Nitrogen Fertilization of Apple Orchards

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Nitrogen (N) management plays a very important role in determining apple yield and quality. For example, orchard soils with high organic matter content can naturally release a substantial amount of N during the summer from the decay of organic matter. With these soils, heavy N fertilization late in the spring coupled with the natural release of N from the soil during the summer can elevate tree N status to excess levels during the late summer when fruit quality develops. This high tree N status can lead to vigorous vegetative growth, poor fruit color development, and fruit storage disorders. Vigorous trees are also more susceptible to diseases during the growing season and freezing damage in the winter. In contrast, lack of N supply on soils with low organic matter can result in small fruit size, low yield, and alternate bearing.

Nitrogen Demand-Supply Relationship

When developing a nitrogen fertilization program, the N demand-supply relationship of an apple tree must be taken into consideration. There are three sources of nitrogen supply. First is the nitrogen supplied by reserves in the tree that have accumulated during the previous growing season. This pool of nitrogen is readily available for initial tree growth during the spring. The second source is the nitrogen supplied from the soil by the natural mineralization process. This process can provide a substantial amount of nitrogen for trees growing on soils with high organic matter (Stiles and Reid, 1991). The third source is the nitrogen supplied from fertilizers, either applied into the soil or to foliage.

Demand for nitrogen is high during the early season when canopy development and fruit growth both require large amounts of N, but fruit quality at harvest is low from high nitrogen trees. Thus an ideal pattern of tree nitrogen status is for trees to have a relatively high nitrogen status early in the season to promote rapid leaf development and early fruit growth, but as the season progresses, nitrogen status should decline gradually to guarantee fruit quality development and wood maturity. The nitrogen demand-supply relationship provides a basic framework for guiding nitrogen management in apple orchards. Nitrogen management of apple orchards is all about matching nitrogen supplies with tree N demand in an environmentally sound way.

Tree N Status

Determining tree N status is critical 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, leaf analysis provides a good tool for developing an effective fertilization program. Apple leaf analysis standards for nitrogen are listed in Table 1 (Stiles and Reid, 1991).

The desired levels of leaf N depends on tree age, type of fruit, and the intended market. Since rapid growth of young trees is highly desirable for developing the canopy to capture sunlight for promoting early cropping, the optimum leaf N for young apple trees is approximately 2.4 to 2.6 percent. As trees mature, less vegetative growth is desired and the optimum leaf N level is lower. Lower leaf nitrogen results in improved fruit color, firmness, and storage quality.

Varietal differences in fruit coloring, flesh firmness and storage quality are also important considerations. Apple varieties can be categorized into two groups based on their optimum N status required for fruit quality. Soft varieties, including Cortland, Empress, Golden Delicious, Honeycrisp, Jerseymac, Jonagold, Jonamac, Jonathan, Macoun, McIntosh, Mutsu, Paulared, Spartan, Tydeman Red, and early ripening varieties. Hard varieties, including Delicious, Empire, Gala, Idared, Liberty, Melrose, R.I. Greening, Rome, Stayman, York Imperial, and any other varieties if the fruit is intended for processing markets.

The ideal seasonal pattern of tree nitrogen status is one in which trees have a relatively high nitrogen status early in the season to promote rapid leaf development and early fruit growth. As the season progresses, nitrogen status should decline gradually to guarantee high fruit quality at harvest and wood maturity prior to winter. Our data show that under our climatic conditions, N applications either early in the season (budbreak to bloom) or in the fall as foliar urea can fit the seasonal pattern of tree nitrogen demand. However, fall foliar urea applications do not seem to have any advantage over soil N applications in the spring.

TABLE 1

Apple leaf analysis standards for nitrogen (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	2.2 – 2.4

Care must be taken when interpreting leaf analysis results since many factors influence leaf 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. This is a result of N accumulation caused by the limited growth.

Shoot growth, leaf color, and fruit set, size, yield and maturity may also indicate tree N status. Trees with a low N status have light green/yellow green leaves, short terminal shoots (less than 8 inches), poor fruit set and heavy June drop, small but highly colored fruit, advanced fruit maturity, early leaf drop in the fall, and increased tendency for biennial bearing. Trees with excessive N have vigorous terminal shoots (longer than 18 inches), large dark-green leaves, large but poor-colored fruit, and delayed fruit maturity and delayed leaf fall. Trees with normal N status have terminal shoots of 10 to 16 inches, good fruit set, size and color and high yield.

Highly experienced growers may be able to diagnose tree N status by using the tree indicators alone. However, by the time nitrogen deficiency or excess symptoms show up, its negative effects on tree growth, yield, and fruit quality have taken place. Therefore, the proper assessment of tree N status is best achieved by combining leaf analysis with careful examination of tree growth and development.

Fertilization Program for Young Trees

When new trees are planted in spring, an immediate adequate supply of water is essential to settle the soil around the roots, but application of nitrogen fertilizer is not recommended. This is because the initial tree growth is mainly supported by the nutrient reserves within the tree and the uptake of nutrients from the soil is often delayed due to the damaged root system (Cheng, 2002). In addition, the application of large amounts of dry fertilizers at planting may cause damage to the roots. The first application of nitrogen fertilizer should be made two weeks after budbreak at a rate of 0.6 to 1.0 ounce of actual nitrogen per tree. Liquid nitrogen fertilizers are preferred. If dry fertilizers have to be used, make sure to avoid any contact with the trunk. A second application at the same rate may be needed on coarse-textured soils that are low in organic matter. If trees show nitrogen deficiency, two to three sprays of 6 lbs. of urea per 100-gal water is recommended at 10 to 14-day intervals. In early October, two sprays of foliar urea at 25 lbs. per 100 gal are also suggested to allow the tree to increase nitrogen reserves for better growth the second year.

In the second year, just before the new shoots begin their rapid growth, apply 0.1 to 0.2 pounds of actual nitrogen per tree. If trees have a substantial crop and the variety is susceptible to bitterpit, a foliar calcium program is also recommended.

Fertilization Programs for Established Trees

Many trials have demonstrated that increasing the nitrogen status of mature apple trees increases fruit set and size but results in reduced fruit color, flesh firmness, and storage quality. One of the goals of nitrogen management is to achieve and maintain a tree N status that balances these opposite effects. It is important to keep in mind that the tree N status that accomplishes this varies among cultivars.

1. Amount of N fertilizer. How much N fertilizer should I apply? Before we answer this question, let's look at how much N is required by apple trees and the contribution from each of the three supply sources. The amount of N required by the annual new growth (including shoots and leaves, flower and fruit, and growth of perennial parts) is estimated to be about 60 to 90 lbs for mature apple trees on semi-dwarf and dwarf rootstocks. Of this total amount, 30 to 50 percent comes from nitrogen that is stored in the perennial parts of the tree. The supply from the 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 percent of the total organic nitrogen pool in the soil (Lathwell and Peech, 1964). For a soil that has a 3 percent organic matter, the amount of nitrogen released from soil mineralization process is about 50 to 70 lbs. However, only a small proportion of the released nitrogen is taken up by the tree. Assuming 40 percent of the 50 to 70 lbs of N is taken by the tree, this would contribute 20 to 30 lbs N to the tree. The difference between the total demand and the contributions from reserve N and soil N is the amount of N the trees need from fertilizer.

Again, because the tree does not absorb all the nitrogen from the fertilizer, the nitrogen fertilizer use efficiency should be factored in when determining the actual amount of fertilizer nitrogen that should be applied. So, the answer to the question really depends on the capacity of the soil to supply N and the tree N status.

For soils with high organic matter, the natural supply of N from the soil 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 60 lbs/acre, which would contribute 0 to 20 lbs of N to the trees, assuming the fertilizer uptake efficiency is between 30 to 40 percent. As a rule of thumb, every 10 percent increase in N fertilizer application results in a 0.1 percent increase in leaf N. 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.

2. Timing of N application. What is the best timing for soil N application? In principle, nitrogen can be applied at any time when a nitrogen deficiency is detected during the growing season, but the best result is achieved by considering the seasonal pattern of tree N demand. Early-season canopy development and fruit growth require large amounts of N, while fruit quality development requires a minimum supply of N. Over the last three years we used ^{15}N-labelled ammonium nitrate to determine N uptake from the fertilizer and its contribution to the N economy of mature Empire/M9 trees. The same amount of N fertilizer, 40 lbs actual N per acre, was applied at budbreak (early April), the beginning of active shoot growth (late May), or one week before fruit harvest in the fall.

Nitrogen applied at budbreak significantly increased early season spur leaf N, shoot leaf N, and fruit N, and contributed equally (30 percent) to the N pool in spur leaves, shoot leaves, and fruit (Tables 2, 3, 4). By harvest, tree N status in the budbreak N treatment decreased to a similar level found in control trees.

Nitrogen applied at active shoot growth significantly increased mid-season N content of spur leaves, shoot leaves, and fruit. It contributed more to shoot leaves (40 percent) than to spur leaves (18 percent) (Tables 2, 3, 4). At harvest, fruit of these treated trees still had higher N than that of control trees.

Preharvest N application did not significantly increase N content of spur leaves, shoot leaves or fruit, and contributed very little to their corresponding N pool (Table 6, 7, 8). However, nitrogen applied one week before harvest contributed about 25 percent to the N pool in spur leaves and shoot leaves the following year (Table 5).

When the experiment was repeated in 2002, we included an N treatment at bloom. Nitrogen applied to soil at budbreak significantly increased N content of blossom and young fruit, and contributed 35 to 40 percent to the N in fruit (Table 6). Nitrogen applied at bloom significantly increased N content of fruit throughout the growing season, and contributed about 34 to 40 percent to the N pool in the fruit. Nitrogen application during active shoot growth significantly elevated mid-season fruit N and the harvested fruit had the highest N content among all the treatments.

Our data show that apple trees grown under our climatic conditions are able to take up significant amount of fertilizer nitrogen between budbreak and the end of spur leaf growth. Another advantage of early N application is that when it comes to harvest, fruit N content 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 bloom) and in the fall can fit the seasonal pattern of tree nitrogen demand. N 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 are used to support leaf development and fruit growth the following year. Considering the uncertainty of N leaching loss during the winter, early soil applications of nitrogen between budbreak and bloom are probably the most practical ways to meet the tree N demand.

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

3. 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 sprays are beneficial for fruit set and early fruit growth when leaf analysis shows N concentration the previous year was less than 2.2 percent. Foliar N spray can extend the effective pollination period and promote cell division. The spray concentration needs to be low to avoid any damage on the tender foliage early in the season. We recommend 3 lbs of urea per 100 gallons of water prior to bloom and 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 (See *Cornell Recommends for Tree Fruits*).

Foliar urea applications after harvest can improve reserve N status of apple trees. A concern of late season applications of foliar N application is that it may reduce tree cold hardiness. We have tested this in both young trees and mature apple trees and found that postharvest foliar urea applications do not affect tree cold hardiness (Schupp et al., 2001; Cheng and Schupp, 2002). The effectiveness of postharvest foliar urea applications on tree N reserves is dependent on the tree N status, with low N trees being much more responsive than

TABLE 2

Empire spur leaf N content and the contribution from fertilizer (2000)

N Treatment	May 19		July 19		Sept. 28	
	N (%)	NDFF (%)	N (%)	NDFF (%)	N (%)	NDFF (%)
Budbreak N	3.89	31.8	2.47	33.7	2.13	29.5
Active shoot growth N	-	-	2.45	18.9	2.15	17.8
Pre-harvest N	-	-	-	-	2.15	2.6
Control	3.28	0.0	2.34	0.0	2.08	0.0

NDFF: nitrogen derived from fertilizer, which represents the percentage contribution of fertilizer N to tissue N.

TABLE 3

Empire shoot leaf N content and the contribution from fertilizer (2000)

N Treatment	May19		July 19		Sept. 28	
	N (%)	NDFF (%)	N (%)	NDFF (%)	N (%)	NDFF (%)
Budbreak N	4.04	31.3	2.45	35.4	2.10	33.9
Active shoot growth N	-	-	2.47	44.8	2.26	40.7
Pre-harvest N	-	-	-	-	2.21	1.9
Control	3.40	0.0	2.32	0.0	2.14	0.0

TABLE 4

Empire fruit N content and the contribution from fertilizer (2000)

N Treatment	May 19		July 19		Sept. 28	
	N (%)	NDFF (%)	N (%)	NDFF (%)	N (%)	NDFF (%)
Budbreak N	3.78	30.7	0.56	30.5	0.22	31.1
Active shoot growth N	-	-	0.60	27.1	0.28	30.0
Pre-harvest N	-	-	-	-	0.22	0.3
Control	3.43	0.0	0.50	0.0	0.22	0.0

TABLE 5

Leaf N and the contribution from fertilizer the following year at harvest (2001)

N Treatment	Spur leaf		Shoot leaf	
	N (%)	NDFF (%)	N (%)	NDFF (%)
Budbreak N	2.21	11.7	2.29	11.3
Active shoot growth N	2.19	18.7	2.42	17.6
Pre-harvest N	2.26	26.3	2.34	24.8
Control	2.12	00.0	2.23	00.0

TABLE 6

Empire fruit N content and the contribution from fertilizer (2002)

N Treatment	May 3		June 2		Aug. 19		Sept. 29	
	N	NDFF	N	NDFF	N	NDFF	N	NDFF
Budbreak N	3.42	35.0	3.18	42.2	0.29	38.6	0.25	35.9
Bloom N	-	-	2.78	33.4	0.33	40.2	0.38	34.2
Active shoot growth N	-	-	-	-	0.34	33.0	0.45	29.7
Pre-harvest N	- -	- -	-	-	-	-	0.22	0.3
Control	3.18	0.0	2.40	0.0	0.26	0.0	0.21	0.0

high N trees (Cheng et al., 2002). It appears that apple trees have a feedback mechanism to regulate N uptake from foliage. 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 percent have been found in the literature, but 3 percent urea sprays (25 lbs of urea in 100 gal water) are very common and safe.

We have also compared postharvest foliar urea sprays with soil N application in the spring at the same rate on both mature McIntosh and Empire trees. Two applications of 3 percent foliar urea can increase the nitrogen concentration of spurs and extension shoots significantly. The nitrogen derived from foliar urea is also translocated to the 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. Considering the small window between harvest and leaf fall and the uncertainty of weather conditions, the practical use of postharvest foliar urea application may be limited in the Northeast although it remains as a viable option.

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