Mineral Nutrition as a Factor In Cold Tolerance Of Apple Trees

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This work was funded in part by the New York Apple Research and Development program.

Tree nutritional levels must be kept at optimum for reducing the risk of cold injury to fruit trees. Carbohydrates, nitrogen, potassium, boron, copper, zinc, and manganese are all involved.

Cold injury to plant tissue occurs when the water inside cells freezes. When this happens, the cell membranes fail, and the cell contents leak out, resulting in death. The development of cold hardiness can only begin when the plant has stopped growing. It is a series of processes by which the cells in the plant become increasingly resistant to intra-cellular freezing. How many cells die, and how well the plant is able to heal the damage by creating new cells to replace those that have been lost, are the key factors that determine the extent of injury and the chances of recovery.

Cold injury to apple trees can occur at various times of the year and be evident in different forms according to when the injury occurs. Although absolute mid-winter low temperatures can be of concern in some years, many of the cold damage problems encountered in the Northeastern US occur in late fall and early winter when hardening of the trees is delayed, or with spring frost damage. In this article, we review the roles of various nutrients in determining cold tolerance of trees and report on three research projects pertaining to apple tree cold hardiness that are ongoing or recently concluded. The first of these studies was to determine if foliar sprays of copper chelate can induce earlier cold tolerance, the second was on the impact of fall foliar urea on cold hardiness, and the third was on remedial treatments for cold damaged trees. Finally, we offer some suggestions for minimizing the potential for cold damage to apple trees.

Nutritional Factors and Interactions

Carbohydrates - These are the most important "nutrients" involved in cold hardiness. Hardening off is a biological process that requires carbohydrate reserves both for energy to drive the various biochemical processes along, and for providing carbon, the building blocks of the many organic molecules that are needed in the process. There is also evidence that plants synthesize sugar alcohols that act as anti-freeze inside the cells.

Trees that are over-cropped or lose adequate effective leaf surface prematurely due to insects, mites or disease have low carbohydrate reserves and lack cold hardiness. Likewise, any mineral nutrient deficiency that limits the photosynthetic potential of the leaves or interferes with energy storage or utilization will also reduce cold hardiness of fruit trees.

The effects of individual mineral nutrients on cold hardiness are usually indirect and result from disturbances of normal growth patterns or disruption of normal physiological processes within the tree. The following are some of the more commonly observed relationships of various nutrient elements to cold tolerance, or susceptibility to cold damage.

Nitrogen - Low tolerance of nitrogen deficient trees to cold damage is associated with poor tree growth. While nitrogen deficient trees usually cease growth and harden off earlier than trees with adequate N, such trees do not reach the same level of mid-winter cold tolerance. At the opposite extreme, excessive nitrogen often extends the growth of plant tissues late in the fall, delaying hardening of the trees, thus predisposing the trees to cold damage. This condition is often associated with young trees that are being pushed to grow with high fertilizer rates in an effort to fill their allotted space in the new planting.

It is desirable to have a relatively high nitrogen level early in the spring to encourage adequate growth of young trees and to favor fruit set on bearing trees. Trees that produce good extension shoot growth early in the growing season, and then set terminal buds relatively early are usually more cold tolerant than those that continue growing late into the fall. In this regard, young non-bearing trees and varieties such as McIntosh can be troublesome since they often continue growing until frost occurs. This problem is accentuated in seasons when an extended dry period is followed by late summer rains.

Potassium - Inadequate potassium leads to greater susceptibility of vegetative tissues, trunks, and flowers to cold damage. The greater susceptibility of trees to cold damage after bearing a heavy crop load is related in part to the effects of the crop on the potassium status of the trees. Potassium requirements are determined to a large extent by crop load and potassium moves from leaves and other tissues into the fruit as the fruit matures. Further, when the available supply of potassium is inadequate, fruit maturation is delayed and the period of time between harvest and the occurrence of killing frosts is shortened. This further leads to greater susceptibility of the trees to cold damage because of the reduced photosynthate that the trees are able to produce during this critical period. As mid-summer leaf potassium levels decrease below about 1.5%, cold tolerance of apple trees has been shown to decrease.

Nitrogen-Potassium Relationship - In addition to the individual influences of nitrogen and potassium on cold tolerance, the relationship between levels of these two elements is also of concern. Potassium requirements become greater as the nitrogen level is increased. Thus, a higher level of potassium in leaf tissue samples is required at higher levels of nitrogen in the tissues. It should be emphasized, however, that the effects of high nitrogen cannot be totally overcome by increasing potassium supplies.

Magnesium - Trees that are deficient in magnesium produce weak growth, small spurs and flowers as a result of reduced carbohydrate supply. Such trees are less cold tolerant. Magnesium requirements become greater as the potassium levels increase, and leaf sample ratios of potassium to magnesium that approach or exceed 4:1 indicate magnesium deficiency even when the magnesium levels are in the sufficient range.

***ZINC* -** Zinc deficient plants show increased susceptibility to cold injury, including both winter injury and frost damage to flowers. The reduced photosynthesis resulting from poor shoot growth and leaf development has been implicated, but this does not appear to explain the total role of zinc in this arena. Zinc is essential in the development of hormones that have a myriad of effects on plant growth regulation in trees. It would appear that the zinc level required to assure best cold tolerance may be somewhat higher than is usually considered to be adequate for normal crop development.

Copper - Copper deficient trees also exhibit poor quality of growth, similar to that shown by zinc deficient trees. Further, normal development of woody tissues in shoots and roots is impaired. Low cold tolerance of such trees has been attributed to reduced carbohydrate supply resulting from stunted shoot growth and small leaves.

Manganese - Leaves on trees that are deficient in manganese are relatively thin and show loss of chlorophyll which also results in reduced photosynthesis and carbohydrate supply.

Boron - Boron plays several roles that have direct or indirect bearing on the development of cold tolerance or recovery of cold-injured trees. It is essential for root development that is necessary for uptake of other nutrient elements. Boron is involved in sugar transport within the tree and appears to have a role in stimulating development of cambial activity that is necessary in the recovery of the trees from cold injury.

Recent Research to Enhance Cold Tolerance

Cold damage to apple trees occurs quite frequently in the Champlain and Hudson Valley regions of New York State. Often this damage can be associated with high N levels or with weather conditions that encourage prolonged late-season growth and delayed hardening of the trees. Studies were initiated to develop methods that might promote earlier dormancy and hardening off of the trees. The approach used was to apply a series of post-harvest foliar sprays of copper chelate (Cu-EDTA) plus oil for enhancing dormancy. Fruit tree nurseries use Cu-EDTA sprays to defoliate nursery stock prior to digging in the fall, but since nursery trees are stored indoors after digging, the effect of chemical defoliation on cold hardiness is not known.

In 1994, Drs. Stover and Stiles initiated studies to encourage earlier dormancy and increase cold hardiness in young apple trees. Dilute foliar sprays of copper chelate (Cu-EDTA), plus ultrafine spray oil, applied in mid-October, accelerated leaf drop of apple trees by three to four weeks compared to untreated trees. Copper-EDTA sprays increased early winter cold hardiness in laboratory cold chamber studies with detached twigs. Mid-winter hardiness was not adversely affected, and there was less visible bud injury on Cu-EDTA treated trees. These initial studies suggested that mid-October applications of Cu-EDTA plus oil might have potential for increasing early winter hardiness of apple by hastening dormancy.

This line of research was resumed in 1999. Additional research was needed to confirm these results and to make the transition from small plots applied by handgun to full-scale orchard treatments applied by air-blast sprayer.

In 1999, we tested four concentrations of Cu-EDTA applied by handgun, and evaluated air-blast sprays of 150 and 75 gallons per acre on young McIntosh/M.26 apple trees growing in a commercial orchard. Shoots were collected in early December, and again in late January, and subjected to a range of cold temperatures in a programmable cold chamber at the Hudson Valley Lab. Cold injury resulting from these temperatures was evaluated by determining electrolyte leakage, using a conductivity meter. Results of this research showed that while both handgun and air-blast sprays of Cu-EDTA were highly effective defoliants at concentrations of 0.1% copper and up (Figures 1, 2a and b), they did not enhance early winter cold hardiness (data not presented).

In September 2000, a block of late growing young trees was identified in a commercial orchard. The trees were three-year-old McIntosh on M.9/111 with active terminal shoots. The treatments were: a) Untreated control; b) Apogee; c) Cu-EDTA; and d) Apogee, followed by Cu-EDTA. Apogee plant growth regulator was applied at 250 ppm (12 ounces per 100 gallons) on 5 October, with 0.05% Silwet surfactant. Copper-EDTA (1.2%) was applied on 19 October, with 0.1% ultra-fine oil.

Defoliation was estimated thereafter on a weekly basis, until defoliation was complete for all treatments. Shoots were collected on 4 December, and again on 22 January 2001, and subjected to a range of cold temperatures in a programmable cold chamber at the Hudson Valley Lab. Cold injury resulting from these temperatures was evaluated by determining electrolyte leakage, using a conductivity meter.

Both Apogee and Copper-EDTA accelerated defoliation (Figure 3). Copper-treated trees were defoliated by 7 November, while untreated trees weren't defoliated until 20 November. The pattern of defoliation was uncharacteristic compared to that of previous seasons in that more of the leaves from untreated trees dropped earlier. However, after 31 October all remaining leaves were young green leaves on current season growth, indicating that these shoots were still actively growing late in the season.

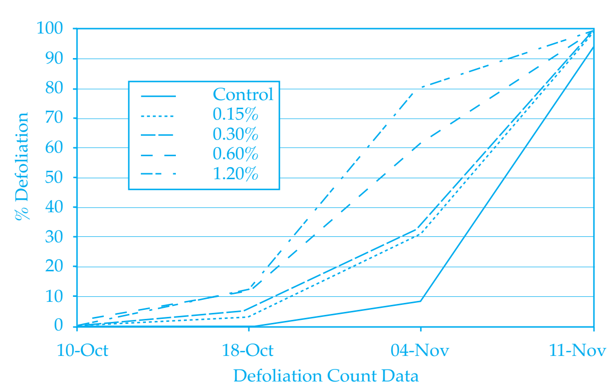

Figure 1. Effect of Cu-EDTA on defoliation, 1999.

Figure 2. Natural defoliation of unsprayed McIntosh (a) compared to similar Copper EDTA sprayed trees (b).

Shoots from all treatments demonstrated cold hardiness to about 0F by early December (Figure 4). Apogee treated trees had 17% and 25% less electrolyte leakage at –11F and –22F, respectively than untreated controls. Trees treated with Cu-EDTA had the same amount of electrolyte leakage as the untreated controls throughout the range of test temperatures, while trees that received both Apogee and Cu-EDTA had about 20% greater electrolyte leakage when exposed to temperatures of –11F and lower. All treatments had severe electrolyte leakage when exposed to -33F in early December.

In January 2001, electrolyte leakage from shoot samples exposed to –11F and –22F was lower than in December and the relative differences between treatments were lessened (data not presented). Apogee alone and Cu-EDTA alone had 18% less electrolyte leakage than controls at –22F, while the combination of Apogee and Cu-EDTA increased electrolyte leakage by 12%. All treatments had sharply increased electrolyte leakage at -33F and –44F.

Treatment with Cu-EDTA had no effect on cold hardiness, which agrees with our results from the studies conducted in Peru, NY, in 1999. Although we have been able to reproduce the accelerated leaf drop by Cu-EDTA sprays, as shown by Stover and Stiles, we have not been able to demonstrate improvement in cold hardiness for the past two seasons

These results provide strong initial evidence that treating actively growing trees in the autumn with Apogee increased early winter cold hardiness. Further study is needed to confirm these results and to determine the optimal timing and concentration of Apogee that is needed. Further study is also needed to evaluate the effect of late season Apogee on growth in the following season. Apogee is a growth retardant, and late season sprays might result in carry over effects on growth the following year which, while of potential benefit to established trees, could cause a delay in the time it takes a young trees to fill its allotted space in the orchard.

Although treatment differences were less apparent in January than in December, trees that received both Apogee and Cu-EDTA appeared to have more winter injury. This apparent increase in sensitivity to cold injury from combining the two treatments is difficult to explain, even more so because Apogee alone reduced winter injury. One possible explanation is the combination of treatments so accelerated leaf drop that remobilization of carbohydrates and mineral nutrients or some dormancy promoter back into the stems was limited.

Effects of Postharvest Foliar Urea Application on Tree Cold Hardiness

Although postharvest foliar urea spray has been widely used in other apple growing regions, it is not a common practice in our area. One of the concerns associated with foliar urea application late in the season is that tree cold hardiness may be reduced. To evaluate the effect of fall foliar urea sprays on tree cold hardiness, two experiments were initiated in the fall of 1999, one on Marshall Mac/M.9 at Lansing Experimental Orchard and the other on Empire/M.7 in the Hudson Valley. Experimental trees received one of the following four N treatments at the same rate of 46 lb

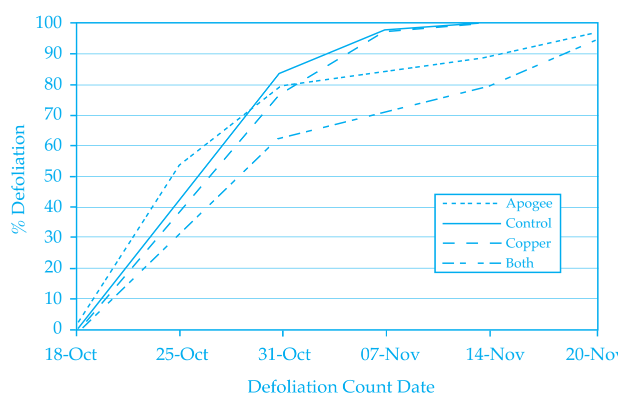

Figure 3. Effect of Cu-EDTA and Apogee on defoliation, 2000.

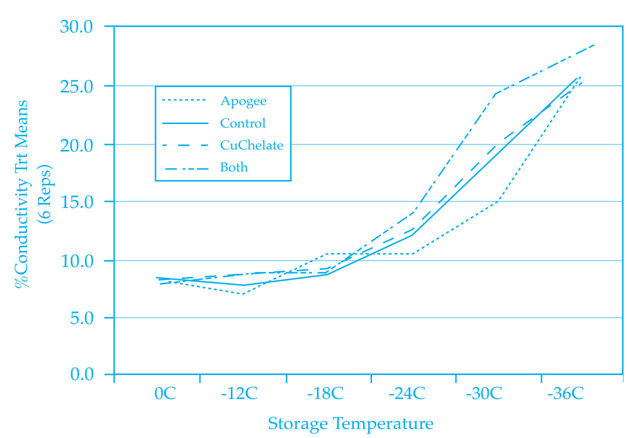

Figure 4. Cu-EDTA/Apogee study on cold hardiness, December, 2000.

N/acre:

1) Soil-applied N in spring - 100 lb urea/acre was applied to soil in early to mid-May;
2) Fall foliar N - 3% foliar urea (25 lb urea/100 gal) was sprayed at 200 gallons/acre twice at weekly intervals after harvest in late September and early October;
3) 50/50 split between fall foliar and spring soil application - Half of the N was applied as a 3% urea foliar spray after harvest in late September, while the other half applied to soil in mid May the next spring;
4) 36/64 split between spring foliar and soil-application - foliar urea (6 lb urea/100 gal at 200 gallons/acre) was applied at pink, petal fall and first cover, with the rest N applied to soil in mid May.

Tree cold hardiness was evaluated in December 1999 and January 2000 after foliar urea application in the fall of 1999, and evaluated again in December 2000 after foliar urea application in the fall of 2000. Fall foliar urea had no effect on cold hardiness in December 1999, or January 2000 on both Marshall Mac and Empire (Data similar to Fig. 4 but not shown here). There was no difference in cold hardiness in December 2000 among the four N treatments (Figure 5). This is consistent with the result we obtained with Fuji nursery trees. The data suggest that as long as tissues are well matured, foliar application of urea after fruit harvesting will not compromise the cold hardiness of the tree.

Research on Nutritional Treatments to Aid in Recovery from Cold Damage

Cold damage to spur tissues and flower buds that occurs during the winter often results in loss of cropping potential. Prebloom application of foliar sprays of boron, zinc and urea to trees that show discoloration of spur wood or flower buds has been recommended by Stiles on the basis of experience gained while working in Maine. However, it was deemed necessary to evaluate the efficacy of this recommendation under various conditions in the Champlain Valley and Hudson Valley regions.

A range of treatments was applied to McIntosh and Empire apple trees at two sites in 1994 and 1995. Treatments and application timings were as follows (all treatments applied dilute to drip):

1. Non-treated control
2. Solubor (1 lb / 100 gallons) at half-inch green stage
3. EDTA-zinc chelate (1 lb / 100 gallons) at half-inch green stage
4. Solubor plus EDTA-zinc chelate at half-inch green stage
5. olubor plus EDTA-zinc chelate plus urea (3 lbs / 100 gallons) at half-inch green
6. Solubor plus EDTA-zinc chelate at half-inch green followed by Solubor plus EDTA-zinc chelate plus urea at pink

In 1994, following a very severe winter (mid-winter low temperatures of -35F and -44F, respectively, at Hudson Valley and Champlain Valley sites) that caused visible damage to vascular tissue, Empire at both sites and McIntosh at the Hudson Valley site showed a tendancy for increased numbers of fruit/cm^2 of trunk cross-sectional area as more nutrients were applied. The combined half-inch green plus pink treatment increased cropping by about 24 % in comparison to the non-treated controls in the Hudson Valley. In the Champlain Valley, all treatments that contained a combination of boron and zinc significantly increased cropping. The combination of the half-inch green plus pink treatment produced a 43 % increase.

In 1995, following a relatively mild winter, Empire at both sites showed significant gains in cropping from the prebloom treatments. Treatments did not result in increased fruit set of McIntosh at either site. Mid-winter low temperatures of -11F and -18F were recorded at the Hudson Valley and Champlain Valley sites, respectively.

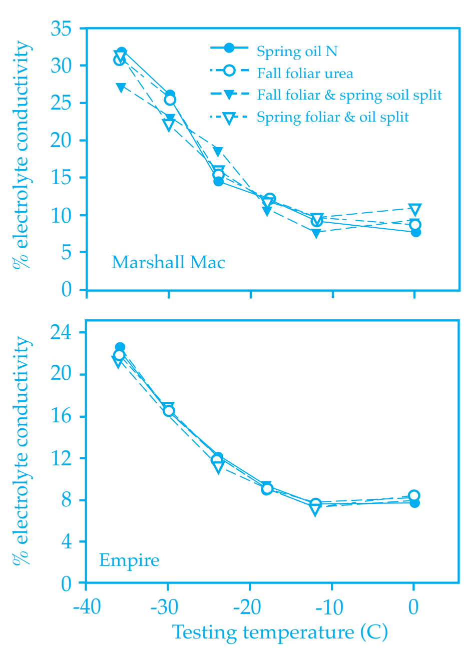

Figure 5. Effects of N treatments on tree cold hardiness as measured by electrolyte leakage method (December 2000).

In 1996, only the combination of the half-inch green plus pink treatment was tested on McIntosh and Empire in seven orchards. Across these seven orchards, cropping of McIntosh was significantly increased by an average of 9.6 %, but there was no effect on Empire. Factors influencing differences in response were not apparent from this study, but it appears that a complex of factors influencing bud development may be involved. Apparently, prebloom nutrient applications enhance cropping by increasing retention of flower buds that would otherwise abscise during early bud development.

In all cases, when increased cropping was observed there was no significant reduction in average fruit size (weight) from the increased cropload.

Suggestions for Minimizing Damage and Remedial Treatments for Cold Damaged Trees

Based on our present knowledge about the relationships between nutritional factors and cold tolerance of apple trees, the following suggestions are presented:

1. Closely monitor the nutrient status of the orchard by means of leaf analysis and soil testing.
2. Adjust the use of nitrogen fertilizers according to the individual orchard situation. This includes recognition of the impact of various components of the production system and management practices on nitrogen requirements of the trees.
3. Maintain adequate supplies of all other essential nutrient elements.
4. When trees begin to leaf out in the spring, closely examine buds and spur tissues for signs of cold damage. If this is evident, consider application of a combination of boron plus EDTA-zinc chelate at the half-inch green stage of development and follow this with a combination of boron plus EDTA-zinc chelate plus urea at pink.

Jim Schupp is an assistant professor at the Hudson Valley Lab who continues his interest in cold hardiness. Lailiang Cheng is an assistant professor whose research interests include the physiology of mineral nutrition. Warren Stiles is enjoying retirement in New Jersey but still takes time to serve the NY Fruit Industry. Ed Stover is a researcher at the University of Florida who initiated much of this work while in the Hudson Valley. Kevin Iungerman leads the NE NY Fruit Program and is keenly interested in cold hardiness.