**Introduction**

Nitrogen is the fertilizer element most likely to be deficient in vineyards. It is also the fertilizer element most commonly applied by grapegrowers. And yet, in spite of widespread usage, the chemical and physical nature of nitrogen fertilizer and its effect on grapevine physiology are not well understood by many growers. The University of California has found that a large percentage of California vineyards have nitrogen levels that are either higher than necessary for normal growth or potentially toxic to a vine.

In the past, when nitrogen fertilizer was inexpensive, application cost was low and winery standards for acceptable fruit quality were less stringent, the economic impact of a poorly-conceived nitrogen program was small. Today, however, the grapegrower is faced with rising fertilizer costs and lower prices from wineries for grapes that fail to meet current stricter quality requirements.

Because both nitrogen deficiency and nitrogen excess may contribute to reduced yield, poorer fruit quality and lower cash returns, it is essential that the grower be familiar with the factors that affect nitrogen uptake and utilization by the grapevine. The vineyard operator with a clear understanding of these factors will be able to develop a cost-effective nitrogen fertilization program.

In this discussion, we will examine the interaction of various nitrogen fertilizers with the soil, water and the grapevine. Diagnosis of vineyard nitrogen status and the types of fertilizers and methods of application will also be reviewed.

**Nitrogen and the Soil**

Nitrogen is taken up by grapevines from sources in the soil. Of the many forms of nitrogen that exist, only the nitrate (NO$_3^-$) and ammonium (NH$_4^+$) ions are absorbed by the roots of vines. Although vines can utilize either of these forms of nitrogen for normal growth, most of the nitrogen taken up by the plant is in the nitrate form. This occurs for two reasons.

First, nitrate is mobile in the soil because it has a negative charge. Ammonium, on the other hand, has a positive charge which causes it to be held by magnetic attraction (adsorbed) by the negatively charged soil particles. This adsorption renders most of the ammonium unavailable to the plant, while nitrate exists as an available ion in the water found between the soil particles.

Secondly, under certain temperature, moisture, and aeration conditions, the ammonium form of nitrogen is converted by soil micro-organisms to the nitrate form. In fact, all forms of nitrogen are eventually converted to nitrate by these microbial soil organisms.

There are many reactions that occur in the soil involving nitrogen and soil micro-organisms, and the sum of these reactions make up the nitrogen cycle, illustrated here. We see that the nitrogen supply in the soil is in constant flux.

Grapevines respond to the addition of nitrogen above the levels usually found in nature. From a practical standpoint, the grower wants to add enough nitrogen in the form of chemical fertilizer to bring the amount in the soil to an optimal level for...
healthy growth and crop production. Ideally, this addition is done so that the nitrogen is available at proper levels when the grapevine has its greatest need for it, and in such a way that losses of nitrogen are minimized for greatest cost-effectiveness.

Individual soils vary in their ability to supply nitrogen to the vine. Soil physical factors such as aeration, presence of hardpan, claypan, bedrock or water table, and texture greatly determine the effective root zone. Within this root zone, the cation exchange capacity (CEC—a measure of a soil's ability to adsorb nutrient elements), the available moisture and the abundance of nutrient elements determine the extent to which the vine's roots will utilize the available soil volume.

In order for a root to absorb nitrogen, it must come into contact with the nutrient. The nitrogen may move to the root carried by water, or the root may grow to the site of the nutrient. Because newly-initiated roots are most effective in absorbing mineral nutrients, much nitrogen uptake occurs through young roots, often called rootlets.

Tiny roots penetrate the soil seeking moisture and nutrients, and have a brief effective lifespan. Many of them die back, and are replaced by new rootlets, much in the same way that the above-ground portion of a vine discards older leaves while producing new ones. As long as moisture in the soil during the growing season permits root growth, the vine continues to develop new rootlets, encountering nutrient elements in the process. However, new roots will not develop in soils that do not have available water.

Nitrogen and Water

Water plays an important role in the movement of nitrogen through the soil. It is with the downward movement of water that the nitrogen reaches the root zone of the vine. Fertilizers consisting of the nitrate form of nitrogen will move with the soil water. With excessive water, such nitrogen may ultimately be carried below the root zone. This is referred to as leaching. Fertilizers consisting of ammonium or other positively-charged ions will move downward with water only until an available negatively-charged position on a soil colloid is reached. The ammonium ion is adsorbed by the soil, and further movement is not possible until it is converted into a nitrate by soil microorganisms.

Available water is required for new root growth, and new root growth is very important for nutrient uptake by the vine. In vineyards where the most practical application method of nitrogen fertilizer is by broadcasting onto the soil surface, a negative effect of moisture must be considered. Volatilization loss to the atmosphere occurs when ammonium-containing nitrogen fertilizer in contact with the soil surface becomes wet. The nitrate portion is not, however, susceptible to this kind of loss. All ammonium-containing fertilizers are volatile to some extent. Losses of up to 40% of the total nitrogen applied are possible in a very short period.

Insofar as possible, the broadcasting of nitrogen fertilizer should be scheduled so that rainfall or irrigation water will immediately carry the nitrogen into the soil, safe from volatilization loss. Research indicates that the volatility of nitrogen fertilizers is especially great on acid soils.

In order to avoid leaching losses, fertilizer application must be timed so that anticipated irrigation or rainfall will carry the nitrogen into the root zone. In making this decision, the grower will be greatly assisted by knowledge of the typical rainfall pattern for the area and the waterholding capacity of the soil.

Vineyard soils hold between 3/4" (sandy soils) to 1 1/2" (fine-textured soils) of available water per foot of depth. An inch of water will move to a depth of between 8 and 16 inches. Usually, the effective root zone is from one to six feet in depth, in the absence of other soil factors.

With determinations made for a given vineyard, the timing of the application attempts to anticipate the amount of rainfall that will occur, with the goal of placing the nitrogen in the root zone at the time when the vine will require a supply for the growth cycle.

In irrigated vineyards, nitrogen may be applied along with irrigation water. The grower should calculate the movement of the nitrogen in a similar way, as just discussed, with the goal of delivering the nitrogen into the root zone to coincide with the vine's need for it.

Nitrogen and the Grapevine

The need for nitrogen is greatest during the period of rapid vegetative growth early in the season, when rapid synthesis of vital plant compounds places a large demand on available supplies of nitrogen. Grapevine nitrogen levels are highest just prior to bloom. The level of nitrogen in the tissue drops rapidly as vegetative growth slows near bloom and fruit set.

Because nitrogen is needed for protein production, chlorophyll synthesis, nucleic acid formation and enzyme synthesis, a deficiency reduces total growth of the vine. Reduced growth can mean less foliage, an imbalance of sugar and acid in the ripening fruit, and lower yield.

Individual grape varieties differ in their level of nitrogen accumulation (PW p.26-32 May/June 1985). In an unpublished trial, the University of California found that bloomtime levels of 37 varieties tested ranged from 136 ppm nitrate-nitrogen all the way up to nearly 2,500 ppm nitrate-nitrogen. (J.A. Cook, personal communication). All varieties in the trials were judged by other indicators to be at good nitrogen levels.

The influence of rootstock on yield and petiole nitrate levels has been well-documented. A six-year University of California study of three rootstocks and 22 scion varieties in Napa Valley
showed that rootstocks vary in their ability to provide nitrogen to the vine.

Rootstock AXR 1 gave the highest yield and had intermediate nitrate levels. Variety 99-R was the weakest stock, lowest in yield and nitrate, but was the most efficient fruit producer per unit of growth. St. George produced the highest petiole nitrate levels. In seasons that favored high nitrate accumulation, St. George had excessive amounts which were inversely correlated with yield. The research suggests that the erratic performance of St. George in some vineyards was related to its nitrate behavior.

Alternating periods of warm and cool weather, particularly in the spring, may cause changes in the metabolism of nitrogen in the grapevine. White deposits consisting of the salts of amino acids are occasionally produced along the edge of the leaf during cool periods, and this is an indication of high nitrogen levels.

**Diagnosing Vineyard Nitrogen Status**

A number of diagnostic methods are available to the grower for the development of a good nitrogen fertilization program. Correlating the results from these diagnoses, the grower can tailor the fertilizer program to suit the exact conditions in that vineyard. Specifically, the grower should collect information in the following areas:

1) **Soil type**—
   - What is the cation exchange capacity of the soil?
   - What is the water-holding capacity of the soil? This indicates how water will move in the soil and how well the soil will support root growth.
   - Do impediments in the soil profile exist which will limit root development and water and nitrogen movement?
   - What is the volume of the root zone? Use this to calculate the zone in which nitrogen is to be placed.

2) **Vine factors**—
   - Does the rootstock promote or restrict nitrate accumulation?
   - Is the variety a high, intermediate or low accumulator of nitrate?

3) **Fertilization history of the vineyard**—
   - Can current vineyard conditions be correlated to previous fertilization practices?

4) **Observation**—
   - Vineyard appearance and yield are important indicators of the nutrient status of the vine:
     - How does the yield compare with normal for the variety and the location?
     - What is the level of vegetative growth, and how does this compare with other vineyards in the area?
   - Tissue symptoms can be important clues to nutritional problems:
     - Is the foliage low in color, with low vegetative growth and yield? These together might indicate low nitrogen levels.
     - Do white deposits of the salts of amino acids occur along leaf margins during cool spells in early spring? Correlated with high vigor and low yield, these factors might mean excess nitrate levels.

5) **Petiole analysis**—
   - Analysis of plant tissue is an essential part of mineral nutrition diagnosis. Properly collected samples are chemically analyzed and the results are interpreted, taking into account seasonal differences, rootstock and variety. Depending upon vineyard location and weather of a given season, full bloom usually occurs in May or early June. Varieties differ in their period of bloom, so a grower may have to sample at different times.

In order to insure accuracy, a large enough number of petioles must be collected. These are chosen randomly, taking a petiole from a leaf that is next to a cluster, and discarding the leaf blade.
immediately. Usually a minimum of 100 petioles is collected from a block no larger than 10 acres. A paper bag is used to collect the samples, so that there is good air circulation. Use of plastic bags can promote development of microbial growth on the sample tissue, distorting the laboratory results.

The samples should be delivered to the laboratory as soon as possible, but may be stored in open paper bags until delivered. Drying does not affect the accuracy of the analysis. For a detailed discussion of petiole analysis, please refer to *Grapevine Nutrition and Fertilization* published by the University of California. There is potential for error in petiole analysis in several steps of the process. By understanding these steps, the grower can make the most of his sampling results.

First is sampling error in the vineyard. Areas of different soil types should not be mixed in one sample, and the sample size should be sufficient to overcome individual plant variation. Second is time of collection. This is probably the greatest source of error in petiole analysis, because the level of nitrate drops rapidly from a high prior to full bloom. Judging the exact time of full bloom is often difficult, so the numerical result of the sample may not be precisely the full bloom level of nitrate upon which standards are based.

Third is contamination, either before collection from vineyard sprays, or afterwards before delivery to the laboratory. Finally, utilize a dependable laboratory.

**Comparison of Nitrogen Fertilizers**

<table>
<thead>
<tr>
<th>Type</th>
<th>% Nitrogen</th>
<th>$/lb Nitrogen*</th>
<th>Volatility</th>
<th>Acid-Forming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium nitrate</td>
<td>34</td>
<td>$0.42/lb</td>
<td>low</td>
<td>yes</td>
</tr>
<tr>
<td>Ammonium sulfate</td>
<td>21</td>
<td>$0.45/lb</td>
<td>low</td>
<td>yes</td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td>15.5</td>
<td>$0.70/lb</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Urea</td>
<td>46</td>
<td>$0.35/lb</td>
<td>high</td>
<td>yes</td>
</tr>
</tbody>
</table>

*Based on typical retail prices in California, Fall 1985

Types of Nitrogen Fertilizer

Nitrogen fertilizers are produced in a number of common formulations. Too often, one is chosen only on a cost-per-pound of nitrogen basis. There are other considerations, as discussed above, which can give the grower a specific reason to choose another formulation. Occasionally, a grower might have a specific reason to choose another formulation. For example, in acid soils, calcium nitrate might be used to counter the low pH; or, the relative mobility of the nitrogen might suit a particular timing or method of application.

Comparison of Nitrogen Fertilizer

Of the commonly used fertilizers, urea and those with nitrate formulations are mobile in the soil. Those with ammonium formulations are adsorbed, and only become mobile after microbial transformation to nitrate. Urea is especially subject to volatilization. Various granular and liquid preparations are available, depending on the type of application method used.

Application Methods

Common ways of applying nitrogen fertilizer include broadcasting, banding and spot placement; sub-surface placement; and injection into irrigation water. All surface applications of ammonium-containing formulations should be timed to coincide with rainfall or irrigation in order to minimize volatilization. Incorporation of these materials into the soil reduces potential loss. If nitrogen is to be injected into irrigation water, the amount of water applied should be calculated to move the nitrogen into the root zone.

Summary

Nitrogen contained in the soil is dynamic in nature, constantly changing in form and availability. The best use of nitrogen will be determined by yield response and fruit quality, petiole analysis, and the observations and knowledge of the grower. Although nitrogen fertilization is only one aspect of a comprehensive management system, it has a wide-reaching impact on the health, productivity and profitability of a vineyard.

References


Some soil organisms especially important in the nitrogen cycle. (Left to right) Azotobacter, nitrate bacteria, and nodule organisms of alfalfa.
SCHEMATIC PATHWAY OF NITROGEN IN GRAPEVINES

PROTEINS

Nitrate (NO$_3^-$) $\rightarrow$ ammonium (NH$_4^+$) + glutamic acid

other amino acids $\leftarrow$ glutamine

reductase enzymes
light
warm temps.
carbohydrates

NO$_3^-$

amino acids

53
Nitrogen (N) fertilization is a key factor toward promoting and managing an effective leaf canopy in table grape vineyards. The goal is to fully utilize the trellis system for optimum photosynthesis without unnecessary leaf shading within the canopy.

N deficiency is generally not a problem in table grape vineyards. Most are receiving at least adequate amounts of N. However, excess N is not uncommon and can contribute to adverse effects, especially with certain varieties and trellis systems.

To understand N's role in vine canopy management, let's review its pathway in grapevines. Much of this knowledge of N in grapevines has been developed by Dr. Mark Kliewer at U. C. Davis.

Most of the N compounds in the soil, whether from ammonia, urea, or organic sources, are eventually converted to the nitrate form by soil organisms. Nitrates are absorbed by vine roots and moved with the transpirational stream through the xylem to the leaves. There they are converted to amino acids which are the protein building blocks. Amino acids move to the vines' growth and storage areas, such as fruit, shoots, and roots, where they are formed into proteins for growth or become stored N, mostly as the amino acid arginine. Many complicated biochemical steps are involved, but the major ones are shown in the following diagram.

These reactions help us to understand certain vineyard problems associated with high N levels.

**Spring N Build-up**

This is a weather-related condition found in vineyards of moderately high to very high N levels. It is more common in young, vigorous vineyards, especially of Thompson Seedless, Cardinal, Ribier, Italia, and Muscat of Alexandria. Vine foliage levels of nitrates, ammonium, and amino acids temporarily build-up to high levels. White, salt-like deposits of amino acids (glutamine) appear on the leaf edges where they remain after being exuded through pores (hydrathodes) on the leaf edges. Direct toxicity from ammonium and/or nitrate can occur in extreme cases, resulting in a water-soaked appearance and burning of leaf tissue. Also, an excessive shatter or burning of flower clusters prior to and during bloom is sometimes associated with N build-up, particularly in Cardinal and Muscat of Alexandria. The symptoms are temporary, lasting about 2 to 5 weeks, with the vines ultimately resuming normal growth.

N build-up is associated with one or several cycles of alternating warm and cool periods in the spring. It seems logical that it is caused by reduced N conversion rates in the leaves during cool and sometimes cloudy weather. Low light and temperatures reduce the rate of enzyme and photosynthetic activity involved in N's pathway. Individual grape variety differences in susceptibility may be explained by their inherited differences in potential N-reducing enzyme activity.
Petiole nitrate levels associated with this condition in Fresno County are as follows:

<table>
<thead>
<tr>
<th>Nitrate-N, ppm</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1700 and above</td>
<td>Amino acid exudate deposits may occur.</td>
</tr>
<tr>
<td>3500 and above</td>
<td>Toxicity symptoms, including leaf burn, may occur.</td>
</tr>
<tr>
<td>8300</td>
<td>Highest level found in severely affected Cardinals.</td>
</tr>
<tr>
<td>8800</td>
<td>Highest level found in severely affected Thompson Seedless.</td>
</tr>
</tbody>
</table>

These symptoms and their associated nitrate levels vary widely with variety and season. For example, nitrate-N levels up to 7200 ppm have been found in petioles with no leaf burn—only amino acid exudate.

The extreme symptoms described here are not common. Usually, the only visual indication of a temporary N build-up is the presence of amino acid deposits on leaves.

**Extreme or High Vigor**

This is the most common problem related to high N. A reduced fruit set is sometimes associated with an extreme rate of vigor. However, the more common effects include excessive shading within the leaf canopy and poor cane selection at pruning. Many shoots are of excessive diameter and internode length; they will tend to be of poorer maturity at dormancy.

Lower bud fruitfulness is especially a problem in Thompson Seedless where the dense canopy contributes to a high percent of "shade canes." "Shade canes" are those which developed mostly in the shaded interior of the canopy. They have been demonstrated to have a lower percent bud break, percent fruitfulness, and poorer cluster development as compared to "sun canes." "Sun canes" are those which develop from shoots with leaves exposed to full sunlight on the outer part of the vine foliage canopy.

The problem of cane selection in vigorous Thompson Seedless vines seems to be compounded when they are headed low ("crowned low") under a high, wide "T" trellis or a double trellis. Renewal shoots for next year's canes must then grow 2½ to 3½ feet from the head where they originate to reach full sunlight on the vine canopy's exterior.

Thus, at least this lower portion of all fruiting canes are somewhat shaded during their period of fruit bud development the previous growing season. Also, only so many leaves can occupy the space provided on the canopy's sunny exterior. Therefore, excess growth merely produces more shoots to shade one another.

Obviously then, N fertilization should be geared mainly to vine growth and vigor needs. A basic rate is 40 to 60 lbs. of actual N/acre. An additional 20 to 30 lbs./acre may be needed to support grass culture or to compensate for leaching losses in sandy soils. Vines with root problems or old Emperor vines may need up to 100 lbs./acre to encourage growth.

Caution against excessive N is especially needed in fertile, deep fine sandy loams. Also, the nitrate content of well waters should be determined by an experienced commercial laboratory and taken into consideration in N programs.
<table>
<thead>
<tr>
<th>Nitrate-Nitrogen</th>
<th>Grape varieties ranked by petiole NO₃N levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bloomtime Samples</td>
<td>U.C. Kearney Agricultural Center</td>
</tr>
<tr>
<td>High, above 1000 ppm</td>
<td>Zante Currant, Chenin blanc, Queen, Grenache, Sauvignon blanc, Petite Sirah, Malbec, Merlot, White Riesling</td>
</tr>
<tr>
<td>Medium-High, 800-1000 ppm</td>
<td>Red Malaga, Cardinal, Thompson Seedless, Emperor, Muscat of Alexandria, Emerald Riesling, Gray Riesling</td>
</tr>
<tr>
<td>Medium, 600-800 ppm</td>
<td>Palomino, Thompson Seedless, Calmeria, Exotic, Semillon, Rubired, Ruby Cabernet, Pinot noir, Alicante Bouschet, Cabernet Sauvignon, Chardonnay, Grignolino</td>
</tr>
<tr>
<td>Medium-Low, 500-600 ppm</td>
<td>Barbera, Zinfandel, Carignane, French Colombard, Italia, Gewürztraminer, Pinot blanc, Tokay</td>
</tr>
<tr>
<td>Low, below 500 ppm</td>
<td>Perlette, Flame Seedless, Ribier, Salvador, Sylvaner</td>
</tr>
</tbody>
</table>
NITROGEN fertilizer is too expensive to waste. However, many fruit growers may be doing exactly that by applying it at the wrong time, even if they are following their state recommendations.

Recommendations for time of nitrogen application to fruit plants are confusing and vary considerably from state to state. In many cases, recommendations concerning the time of nitrogen application to fruits do not correspond to data relating to time and conditions of maximum nitrogen uptake.

Nitrogen is highly soluble in water, and must be applied at times when nitrogen uptake by the plant is taking place. If it is applied at other times it is often lost due to leaching through the soil profile or run-off.

**Narrow Uptake Periods**

The entire root system including the large older suberized roots are capable of nutrient absorption. The rate of absorption is greatest in the newly produced “white roots” (root tips). Thus, the period of greatest nutrient uptake would coincide with the period of maximum root growth, since there should be the greatest amount of “white roots” at this time. This period varies with locale and fruit species, but generally would be from March through October.

Leaves are also necessary for efficient nitrate uptake. Nitrate uptake is very low from the period of leaf fall to the commencement of shoot growth the following spring. Nitrate uptake increases with shoot elongation and remains high until leaf fall. It is also known that the later nitrogen is applied during the season the less it is used the year of application, and the greater is its contribution the next year.

Stored nitrogen during the dormant period (February) was highest (20% greater) in trees that received August nitrogen applications when compared to March applications. It has also been shown that the nitrogen content of apricot blooms was 34 fold greater when nitrogen was applied late in the previous summer.

**Stored N Important**

It was concluded that nitrogen had to be applied prior to leaf fall in order for it to reach reproductive organs by bloom. Thus nitrogen applied late in the year is stored (primarily in the root system) for use the following year.

Nitrogen is accumulated in plant tissue according to the supply during the year. It is utilized for growth and flowering the following season irrespective of the nitrogen supplied during the winter or spring in question.

Thus, nitrogen utilized during bloom and the period of rapid shoot elongation following bloom is dependent upon the redistribution of stored nitrogen from the previous year's application. However, during late spring or early summer, shoot growth becomes dependent upon the external nitrogen supply. All stored nitrogen was found to be exhausted by the end of June.

When one takes all of these factors into consideration it becomes clear that nitrogen must be applied during periods of active uptake or one may expect excessive nitrogen loss due to leaching. The nitrogen utilized in the fruit plant in early spring comes primarily from stored reserves from nitrogen application during the previous summer or fall. Nitrogen utilized in late spring and summer comes primarily from current season's nitrogen applications.

**Apply in Fall and Late Spring**

Thus, an application of nitrogen in the fall of the year should build up the stored nitrogen reserves for the following spring. A second application in middle to late spring (not early spring or late winter) should be sufficient to supply the nitrogen needs of the tree during spring and summer.

Care should be taken not to overfertilize trees with nitrogen during the late spring or early summer. The result could be delayed fruit maturity and poor fruit color. Nitrogen application during this period should result in less nitrogen loss and more efficient utilization when compared to nitrogen applications during the dormant period (i.e. 6 weeks before bloom). This reasoning seems to hold true for other woody plants and supports the data that show the beneficial early season effects of fall nitrogen applications over dormant season applications.

Fruit species with low chilling requirements are not in a deep state of growth inhibition at the end of summer. Thus, nitrogen application could result in vegetative regrowth. Because of this problem nitrogen application to these species should be delayed until October or following the first day in the fall that the temperature drops to 40°F. These plants are inhibited by this time to such an extent that regrowth will not occur. Since peaches, pears, apples, etc. have a long rest period, they generally are in deep rest by late September. Nitrogen application at this time should not result in vegetative regrowth.
Late-fall nitrogen application in vineyards is inefficient

William L. Peacock  Francis E. Broadbent  L. Peter Christensen

Grapevines are fertilized with nitrogen (N) in amounts intended to promote proper shoot, leaf, and berry development and to provide for maturation of the crop. The need for N is greatest during rapid shoot growth in the spring through the berry development stage, then diminishes after mid-summer when ripening begins. Application should be timed to ensure an adequate N supply during spring development, but available N in late summer should not be high enough to encourage late-season shoot growth, delay maturity, and promote immature canes. Fertilizer N should also be used to maximize uptake efficiency and minimize losses by volatilization and leaching. Immediate incorporation of all ammonic fertilizers can greatly reduce volatilization. Appropriate timing of nitrogen application and avoiding over-application of water can decrease leaching and denitrification.

Fall application of nitrogen fertilizer in the San Joaquin Valley is convenient for the grower and has increased in popularity in recent years. It allows better use of time and labor, and the grower can take advantage of lower fertilizer prices when working conditions in the vineyard are good. It has been assumed that N applied in the late fall remains in the root zone over the winter and is available for use by the plant when it breaks dormancy the following spring. This assumption is based on the relatively low winter rainfall of the southern San Joaquin Valley, but experimental data to support it are lacking.

A study to evaluate the relative leaching and denitrification losses of late-fall and spring applications of N to vineyards was conducted in 1979-80 at two locations, one in Tulare County on Greenfield sandy loam, Delhi sand is a wind-deposited soil with a deep, uniform, well-drained profile. Greenfield sandy loam absorbs water readily, but drainage is impeded by a hardpan at 4 feet. Both vineyards are in mature Thompson Seedless grapes produced for raisins.

A randomized complete block design was used with five blocks and three treatments. Plots, with four vines each, were 12 by 24 feet. Treatments consisted of the unfertilized control, 100 pounds N per acre applied November 9, 1979, and 100 pounds N per acre applied March 12, 1980. The fertilizer was "^15N-depleted ammonium sulfate, isotopically labeled to permit distinction between fertilizer and soil nitrogen. It was applied in a 6-foot strip on each side of the row by a hand-held boom on a backpack sprayer and then incorporated by diskling. Distribution of inorganic N in the soil was followed by sampling the profile to a depth of 4 feet in increments 0 to 0.5, 0.5 to 1, 1 to 2, 2 to 3, and 3 to 4 feet. Soil cores were taken from four locations in each plot, and the cores composited for laboratory analysis. Soil samples were taken from the Delhi location on December 4, 1979, and on April 11 and May 23, 1980. Sampling dates at the Greenfield site were December 6, 1979, and April 13 and May 23, 1980. Soil samples were immediately frozen and stored in a freezer before analysis. In the laboratory, inorganic N, consisting of ammonic and nitrate forms, was extracted and the isotopic composition determined to identify the portion derived from the added fertilizer.

N concentrations in soils

As expected, with no fertilizer application, inorganic N concentrations in the Delhi sandy loam profile remained low at all sampling times and did not vary greatly with depth (fig. 1). During the 25 days between the November fertilizer application and the December 4 sampling, 0.70 inch of rain fell. The December sampling reflects the November fertilizer application: no appreciable leaching had occurred. By April 11, 1980, however, when 10.7 inches of rain had fallen since the November fertilizer application and the grower had applied an additional 3 to 4 inches of irrigation water, the April 11 sampling revealed a surface inorganic N concentration somewhat lower than the maximum observed with the November application to this soil. By May 23, even the spring application had disappeared. Presumably all the fertilizer N applied in March had been absorbed by plants or leached below 4 feet.

The Greenfield-sandy-loam location received approximately the same amount of rainfall as the Delhi site. Vines were irrigated for frost protection in the last week of March, and two additional irrigations totaling 8 to 12 inches were applied before the May 23 sampling. Inorganic N after the November fertilizer application was high near the surface on December 6, but by April 13 concentrations were not much different from those of the control soil. By May 23, concentrations had increased a little in the surface 2 feet because of mineralization of soil N as temperatures increased. In the case of the March application, the April 13 sampling reflected the recent addition of fertilizer to the soil. By May 23 some downward displacement of this
fertilizer had clearly occurred, but most of the N remained within the surface 4 feet of soil.

**Fertilizer-derived N**

Figures 1 and 2 reflect the combined fertilizer and soil N present in the profile. Figure 3 shows concentrations of fertilizer-derived N, calculated on the basis of isotopic data. In Greenfield sandy loam, high concentrations of November-applied fertilizer were present in the December sampling, whereas by April and May most of this N had disappeared. Fertilizer applied to this soil in March was displaced downward between the April and May samplings.

In the Delhi soil the concentration of fertilizer N in the surface 6 inches of soil receiving a November application decreased from 22 parts per million (ppm) on December 4 to less than 1 ppm by the following April. Where Delhi sand received fertilizer in March, some leaching had occurred by April, and by May 23 fertilizer N throughout the profile had dropped to a very low value.

**Discussion**

These data indicate that ammonic nitrogen applied in the late fall was subject to severe leaching losses by normal rainfall and irrigation between November and May. Soil temperature was not low enough during the winter to retard nitrification significantly. This study suggests that N should be applied in the spring just before frost-protection irrigation on loam or sandier soils. Subsequent irrigation will leach the N into the root zone for uptake during the most critical period of need. On very sandy soils, such as the Delhi sand, it would be useful to split the fertilizer application, with half applied in March and the remainder in May.

Still unanswered is the question of the value of early-fall application (September to mid-October), when the vines may be active enough to take up a significant amount of N and store it in canes, trunk, and roots. There is concern as to whether this uptake can be accomplished without stimulating undesirable late shoot development. Further study is in progress to develop information on summer and early-fall fertilizer application to grapes, but present evidence suggests that late-fall fertilization is highly inefficient.

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SUMMARY OF THE RESEARCH

of

L. PETER CHRISTENSEN

Extension Viticulturist

UC Kearney Agricultural Center, Parlier

The Influence of Nitrogen Fertilizer Timing
of Raisin, Table and Wine Grapes

It has been shown that rapid shoot elongation in the spring for both grapevines and deciduous fruit trees is heavily dependent on the redistribution of nitrogen (N) previously stored in roots, trunk, canes or limbs. Since the grapevines’ need for N is greatest in the spring it can be inferred that N fertilizer should be applied when the vine can best absorb and incorporate it as part of the N reserve while minimizing N loss from the soil. This information has prompted continuing studies on N fertilizer timing under drip and furrow (flood) irrigation utilizing isotopically labeled $^{15}$N-depleted. Under furrow irrigation, winter and spring applications of N were found to be inefficient in vine N uptake and very susceptible to leaching by irrigation and rainfall. In contrast, late spring, summer, and postharvest fall treatments provided for considerably more N storage in the roots and trunk to support early shoot growth the following year. These findings have been substantiated in subsequent studies in raisin, table, and wine grape vineyards. They have demonstrated postharvest and fruit-set stage N applications to be the most efficient, budbreak the least efficient, and veraison intermediate in N utilization. No adverse effects on vine growth and bud fruitfulness due to N fertilizer timing have been found. However, N fertilizer, regardless of timing, tends to delay fruit soluble solids accumulation as compared to no N fertilizer.

Information provided by this work is rapidly changing grower practice. Many growers are avoiding N fertilizer applications during winter dormancy through budbreak in irrigated vineyards. Many are waiting until berry set when fertilizer uptake and efficiency of use improves. Post harvest timing is an increasing practice, recognizing its potential for vine N storage. However, it is only recommended where there will be at least 4 to 6 weeks of an intact, functioning leaf area in the fall to provide N uptake, assimilation, and storage by the grapevine. Veraison applications are presently not recommended because of the potential to adversely influence fruit ripening. Also, N applied at that time would tend to accumulate in the fruit, of no benefit to the grower and of questionable value to wine quality.

Because of improved N fertilizer efficiency with berry set under furrow irrigation and/or post harvest timing, growers are now using rates of 20 to 40 lbs. N/ac. This compares with the previously used rates of 40 to 80 lbs. N/ac. in the late winter, early spring. Reduced N rates and improved N efficiency of vine use are lowering grower costs and possible NO$_3$ contamination of ground water.
Drip irrigation offers an efficient and convenient method to apply fertilizer directly to zones of root concentration. N timing and rate studies conducted by Bill Peacock, Farm Advisor, Tulare County, using isotopically-labelled N, have shown that timing (spring vs. summer) did not influence N fertilizer efficiency, provided that water application rates did not exceed vine water use (ET).

Drip irrigation also provides the capability of supplying nutrients in small increments during periods of peak demand. Thus, fertilizer efficiency may be improved by sequencing or partitioning application over an extended period to minimize losses due to leaching. This was also evaluated in the drip N timing study by comparing a single application of 40 lbs. N/ac., split applications of 20 lbs. N/ac. 2 weeks apart, and partitioning 40 lbs. N/ac. into 8 weekly applications. The results showed no differences due to N fertilizer sequencing in leaf and dormant vine tissues over a 10-month period.

These results indicate that drip irrigation can be timed according to the vine’s immediate needs and with less concern of timing to avoid leaching losses from the soil. Also, the amount required can be applied within a short or over an extended period time without reducing application efficiency. This potential of application efficiency under drip, provided vine water ET demands are not exceeded, offers potential for reduced N application rates as compared to those under furrow irrigation.

Long-term N timing and rate studies are continuing in wine, raisin, and table grape vineyards to further refine our strategies for efficient fertilizer use. A better understanding of grape cultivar, rootstock, and trellising effects and the role of covercropping systems are among our goals.
The chart summarizes the characteristics of the principal commercial sources of nitrogen for fruit trees.

<table>
<thead>
<tr>
<th>NAME</th>
<th>PER CENT NITROGEN</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anhydrous ammonia</td>
<td>82</td>
<td>High nitrogen percentage; ease of application; no residue problem; little danger of leaching.</td>
<td>(a) In irrigation water: Uneven distribution if irrigation system not adapted to its use. Cannot be used with sprinklers.</td>
</tr>
<tr>
<td>Ammonia solution</td>
<td>Usually 20</td>
<td>Easier to handle than anhydrous; no residue problem.</td>
<td>(b) Dry injection: Some loss if ground is trashy or cloddy.</td>
</tr>
<tr>
<td>Ammonia sulfate</td>
<td>21</td>
<td>Acid residue (good for alkaline soils); little danger of loss by leaching; ease of handling.</td>
<td>Acid residue (not suggested for very acid soils). Delayed availability during nitrification.</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>33</td>
<td>High N percentage; no residue problem. Half immediately available, half delayed.</td>
<td>Same as ammonium sulfate.</td>
</tr>
<tr>
<td>Ammonium phosphate-sulfate (16-20) mixture</td>
<td>16</td>
<td>Same as ammonium sulfate. Carries phosphate if needed for cover crop.</td>
<td>Same as ammonium sulfate.</td>
</tr>
<tr>
<td>Ammonium phosphates (11-48) and (21-53)</td>
<td>11</td>
<td>High phosphate content where needed for cover crop.</td>
<td>Low N percentage.</td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td>15.5</td>
<td>Calcium residue (for acid or high sodium soils). Immediately available.</td>
<td>May be leached.</td>
</tr>
<tr>
<td>Urea</td>
<td>42</td>
<td>High N percentage. Is not fixed if irrigated at once before conversion to ammonium carbonate; no residue problem.</td>
<td>May be toxic in high concentrations.</td>
</tr>
<tr>
<td>Sodium nitrate</td>
<td>16</td>
<td>Alkaline residue (for acid soils); immediately available.</td>
<td>Sodium residue undesirable on high sodium soils. May be leached.</td>
</tr>
<tr>
<td>Calcium cyanamide</td>
<td>24</td>
<td>Alkaline residue (for acid soils); calcium residue.</td>
<td>Danger of burning, especially at high rates or in growing season.</td>
</tr>
</tbody>
</table>

*There is no serious trouble with the physical properties of any of these materials unless they are stored too long or under adverse conditions.