When and How Much Nitrogen Should Be Applied in Apple Orchards?

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Nitrogen plays a very important role in determining apple tree growth and development, fruit yield and quality. This has been demonstrated in many sand culture experiments and field trials. In a sand culture experiment where five-year-old 'Gala'/M.26 were supplied with a total of 3, 10, 20 or 40g nitrogen (equivalent to 8.3, 25, 50 or 100 lbs of actual nitrogen per acre) for the entire growing season via fertigation using a complete nutrient solution and their cropload was adjusted to a medium level (6.5 fruit per cm^2 trunk cross-sectional area), we found that, as N supply increased, the proportion of long shoots (>5 cm) in the canopy and the length of these long shoots increased, resulting in a larger total canopy leaf area whereas the total leaf area of short shoots (<5 cm) remained unchanged (Cheng et al., 2007; Xia et al., 2009). The net dry matter accumulation from budbreak to fruit harvest almost doubled from the lowest N supply to the highest N supply, and the partitioning of dry matter to fruit (harvest index) decreased as N supply increased. Average fruit size increased from about 130 g to about 180 g, which was primarily caused by an increase in the number of cells per fruit. Fruit soluble solids increased with increasing N supply, but fruit firmness decreased slightly. These results indicate that within the range of N supply used, increasing N supply improves leaf function, leaf area to fruit ratio, and fruit cell division, leading to larger fruit and higher soluble solids.

> **"Our research has shown the best time to apply N fertilizer is from bud break to the beginning of rapid shoot growth (shortly after petal fall) or post harvest. How much N fertilizer should be applied? The answer to this question depends on three factors: 1) tree nitrogen requirement; 2) natural supply of nitrogen from soil; and 3) uptake efficiency of applied fertilizers."**

In commercial orchards, however, some orchard soils with high organic matter provide a substantial amount of N during the summer, heavy N fertilization late in the spring with natural release of N from the soil during the summer can elevate tree N status to excess levels, leading to vigorous vegetative growth, poor fruit color development, and storage quality problems. At the other extreme, lack of N supply on soils with low organic matter can result in poor fruit set, small fruit size, low yield, and alternate bearing. Because the effect of nitrogen on fruit set and size is just opposite to that of fruit color, flesh firmness, and storage quality, orchard nitrogen management has to be optimized to balance these opposite effects with the ultimate goal of producing high yield of quality fruit.

Nitrogen Demand-Supply Relationship of Apple Trees

When developing a nitrogen fertilization program, the N demand-supply relationship of apple trees must be taken into consideration. Early season canopy development and fruit growth require high N supply whereas fruit quality development only requires baseline N supply. Our work with 6-year-old 'Gala'/M.26 trees grown in sand culture showed that total tree N increased very rapidly from bloom to the end of shoot growth, and then continued to increase but at a much slower rate till fruit harvest (Fig. 1A). The net gain of total N from budbreak to fruit harvest is 20g per tree, which is equivalent to 50 lbs actual nitrogen per acre (Cheng and Raba, 2009a). The total N accumulation in new growth (shoots and leaves and fruit) accounted for all the net N accumulation in the entire tree (Fig 1B). Shoots and leaves and fruit have differential N requirements (Fig 1B). Total N in shoots and leaves increased very rapidly from bloom to the end of shoot growth, and then remained unchanged till fruit harvest. In contrast, total N in fruit increased gradually from bloom to the end of shoot growth, and then increased rapidly till fruit harvest.

There are three sources of nitrogen supply. The first source is the reserve nitrogen that has accumulated in the tree from

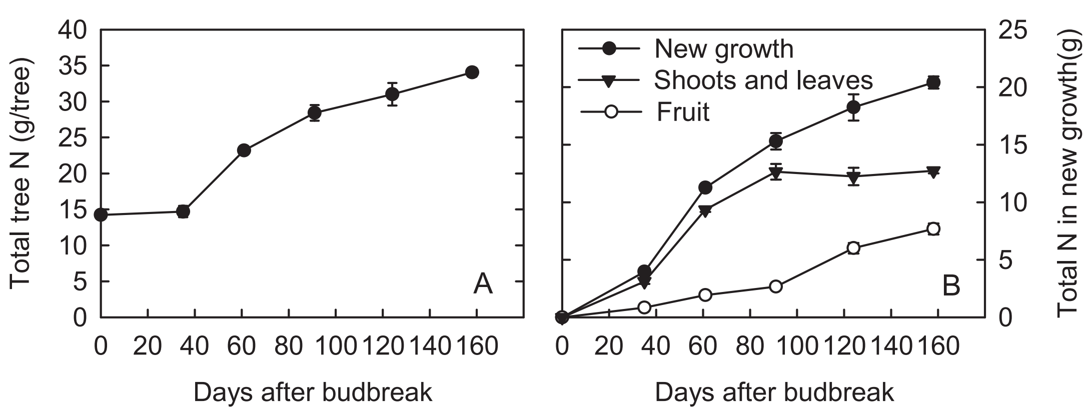

Figure 1. Total N accumulation in the entire tree (A) and in new growth (B) of 6-year-old 'Gala'/M.26 trees grown in sand culture under an optimal N supply regime. The six points correspond with budbreak, bloom, end of spur leaf growth, end of shoot growth, rapid fruit expansion period, and fruit harvest, respectively. Each point is mean ± SE of four replicates.

Table 1. Apple leaf analysis standards for nitrogen (from Stiles and Reid, 1991)

Tree type	Desired levels of leaf N (%)
Young non-bearing apples	2.4 – 2.6
Young bearing apples	2.2 – 2.4
Mature soft apples	1.8 – 2.2
Mature hard apples and processing	2.0 – 2.4

the previous growing seasons. This pool of nitrogen is readily available for the initial growth during spring. ^{15}N-labelling studies clearly indicated that the majority of the N required for spur leaf growth of apple trees is supported by tree reserve N (Neilsen et al., 1997). Better N supply to spur leaves and young fruits may improve spur leaf development and early fruit growth by promoting cell division. The second source is the natural N supply from the soil mineralization process. The supply capacity of this process depends on soil organic matter content, soil temperature, moisture, and aeration of the soil. This process provides substantial amount of nitrogen for trees growing on soils with high organic matter (Stiles and Reid, 1991). The third source is nitrogen supply from fertilizers, either applied into the soil or to foliage.

The nitrogen demand-supply relationship is reflected in tree N status. Throughout the growing season, an ideal pattern of tree nitrogen status is that trees have relatively high nitrogen status early in the season to promote rapid leaf area development and early fruit growth. As the season progresses, nitrogen status declines gradually to guarantee fruit quality development and wood maturity. This provides a basic framework for guiding N management in apple orchards. Nitrogen management in apple orchards is all about matching tree N demand with the three supply sources in an environmentally sound way.

Tree and Fruit Nitrogen Status

Determining tree N status is important for making decisions about whether and how much nitrogen fertilizer should be applied. Leaf analysis is highly recommended for this purpose as it indicates nitrogen and other mineral nutrients present in the foliage. If leaf samples are taken correctly and the results are interpreted properly, it provides a good tool for developing an effective fertilization program. Apple leaf analysis standards for nitrogen are listed in Table 1.

Tree growth is directly related to its nitrogen status. Rapid growth of young trees is highly desirable for developing the canopy to capture sunlight for promoting early cropping. The optimum leaf N for the growth of young apple trees is approximately 2.4 to 2.6%. As trees mature, less vegetative growth is desired and the optimum leaf N level should decrease to improve fruit color, firmness, and storage quality.

Varietal difference in fruit coloring and/or flesh firmness and storage quality is another important consideration. Apple varieties can be categorized into two groups, soft varieties and hard varieties, based on their optimum N status required for fruit quality.

Soft varieties include Cortland, Golden Delicious, Honeycrisp, Jerseymac, Jonagold, Jonamac, Jonathan, Macoun, McIntosh, Mutsu, Paulared, Spartan, Tydeman Red, and other early ripening varieties.

Hard varieties include Delicious, Empire, Gala, Idared, Liberty, Melrose, R.I. Greening, Rome, Stayman, York Imperial, and any other varieties if the fruit is for processing market.

Care must be taken when interpreting leaf analysis results, as many factors influence leaf mineral composition, especially, cropload and tree vigor. Leaf N tends to be higher on trees with a heavy crop than those with a light crop. Off-year trees are generally lower in leaf N than on-year trees. This is because more vegetative growth of the light cropping trees dilutes the nitrogen in leaves. In contrast, trees that are spur-bound with very limited new growth tend to have higher than desired levels of nitrogen in their foliage, a result of N accumulation caused by the limited growth. To properly diagnose tree N status, one needs to combine leaf analysis with careful examination of tree growth.

In addition to leaf analysis, fruit N status must be considered because fruit N status may change significantly with relatively small changes in leaf N. Our work with 'Gala' showed that leaf N had a curvilinear relationship with soil N supply whereas fruit N was linearly related to soil N supply (Fig 2). As N supply increased from 22 lbs to 262 lbs per acre, fruit N concentration increased 10 times (from 0.03% to 0.31%) whereas leaf N only doubled (from 1.5% to 3.0%).

Timing of Nitrogen Application

What is the best timing for N application? In principle, you can apply nitrogen any time when you detect a nitrogen deficiency during the growing season, but the best result is achieved by considering the seasonal pattern of tree N demand, that is, early season canopy development and fruit growth require large amounts of N while fruit quality development only requires baseline supply of N. We reasoned that there are two windows for regular soil N application that would fit the tree nitrogen demand pattern: one is from budbreak to the beginning of rapid shoot growth and other is late in the season when soil N application no longer affects fruit quality (just before or shortly after fruit harvest).

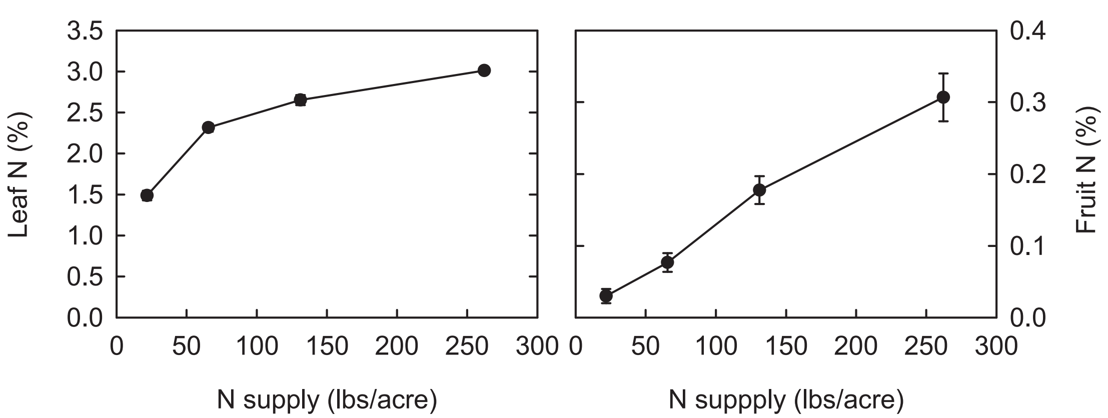

Figure 2. 'Gala' leaf N and fruit N concentrations in response to N supply. Seven-year-old 'Gala'/M.26 trees were grown in sand culture and provided with 21.8, 65.5, 131.1, or 262.2 lb N per acre in Hoagland's solution via fertigation at a spacing of 3.5 × 11.0 feet in sand culture experiment. Each point is mean ± SE of five replicates.

Over three years (2000 to 2002), we used ^{15}N-labelled ammonium nitrate to determine the effect of timing of N fertilization on fertilizer N uptake and fruit N status, and found that apple trees grown under New York climate conditions were able to take up significant amount of fertilizer N between budbreak and end of spur leaf growth (For details, see Cheng and Schupp, 2004). An advantage of early N application is that when it comes to harvest, fruit N status has decreased to a similar level found in control trees, suggesting no negative effect on fruit quality. It appears that both N applications early in the season (budbreak to petal fall) and late in the season just before fruit harvest fit the seasonal pattern of tree nitrogen demand. Nitrogen applied early in the season contributes directly to the spur and shoot leaf development and fruit growth in the current season while N applied late in the fall helps to build up nitrogen reserves, which is used to support leaf development and fruit growth the following year. Considering the uncertainty of N leaching loss during the winter, early soil application of nitrogen between budbreak and petal fall is probably the most practical way to meet the tree N demand early in the season. If more than 40 lbs actual N/acre is to be applied, a split application, half at a couple weeks after budbreak and the other half at petal fall or shortly thereafter, is recommended. If nitrogen is provided via fertigation, application should be targeted to the high demand period from bloom to end of shoot growth.

For soils that have low cation exchange capacity, such as sandy soil with low organic matter, or varieties whose fruit quality is not sensitive to N, multiple split application during spring-summer period may be desirable.

Amount of Nitrogen Fertilizer

How much N fertilizer should be applied? The answer to this question depends on three factors: 1) tree nitrogen requirement; 2) natural supply of nitrogen from soil; and 3) uptake efficiency of applied fertilizers. The annual N requirement is estimated to be about 50 to 80 lbs for mature apple trees on dwarfing rootstocks in high density plantings. The actual N requirement varies from block to block and fruit yield should be taken into account (Cheng and Raba, 2009b). The N supply from soil mineralization process depends on soil organic matter content, soil temperature, moisture, and aeration of the soil. Because orchard soils are not disturbed frequently, the annual mineralization of soil organic nitrogen is less than 1% of the total organic nitrogen pool in the soil (Lathwell and Peech, 1964). For a soil that has a 3% organic matter, the amount of nitrogen released from soil mineralization process is about 50 to 70 lbs. However, only a proportion of the released nitrogen is taken up by the tree. Assuming 60% of the 50 to 70 lbs of N is taken by the tree, this would contribute about 30 to 40 lbs N to the tree. The difference between the total demand and the contributions from soil N is the amount of N the trees need from the fertilizer. Because not all the fertilizer nitrogen is taken up by the trees, nitrogen fertilizer use efficiency should be factored in when determining the actual amount of fertilizer nitrogen to be applied. For soils with high organic matter, the natural supply of N from soils may be sufficient to meet the tree N demand and there is no need to apply any N fertilizer. Generally speaking, for orchard soils in New York and the Northeast, the amount of fertilizer N required is anywhere between 0 and 80 lbs, which would contribute 0 to 30 lbs of N to the trees, assuming the fertilizer uptake efficiency is between 30 to 40%. As a rule of thumb, every 10% increase in N fertilizer application results in a 0.1% increase in leaf N. If N is provided via fertigation, less N is needed as N uptake efficiency is higher in fertigation than in regular soil application.

Because each orchard soil is unique and all the fertilizer field trials are site specific, the best way to fine-tune the amount of N fertilizer you should apply is to have your own N rate trial on your farm based on leaf analysis and tree indicators.

Foliar Nitrogen Application

In addition to soil application of N fertilizers, foliar N application can help to satisfy the tree nitrogen demand early in the season or to improve tree reserve nitrogen status after harvest in the fall.

Early foliar N spray is beneficial for fruit set and early fruit growth when leaf analysis shows less than 2.2% leaf N the previous year. Foliar N spray can extend the effective pollination period and promote cell division. The spray concentration has to be low to avoid any damage on the tender foliage early in the season. Generally, 3 lbs of urea per 100 gallons of water is used prior to bloom and this can increase to 5 to 6 lbs of urea per 100 gallons at petal fall and early cover sprays. Foliar urea sprays can be tank mixed with Solubor and zinc chelate (Stiles and Reid 1991).

Foliar urea application late in the season can be used to increase reserve N levels in nursery apple trees and consequently improve their growth performance (Cheng and Fuchigami, 2002). The effect of foliar urea application after harvest on reserve N status of mature apple trees was first reported by Oland (1960), and since then many experiments have been conducted on apple trees. The effectiveness of postharvest foliar urea application on tree N reserves is dependent on the tree background N status, with low N trees being much more responsive than high N trees (Cheng et al., 2002). It appears that apple trees have a feedback mechanism to regulate N uptake from foliage. One of the concerns about postharvest foliar urea application is that foliar N application this late may reduce tree cold hardiness. We have tested this in both young trees and mature apple trees and found that postharvest foliar urea application does not affect tree cold hardiness (Schupp et al., 2001). The advantage of postharvest foliar N application is that high concentrations can be used because the foliage is less sensitive to burn late in the season. Foliar urea sprays at concentrations up to 10% have been found in the literature, but 3% urea spray (25 lbs of urea in 100 gal water) is very common and proves to be safe.

We have also compared postharvest foliar urea spray with soil N application in the spring at the same rate on both mature McIntosh and Empire trees. Two applications of 3% foliar urea can increase the nitrogen concentration of spurs and extension shoots significantly. The nitrogen derived from foliar urea is also translocated to trunk and the root system of field-grown mature

apple trees (Cheng, unpublished data). However, it does not seem to have any advantage over soil N application in the spring when applied at the same rate. Although it remains as a viable option in apple-producing regions with a relatively long postharvest leaf retention period, the practical use of postharvest foliar urea application may be limited in the Northeastern US due to the small window between fruit harvest and leaf fall and the uncertainty of weather conditions. However, it was reported by Sutton et al (2000) that 5% foliar urea spray applied to apple trees before leaf fall (October 12) in the northeastern US reduced the number of ascospores trapped by 97%. This beneficial effect of fall foliar urea application on scab control may provide another incentive for growers to use fall foliar urea application in addition to increasing tree N reserves.

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