Calcium Nutrition and Control of Calcium-related Disorders

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Adequate Ca in the fruit is essential to minimize bitterpit and other Ca-related disorders of the fruit. Many varieties need foliar calcium sprays to control these disorders. This article details the essential steps in a successful foliar calcium spray program and compares many of the common calcium spray products.

The role of calcium nutrition in fruit quality has been well established, and all growers are aware that maintaining adequate calcium levels in fruit is important for minimizing the risk of calcium-related physiological disorders. The most obvious of these is bitter pit, but disorders such as cork spot, Jonathon spot and senescent breakdown are also associated with low fruit calcium. Other disorders that have been related to low calcium include watercore, and susceptibility to low oxygen injury during storage. In addition, because of the importance of calcium in cell walls and membranes, claims are often made that increased levels of this mineral delay senescence and affect fruit firmness. Usually, however, these effects can be observed only when fruit has been stored beyond meaningful storage periods for saleable quality (Table 1), or when highly sophisticated postharvest treatment techniques such as vacuum or pressure infiltration have been used to increase calcium levels well above those that can be achieved in the field.

Calcium levels in fruit are affected by at least four factors:

1. The balance between fruit and vegetative material on the tree,
2. Calcium availability in the soil,
3. Calcium sprays on the tree,
4. Postharvest calcium treatments.

Factors 1 and 2 should be your first line of defense against calcium deficiency. Indeed, an important aspect of calcium management is that protocols to ensure good nutritional balance with calcium are the same as for all other nutrients; and they should be based on soil and leaf analyses and good horticultural practices. A preharvest calcium spray program will be necessary on those orchard blocks with special problems, such as excessive N or Mg fertilization, low crop load, or low soil pH, and in blocks containing varieties that are highly susceptible to bitter pit or senescent breakdown.

Traditionally these varieties have been Cortland, Jonagold, Mutsu and Northern Spy. As growers strive to increase fruit size, the risk of calcium-related disorders increases, even in varieties that are not usually susceptible to low calcium-related disorders. For example, bitter pit is not a disorder usually documented on McIntosh, but 80 ct. Macs in the Champlain have developed this disorder. Also, increasing experience with Honeycrisp has demonstrated its susceptibility to bitter pit and the need for effective calcium management programs in the orchard.

This article provides an overview of the current recommendation for maintaining optimum calcium nutrition in the orchard.

The Balance Between Fruit and Leaves

Calcium is an immobile nutrient in plant systems. It moves from the soil to the leaves and fruit, along with water, via the passive xylem transport system, but movement from leaves to fruit is restricted. The flow of calcium into plant parts is driven by demand of the tissues. Leaves compete more effectively than fruit for available calcium. Thus a program to maximize fruit calcium levels should involve cultural practices to manage this competition. The balance between leaves and fruit can be affected by tree vigor and fruit density. Appropriate tree vigor should be maintained by avoiding excessive pruning or nitrogen application. Tree spacing recommended for the rootstock should be used to avoid overcrowding of trees. The goal is uniform, moderate tree vigor.

TABLE 1

Effect of calcium tree sprays and dips on the condition of McIntosh apples after removal from CA storage plus one week at room temperature, March 1981. (Blanpied, unpublished).

Treatment	Flesh firmness(lb)	Senescent Breakdown (%)
Control	7.3a	30a
Ca tree spray[x]	7.5a	14b
Postharvest $CaCl_2$ dip (25 lb/100 gal)	8.4b	4c
Ca tree spray plus dip	8.4b	2c

[x]5 summer sprays of Stollar CaB @ 2 pints/acre + early fall spray of $CaCl_2$ @ 2 lb acre.

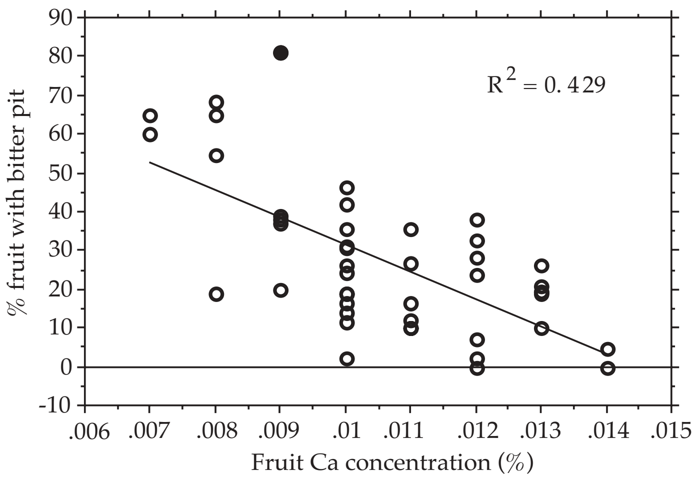

Figure 1. Percentage bitter pit in Honeycrisp apples in relation to calcium concentration of the flesh.

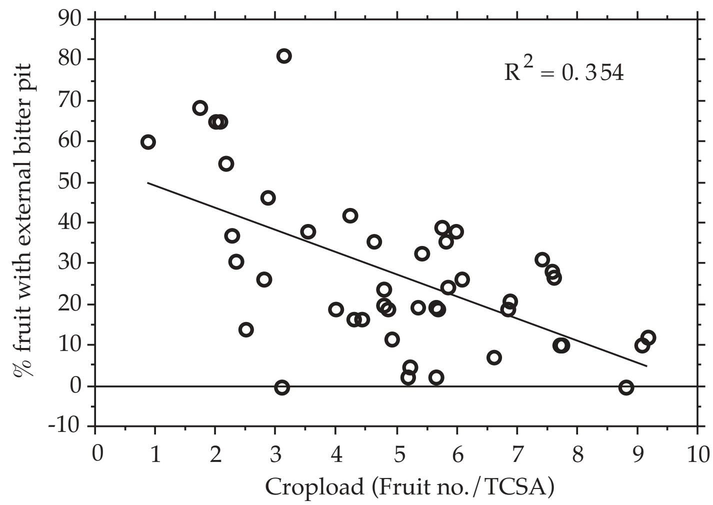

Figure 2. Percentage bitter pit in Honeycrisp apples in relation to cropload.

Crop load should be adjusted to obtain optimum size (i.e., the size required for maximum profitability) and annual bearing. Biennial bearing can be a major factor influencing calcium concentrations in fruit because low calcium levels and increased susceptibility of fruit to bitter pit and breakdown are associated with large fruit on light- cropping trees. Examples of the effect of calcium content as influenced by fruit size and crop load on bitter pit on Honeycrisp are shown in Figures 1 and 2. Table 2 contains a list of factors that should be considered for maintaining appropriate vigor and fruit density in the orchard.

Soil, Leaf and Fruit Analysis

The Cornell recommendation for preharvest calcium application principally involves soil nutrition. While development of visual symptoms of disorders in the orchard or in storage may alert you to the existence of problems, your program should be based on leaf and soil analyses. The important aspects of a calcium analysis program are outlined by Stiles and Shaw (1991):

Soil. Low levels of calcium in the soil are usually associated with low soil pH and low cation exchange capacity, particularly in subsurface soils. If properly limed, the soil should have an abundant supply of calcium, and surface applications of lime should be made to maintain a pH of 6.5 in the topsoil and at least 6.0 in the subsoil.

Leaf. The calcium content of leaf samples is considered adequate if in the range of 1.3 to 2.0%. Values above 1.6% are generally required to minimize low calcium-related fruit problems. Low calcium levels in leaves is often associated with low soil pH and calcium supply, but can result from boron and/or zinc deficiency. High magnesium and potash levels in soils or excessive foliar applications of Mg and K can also interfere with the uptake of calcium. Reduced uptake of Ca impacts all tissues.

Fruit. Correlations between storage disorders and fruit mineral content have been demonstrated in the US and other countries, and are sometimes utilized commercially to eliminate high-risk fruit from storage. In many of these studies, fruit calcium is usually correlated to storage disorders. There is no recommendation for the optimum range of fruit calcium content for New York, although Bramlage et al. (1985) developed a regression equation based on calcium that successfully predicted breakdown in McIntosh grown in Massachusetts. Development and use of such schemes has been limited in the US, however, probably because bitter pit and other disorders that cannot be solved by preharvest strategies have been rare. Therefore the coordination and costs required for implementation of mineral analysis schemes for fruit has not been justifiable. In addition, proper attention to harvest maturity, and modern postharvest management methods such as rapid cooling and controlled atmosphere storage, together with shorter air storage periods have reduced the extent of commercially relevant problems with the exception of varieties with high incidences of disorders on fruit while on the tree.

Calcium Spray Treatments

The recommended preharvest calcium spray program is to use low calcium concentrations during the early part of the growing season because of greater susceptibility of young foliage to salt damage. This is followed by higher concentrations once foliage is mature (Stiles and Reid, 1991).

1. Beginning 7 to 10 days after petal fall, apply 3 to 4 cover sprays of 1 to 2 lbs of calcium chloride (78% $CaCl_2$), or its equivalent per 100 gallons (dilute basis) at 14-day intervals.
2. At four and two weeks prior to harvest, apply 2 additional sprays of 3 to 4 lb per hundred gallons. These rates provide 27-48 lbs of $CaCl_2$ (7.5-13.4 lbs of actual calcium) per acre for orchards that require 300 gallons of dilute spray per acre.

Basic principles of a calcium spray program. The basic principles of a good calcium spray program are based on the following facts:

1. Complete coverage of fruit is essential because calcium spray deposits on leaves do not benefit the fruit.
2. Frequent applications are more important than exact spray timing. No selected stage of fruit growth is more important than another.
3. Effectiveness of calcium sprays increases with increasing concentration, but concentrations are limited because high calcium concentrations cause damage to the fruit and leaves.

There are a number of additional issues to consider when applying calcium sprays. The first is a reminder that the initial pH of technical $CaCl_2$ in water is about 10.3, and this high pH may reduce the effectiveness of some pesticides. Adding 2/3 oz. of vinegar (5% acid content) per lb. of $CaCl_2$ will neutralize the alkalinity and

TABLE 2

Causes of excessive vegetative growth that may compete for available calcium, their modes of action, and corrective measures. (Modified from the 2002-2003 Pennsylvania Tree Fruit Production Guide)

Cause	Mode of action	Corrective measure
Excessive pruning	Over-invigoration of tree	1. Reduce tree vigor so that moderate pruning can be used to maintain tree size 2. Maintain an annual, moderate pruning program
Excessive nitrogen	Overly vigorous trees	Maintain a nutritionally healthy tree so that a minimum level of N can be used to maintain moderate tree vigor
Inadequate spacing	Trees planted too closely can develop a cycle of excessive pruning followed by excessive vigor	Integrate variety, rootstock, soil type, and your management intentions into plant spacing considerations
Low fruit load	Light cropping trees generally have excessive vegetation	Maintain a system of annual cropping to avoid excessive tree vigor

TABLE 3

Maturity of McIntosh and Empire apples after a calcium spray program in the Champlain, Western New York (WNY) and Hudson Valley regions (1995 season)

Variety	Growing region	Internal ethylene concentration (ppm)		Firmness (lb)		Starch index (1-8)	
		- Ca	*+ Ca*	*- Ca*	*+ Ca*	*- Ca*	*+ Ca*
McIntosh	Champlain	5	40	15.3	14.6	5.8	6.7
	WNY	81	82	14.2	14.3	6.4	6.3
	Hudson V.	38	71	13.6	13.2	6.3	6.6
Empire	Champlain	2	4	16.9	16.8	4.8	5.9
	WNY	10	6	18.1	17.9	5.8	5.6
	Hudson V.	3	19	16.9	16.9	4.7	5.0

Modified from Watkins (1997)

bring the spray solution to about pH 6.0. Addition of vinegar does not affect uptake of Ca by the apples. Materials that will buffer the solution to about pH 6.0 may also be used as an alternative to vinegar. Since $Ca(NO_3)_2$ does not raise the pH of the spray solution, vinegar is not required when this form of calcium is used.

$CaCl_2$ is a caustic salt that will corrode sprayer parts, so sprayers must be washed thoroughly after each spray. Newer sprayers made of stainless steel, fiberglass, or various plastics are rust resistant and are therefore preferable for making calcium applications.

Calcium applications should be avoided when temperatures are above 80ºF, particularly when the humidity is also high. Also, do not re-apply calcium unless it has rained since the last application. Residues left from earlier sprays may increase the risk of leaf burn when no rainfall occurs between applications.

There is limited information and some disagreement about the compatibility of $CaCl_2$ with apple pesticides. Potential problems include physical incompatibilities of various mixtures, inactivation of pesticides by $CaCl_2$ sprays, and increased phytotoxicity of some mixtures. However, grower experience indicates that $CaCl_2$ can be tank mixed with many pesticides. Growers can test compatibility by mixing materials in a jar and looking for precipitates, but this may not always be a reliable indicator of a reduction in pesticide efficacy. Consult the manufacturers of proprietary calcium products to determine their compatibility with pesticides. If $CaCl_2$ is applied apart from pesticides, a non-ionic wetting agent should be added. The wetting agent may reduce the potential for leaf injury and increase uptake. Since most pesticide formulations include wetting agents, none should be needed when $CaCl_2$ and pesticides are combined.

Calcium chloride is incompatible with Epsom salts ($MgSO_4$). It is generally recommended that $CaCl_2$ should not be tank mixed with plant growth regulators. Calcium inactivates the growth regulator Apogee (Schupp et al. 2001). Additionally, Ca should not be mixed with captan. In New York, considerable fruit spotting occurred on Empire fruit during the 1998 in orchards where calcium sprays were tank mixed with captan (Rosenberger, 1999). The captan burn was most severe where liquid calcium formulations were used, or where adjuvants were included in the tank mix. These likely enhanced the uptake of captan into fruit. Fruit were especially susceptible in 1998 because of the cloudy, cool summer weather which resulted in less cuticular development on fruit. To be effective, fruit must absorb calcium, and liquid formulations of calcium often include adjuvants that enhance absorption. With captan, enhanced uptake will almost always cause phytotoxicity. Lastly, some problems (increased foliar burn) have been reported in Michigan when $CaCl_2$ was mixed with either azinphos, or basic coppers.

Agitation must be sufficient to maintain thorough mixing during application. Risk of damage is greatest on weak trees and injured foliage. Under cool, moist conditions, use caution when applying foliar calcium as part of a complex tank mix. Slow drying may increase absorption and increase the risk of injury.

Calcium injury appears as a burn at the margins of the leaves. In most cases this injury is thought to be associated with inaccurate sprayer calibration, since the injury is not as prominent when dilute applications are used. Concentrations up to 10X have been very effective, but any inaccuracy in calibration is magnified when applications are made at higher concentrations. These errors can result in leaf burn. To reduce the risk of injury to the fruit and foliage, Washington State Cooperative Extension recommends applying $CaCl_2$ with at least 100 gallons of spray water per acre. $CaCl_2$ should be mixed in a pail of water and be added last, when the sprayer tank is nearly full, to ensure thorough mixing.

We have found that $CaCl_2$ can cause advanced fruit ripening in McIntosh and Empire fruit in some regions of New York in some years (Table 3). It is likely that the calcium sprays caused stress on the trees in the Hudson Valley and Champlain even though sprays were applied as recommended. This could be serious if weather that promotes poor fruit color-

TABLE 4

Calcium materials for use on apples. (From the 2002-2003 Pennsylvania Tree Fruit Production Guide)

Product Name	Elemental Ca (%)	Pounds Ca per Gallon or Pound	Manufacturer	Amount Product per Acre per Spray (min-max)	Pounds Ca per Acre per Spray (min-max)
CaB	6	0.60	Stoller, Inc.	3-6 pt.	0.22-0.45
CaB'y	10	1.19	Stoller, Inc.	2-4 qt.	0.58-1.19
Calcium chloride (77-80% $CaCl_2$)	27.8	0.28	many	1.8-6.2 lb.	0.50-1.74
Calcium chloride (35% $CaCl_2$)	12.6	1.42	many	0.35-1.24 gal.	0.50-1.76
Cor-Clear Dry	34.5	0.34	SEGO Intl.	4-8 lb.	1.36-2.72
Foliar Ca. Folical	10	0.96	Agrimar Corp.	1 gal.	0.96
Fung-Aid	10	1.19	Stoller, Inc.	2-4 qt.	0.58-1.19
Link Calcium 6%	6	0.62	Wilbur-Ellis Co.	2-4 qt.	0.31-0.62
Mora-Leaf Ca. (94% $CaCl_2$)	34	0.34	Wilbur-Ellis Co.	4-8 lb.	1.36-2.72
Nutri-Cal 8% Calcium Solution	8	0.89	CSI Chem. Corp.	1-2 qt.	0.22-0.44
Nutra-Phos 10	10	0.10	Leffingwell Div.	3-10 lb.	0.30-1.00
Nutra-Phos 12	11	0.11	Leffingwell Div.	3-10 lb.	0.33-1.10
Nutra-Phos 24	20	0.20	Leffingwell Div.	3-10 lb.	0.60-2.00
Nutra-Phos Mg	10	0.10	Leffingwell Div.	3-10 lb.	0.30-1.00
Nutra-Plus Cal-Gard	6	0.60	Custom Chemicides	1-3 qt.	0.15-0.45
Pit-Stop Dry Con. Foliar Cal. 32.5%	32.5	0.32	Ag-Chem, Inc.	4-8 lb.	1.28-2.56
Pit-Stop Foliar Calcium 12%	12	1.35	Ag-Chem, Inc.	1.5 gal.	2.02
Sett	8	0.91	Stoller, Inc.	1 gal.	0.91
Sorba-Spray Cal	8	0.86	Leffingwell Div.	1-4 qt.	0.21-0.86
Sorba-Spray CaB	5	0.50	Leffingwell Div.	1-4 qt.	0.12-0.50
Stopit Ca. Conc.	12	1.28	Shield-Brite Div.	2-4 qt.	0.64-1.28
Tracite Ca. 6%	6	0.60	Helena Chem Co	3-6 pt.	0.22-0.45
Traco Pit-Cal Liquid Calcium	12	1.40	Traylor Chem Co	0.5-2 gal.	0.7-2.80
Wuxal Calcium	10.7	1.42	Aglukon Div.	3-4 pt.	0.53-0.71

ing occurs before harvest. Growers who apply calcium need to aware that advanced ripening is a possibility and that early harvest might be anticipated.

There are many calcium formulations available (Table 4), often claiming greater calcium uptake, effectiveness in reducing disorders, or reduced risk of injury to leaves and fruit. We recommend $CaCl_2$ because of its proven effectiveness. It also is less expensive than most other sources. Other formulations often have lower than recommended rates of calcium application. Regardless of the product used, follow the manufacturer's recommendations for rates and timing.

$Ca(NO_3)_2$ may be substituted for $CaCl_2$. In Massachusetts they have tested $Ca(NO_3)_2$ only on McIntosh, and have experienced no fruit injury; however, there are reports that $Ca(NO_3)_2$ causes fruit spotting on Delicious and Golden Delicious. No increase in leaf nitrogen level results when the recommended dosage of $Ca(NO_3)_2$ is applied.

Determining the amount of elemental calcium in a commercially formulated product

Because of the number of different calcium formulations and associated cost effectiveness of each, it is important to compare them to determine actual prices per pound of calcium being purchased. The following guide and examples are available in the Pennsylvania Tree Fruit Production guide, 2002-2003.

1. Look for, or determine, the percentage of elemental calcium in the product. This should be listed somewhere on the label.
2. For a liquid formulation, multiply the percentage by the weight of the material per gallon. For a solid, multiply the percentage by the weight of material you will add to the tank. Result equals the pounds of calcium per gallon or pound of formulated product.
3. Determine the rate of formulated material you intend to apply per acre per application. For a specific calcium product this is usually listed on the label.
4. Multiply the amount of material per acre by the number of applications to be made during the season. Remember to adjust rate per acre for the last two applications of the season if higher rates are used in late-season applications. Result equals the amount of total product per acre per season.
5. Multiply the amount of total product per acre per season (from Step 4) by the pounds of calcium per gallon or pound of formulated product (from Step 2). Result equals the total amount of elemental calcium per acre per season.
6. Compare the result from Step 5 with our recommendation of 7.5 to 14 pounds of elemental calcium per acre per season for orchards that require 300 gal/A of dilute sprays.
7. Compare the season-long cost of materials. Multiply the amount of material used per season times the cost of the material.

Example: Product A sells for $6.50 per gallon and is a liquid listed as containing 15% elemental calcium. The weight per gallon is 12 pounds. The label recommends 2 to 4 quarts per acre per application with eight applications suggested per season. You decide to apply 2 quarts per acre per application.

Step 1: You determine that the product contains 15% elemental calcium.

Step 2: 12 lb x 0.15 = 1.8 lb of elemental calcium per gal.

Step 3: You choose to apply 2 quarts (or 0.5 gal) per acre per application.

Step 4: 0.5 gal per acre per application x 8 applications per season = 4 gal of material
per acre per season.

Step 5: 4 gal x 1.8 = 7.2 lb of elemental calcium per acre per season.

Step 5: Our recommendation is 7.5 to 14.0 lb of elemental calcium per acre per season.

Step 7: 4.0 gal x $6.50 per gal = $26.00.

Comparing costs. You wish to compare the cost per pound of elemental calcium in two products. For Products A and

B we can determine which is less expensive.

1. Determine the number of pounds of elemental calcium per gallon or pounds of formulated product for each product you are considering. (Same as in Step 2 above).
2. Determine the cost per pound of elemental calcium in each product.
3. Compare the cost of the two materials.

Compare the two products to determine the rate needed to achieve 14 pounds of elemental calcium per acre per season assuming that you will be making eight applications during the season:

1. Divide the number of pounds of elemental calcium desired per season by the number of applications. Result is the pounds of elemental calcium needed per acre per application by the amount of elemental calcium per gallon or pound of material.
2. Divide the pounds of elemental calcium needed per acre per application by the amount of elemental calcium per gallon of pound of material. Result is the gallons or pounds of formulated material needed per acre per spray.

In summary, to effectively evaluate materials other than dry $CaCl_2$, the cost per pound of actual calcium must be determined for the formulation in question and the label must be examined to determine if the formulation will allow application of the recommended 7.5 to 14 pounds of actual calcium per acre per season.

Postharvest Calcium Dips

Postharvest dips or drenches of $CaCl_2$ can be used to increase the calcium content of apples, and will sometimes reduce the incidence of storage disorders related to calcium deficiencies, but we believe that they should be used only as the last resort. Postharvest application of calcium will not control development of bitter pit if growing conditions, early harvest, or slow cooling after harvest have predisposed the fruit to severe bitter bit.

Materials containing $CaCl_2$ are the only sources of calcium that may be used. Dry $CaCl_2$ at 94% purity or higher may be used, and it should be used at no more than 12 lbs./100 gallons of water, since damage to the fruit may occur at higher concentrations. Vinegar (5%) at 8 to 10 oz. per 100 gallons can be used to counteract the alkalinity of the calcium chloride solution. Two commercial liquid formulations of calcium chloride are also labeled for use. "STOPIT" liquid calcium concentrate (Shield-Brite Corp.; 12% calcium) is labeled for use at 1 gallon per 74 gallons of drench water. "Decco Calcium Chloride-EC 405" (12% calcium) is labeled for use at 1 gallon per 79 gallons of drench water. Both of these labeled rates result in markedly lower calcium concentrations in the solution than does 12 lbs. of dry calcium chloride (94%) per 100 gallons. However, the liquid formulations are easier to use than 94% calcium chloride pellets.

All of these calcium materials may be combined with scald-inhibiting chemicals. No postharvest dip or drench should be used without inclusion of fungicide to control postharvest decays.

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