5.5-6.5) forces the aluminum to precipitate out, opening the cation exchange sites to the desired cations and restoring the soils' potential to hold nutrients. Soil pH also affects the activity of bacteria in the soil, impacting rates of nitrogen fixation, nitrification, and organic matter breakdown.

Nitrogen in the vines. Research on Concord has shown that the majority (about 75%) of stored nitrogen in dormant vines is found in the roots, with the remainder stored in trunks and canes (Bates et al. 2002). These stored reserves supply the nitrogen for most of the vines' prebloom growth. Uptake of nitrogen from the soil doesn't begin in earnest until midway between budbreak and bloom, as soils warm and new root tips develop. Peak nitrogen demand is split into two distinct periods: the two to three weeks prior to bloom and about a month-long stretch (the majority of the canopy development stage) starting two weeks after bloom (Figure 1). Overall, the annual nitrogen requirement of Concord vines corresponds to about 50 lb / acre, with a portion derived from the breakdown of organic matter and the remainder supplied by the grower. After harvest, the vines sequester the remaining available nitrogen (found in the soil, leaves and shoots) into their roots and canes in preparation for the next growing season.

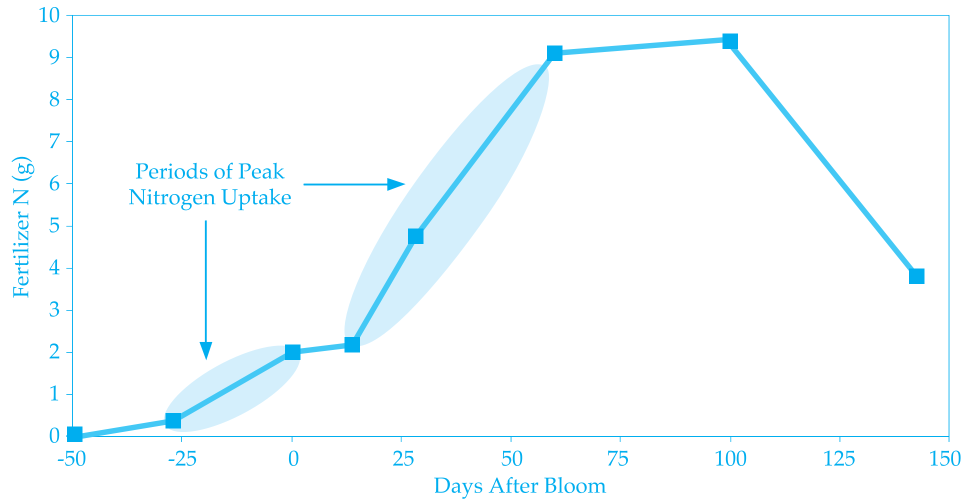

Figure 1. Total vine uptake of fertilizer N by mature Concord vines fertilized with 50 lb N as ^{15}N-enriched ammonium nitrate at budbreak. Redrawn from Cheng et al. 2004.

Managing Nitrogen Fertilization Sustainably

The ultimate goals of a sustainable nitrogen fertilization program are to:

1. Provide grapevines with sufficient nitrogen to meet quality and yield goals.
2. Match nitrogen supply and demand through use of tailored rates and timing of applications.
3. Minimize inputs of fertilizer nitrogen by improving soil health.
4. Minimize nitrogen losses from leaching, volatilization, and run-off.

While there is no magic formula for determining how much nitrogen to apply, application rates and timing should be tailored to the needs of individual vineyard blocks, rather than uniformly applying a standard rate to all of your vineyards. Doing so involves consideration of the leachability, organic matter content and water-holding capacity of your soils, careful observation of vine vigor, and your management goals for the vineyard.

Concords and bulk hybrid varieties are generally managed to maximize cropping level and production, and their responses to N fertilization are well understood. *V. vinifera* grapes and premium hybrids are managed for moderate yields and wine quality, generally at less than their maximum cropping capacity. Therefore, rates for Concord production represent the high end of N requirements in NY vineyards.

For soils with at least 2% organic matter, there is no yield or vine size response to more than 50 lb / acre of nitrogen. A long-term experiment called the 'West Tier Factorial' has measured the impact of rootstock, cover crops, nitrogen fertilization, and training system on Concord yield and quality over the past 40 years. Three N fertilization rates (0, 50 and 100 lb / acre of actual N) were used on deep, gravelly soils at the Fredonia Vineyard Laboratory. Yield and vine size (as measured by pruning weights) increased with 50 lb / acre of actual nitrogen, but increasing the rate to 100 lb / acre had no effect on yield and increased pruning weight by only 0.1 lb per vine.

More recently, direct measurement of nitrogen in mature Concord vines indicated that each vine incorporates about 40 grams of N into each season's growth - equivalent to about 53 lb / acre (Bates et al. 2002). In the same study it was found that of the 50 lb / acre, actual N applied, about 12 lb / acre was derived from the fertilizer, with the remainder supplied by the 2% organic matter in the soil.

Although nitrogen promotes vine growth and can lead to excess vigor, it doesn't follow that applying more nitrogen will automatically increase the size of small vines. Inadequate water supply, rooting depth, or drainage, disease and insect infestations, inappropriate cropping levels (too much fruit), low soil pH or other nutrient deficiencies can limit vine size, and applying excess nitrogen won't overcome other factors that limit

TABLE 1

Estimated contribution by soil organic matter to vine nitrogen needs for mature Concord vines.*

	Soil Organic Matter 1%	2%	3%	5%
Vine nitrogen need (lb/acer)	50	50	50	50
Nitrogen from organic matter	20	40	60	80
N needed	30	10	(10)	(30)
Fertilizer N at 25% Efficiency	120	40	0	0

* Information supplied by Terry Bates

vigor. On the other hand, excess vigor caused by overapplication of nitrogen promotes shaded canopies which reduce fruit quality, promotes disease development, and reduces bud fruitfulness.

Organic matter and nitrogen supply. The *breakdown* of organic matter is a major source of nitrogen. It is important to measure the percentage of soil organic matter in each block of your vineyard, as every 1% supplies 15 to 20 lb / acre / year of nitrogen. This nitrogen is released slowly, and its rate of production increases as soils warm-up and microbial activity increases. Table 1 illustrates the relative contribution of different organic matter levels to N needs. Note that above 3% organic matter, the soil's nitrogen-supplying ability exceeds annual vine demand, though during peak canopy development, a small supplemental application (as low as 10 lb / acre) may still be necessary to match demand. As inorganic nitrogen costs continue to rise, deriving a greater share of nutrients from organic sources makes good business sense. Pomace, mulch, cover crops, cane prunings and herbaceous plant tissues can all improve soil organic matter over time; the amount of these materials to be applied or utilized will depend upon availability and desired level of amendment.

Timing. From budburst to bloom, vines support the majority of new growth by mobilizing nitrogen and carbohydrates stored in roots, canes, and trunks. It is not necessary, nor is it desirable to apply fertilizer nitrogen early. It's better to apply it just ahead of when the vine's demand starts to increase. Delaying soil application until a few weeks before bloom is likely to improve N availability at the time vines start to need it. In New York State, this would correspond to a two-week window between 15 May and June 1. For heavier soils with adequate depth and high silt and clay content, a single application should be sufficient.

Soil texture influences both the leaching and water-holding capacity of soils. Coarse-textured, excessively well-drained soils, such as gravelly loams and sandy soils suffer more N losses via leaching than heavier soils. Split applications, with 1/3 to 1/2 of the total amount applied before bloom and 1/2 to 2/3 applied 1-2 weeks after bloom, should provide extended uptake while limiting losses to leaching.

After harvest, nitrogen taken up by vines is translocated to roots and canes and stored until growth resumes in the spring. In a few situations, a light application of N post-harvest can improve reserve N content to support better spring growth. This is best suited to early ripening varieties that still maintain a green, functioning canopy in the post-harvest period.

Adjusting for cropping level. Premium *V. vinifera* and hybrid wine varieties are often managed for a moderate crop to maximize quality. These vines will take less nitrogen to maintain vine size than heavily cropped natives and bulk hybrids. Thirty lb N / acre or less is generally a good range for premium varieties. Also, growers can omit nitrogen for vines with a small crop due to winter injury.

Soil and petiole tests. Soil samples and grape tissue tests can be tools for determining soil N status or the vine tissue N content, but they have important limitations. Soil nitrate levels can change between sample collection and analysis, due to microbial activity, and may not be good indicators of available nitrogen. Petiole samples, taken at bloom from petioles in the cluster zone, can give some indication of vine N status, but are best used to compare problem areas within vineyards to more 'normal' vines. Many factors, including whether samples are collected on a sunny or cloudy day, cause N content in petioles to fluctuate. Petiole samples collected at 70 days post-bloom are not good indicators of vine nitrogen status. Sampling soils and tissues should always be accompanied by visual estimates of vine vigor.

Adjusting N fertilization. Direct observation of vine growth is an important indicator of vine nitrogen status and the need for supplemental nitrogen. Growers need to recognize the signs of both excessive nitrogen uptake and nitrogen deficiency and use these signs to plan their N fertilization programs. Visual symptoms for evaluating vine N status are summarized in Table 2. It's important to note that excess or inadequate vine vigor may or may not be related to vine nitrogen status, as detailed in an earlier section.

If excess shoot vigor is observed, it should be safe to omit nitrogen for one year and observe the vines' response. In subsequent years, observe vines and gradually increase N in 10 to 15 lb increments as necessary. When correcting visible nitrogen deficiency, a good starting point is to apply 30-50 lb N per acre for Concord, <10 lb / acre for vinifera in heavier soils, or 10-20 lb / acre for vinifera in sandy soils. Carefully observe results over the following two years. Response may be delayed until the year following first application because of the vines' reliance on stored reserves during early shoot growth.

Small amounts of foliar-applied nitrogen may help growers react to nitrogen deficiencies, particularly under drought conditions when N uptake from the soil might be limited. In dry years, foliar urea (5 lb urea per 100 gal water) applied around veraison can increase available nitrogen in the fruit. This can help wineries avoid stuck fermentations and may also delay the appearance of the atypical aging wine defect in white wines.

Fertigation in irrigated vineyards. Drip irrigation permits efficient application of fertilizer directly to the root zone. Fertigation avoids the labor expense and nitrogen losses associated with ground-applied materials. Particularly during the summer, ground-applied nitrogen is dependent on rainfall for incorporation. Without incorporation, losses to volatilization may be significant.

Reducing supplemental nitrogen use over the long term. Soils in many older vineyards have been depleted of organic matter, and subject to soil compaction. Adding organic matter to soils via cover crops (particularly legumes) or surface application of straw mulch or compost may be an effective strategy for reducing reliance on expensive fertilizer nitrogen. It may take a few years to start seeing significant results, but adding organic matter, much like liming soils, can have long-term benefits in improving many soil characteristics. In addition to its nutritive value, organic matter improves soil structure, enhances soil water holding capacity, buffers soil pH and raises soil CEC.

Summary

The key to sustainably managing nitrogen is understanding the needs of your vines. Maintaining detailed records of inputs, soil organic matter, growth and yields through successive years will narrow the focus on the most efficient nitrogen application rates for individual blocks. Strive to minimize inputs (through tailoring rates, incorporating organic matter, etc.) and minimize the loss of inputs (through proper timing and split of application, elimination of surface run-off, etc.). Incorporating the ideals of sustainability into your nitrogen fertilization programs will be cost effective, improve water quality, and reduce health risks to you, your workers, and your communities. Best management practices for nitrogen fertilization are:

- Delay first application until two to three weeks pre-bloom.
- Split the total amount of nitrogen applied into pre-bloom and post-bloom applications.
- Track soil characteristics to assess natural nitrogen supply and vine demand.
- Evaluate vine vigor and adjust rates accordingly.
- Tailor application rates to vine demand on a block-by-block basis.
- Use fertigation to apply nitrogen in irrigated vineyards.
- Optimize soil pH levels.
- Raise soil organic matter levels to increase nitrogen supply from natural sources.
- Maintain detailed records on nitrogen inputs, soil organic matter, vine vigor and yield.

Fifty lb actual N per acre should be considered an upper limit for N fertilizer use in heavily cropped Concord vines. Moderately cropped premium wine varieties will need less. Organic matter is an important source of nitrogen, and the soil's N-supplying ability should be used to reduce fertilizer N rates. Every grower should test their soils periodically (3-5 years) to determine organic matter content and soil pH and amend as necessary. Nitrogen applications should be split in vineyards with high leaching potential. Vine vigor should be evaluated and used to modify nitrogen rates. Fertigation offers the most efficient delivery of N in irrigated vineyards, and allows growers to make multiple applications at low doses with a minimum of additional labor. Adding organic matter to vineyard soils may reduce dependence on N fertilizers, while improving many soil characteristics.

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Jamie Hawk is an extension aide in the Finger Lakes Grape program who works in the Sustainable Viticuluture Program. Tim Martinson is a senior extension associate who has statewide responsibility and leads Cornell's grape extension program.