Uptake, Storage, and Utilization of Nitrogen by Grapevines as influenced by Time of Application under Furrow and Drip Irrigation

Peter Christensen
President, American Society of Enology and Viticulture;
Extension Viticulturist, Department of Viticulture & Enology,
University of California Davis, headquartered at Kearney Agriculture Center, Parlier

Background

Nitrogen (N) is the most widely needed and used fertilizer element used in California vineyards (4). Manufactured commercial fertilizers are the most common source of N used. Other N sources include animal manures, commercial composts, and nitrogen-fixing legume cover crops. Rates of application can range from 0 to 90 Kg N/ha, depending on need, with 27 to 54 Kg N/ha being the most commonly used. Rate depends on soil type, rootstock and scion cultivar, trellis system, commercial use of the grape, and geographical area. Generally, table grape vineyards receive more N because of the large trellis systems used and the need for a good foliage canopy to protect the fruit from sun exposure and heat damage. Vineyards in the hot, interior valleys and those on sandy soils also tend to receive more N because of longer growing seasons, larger canopies, and furrow or flood irrigation practices which tend to leach N below the root zone.

Growers base their N fertilizer practices on observation of vine growth and laboratory analysis (4). The most widely used laboratory diagnostic method used is leaf petiole analysis taken during the bloom period. Sampling consists of taking leaf petioles which are positioned on the shoot opposite flower clusters at bloom. Laboratory analysis is for nitrate (NO_3) content on a dry-weight basis. Studies in California have shown petiole NO_3 to be a sensitive indicator of N status. Guidelines are based on field studies conducted with the Thompson Seedless cultivar (12,13). However, it is recognized that there are seasonal and inherent cultivar differences in petiole NO_3 levels (5). Thus, interpretation should not be based on one season alone and critical tissue levels for individual cultivars will need to be established. Kliewer (15,16) suggests the use of total free amino acids in petioles or arginine in grape canes and fruits as indicators of N status of grapevines. The basis of this recommendation is the importance of amino acids as N storage compounds in grapevines (14). Arginine has been found to be the principal amino acid in fruit at harvest and in permanent vine parts at dormancy. Analysis for arginine in certain vine parts has been correlated with bloom petiole NO_3 levels and vine N needs. Kliewer (14,15) found relatively large amounts of soluble N and arginine in vine roots and woody parts during dormancy; utilization of these reserves following budbreak was first from canes, then from the trunk, and lastly from roots (15). This work provided background for future studies on N partitioning and utilization in grapevines.

Conradie (7,8) published work in 1980-81 on vine N uptake and distribution using whole plants in sand culture. It provided an illustration of vine N use throughout the season; the importance of postharvest N storage in permanent vine parts and its support of vine growth in the spring was also demonstrated. A better understanding of how vines use N has led to studies on how N fertilizer can be applied to improve efficiency of vine N use. Peacock (17,19) and Conradie (10,11), using isotopic ^{15}N labeled fertilizer have studied the influence of application timing on N losses and vine utilization. The results are rapidly changing N fertilizer practices by grape growers in California.

The traditional timing of N fertilization in vineyards has been during winter to early-spring. This timing was chosen to enable winter rainfall to move the N into the root zone by the beginning of new spring growth. Thus, N would be available to support the rapid shoot, leaf, and cluster development in the spring and early summer (4). However, current N timing research is modifying this practice.

Current Research on N Timing

Peacock (17) found winter application in November to be highly inefficient due to excessive leaching from rainfall and spring irrigations. Early spring application in March was more efficient in providing vine uptake but was still quite susceptible to leaching from irrigation. Subsequent work with ^{15}N-labeled fertilizer demonstrated vine N distribution in various vine parts over time as influenced by fertilizer timing (10,19). It was found that, as with other deciduous crops, the grapevine relies heavily on reserve N during the stage from budbreak to the end of bloom. During this period root uptake of N is limited and provides minimal amounts of N for growth. From the end of bloom to harvest the grapevine is capable of absorbing large quantities of N but the major share of this newly acquired N is utilized by the bunches, leaves, and shoots. The fastest rate of N uptake is from the end of rapid shoot growth to veraison at a time when the requirement of developing clusters is high. Conradie (10) showed that 60% of the N absorbed during that period went to the clusters.

From veraison (berry softening) to harvest the rate of N uptake decreases with the ripening fruit still being the largest sink. Overall, Conradie (10) showed that 43% of the total N was removed with the harvested fruit.

The postharvest period shows another stage of rapid N uptake which may amount to 27% of the seasonal total (10). Postharvest N absorption provides the greatest amount of stored N to support new growth the following spring (10,19) as the permanent vine parts, including the roots, are the dominant sink. As the N cycle is continued into the following spring, this storage N is utilized in substantial amounts to support new growth. This relationship is shown in figure 1 where four dates of fertilization are compared: 4 April, 24 July, and 22 September 1983, and 15 March 1984. Isotopic ^{15}N under furrow irrigation was used in this study. Leaf blades were analyzed for labeled N on five dates subsequent to the initiation of the study. The data clearly shows the large amount of post harvest-applied N available to support growth from budbreak through bloom in the following year, 1984. Budbreak timing was the poorest in supplying N by bloom of the years of application and of contributing to carryover N in the following year. Summer application was intermediate.

Recent Studies with Furrow Irrigation

We are now refining our knowledge of timing and vine use efficiency with field studies under a variety of conditions. This includes studies of N timing with various rates over multiple years, different cultivars, and varying vineyard conditions and irrigation practices. Studies are centered on comparing timing treatments at different phenological stages of vine development--budbreak, fruit set, veraison, and post harvest--plus a split-timing treatment with the N rate divided between fruit set and post harvest applications.

One study involved 4 commercial vineyards of Thompson Seedless and Flame Seedless over 3 years (20). The results showed the budbreak treatment to be least effective in supplying inorganic N (NO_3 + NH_4 in petioles) during the period of rapid shoot growth. Fertilizer N uptake and incorporation into leaf tissue was more rapid from fruit set to veraison than from budbreak to fruit set. The timing treatments of fruit set, veraison, and post harvest were fairly equal in N supply over 3 years. The exception was a Thompson Seedless raisin vineyard on sandy soil which showed benefit from split application (fruit set + post harvest). The advantages of split application on sandy soils is understandable considering the potential for leaching from irrigation. Also, the budbreak treatment produced the lowest yield response in sandy soil, again demonstrating poorer N use efficiency with this timing.

A recently completed 4-year study on N fertilizer rates and timing of 4 wine cultivars--Chenin blanc, Colombard, Barbera, and Grenache--is further verifying our earlier results. Through the second and third years of study the post harvest N treatment at 55 kg/ha was equal to bud break N treatment at 110 kg/ha and sometimes better than bud break 55 kg/ha in supplying inorganic N during the rapid shoot and berry growth period. This is shown in table 1 where the values for total inorganic N (NO_3 + NH_4) in petioles at bloom and veraison are given. Berry set and veraison timings were fairly equal in overall N supply when considering both bloom and veraison petiole inorganic N levels. Of interest to winemakers was how vine N status changed during fruit development with different fertilizer timing. The postharvest treatment provided good N status during the earlier stages of vine and berry growth but resulted in a fairly low N status at veraison. This may result in lower concentrations of certain N compounds in ripe fruit, of possible importance to ethyl carbamate formation in resulting wines.

It is interesting to note that N response differences were cultivar dependent. Barbera tended to be the least responsive while Grenache was quite responsive in N status change, fruit composition, and grape yield due to N treatment (tables 1 and 2). French Colombard and Chenin blanc were intermediate in N response. Grape yield responses in Grenache (table 2) demonstrated 55 kg N/ha at berry set to be equal to 110 kg N/ha budbreak. Control, non-fertilized and veraison 55 kg N/ha produced the lowest yield.

There are concerns about possible detrimental effects of some timing treatments such as a delay of fruit maturation from veraison treatment and late stimulation of shoot growth from post harvest application. Generally, it has been found that all N treatments, regardless of timing, tends to delay fruit maturation as compared to control, unfertilized. This has been demonstrated in our raisin, table grape, and winegrape trials (see table 2). Additionally, there is a tendency for higher N rates to delay fruit ripening and produce more vegetative growth regardless of timing. Poorer raisin quality from veraison N timing in Thompson Seedless also suggests that this timing may not be desirable in some vineyard situations. To date, late season vine vegetative growth due to N timing has not been a problem.

Influence on Fertilization Prqctices by Growers

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 and/or post harvest timing, growers are now using rates of 22 to 44 kg N/ha. This compares with the previously used rates of 44 to 88 kg N/ha in 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.

Studies with Drip Irrigation

Nitrogen fertilizer timing under drip irrigation has also been studied. In a Thompson Seedless vineyard trial (6,18) utilizing isotopic labeled N it was found that spring N applications are just as efficient as summer applications under drip. This is shown in table 3 where single and split applications in spring 27 April (27 April + 21 May) are compared with summer 12 June (12 June + 7 July) totaling 45 Kg N/ha. Spring applications increased vine leaf N to greater concentrations by harvest on 20 September 1984. However, the summer applications ultimately provided comparable concentrations of stored N in permanent vine parts at dormancy and in leaf tissue the following spring, 5 May 1985.

Drip irrigation provides the capability of supplying nutrients in small increments during periods of peak demand. Also, fertilizer efficiency may be improved by partitioning application over an extended period to minimize losses due to leaching. This was evaluated in the drip N timing study by comparing a single application of 45 Kg N/ha, split applications of 22.5 Kg N/ha 2 weeks apart, and partitioning 45 Kg N/ha into 8 weekly applications. The results in table 4 show no differences due to N partitioning in leaf and dormant vine tissues over a 10-month period.

Varying rates of total N have also been studied under drip irrigation to determine fertilizer efficiencies. 0, 22.5, and 45 Kg N/ha rates were compared in a spring to summer treatment period over 8 weeks. The results in table 5 show tissue fertilizer N levels over 2 years, 1984 and 1985, to be in proportion to N fertilizer rate. This would indicate equal efficiency of fertilizer application and vine N uptake regardless of N rate.

These results may be explained by method of fertilizer application and efficiency of irrigation under drip. Fertilizer is applied directly to areas of root concentration with drip irrigation. Water applications through drip can also be easily managed so as to not exceed the evapotranspirational demand of the vineyard. Thus N is not readily leached below the root zone as is experienced with furrow irrigation.

Because of the high potential for water and N fertilizer efficiency under drip we are recommending that growers apply N according to vine crop demand. Studies by Williams (20,21,22) have shown a grape crop to remove about 22 to 34 kg N/ha under San Joaquin Valley conditions. Thus growers are utilizing these values to form the basis of annual fertilizer rates of application. Timing of N is largely based on their judgement of vine vigor, fertilizer history, and petiole analysis for NO_3.

Nitrogen timing, rate, and method of delivery (drip vs. furrow irrigation) studies are continuing to further refine the most efficient strategies for our grape growers.

REFERENCES

1. Alexander, D. McE. Seasonal fluctuations in the nitrogen content of the Sultana vine. Austral. J. Agric. Res. 8:162-178. (1957)

2. Araujo, F. J. and L. E. Williams. Dry matter and nitrogen partitioning and root growth of young field-grown Thompson Seedless grapevines. Vitis 27:27-32. (1988)

3. Christensen, L. P. Seasonal changes and distribution of nutritional elements in Thompson Seedless grapevines. Am. J. Enol. Vitic. 20:176-190. (1969)

4. Christensen, L. P., A. N. Kasimatis, and F. L. Jensen. Grapevine nutrition and fertilization in the San Joaquin Valley. Univ. Calif. Div. Agric. Sci. Public. 4087. (1978)

5. Christensen, L. P. Nutrient level comparisons of leaf petioles and blades in twenty-six grape cultivars over three years (1979 through 1981). Am. J. Enol. Vitic. 35:124-133. (1984)

6. Christensen, L. P. and W. L. Peacock. Fertilizing with nitrogen and potassium through drip irrigation. Proc. Table Grape Seminar, Univ. of Calif. Coop. Extension. pp. 16-20, Feb. 26. (1986)

7. Conradie, W. J. Seasonal uptake of nutrients by Chenin blanc in sand culture: I. Nitrogen. S. Afr. J. Enol. Vitic. 1:59-65. (1980)

8. Conradie, W. J. Nutrient consumption by Chenin blanc grown in sand culture and seasonal changes in the chemical composition of leaf blades and petioles. S. Afr. J. Enol. Vitic. 1:15-18. (1981)

9. Conradie, W. J. The uptake and distribution of ^{15}N enriched nitrate by three rootstock cultivars grafted to Chenin blanc. S. Afr. J. Enol. Vitic. 4:45-47. (1983)

10. Conradie, W. J. Utilization of nitrogen by the grapevine as affected by time of application and soil type. S. Afr. J. Enol. Vitic. 7:76-83. (1986)

11. Conradie, W. J. Distribution and translocation of nitrogen absorbed during late spring by two-year-old grapevines grown in sand culture. Am. J. Enol. Vitic. 41:241-250. (1990)

12. Cook, J. A. and T. Kishaba. Petiole nitrate analysis as a criterion of nitrogen needs in California vineyards. Proc. Am. Soc. Hort. Sci. 68:

13. Cook, J. A. and T. Kishaba. Using leaf symptoms and foliar analyses to diagnose fertilizer needs in California vineyards. Extrait, Colloque VI. Congres International de la Science du Sol, Paris. pp. 158-175. (1956)

14. Kliewer, W. M. Annual cyclic changes in the concentration of free amino acids in grapevines. Am. J. Enol. Vitic. 18:126-137. (1967)

15. Kliewer, W. M. and J. A. Cook. Arginine and total free amino acids as indicators of the nitrogen status of grapevines. J. Am. Soc. Hort. Sci. 96:581-587. (1971).

16. Kliewer, W. M. and J. A. Cook. Arginine levels in grape canes and fruits as indicators of nitrogen status of vineyards. Am. J. Enol. Vitic. 25:111-118. (1974)

17. Peacock, W. L., F. E. Broadbent, and L. P. Christensen. Late-fall nitrogen application is inefficient. Calif. Agriculture, pp. 22-23, Jan.-Feb. (1982)

18. Peacock, W. L., L. P. Christensen, and F. E. Broadbent. Nitrogen fertilization of grapevines using drip irrigation. "Grape Notes," Univ. of Calif. Coop. Ext. Tulare County, February. (1988)

19. Peacock, W. L., L. P. Christensen, and F. E. Broadbent. Uptake, storage, and utilization of soil-applied nitrogen by Thompson Seedless as affected by time of application. Am. J. Enol. Vitic. 40:16-20. (1989)

20. Peacock, W. L., L. P. Christensen, and D. J. Hirschfelt. Influence of the timing of nitrogen fertilizer application on grapevines in the San Joaquin Valley. Am. J. Enol. Vitic. In press.

21. Williams, L. E. Growth of Thompson Seedless grapes: II. Nitrogen distribution. J. Am. Soc. Hort. Sci. 112:330-333. (1987)

22. Williams, L. E. Nitrogen requirements and nitrogen fertilizer use of efficiency of Thompson Seedless grapevines. 1988 Raisin Research Reports, Calif. Raisin Adv. Board, pp. 1-8. (1988)

23. Williams, L. E. Nitrogen requirements and nitrogen fertilizer use efficiency of Thompson Seedless grapevines. 1989 Raisin Research Reports, Calif. Raisin Adv. Board, pp. 45-51. (1989)

Table 1.
Wine Grape Nitrogen Fertilizer Timing Trial, 1987-90
Leaf petiole total inorganic N ($NO_3 + NH_4$) at bloom and veraison
Means for 2 years, 1988 and 1989, when all plots received complete N treatments

Treatment		Grenache		Barbera		Chenin blanc		French Colombard	
Timing	Rate N kg/ha	Bloom	Veraison	Bloom	Veraison	Bloom	Veraison	Bloom	Veraison
Budbreak	55	2264b[1]	521b	943ab	377bc	2004abc	725ab	1337bc	322bc
Berry set	55	1522c[3]	660b	843bc	433b	1636bc	852a	1077c	370b
Veraison	55	2022b	315c[4]	898abc	317cd	1836bc	519bc	1528ab	294cd
Postharvest	55	2419ab	327c	880abc	342c	2068ab	610bc	1789a	293cd
Budbreak	110	2830a	874a	1055a	526a	2551a	867a	1789a	439a
--	0	1097d	339c	723c	243d	1348c	400c	999c	240d
		***[2]	***	*	***	**	***	***	***

1 Means within a column with like letters are not significantly different at $p = \leq 0.05$.

2 ns = $p > 0.05$
 * = $p \leq 0.05$
 ** = $p \leq 0.01$
 *** = $p \leq 0.001$

3 Berry set N application in current year had not yet occurred at time of bloom petiole sampling; thus, N is carryover from previous year.

4 Veraison N application in current year had not yet occurred at time of veraison petiole sampling; thus, N is carryover from previous year.

Table 2.
Wine Grape Nitrogen Fertilizer Timing Trial, 1987-90
Fruit °Brix and Vine Yields at Harvest
Means for 2 years, 1988 and 1989, when all plot received complete N treatment

Treatment		Grenache		Barbera		Chenin blanc		French Colombard	
Timing	Rate N kg/ha	°Brix	Yield kg/vine	°Brix	Yield kg/vine	°Brix	Yield kg/vine	°Brix	Yield kg/vine
Budbreak	55	22.6b[1]	34.6a	23.9bc	22.4	18.2ab	23.5	19.5b	32.1
Berry set	55	22.3bc	31.4ab	24.0bc	22.4	18.3ab	23.6	19.3b	32.0
Veraison	55	22.7b	30.3bc	24.6ab	20.7	18.3ab	24.5	19.5b	33.3
Postharvest	55	22.3bc	33.0ab	23.5c	24.2	18.2ab	24.1	19.3b	35.2
Budbreak	110	21.8c	35.3a	23.5c	23.0	17.8b	23.5	19.1b	30.3
	0	23.5a	27.0c	24.9a	20.9	18.7a	23.3	19.8a	26.7
		***[2]	**	**	ns	*	ns	*	ns

1 Means within a column with like letters are not significantly different at $p = \leq 0.05$.

2 ns = $p > 0.05$
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$

Table 3
Drip Irrigated N Trial
% N derived from ^{15}N-depleted labeled fertilizer in leaves sampled
20 Sept 84 and 7 May 85; and roots, trunk and canes sampled in dormancy

Time of Fertilizer Application	Total N Applied kg/ha	Fertilizer N		
		Leaves		Roots/Trunk/Canes[2]
		20 Sept 84	7 May 85	Dormant
Check	0	0 a	0 a	0 a
Applied 27 Apr	45	9.26 b	4.17 b	5.19 b
Applied 12 June	45	4.94 c	6.42 b	4.22 b
Applied 27 Apr and 21 May	45	9.55 b	5.01 b	4.51 b
Applied 12 June and 10 July	45	6.46 c	6.82 b	5.00 b

Mean separation within columns by LSD, 5% level.

1 Fertilizer applied 1984; indicates total N applied for year.
2 Values represent means for root, trunk and cane samples.

Table 4
Drip Irrigation N Trial
% N derived from ^{15}N-depleted labeled fertilizer in leaves sampled
18 July 84, 20 Sept 84 and 7 May 85;
and root, trunk and canes sampled in dormancy

Fertilizer Portioning Treatments	Total N[1] Applied kg/ha	% Fertilizer N			
		Leaves			Roots/Trunk/Canes[2]
		18 July 84	2 Sept 84	7 May 85	Dormant
Check 0	0 a	0 a	0 a	0 a	
1 application (27 Apr)	45	8.48 b	9.26 b	4.17 b	5.19 b
2 applications (27 Apr, 11 May)	45	8.53 b	9.55 b	5.01 b	4.51 b
8 applications (weekly, 27 Apr to 19 June)	45	8.68 b	9.10 b	5.80 b	4.78 b

Mean separation within columns by LSD, 5% level.

1 Fertilizer applied 1984; indicates total N applied for year.
2 Values represent means for root, trunk and cane samples.

Table 5
Drip Irrigation N Trial
% N derived from ^{15}N-depleted labeled fertilizer in leaves
Sampled 20 Sept 84 and 7 May 85;
and roots, trunk and canes sampled in dormancy

Time of Fertilizer Application	Total[1] Applied kg/ha	% Fertilizer N Leaves 20 Sept 84	7 May 85	Roots/Trunk/Canes[2] Dormant
Check	0	0 a	0 a	0 a
27 Apr to 19 June (weekly)	22.5	5.79 b	3.24 b	2.62 b
27 Apr to 19 June (weekly)	45	9.10 c	7.18 c	4.78 c

Mean separation within columns by LSD, 5% level.

[1] Fertilizer applied 1984; indicates total N applied for year.
[2] Values represent means for root, trunk and cane samples.

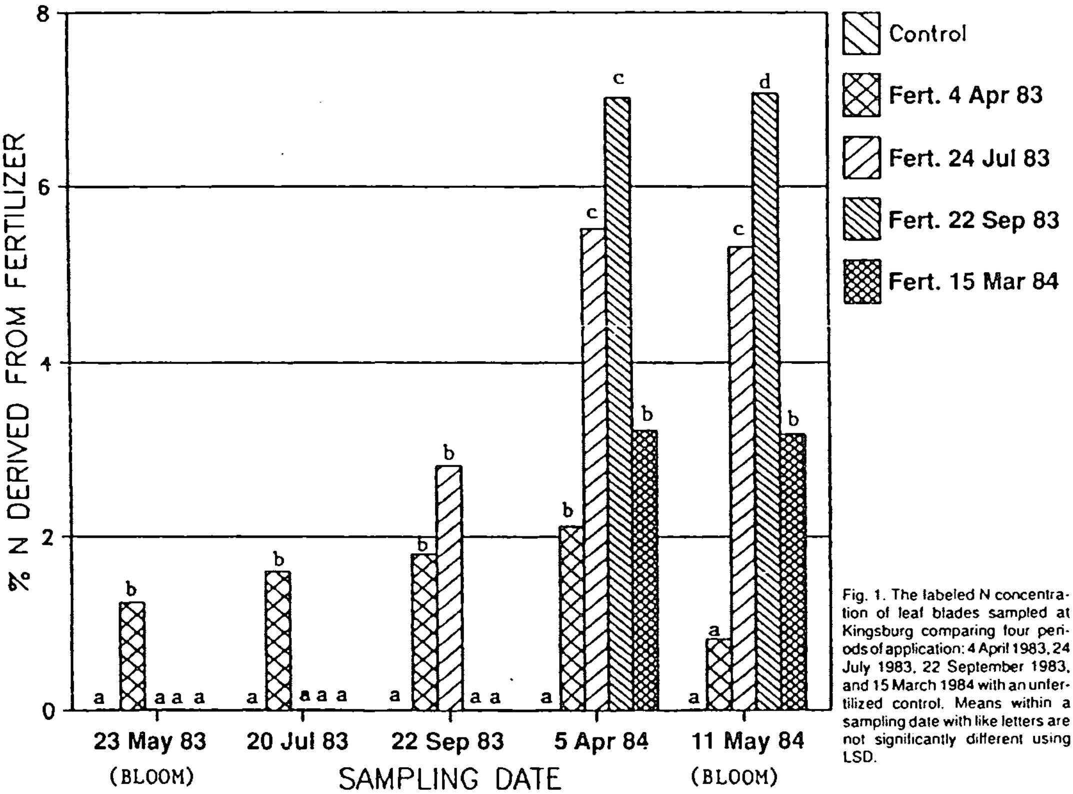

Fig. 1. The labeled N concentration of leaf blades sampled at Kingsburg comparing four periods of application: 4 April 1983, 24 July 1983, 22 September 1983, and 15 March 1984 with an unfertilized control. Means within a sampling date with like letters are not significantly different using LSD.

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