



Nitrogen Management in Deciduous Fruit and Grapes

In response to evidence of nitrate pollution of groundwater, the Central Valley Regional Water Quality Control Board has adopted a regulatory program to protect groundwater resources that requires growers to use best nitrogen (N) management practices to reduce nitrate loading. The objective of this publication is to optimize N use efficiency in deciduous fruit and grapes with the outcome of reducing N leaching.

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Nitrogen is the nutrient required in the largest quantity for better yield and quality in fruit and grapes. Nitrogen is also an integral constituent of proteins, nucleic acids, chlorophyll, co-enzymes, phytohormones, and secondary metabolites, and its deficiency can negatively affect yield. Nitrogen-deficient plants are stunted, with narrow, small, pale leaves. Excessive N application increases vegetative growth and susceptibility to diseases that infect fruit, kill spurs and shoots, and reduce yields in subsequent years.

The 4 R's of Nutrient Management

Traditionally, nutrient management has been based on leaf sampling and collection, analysis, and comparison with established critical values, combined with applying fertilizers when leaf analysis for a particular element falls below a specified critical value. While this approach has been a useful tool for diagnosis of nutrient deficiency or excess, it is now recognized that this approach does not provide sufficient information to define the rate and timing of fertilizer applications.

Many nutrient management tools have been used in annual and permanent crops to guide the quantity and timing of fertilizer application and to diagnose nutrient deficiency or excess. In recent years nutrient budgeting and the 4 R's approach (right rate, right time, right placement, and right source) to fertilizer management have been gaining widespread acceptance (see the International Plant Nutrition Institute website, <http://www.ipni.net/4R>). In the nutrient budget and 4 R's approach,

fertilizers are applied in proportion to the demand of the crop (right rate) and timed with periods of nutrient uptake (right time). Crop demand is satisfied in a timely fashion, avoiding the application of fertilizers in excess of plant capacity for uptake. Placement within the active root zone is essential to maximize fertilizer use and avoid losses.

The goal of any fertilizer management strategy is to ensure that adequate nutrients are available to supply the current demand of the plant. While N is required for all plant processes and in every organ, the development of the fruit represents the largest sink for N in deciduous fruit and nuts. Nitrogen uptake is demand driven: the size of the crop determines how much and when N will be taken up by plant roots. While a shortage of N can reduce yield by preventing full fruit growth, adding N in excess of plant demand does not increase yield and may result in loss of N to groundwater and a reduction in efficiency.

A decision on the final quantity of fertilizer applied must also consider the amount of N from secondary sources. Secondary sources of N in agricultural systems include soil organic matter, organic amendments, and N found in the environment. Soil N is derived from organic matter and includes an active fraction consisting of microorganisms, several intermediate stages, and a stable resistant fraction also referred to as humus. These forms are characterized by their carbon to N (C:N) ratio, where matter with a higher C:N ratio takes longer to become plant available. Organic

amendments such as cover crops, manure, and compost are also important N sources. Like soil organic matter, N availability from organic amendments depends on the C:N ratio of the material, with cover crops being the most readily available after tillage, followed by animal manure and finally compost, where the composting process has stabilized much of the organic N. Finally, N availability is contingent on the transformations of organic N into inorganic N. Other secondary N sources include nitrate in irrigation water and N deposition from air pollution such as smog. These environmental inputs are nontrivial amounts of N in agricultural systems, but the amount depends on the air and water quality of the region.

Nitrogen Management in Deciduous Fruit

Peach

A detailed study conducted with selected peach varieties showed that N demand in peach is driven by vegetative growth, and a smaller amount of the total N is partitioned into the fruit (El-Jendoubi et al. 2013). The total N demand depends on tree age and yield. Table 1 shows N partitioned into different organs of different peach varieties in Spain with 170 lb/ac annual N application. Total N removal from the soil ranged from 152 lb/ac for Calanda to 61.5 lb and 58.3 lb/ac for Catherina and Babygold5, respectively. Harvested fruit accounted for 30.7 lb/ac N in Calanda (13.5 T/ac yield), 12.4 lb/ac in Catherina (3.88 T/ac yield), and 9.14 lb/ac in Babygold5 (4.0 T/ac yield). Nitrogen removal in harvested fruit per 1,000 lb fresh yield was 1.14 lb, 1.6 lb, and 1.15 lb for Calanda, Catherina, and Babygold 5, respectively. Fruit contributed to 20% of the total N removal in Calanda and Catherina and 16% in Babygold5. From 80 to 84% of the total N taken up from the soil accumulated in leaves, pruning, and thinned fruit.

The seasonal N demand pattern of peach is less studied. Most of the N is partitioned into vegetative growth, which occurs mostly during the spring and early summer and continues through late summer at a much lower rate. As a result, the seasonal N demand for peach would be high early in the season, when the vegetative growth rate is high.

Table 1. Nitrogen partitioning (lb/ac) in selected organs of three peach varieties

Variety	Flower thinning	Fruit harvest	Fruit thinning	Summer pruning	Winter pruning	Leaf litter	Total
Calanda (canning peach)	.06	30.7	3.9	26.7	50.8	38.4	151.2
Catherina (midseason peach)	.05	12.4	2.4	10.6	18.5	17	61.4
Babygold 5 (late harvest peach)	.05	12.4	2.4	10.6	18.5	17	61.4

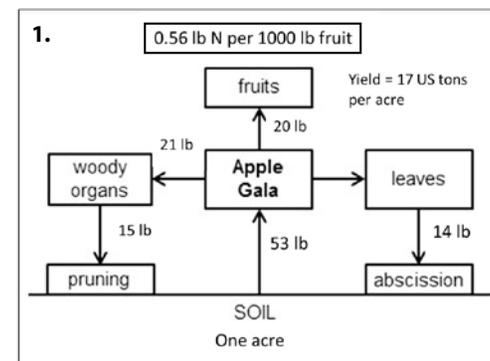
Like other deciduous fruit, peach trees store significant amounts of N in the perennial structures, which have been recorded as 10.6, 6, and 6.5 lb/ac for Calanda, Catherina, and Babygold 5, respectively. The stored N is sufficient to meet the demand of flowering and initial fruit set and leaf out in the absence of active soil N uptake. In almond where peach was used as rootstock, N uptake begins only at 70% leaf out, and a similar pattern can be true for peaches. Thus, spring N application in peach can start at 70% leaf out, and the subsequent N demand can be applied in multiple applications. Rufat and DeJong (2001) reported that in O'Henry peach, the first 25 to 30 days of the growing season are supplied exclusively by N storage from perennial tissues. After that, about 0.89 lb/ac/day N is taken up by the trees after the spring flush until harvest. After harvest, a positive net N storage occurs as a result of a large decrease in the N demand by growth.

Apple

The nitrogen demand of an apple orchard depends on tree age, plant density, yield, and rootstock. Nitrogen demand of the fruit is small, and the majority of the N is partitioned into the vegetative growth and leaves, as shown in figure 1. In a mature apple orchard, 0.56 lb N is removed per 1,000 lb fresh yield, which accounts for 20 lb/ac N for 17 T/ac yield. Although 21 lb N is partitioned into the woody organs during the season, 15 lb of this N is returned to the soil in pruning. The leaves take up 14 lb/ac N and are returned to the soil with leaf fall. Hence, the total N accumulation in an orchard with 17 T/ac yield would be 55 lb N/ac/yr; 29 lb of this N is returned to the soil in abscised leaves and pruning. The availability of this N to the plants depends on the decomposition rate of the organic matter: 50% of the N in the leaves becomes available for uptake in the first year, but the N bound in the woody parts decomposes over a longer period of time.

Seasonal N accumulation and percent seasonal N demand for apples is shown in figures 2 and 3 (Tagliavini and Zano-telli 2015). Nitrogen demand is low at the beginning of the

Figure 1. Nitrogen partitioning into selected organs in a mature apple orchard. *Source:* Tagliavini and Scandellari 2013.



Apple

Figure 2. Seasonal accumulation of nitrogen in Fuji apple fruit and shoots during the growing season. Demand is low in the early season, which is filled by N stored in perennial organs. Nitrogen accumulation increases as the tree develops leaves and active growth starts and continues at a high rate until midsummer. Nitrogen accumulation continues at a much slower rate in late summer.

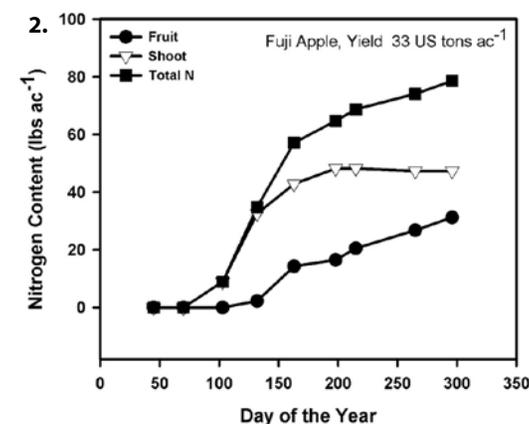
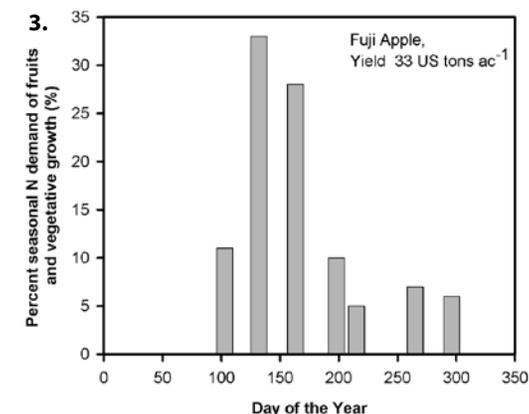


Figure 3. Percent seasonal demand of fruit and vegetative growth as a percent of total seasonal demand. Most of the N accumulates in fruit and vegetative tissues from 102 to 163 DoY (mid April to mid June).

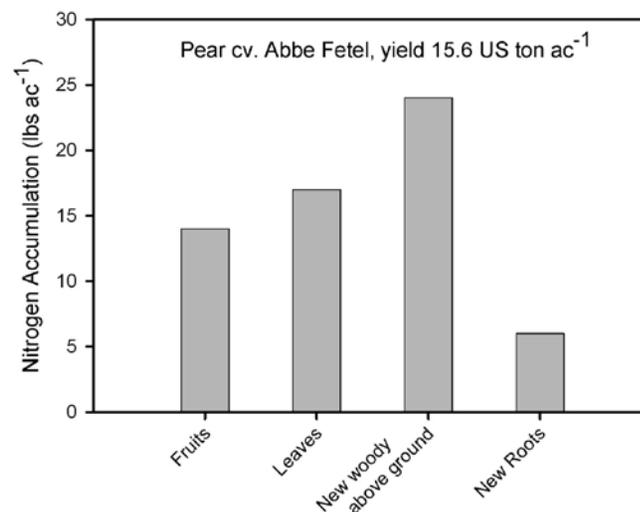


season and is mostly met by the N stored in the perennial organs; 11% of the total N demand of the tree is accumulated in annual growth and flowers by day 102 of the year (DoY). The highest N accumulation occurs between 103 and 132 DoY (33% of the total seasonal N demand) and between 132 and 163 DoY (28% of the total seasonal N demand). Nitrogen demand then decreases, and 10% of the total seasonal N demand accumulates in the tree from 163 to 198 DoY. Nitrogen demand continues with lower rates until senescence begins.

Pear

In pear, like apples, fruit are a smaller sink for N, and a majority of the annual N demand is partitioned to the new aboveground perennial organs and leaves. In a mature Abbé Fétel pear orchard, 0.46 lb N was exported in harvested fruit per 1,000 lb fresh fruit, and fruit accounted for 14 lb N in a fruit yield of 15.6 T/ac. Nitrogen partitioning into organs was 17, 24, and 6 lb/ac in leaves, new woody aboveground organs, and new roots, respectively (fig. 4) (Tagliavini and Zanotelli 2015). The seasonal pattern of N demand is not available for pears. However, this pattern is expected to resemble the N accumulation pattern in apples, as pear is closely related to apple in growth and fruiting pattern.

Figure 4. Nitrogen partitioning in selected organs of pear cv. Abbé Fétel for a fresh yield of 15.6 ton/ac. The majority of the N was partitioned to new woody aboveground tissues and leaves. Source: Tagliavini and Zanotelli 2015.



Sweet Cherry

In sweet cherry, 2.0 to 2.35 lb N is removed in fruit per 1,000 lb of fresh fruit. The greater stone-to-fruit mesocarp ratio for sweet cherry explains the higher fruit N demand for sweet cherry compared with other deciduous fruit. More N is present in the fruit stones than in the fruit mesocarp of flesh. Data on N demand of the vegetative growth and leaves and the seasonal pattern of N accumulation in cherry is currently unavailable. As a cherry tree has significant vegetative growth and large leaf biomass, the N demand of the vegetative growth and leaves is expected to be higher than the demand of the fruit. The N uptake pattern is expected to resemble to the N uptake in peaches, with high demand in spring and early summer and lower demand in summer and later in the season.

Nitrogen Management in Grapes

Grapes have similar demand for N as deciduous fruit and lower N demand than nut crops. The N requirement of grape species varies on the basis of yield, vine age, and canopy size as determined by trellis system. There is no significant difference in fruit N demand between table grapes (1.3 to 1.9 lb N per 1,000 lb fruit) and wine grapes (0.8 to 2.0 lb N per 1,000 lb fruit). However, with higher yields and larger vines, table grapes have higher overall N demand and are the focus of this discussion, although wine grape information is presented for comparison. Knowledge of N partitioning during the growing season allows for optimal timing of N delivery.

Vine nutrient demand and timing of N allocation for a 7-year-old Red Globe vineyard in China with 12 ton yield was determined by in-season sampling of various plant organs for an estimate of the total vine (Tong et al. 2010). In early spring, 27 lb/ac N are stored in perennial woody tissues prior to leaf out. Throughout spring into summer and harvest, total N increases from 27 to 114 lb/ac N, with a net accumulation in leaves, fruit, and new shoots of 31, 29, and 25 lb/ac N, respectively. Growth of perennial tissues increases net N accumulation of 5 to 6 lb/ac in branches, trunk, and roots (table 2). Accumulation of N throughout the growing season occurred

Table 2. Nitrogen accumulation and distribution (lb/ac) in plant organs at selected sampling stages of table grape (*Vitis vinifera* ‘Red Globe’)

Plant organ	Sampling date						Net accumulated N
	March 30	May 10	June 30	Aug. 20	Sept. 30	Nov. 30	
Leaves	—	2.6	17	27	31	—	31
Fruit	—	—	5.5	18	29	—	29
New shoots	—	—	18	19	25	25	25
Branches	3.9	4.4	4.7	5.3	5.5	6.2	2.3
Trunk	5.1	5.1	5.2	5.5	5.9	6.4	1.3
Roots	18	16	12	13	17.6	20	2.4
Total vine	27	28	62	88	114	58	91

Source: Tong et al. 2010.

Note: Net accumulated N in leaves, fruit, and new shoots equals total accumulated in the last sampling. Net accumulated N in branches, trunks, and roots equals N accumulation in the last sampling value minus N accumulation in the first sampling value.

in three distinct stages: about 38% of total N during sprouting and early foliage growth and new shoot and fruit development; 29% during early fruit development and fruit expansion; and 29% during fruit expansion and fruit maturity (fig. 5).

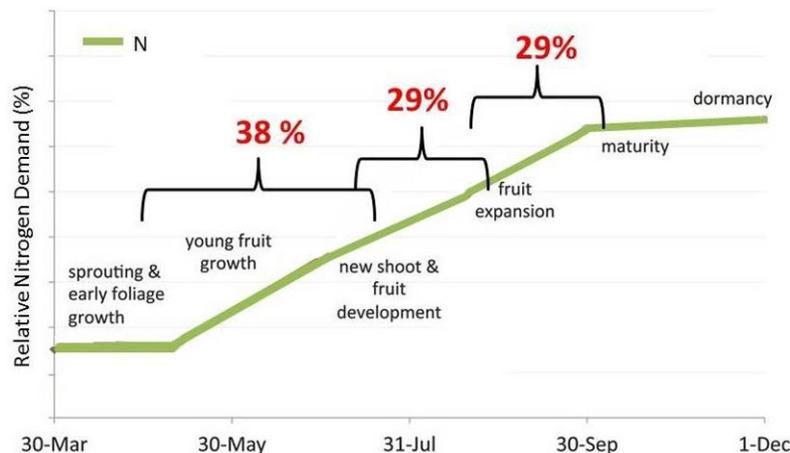


Figure 5. Nitrogen accumulation throughout the growing season in three stages of table grape (*Vitis vinifera* ‘Red Globe’). Source: Modified from data reported by Tong et al. 2010.

Compared with table grape, N partitioning in a vineyard of low-vigor and low-yield (3.5 T/ac) Italian wine grape Cabernet Sauvignon had lower N demand yet had similar partitioning to plant organs (Tagliavini and Scandellari 2012). Allocation to leaves and shoots was 29 lb/ac N, of which the vast majority returns to the ground during abscission or pruning. A total of 8 lb/ac N was exported from the vineyard (fig. 6). The length of time needed before nitrogen in leaves and pruned shoots become available for subsequent plant uptake depends on local environmental conditions, practices implemented such as tillage or chipping, and soil type. Information on the timing of mineralization and decomposition processes and the timing of uptake is required to better understand the role of recycled materials to vineyard N balance.

During the growing season and postharvest, N also moves throughout the vine to drive growth and yield as well as remobilize N for storage in perennial tissues. In a table grape Thompson Seedless vineyard in California, the vine trunk remains fairly constant in its N concentration and N biomass while the roots change during the season (L. Williams, unpublished data). At bud break to anthesis and past veraison the N concentration and N biomass in the roots decreases. This pattern suggests that stored

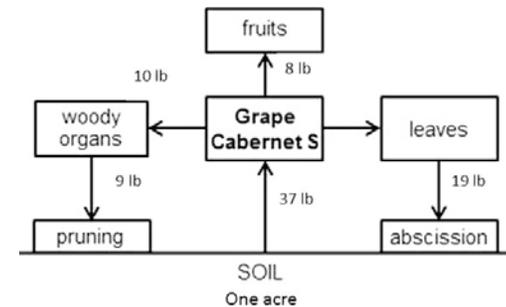


Figure 6. Nitrogen partitioning of a 3.5-ton Italian wine grape (*Vitis vinifera* ‘Cabernet Sauvignon’) vineyard from soil uptake and allocation to fruit, leaves, and woody organs with N returned to vineyard from pruning and abscission. Source: Tagliavini and Scandellari 2012.

root N at the beginning of the season is being translocated to the annual portions of the vine, including leaves, shoots, and fruit. After harvest, N is remobilized back into the roots of the vine for storage until the next season (fig. 7).

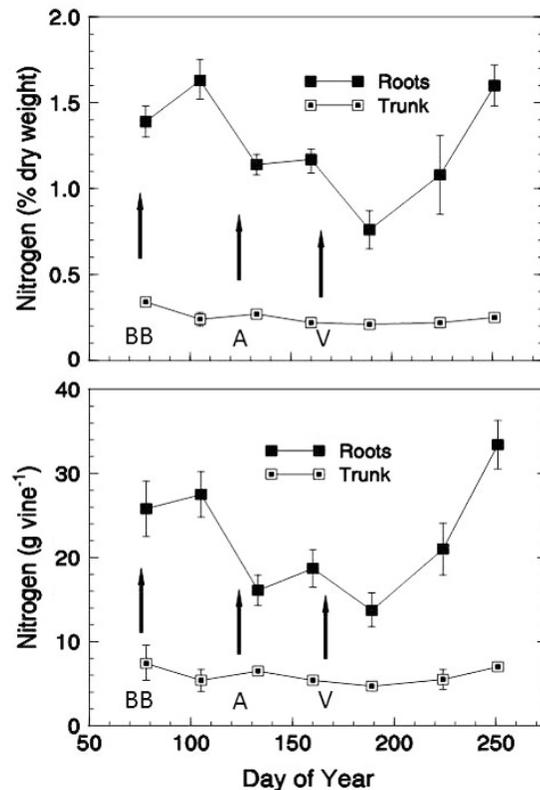
Total annual N demand, consisting of the sum of leaves, stems, and fruit in California vineyards of multiple California table grape varieties were Flame Seedless, 181 lb/ac; Scarlet Royal, 160 lb/ac; Crimson Seedless, 91 lb/ac; and Thompson Seedless, 75 lb/ac. Variations are due to differences in trellis systems, harvest dates, and leaf and stem biomass. Flame Seedless are harvested earlier; the N concentration in leaves and stems is higher at the end of the trellis system because less N is allocated to the fruit. Normalizing for leaf and stem data to 8-ft vine spacing, Flame Seedless has

33% and 58% more leaf and stem biomass than does Thompson Seedless. Scarlet Royal normalized to 8-ft vine spacings has 95% and 195% more leaf and stem biomass than Thompson Seedless. Since the Flame Seedless and Scarlet Royal are planted on 10-ft row spacings and Thompson Seedless on 12-ft rows, Flame Seedless has 60% and 90% more leaf and stem biomass, respectively, per unit land area than does Thompson Seedless. Flame Seedless and Scarlet Royal vines have more leaf and stem biomass at harvest than Thompson Seedless because of closer row spacing and the higher N concentration in leaf and stem tissues.

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Figure 7. Nitrogen use by roots and trunks in grapevines. Vines were harvested throughout the growing season to quantify the use of N. Data is expressed as percent dry weight and total N per vine. Stages of development are noted by black arrows, including bud break (BB), anthesis (A), and veraison (V). Total N values are equivalent to lb/ac at 454 vines/ac. *Source:* L. Williams, unpublished data.



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