N E W Y O R K
F R U I T Q U A R T E R L Y

Editorial

Mineral Nutrition in the Modern Orchard

Springtime brings numerous orchard tasks like pruning, fertilizing, weed control and pest control. For experienced growers, the tasks of the new growing season are part of a comfortable and familiar routine. Each year, new problems such as insect or disease outbreaks and weather challenges keep growers from becoming complacent. Fortunately, research continues to provide new answers to both old and new problems faced by growers. Hopefully, the new answers will keep us one step ahead of the problems. It is our job in research and extension to educate growers about the new answers garnered from research. Many of these are presented at winter fruit schools and other workshops over the winter season. Fruit growers in New York have a long tradition of attending these educational events, and trying to improve their orchard management practices.

Many growers pay keen attention to advances in new pesticides and growth regulators, but the topic of mineral nutrition has become stagnant for many people because little seems to change from year to year. Although many of the dramatic advances in mineral nutrition were made years ago, there continues to be significant advances that all growers should pay attention to. In recent years, much of the focus has been on the environmental impacts of modern fertilization practices. This has given rise to the term “nutrient management” instead of fertilization.

Modern nutrient management is based on understanding the plant’s need for each nutrient and then supplying it at the right time of year in an environmentally safe manner. Greater emphasis on environmentally responsible fertilization programs has arisen from the excessive use of fertilizers which has resulted in leaching of nutrients (primarily nitrogen) into the ground water, and the contamination of surface water resources by runoff.

Fortunately for fruit growers, the soil management systems used in orchards incorporate many good soil and nutrient management characteristics. Fruit orchards, then, have one of the least negative impacts on the environment of any agricultural crop. Using sod-row middles limits surface runoff of applied fertilizers, and the lack of soil tillage limits soil and nutrient erosion. In addition, the negative impact of high nitrogen on fruit quality has limited the excessive use of nitrogen on fruit trees as growers have become more conscious of high fruit quality.

Yet we must continue to ask ourselves this question—can we improve the soil and nutrient management systems we are currently using? The question is important from a fruit production/quality standpoint because high yield and fruit quality are so important to the successful marketing of apples, but the question is also important from an environmental perspective. Environmental impact issues are becoming more important for the successful marketing of apples with the institution of Eurepgap certification for export apples.

Both this issue and the next of the *NY Fruit Quarterly* focus on mineral nutrition and fertilization of apple and pear. The collection of papers was developed for the 2003 in-depth winter fruit school held in both Eastern and Western New York. These papers represent up-to-date research along with the current recommendations from Cornell for managing mineral nutrients in the orchard. The focus is still on nutrient management to improve yield or fruit quality, but you will also find a common and significant thread of environmental stewardship throughout the papers. Although the basics of mineral nutrition have not changed, I hope these papers will help you evaluate your mineral nutrient management program and incorporate the latest research-based methods of managing nutrients in an environmentally safe and profitable manner.

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FRONT COVER: Nutrient management is based on the apple trees need for nutrients and minerals. This entire issue is devoted to that topic.
BACK COVER: Spring planting reminds us that damage from inadequate nutrient management will result in late-season symptoms.

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Soil Analysis and Interpretation

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> **Soil chemical analysis prior to planting a new orchard is essential. It provides the best information for proper soil nutrient improvement before planting. After planting, soil chemical analysis is used to supplement leaf tissue analysis in developing fertilization programs.**

Before planting an orchard a thorough evaluation of the soil chemical conditions through soil testing provides the best information on which to base decisions concerning the need for and extent of modifications required. In established orchards, soil testing is critical to monitor pH and provides additional information needed for satisfactory interpretation of results of leaf analysis and developing fertilizer management programs.

Soil Sampling Procedures

How, when and where samples are collected all influence the results of soil analysis. Both topsoil and subsoil samples are needed to obtain the best analysis of conditions throughout the rooting zone. Topsoil samples (0 to 8 inch depth) reflect the effects of recent lime and fertilizer additions and are important in monitoring pH and nutrient availability in the upper portion of the rooting zone. However, topsoil samples alone are not representative of the total root zone and may not show good correlation with crop response. Subsoil (8 to 16 inch depth) samples indicate inherent problems such as low pH and lack of fertility, reflect the long-term response to lime and fertilizer additions, and supplement the information obtained from topsoil analysis.

During pre-plant soil preparation, soil samples can be taken at any time that is convenient. However, in established orchards the preferred time of sampling is in mid- to late-summer or in the fall after harvest. Samples collected in the fall usually show lower phosphorus (P) and potassium (K) as a reflection of crop removal. Those collected in the spring reflect winter "recharge" for various elements.

Thorough sampling is necessary if the results are to be meaningful. In a 10-acre orchard, a minimum of 10 to 20 sub samples are usually needed in collecting one soil sample for analysis. In established orchards these sub samples should be coordinated with leaf samples taken in the same area. Samples should be taken from within the tree row where most of the nutrient elements are taken up by the trees, not in the middle of the alleyways.

Soil pH, Cation Exchange Capacity and Base Saturation

Soil pH and Soil Acidity. The term "pH" is used to describe relative acidity or basicity and is a measure of hydrogen ion (H+) activity expressed in logarithmic terms. The pH scale covers a range of 0 to 14, with a value of 7 indicating neutrality. Values from 0 to 7 indicate acidity and those from 7 to 14 indicate basicity. Since this is a logarithmic scale, each 1.0 unit change indicates a 10-fold change in acidity or basicity. Soil pH can range from 4 to 9.

The term "active acidity" refers to concentrations of hydrogen ions in the soil solution and is measured using a suspension of soil in water. "Reserve acidity" (exchangeable acidity) includes hydrogen ions held on negatively charged soil particles of clay and organic matter plus other positively charged ions such as aluminum. Both "active" and "reserve" acidity are involved in determining the amount of lime that may be needed to adjust soil pH. In the Cornell soil test reports, "reserve" acidity is reported as meq of hydrogen (H+) per 100 grams of soil. Reserve acidity must be included when estimating total cation exchange capacity of the soil.

Problems associated with low pH (below 5.5) include measles associated with excessive uptake of manganese; calcium and magnesium deficiencies; restricted root growth or regeneration, particularly of new lateral roots affected by aluminum toxicity; reduced availability of phosphorus; reduced efficiency of nitrogen and potassium use; and poor response to applied nitrogen and potassium fertilizers.

High pH may be associated with soil parent materials, in some cases with excessive lime applications, or a reflection of carbonate accumulation due to poor internal soil drainage. High soil pH (>7.0) may reduce availability of manganese, copper, zinc and boron.

During pre-plant site preparation, suggested targets for pH adjustment are pH 7.0 for the topsoil and 6.5 for the subsoil. In established orchards, these targets should be 6.5 for the topsoil and 6.0 for the subsoil. Soil pH should be maintained in the range of 6.0 to 6.5 throughout the total root zone to optimize nutrient availability.

Soil pH is usually measured using a mixture of one part soil and one part water. In some cases pH may be measured using a mixture of one part soil and two parts CaCl2 solution, in which case the resulting pH is about 0.6 unit lower than with water. Likewise, pH measured using 1 Normal KCl (potassium chloride) solutions is somewhat lower than that obtained using soil:water suspensions.

Cation Exchange Capacity (CEC). Soil clay particles and humus, collectively called colloids, have negative charges. They adsorb positively charged ions (cations). Cation exchange capacity (CEC) is the sum total of exchangeable cations that are adsorbed on the soil colloids and is a measure of the ability of a soil to hold cations. CEC is expressed as milliequivalents of cations per 100 grams of soil. There are two types of cations on the soil colloids: acid forming cations (H^+, Al^{3+}, Fe^{3+}, Mn^{2+}) and base cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+). The sum of exchangeable acid forming cations is called exchange acidity or reserve acidity. It is expressed as milliequivalents of hydrogen ion per 100 grams of soil. The sum of exchangeable bases and the exchange acidity is equal to CEC. The percentage of CEC that is accounted for by exchangeable bases is base saturation. Cation exchange capacity is important in estimating the quantities of calcium and magnesium needed in managing the specific soil.

The term "equivalent" refers to the quantity of various elements that is equal to 1 equivalent of hydrogen. On a comparative basis, equivalent weights of common cations may be expressed as parts per million or as pounds per acre (Table 1). Soil test results reported in PPM are converted to pounds per acre by multiplying by 2, since a 6-inch depth of soil is assumed to weigh 2 million pounds.

The cation exchange capacity of a soil is determined by the type and amount of clay and organic matter content and is influenced by pH. Organic matter has a cation exchange capacity of approximately 200 meq/100 g, thus 1 percent organic matter in a soil provides about 2 meq/100g of cation exchange capacity. The cation exchange capacity of New York soils may range from as low a 3 meq/100g in very coarse sands to as high as 35 to 40 meq/100g in clayey soils (Table 2).

Cation exchange capacity can be estimated by calculating the total milliequivalents of the major basic elements (Ca++, Mg++, and K+) and adding the milliequivalents of reserve acidity (H+). If the value for reserve acidity is not known, CEC can be estimated by dividing the sum of the meq/100grams of the basic elements by the percent base saturation for the pH of the sample.

Base Saturation. Base saturation refers to the degree to which the cation exchange complex is saturated by basic elements such as calcium, magnesium and potassium. It is usually expressed in terms of percentages of the total exchange complex that is represented by these elements, individually or in total. As soil pH increases the percent base saturation also increases. At a given pH "sandy" soils have a higher percentage base saturation than the majority of soils because they have lower total cation exchange capacities and lower buffering capacities.

Calcium (Ca)

Calcium content of soil samples may be expressed as PPM, lbs/acre, meq/100g, or as percent saturation of CEC. Low levels of soil calcium are usually associated with low soil pH and low cation exchange capacity, particularly in sub soils. However, in some fine-textured soils calcium availability and uptake may be more directly related to exchangeable acidity than to pH or the total amount of calcium in the soil.

Imbalances of calcium, magnesium and potassium are frequently cited as problems in orchard soils. In most cases, inadequate amounts of one or more of these nutrient elements are of greater importance than an imbalance in tree nutrition. Such shortages are particularly important in the subsoil.

TABLE 1

Equivalent weight of various cations.

Element	Atomic weight	Equivalent weight	Parts per million	Pounds per acre (6-inch depth)
Hydrogen	1.008	1.008	10	20
Potassium	39.10	39.1	391	782
Calcium	40.08	20.04	200.4	400.8
Magnesium	24.32	12.16	121.6	243.2
Aluminum	26.97	8.99	89.9	179.8

Magnesium (Mg)

Magnesium content of soil samples may be expressed in various terms, as indicated for calcium. Most tree fruits have a high requirement for magnesium and, with some exceptions, most soils in the Northeast are low in magnesium content. Raising pH by applying calcitic (high calcium) lime increases the availability of the magnesium present in the soil but does not correct the long-term problem of low magnesium supply. Applying dolomitic limestones (high in magnesium content) is the usual method for correcting low magnesium supply.

Lime Requirement for Adjusting Soil pH and Soil Ca and Mg Levels

The amount of lime needed to adjust the soil reaction to the desired pH is referred to as the lime requirement. The lime requirement is related to the initial soil pH, the amount of pH change desired, and the cation exchange capacity. Since cation exchange capacity is largely determined by the amounts of clay and organic matter in the soil, the lime requirement is influenced by soil texture and increases as the desired pH for a given soil is raised. Various alternative methods may be used for estimating the lime requirement. (See article by Cheng and Stiles in this issue). Approximate amounts of calcium and magnesium desired in topsoil at pH 6.5 and in the subsoil at pH 6.0 for soils of various soil textures are given in Table 3.

The amount and type of lime to be applied should be determined on the basis of pH adjustment desired and the amounts of calcium and magnesium in both the topsoil and the subsoil, and the amounts of these elements required to achieve their desired concentrations. On an equivalent basis, a 5:1 ratio of calcium:magnesium is presently recommended as a target for most fruit crops in New York State. This is equal to approximately 8.23 pounds of calcium per pound of magnesium. These ratios are used in estimating calcium and magnesium requirements and should not be interpreted as precise requirements. Acceptable ratios may vary within broad ranges depending on the specific soil, crop, and environmental conditions at the individual site.

TABLE 2

Approximate cation exchange capacities of various soil types

Texture	Approximate CEC (meq/100g) 0-8 inch depth	8-16 inch depth
Sand, Gravel	5	3
Sandy Loam	12	8
Silt Loam, Loam	18	12
Silty Clay Loam	20	14
Clay, Silty Clay	25	18

TABLE 3

Approximate Amounts Calcium and Magnesium Needed in Both the Topsoil and Subsoil of Various Textured Soils

Texture	Calcium	Magnesium
Topsoil at pH 6.5 (lbs/acre 0 to 8-inch depth)		
Sand, Gravel	1,500	185
Sandy Loam	3,600	440
Silt Loam, Loam	5,500	660
Silty Clay Loam	6,100	740
Clay, Clay Loam	7,600	900
Subsoil at pH 6.0 (lbs/acre 8 to 16-inch depth)		
Sand, Gravel	800	100
Sandy Loam	2,100	260
Silt Loam, Loam	3,200	385
Silty Clay Loam	3,700	450
Clay, Clay Loam	4,800	580

Potassium (K)

Soil test results for potassium may be reported in various terms: milliequivalents per 100 grams of soil; parts per million; pounds per acre; or percent of potassium saturation of the cation exchange capacity. Results may vary considerably among different laboratories primarily because of the method of extraction employed.

The potassium that is readily available for use by plants occurs primarily as potassium ions in solution or as exchangeable

TABLE 4

Available Potassium of Some NY Soils

Soil type	Texture	K (lb/acre/yr)
Adams	Loamy fine sand	20-60
Arkport	Fine sandy loam	80-100
Elmwood	Fine sandy loam	80-100
Howard	Gravely loam	100-120
Dunkirk	Silt loam	100-120
Hudson	Silt loam/silt clay	120-140

TABLE 6

Boron Soil Test Levels for Soils of Different Textures and Recommended Amounts to Apply Preplant.

	Soil Texture			
Relative Level	Loam, Silt Loam (lb. B / a)	Sandy Loam (lb. B / a)	Loamy Sand (lb. B / a)	B to apply (lb. B/ a)
Very high	> 2.4	> 1.8	> 1.2	none
High	1.6-2.4	1.2-1.8	0.7-1.2	1
Medium	0.8-1.6	0.6-1.2	0.4-0.7	2
Low	< 0.8	< 0.6	< 0.4	3

TABLE 5

Desired Soil Potassium Levels for Various Soil Textures (lbs/acre)

Soil Texture	0 to 8-inches	8 to 16-inches
Sand, Gravel	150	100
Sandy Loam	350	220
Silt Loam, Loam	525	335
Silty Clay Loam	580	370
Clay, Silty Clay	730	465

ions on the cation exchange complex. The majority of potassium in most soils is present in mineral form as a constituent of clay particles. Potassium status, or the ability of a soil to release potassium in available form, therefore varies with soil texture (Table 4).

Soil texture influences potassium availability through its effect on root development. Since potassium is relatively immobile within the soil, extensive root development is required for efficient uptake.

Fine-textured soils, although they may contain larger amounts of potassium, may limit the extent of root development to the extent that the crop may not be able to efficiently access this supply. The more extensive root development by crops grown on coarser-textured soils provides more efficient uptake of the smaller amounts of potassium that they contain. Potassium availability and uptake is improved if an adequate soil moisture supply is maintained.

Potassium status of the soil must be considered in conjunction with that of pH, calcium and magnesium. Potassium availability generally decreases as pH decreases below about 6.0. Generally, liming acid soils increases availability of potassium and reduces losses of potassium by leaching. The percentage of the cation exchange capacity occupied by potassium should be considered in relation to calcium and magnesium. It is not likely that calcium or magnesium would depress potassium uptake, but the reverse may occur - particularly with magnesium.

Approximate values used in interpreting the Cornell soil test results for orchards on soils of different textures are presented in Table 5. Potassium needs approximate 5 percent of those for calcium on an equivalent basis, or about 10 percent of those for calcium on a weight basis.

Phosphorus (P)

Phosphorus needs of most perennial fruit crops are relatively low in comparison to those for nitrogen and potassium and with the needs of herbaceous plants. Soluble phosphorus is precipitated out of solution as insoluble iron, aluminum, or manganese phosphates, or oxides of aluminum, iron, or magnesium in acid soils, and as insoluble calcium phosphates in alkaline soils. Maximum availability of phosphorus occurs when soil pH is maintained between 6.0 and 7.0.

Various extractants may be used by different laboratories to test the availability of phosphorus in soil samples. This results in widely different values from different labs. In most cases, the amount of phosphorus obtained with these methods usually increases as the soil pH increases. Results of soil tests are usually reported in terms of either parts per million or pounds per acre of P (phosphorus).

In the Cornell soil tests, the amounts of phosphorus (pounds of P_2O_5 per acre 6-inch depth) required for pre plant incorporation is calculated as follows: [(10 - sample content) + 40], and for established plantings [(10 - sample content) + 20]. It is recommended that phosphate fertilizers be thoroughly incorporated into the soil during pre plant site preparation. Further soil surface applications after orchards have been established are not recommended unless leaf sample P values are less than 0.08 percent. Even then, low values of leaf sample P are more likely to be associated with low soil pH than with a lack of available soil phosphorus.

Boron (B)

Boron is very soluble and mobile in the soil and is relatively easily leached under humid conditions. Availability of boron decreases as soil pH is increased and liming acid soils to a pH of 6.5 to 7.0 reduces losses by leaching. Finer-textured soils have a higher buffering capacity and require higher concentrations of boron to meet crop needs than those of coarser texture. Likewise, toxicity problems from excessive applications of boron are less frequent in finer-textured soils. Boron availability is reduced when soil moisture supply is low. Leaching losses are increased by excessive rainfall or irrigation.

Various extractants have been used in analyzing soil samples for boron; the most common is hot water. Results of soil tests for boron are most often reported in terms of parts per million or pounds per acre.

Suggested rates of boron application vary with soil texture and the amount of boron already present in the soil (Table 6). Rates of boron application indicated are for apples and pears. Stone fruits, especially peaches, are more sensitive to excess boron and boron applications should be reduced by 50 percent for these crops unless leaf analysis indicates a greater need.

Zinc (Zn)

Availability of zinc in acid to neutral soils decreases sharply as soil pH is increased. For each unit (1.0) increase in pH between 5.0 and 7.0, zinc concentration in the soil solution may decrease by a factor of 30. High organic matter content of the soil may decrease availability of zinc through the formation of insoluble organic complexes. Zinc availability and uptake is inhibited by high levels of phosphorus through the formation of insoluble zinc phosphates. Several extractants have been used in determining zinc availability in soil samples, each providing different relative values. Results of these tests are usually reported in terms of parts per million or pounds per acre. For most fruit crops, standards for interpreting soil zinc values have not been well established.

Copper (Cu)

Copper availability is strongly influenced by soil pH, organic matter content of the soil, and levels of phosphates in the soil in manners similar to zinc. Like zinc, copper is not mobile in soil. Soil test methods used in estimating copper availability are similar to those used for zinc. Likewise, the standards for interpreting soil copper values for fruit crops are not well established.

Iron (Fe)

Availability of iron decreases as soil pH increases. Excessive levels of phosphates or carbonates reduce iron availability through the formation of insoluble iron compounds. Organic matter is a source of iron and also complexes and chelates iron. Soil tests for iron have not been well correlated with response of most fruit crops.

Manganese (Mn)

Excessive amounts of manganese are of concern because of toxic effects on crops. Soil pH has a major role in regulating manganese availability and raising pH of a soil from 4.5 to 6.5 has been shown to reduce the concentration of exchangeable manganese by a factor of 20 to 50 times. Most deficiencies of manganese are associated with higher soil pH or highly leached soils. The manganese content of plants is frequently more closely related to soil pH than to the concentration of manganese in the soil.

Aluminum (Al)

Aluminum is of concern because of its adverse effect on root development and consequently on uptake of other elements. Relatively low levels, 10 to 20 parts per million or less, of aluminum in the soil solution can adversely affect some fruit crops. Using the Cornell soil test methods, 200 pounds of aluminum or of a combination of aluminum, manganese and iron indicates a potential problem situation for these crops. Liming acid soils to a pH of 6.0 to 6.5 may be necessary to adequately limit availability of aluminum. Draining soils to improve aeration helps to reduce the severity of aluminum toxicity problems.

Organic matter

Organic matter serves a multitude of functions in soils. Under usual conditions, organic matter content tends to be lower in coarse-textured soils and higher in finer-textured soils. Organic matter usually accounts for most soil nitrogen. In general, one percent organic matter in the soil will result in the release of 20 pounds of plant-available nitrogen per year. Soils in New York State vary in nitrogen supplying ability, ranging from approximately 30 pounds to as much as 80 pounds per acre per year. Therefore, the contribution of nitrogen from organic matter must be considered in developing nitrogen management programs for fruit crops.

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Warren Stiles is an emeritus professor of pomology who led Cornell's fruit mineral nutrition research and extension program for many years. He is still widely recognized as a world authority on fruit mineral nutrition.

Adjusting Soil pH for Optimum Nutrient Availability

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Adjusting soil pH before planting and maintaining optimum soil pH after planting are essential for nutrient availability. Most NY soils are too acid (low pH) and need lime before planting. This article explains the steps to calculate the amount of lime needed to bring pH up to 6.5-7.0.

Mineral nutrient availability to fruit trees is dependent on the quantity of each nutrient in the soil, and its availability. Nutrient availability is dependent on soil pH, soil texture and water availability. One of the objectives of orchard nutrient management programs is to improve the availability of nutrients in acid soils that are typical of apple growing regions in New York and the Northeast. In this article, we will introduce a few basic concepts first, then use an apple orchard soil survey to illustrate the effect of pH on soil nutrient availability, and at the end, discuss lime requirement for adjusting soil pH.

Concepts of pH, CEC, Exchange Acidity, and Base Saturation

pH is a measure of soil acidity or alkalinity. It is the concentration of hydrogen ion (H+) in soil solution expressed as the negative logarithm. A pH of 7 indicates neutrality. Although the pH scale is from 0 to 14, soil pH generally ranges from 4 to 9. Since pH is a logarithmic scale, each one unit change indicates a 10-fold change in the concentration of hydrogen ion.

Soil clay particles and humus, collectively called colloids, have negative charges. They adsorb positively charged ions (cations).Cation exchange capacity (CEC) is the sum total of exchangeable cations that are adsorbed on the soil colloids. CEC is expressed as milliequivalents of cations per 100 grams of soil. There are two types of cations on the soil colloids: acid forming cations (H^+, Al^{3+}, Fe^{3+}, Mn^{2+}) and base cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+). The sum of exchangeable acid forming cations is called exchange acidity or reserve acidity. It is expressed as milliequivalents of hydrogen ion per 100 grams of soil. The sum of exchangeable bases and the exchange acidity is equal to CEC. The percentage of CEC that is accounted for by exchangeable bases is base saturation. There is a relationship between soil pH and percent base saturation (Table 1). Extremely coarse-textured sandy soils with low organic matter tend to have a higher percentage base saturation at a given pH.

Soil nutrient availability and pH

The availability of many nutrients is affected by soil pH. A survey of 250 apple orchards on Hilton soils in Western New York showed that as soil pH increases from 4.5 to 7.5, exchange acidity decreases (Figure 1A) whereas exchangeable base cations and base saturation increase (Figure 1B, C). The same soil survey showed that the availability of Ca and Mg decreases with decreasing soil pH (Figure 2A, B). This explains why apple trees often show Ca and Mg deficiencies on soils with a pH lower than 5.5. As soil pH decreases, phosphorus availability also tends to decrease (Figure 2D). Although soil potassium and nitrogen did not exhibit significant trends with changing pH (Fig. 1C, nitrogen data not shown), for a given soil, the availability of both potassium and nitrogen generally decreases with decreasing soil pH. Soils with low pH can not hold potassium and nitrogen very well, resulting in more leaching loss and poor response to potassium and nitrogen fertilizers.

In general, the availability of micronutrients is high in acid soils and low in alkaline soils. As shown in Figure 1E, F, G, aluminum, iron, manganese availability increase with decreasing soil pH. High aluminum and iron availability also reduce the availability of phosphorus by precipitating it out of the soil solution. Although zinc availability did not show a particular trend in this survey, for a given soil, the availability of zinc generally decreases at high soil pH. So does the availability of copper and boron. In addition to soil pH, soil parent material and organic matter content also affect the availability of micronutrients to a great extent.

Lime requirement for adjusting soil pH

In apple growing regions of New York and the Northeast, most soils are acid be-

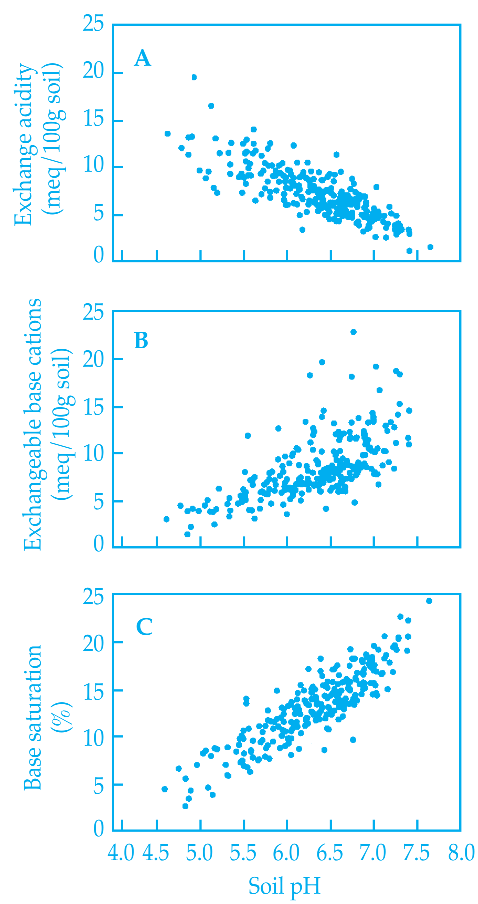

Figure 1. Exchange acidity (A), exchangeable base cations (B), and base saturation (C) in relaiton to soil pH in 250 Hilton soil samples from Western New York apple orchards.

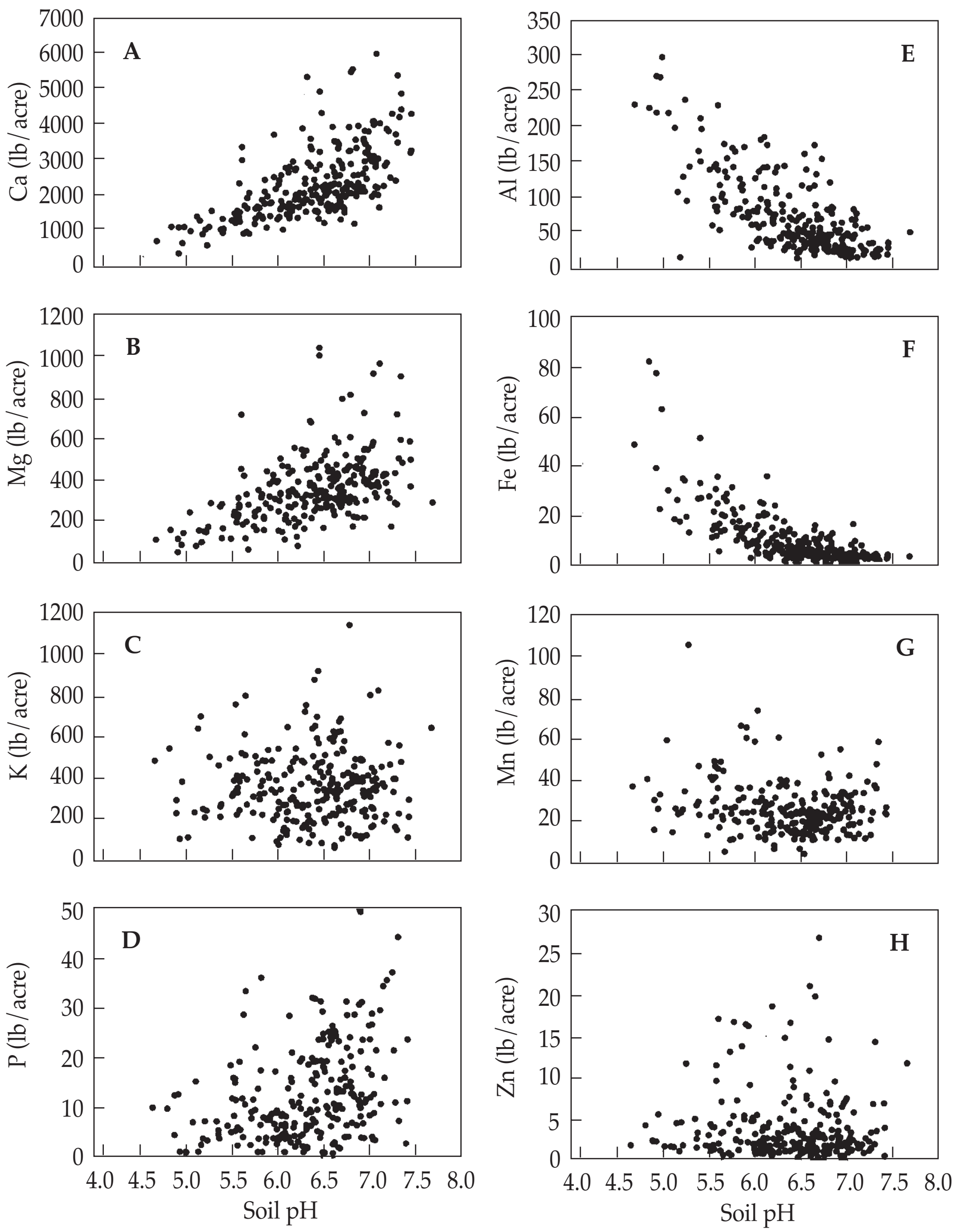

Figure 2. Availability of soil mineral nutrients in relaiton to soil pH in 250 Hilton soil samples from Western New York apple orchards.

TABLE 1

Relationship Between Soil ph And Percentage Base Saturation, 200 New York Soils (from Lathwell and Peech, 1964)

pH*	Approximate % Base Saturation: 200 soils	Approximate % Base Saturation: "Sandy" soils**
8.2	100	—
8.1	98	—
8.0	96	—
7.9	94	—
7.8	92	—
7.7	90	—
7.6	88	—
7.5	86	100
7.4	85	99
7.3	83	99
7.2	82	98
7.1	81	97
7.0	80	96
6.9	78	95
6.8	76	94
6.7	74	93
6.6	73	92
6.5	71	90
6.4	70	88
6.3	68	86
6.2	66	84
6.1	64	82
6.0	62	80
5.9	60	74
5.8	57	68
5.7	54	62
5.6	52	56
5.5	48	50
5.4	42	45
5.3	32	40
5.2	23	33
5.1	17	27
5.0	14	22
4.9	10	19
4.8	7	16
4.7	6	12
4.6	4	9
4.5	2	6

*pH measured in water using 1 part soil to 1 part water. If pH is measured in 0.01 M $CaCl_2$ (1 part soil : 2 parts $CaCl_2$ solution) measured values will be 0.6 pH units lower, i.e. at pH 6.4 base saturation would approximate that at pH 7.0 measured in water.
**Extremely coarse-textured sandy soils with low organic matter content tend to have a higher percentage of base saturation at a given pH.

cause of the high rainfall which has leached base forming cations from the soil over the years. Liming benefits apple growth and development by (1) increasing the availability of calcium and magnesium; (2) reducing the availability of aluminum and manganese; (3) promoting microbial activity in the soil and improving soil structure; and (4) improving root growth and efficient uptake of nitrogen and potassium and other fertilizers.

pH values of orchard soils should be maintained in the range of 6.0 to 6.5 throughout the soil profile to optimize nutrient availability. For preplant soil preparation, we recommend the pH of topsoil (0-8 inch depth) be adjusted to 7.0 and that of subsoil to 6.5. The amount of lime required to adjust topsoil pH to 7.0 and subsoil pH to 6.5 is determined by the current pH values of the topsoil and subsoil (determined from a soil analysis) and the buffering capacity of the soil, i.e. exchange acidity or cation exchange capacity, (CEC), of topsoil and subsoil (also determined from a soil analysis).

There are several ways to estimate the lime requirement. They generally fall into two categories: estimating lime requirement with, or without consideration of Ca and Mg requirements.

1. *Estimating lime requirement without consideration of Ca and Mg requirements.* Based on the current pH and exchange acidity of topsoil and subsoil, one can read the corresponding amount of lime required to adjust pH of topsoil and subsoil to 7.0 and 6.5 directly from lime tables published in the *Cornell Recommends for Tree Fruits*. The total lime requirement is the sum of topsoil and subsoil requirements.
2. *Estimating lime requirement with consideration of Ca and Mg requirements.* This method is based on CEC, base saturation at target pH, and the desired ratio of Ca to Mg ratio (5 to 1) to ensure adequate Ca and Mg supply in the soil while adjusting soil pH.

(1) Calculate exchangeable base cations from soil test report: Based on 1meq Ca/100 g = 400 lbs/acre; 1 meq Mg/100 g = 243 lbs/acre; 1meq K/100

g = 782 lbs/acre and soil test result, exchangeable base cations are calculated. For example, a soil test shows that there are 2400 lb Ca/acre 6" depth, 200 lb Mg/acre 6" depth, and 360 lb K/acre 6" depth with a pH of 5.5, the exchangeable base cations are calculated as:

(2400/400 + 200/243 + 360/782)/0.9 =7.28 meq/100 g soil

Where 0.9 is the extraction efficiency of the chemical soil test for these exchangeable base cations.

(2) Estimate CEC: When exchange acidity is available in the soil test, CEC can be easily calculated as the sum of exchangeable base cations and exchange acidity. When exchange acidity is not known, CEC can be estimated from the sum of exchangeable base cations and the relationship between soil pH and base saturation (Table 1). In this case, the base saturation of a soil with a pH of 5.5 is 48%. Therefore, CEC is 7.28/0.48 = 15.17 meq/100 g soil.

(3) Determine Ca and Mg requirements: If the soil sample is taken from 0 to 8 inches, the target pH for preplant preparation is 7.0, which has a base saturation of 80 percent. The combined requirements for Ca and Mg are 15.17 X 0.8 = 12.14 meq/100 g soil. The desired ratio of Ca to Mg is 5 to 1. The requirement for Mg is 12.14/(5 + 1) = 2.02 meq/100 g soil. The requirement for Ca is 2.02 X 5 = 10.1 meq/100 g soil. Convert these requirements from meq to lbs/acre:

Ca: 10.1 X 400 = 4040 lbs per acre 6-inch depth

Mg: 2.02 X 243 = 490.9 lbs per acre 6-inch depth

If the soil sample is taken from 8 to 16 inches, calculate the Ca and Mg requirements similarly using a base saturation of 71 percent at a target pH of 6.5.

(4) Determine the amount of Ca and Mg needed to reach these targets. Subtract the values for calcium and magnesium reported in the soil test results from the calculated requirement to determine the amounts of calcium and magnesium needed to reach desired levels per 6-inch depth of soil:

Ca: 4040 – 2400 = 1640 lbs per acre 6-inch depth

Mg: 490.9 – 200 = 290.9 lbs per acre 6-inch depth

Increasing these values by one/third (multiply the above numbers by 1.33) shows the amounts needed per 8-inch depth of soil. Adding the amount of Ca needed for topsoil and subsoil together gives the total amount of Ca per acre 16 inches. The total amount of Mg needed can be calculated similarly. The actual pounds of lime product required is calculated as the total amount of Ca needed per acre 16 inch divided by the Ca content of the product. The Mg content of the lime required is the total amount of Mg needed divided by the actual pounds of lime product.

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Diagnosing Apple Tree Nutritional Status: Leaf Analysis Interpretation and Deficiency Symptoms

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Orchardists use several methods for determining an orchard's nutritional needs. These include soil, leaf and fruit nutrient analyses, observations of growth and foliage quality, and the use of deficiency symptoms. Although leaf analysis has become the most common method of assessing an orchards nutritional needs, interpretation of leaf analysis results should not be done without concurrent field evaluations of growth, foliage quality and deficiency symptoms to make sound decisions when developing nutritional programs for orchards.

Essential mineral nutrients are necessary in annual supplies either from those that exist in the environment (soil and air) or as supplemental applications by the fruit grower. Without these nutrients the goals of promoting rapid development of young trees and the consistent production of significant quantities of high quality fruit in established orchards cannot be achieved. There are 17 known essential elements which are categorized either as "macronutrients" including carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), or as "micronutrients" including sulfur (S), iron (Fe), boron (B), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), chlorine (Cl), and nickel (Ni).

Nutritional requirements vary among orchard sites, within the seasons, and can be affected by light, temperature, and available water supply. Nutrient shortages can occur that can create immediately observable effects that severely limit fruit and/or tree quality. Many of the micronutrients are more readily available in the environment and in most cases require less frequent supplementation. For optimum growth and fruiting, essential nutrients must be kept within definable limits. Levels that are too low result in obvious visual symptoms and a reduction in fruit and tree quality. Levels that are too high result in toxicity symptoms, often with the same results as deficiency.

Mineral nutrition of tree fruit has been studied extensively for many years. There are several valuable references available for the fruit grower (Stiles and Reid 1991, Petersen and Stevens 1994, Childers 1966) that outline the details of tree nutrition.

Methods of Assessing Orchard Nutritional Needs

There are several useful methods available for determining an orchard's nutritional needs. These include: 1) the use of analytical methods to assess the nutrient content of tissue, fruit, or soil; 2) observations of growth and foliage quality; and 3) the use of deficiency symptoms. These methods should never be used alone but must be combined and evaluated together to make sound decisions when developing nutritional programs for orchards.

Leaf and soil analyses are the most accurate methods available for determining nutrient requirements. They are based on regular, precise sampling and measured against a set of standards developed over time and have been proven to be accurate. These standards have been specifically developed to assess the quality and quantity of fruit needed to meet the standards of particular markets. Advantages include precise knowledge of nutrient quantities in the tree and in the soil, and an easy method for making comparisons year to year. The disadvantages are cost and the additional time required to collect and process the samples.

Soil tests are important to measure pH and to get a general sense of nutrient content available to the tree in the orchard. Leaf analysis integrates all factors contributing to an orchard's nutritional status including soil nutrient content, tree and root nutrient carryover, ability of the root system and conductive tissue within the tree to transport nutrients to where they are needed, and the tree's ability to use available nutrients when they arrive at needed sites.

Visual deficiency symptoms have been used extensively by orchardists and consultants to adjust orchard nutritional programs by comparing leaf or fruit symptoms in the orchard to published color plates readily available in the literature. This method can provide a fast and inexpensive diagnostic tool for determining nutrient problems in the orchard. Unfortunately, by the time foliar or fruit symptoms occur and a diagnosis is possible, fruit quality and tree growth has already been compromised. Deficiencies can result in poor fruit quality including: small fruit, soft fruit, poor soluble solids; premature fruit drop, physiological disorders of the fruit such as bitterpit, watercore, corkspot, core breakdown; poor storage quality and poor tree growth. Deficiency symptoms can be confused with many other types of injury which cause similar symptoms. In addition, deficiencies of one element can mask deficiencies of another so that in some cases it is only possible to solve nutrient deficiencies one at a time.

Careful observations of terminal shoot growth are also used to assess an orchard's

TABLE 1

Leaf analysis standards for tree fruits (dry weight basis).

Element	Crop	Desired level
Nitrogen	Young nonbearing apples and pears	2.4-2.6%
	Young bearing apples and pears	2.2-2.4%
	Mature soft apples and pears	1.8-2.2%
	Mature hard apples and processing	2.2-2.4%
Phosphorus	All crops	0.13-0.33%
Potassium	All crops	1.35-1.85%
Calcium	All crops	1.3-2.0%
Magnesium	Apples and pears	0.35-0.50%
Boron	Apples and pears	35-50 ppm
Zinc	All crops	35-50 ppm
Copper	All crops	7-12 ppm
Manganese	All crops	50-150 ppm
Iron	All crops	50+ ppm

nutritional status. Non-bearing trees should have 15-18 inches of growth seasonally, bearing trees 8-12 inches of growth. It is an important observation when combined with analytical analysis. This observation can only be made after growth has stopped for the year so it is not timely enough to make same season corrections. Also, observations are often flawed and/or inconsistent, and unless accurate records are kept, they cannot be compared from year to year. In addition, growth outside these stated limits can also be caused by factors other than nutritional imbalances such as drought, root impairment or insect and disease damage.

Leaf Sampling Procedure

Timing of leaf sample collection. Nutrient levels in the leaf change over the season. The levels of most elements also vary between leaves along the shoot. The recommended sampling time represents a compromise between the best sampling times for various mineral elements. Leaf samples should be collected when the concentrations of most elements are relatively stable. The most stable time for sampling has been determined to be between the end of shoot growth and the start of export of nutrients from the leaves to the shoots (typically during mid-July through August) or between 60 and 70 days after petal fall. Leaf samples collected much earlier tend to contain higher concentrations of elements such as nitrogen and potassium, and lower levels of calcium. Conversely, samples collected much later tend to have lower nitrogen and potassium and higher levels of calcium. After harvest, levels of mineral elements in leaves decline. After September 1, the rate of decline increases and leaf analyses can no longer be a reliable indicator of nutrient status. In order to compare leaf samples to established standards, the leaves sampled must be comparable in physiological age to those used in developing the standards.

Method of sample collection. Samples should consist of 100 leaves collected from several trees in the area being sampled. Trees may be selected at random, or by following a predetermined pattern. Sampled trees should be uniformly representative of the general condition of the orchard in terms of vigor, crop load, pruning, etc. Avoid areas with distinctly different soil conditions or tree vigor. If more specific information about such areas is desired sample those areas separately. Collect samples from blocks no larger than five acres. For trouble spots, take separate composite samples from five affected trees and five non-affected trees and label bags accordingly.

Collect only mid-shoot leaves from current-season terminal shoots on the periphery of the tree. No more than two leaves should be taken from an individual terminal shoot. On larger trees, shoots sampled should be approximately 4 -7 feet above ground level. Shoots sampled from young trees and high-density plantings should be representative of the majority of the foliage.

Leaves of different varieties may differ greatly in nutrient composition. Sample the major variety in the orchard. Do not mix leaves from two varieties because the sample will not be representative of either. If more detailed information is desired on varietal differences, they should be sampled separately.

It is essential that careful records be kept. At the time that leaf samples are collected, record observations of such factors as length and thickness of terminal shoot growth, relative size and appearance of leaves, incidence of disease or insect damage, visual symptoms of deficiencies, crop load, severity of pruning, and effectiveness of weed control. These factors are essential in interpreting the results from the leaf analysis.

Sample preparation. In most cases, the content of elements such as nitrogen, phosphorus, potassium, calcium, magnesium, or boron is not affected appreciably by washing samples prior to drying. Surface contamination by dust, soil, pesticide sprays, or foliar nutritional sprays may result in significantly higher levels of iron, manganese, zinc, and copper in samples that are not washed prior to drying. For example, leaves treated with manganese-containing fungicides often have elevated levels of this element and interpretation is difficult without direct observation of the orchard for low pH, poor drainage, and visual symptoms such as "measles" showing manganese toxicity. Washing samples in a mild detergent solution (most dish-washing liquids are suitable), and then rinsing three times in distilled water is helpful in reducing contamination. Caution: Some domestic water supplies contain various amounts of iron, manganese, copper, or zinc. Using distilled water for washing leaf samples helps to avoid this source of contamination. After the final rinse, samples should be drained (spread out on paper toweling) before being placed in paper bags for drying. These bags should be placed in a location conducive to rapid drying with tops open to prevent mold formation. Samples should be stored until processing, in a dry location to prevent rehydration.

Interpretation of Leaf Analysis Results

The first step in evaluating the nutritional status of orchards is to compare results of the leaf analysis with a set of standard values. Standards currently in use in the Leaf Analysis Service Program in New York State are summarized in Table 1. Other companies that offer leaf analysis use their own standards. It is important to know what those standards are for proper interpretation. For example, some Midwestern companies have used corn as their standards values. These values are not appropriate for apples and interpretations using these standards will result in less than successful outcomes.

Nitrogen (N) levels must be considered according to the type of fruit, tree age and variety, crop load, tree vigor, and the purpose for which the fruit is intended. The most desirable nitrogen management program provides a relatively high nitrogen status early in the season to encourage rapid leaf development, fruit set, and flower bud formation, and then allows nitrogen to decline gradually as the season progresses to favor fruit color development and winter hardening of the tree. Optimum growth of young trees is associated with leaf nitrogen values of approximately 2.4 to 2.6 percent. As trees mature, less vegetative growth is desired and the "satisfactory" level of nitrogen is generally reduced to improve color development and fruit firmness. Points to consider in judging nitrogen status from leaf analysis include:

1. Rapid growth of young trees is desirable to develop the fruiting system and encourage early cropping. During the developmental period, rate of tree growth is directly correlated with nitrogen status, but excessive late-season growth must be avoided to allow the trees to develop cold hardiness.

2. Fruit color development in bearing age trees (red and yellow varieties) is delayed when nitrogen levels are too high. If other factors are equal, the percentage of red color is reduced by about 5 percent for each 0.1 percent increase in leaf nitrogen. This relationship is particularly significant with the less-highly colored fruit varieties or strains. Yellowing of Golden Delicious fruit shows a similar reduction as leaf nitrogen increases.

3. Fruit size and flesh firmness are usually inversely related, and both are influenced by the nitrogen status of the tree. Size generally increases with higher nitrogen levels if the crop load is not excessive and other factors are not limiting. Since flesh firmness decreases as fruit size increases, the optimal nitrogen level would be that which provides the best combination of size and firmness determined by the requirements of the market.

4. Varietal differences in fruit color and/or flesh firmness must guide evaluation of leaf nitrogen status. To accommodate such differences, various apple varieties are grouped into two general categories for interpreting leaf nitrogen status in mature orchards. Soft varieties intended for fresh market should have a leaf nitrogen concentration of 1.8-2.2 percent for mature trees, and hard varieties intended for either the fresh or processing market and soft varieties intended for the processing market should have a leaf nitrogen of 2.2-2.4 percent for mature trees.

5. Biennial bearing tendencies of mature apple trees become more pronounced as leaf nitrogen falls below approximately 2.2 percent. Careful attention must be given to fruit thinning to minimize the biennial tendency in Golden Delicious and varieties such as McIntosh when leaf nitrogen is reduced to levels of 1.8-2.0 percent to favor color development.

6. Vigor of shoot growth offers an additional guide if all other nutrients are adequate. Excessive waterspout growth frequently results from excessive pruning, particularly heading cuts, and is not a reliable indicator of vigor of the fruit-bearing shoots. Interpretation of leaf nitrogen levels in trees that are producing very limited amounts of new growth should be done with caution. In such trees, nitrogen accumulates to adequate or higher-than-desired levels because of the limited growth. This condition is often associated with deficiencies of metals such as copper and zinc.

Phosphorus (P) levels in leaf samples vary according to fruit type and variety. Leaf phosphorus levels above 0.13 percent usually indicate an adequate supply within the tree. McIntosh leaf samples generally contain lower concentrations of phosphorus than those of Delicious. Since the availability of phosphorus is strongly influenced by soil pH, low leaf-phosphorus values frequently indicate a low soil pH condition that is limiting uptake of phosphorus. At the other extreme, high values frequently result from the accumulation of phosphorus when growth and leaf expansion are limited by deficiencies of other elements such as zinc.

Potassium (K) values in the range of 1.3 to 1.8 percent are generally considered to be adequate for tree fruit crops. Fruit set on potassium-deficient trees may be normal, but the fruit is smaller than normal, has poor, dull color, and an insipid flavor due to lack of acidity. Trees that are low or deficient in potassium are more susceptible to winter cold injury and spring frost damage to buds and flowers. Leaf potassium shows an inverse relationship with crop load. Thus, a value of 1.3 percent potassium may be adequate in a sample from a heavy cropping orchard, but might indicate a marginal supply in a light cropping or nonbearing orchard. Leaf potassium levels of 2 percent or greater are not uncommon with young nonbearing trees; such levels decline as trees mature and the level of cropping increases. Fruit size and color are correlated positively with leaf potassium, and levels in the range of 1.5-1.8 percent must be sustained to achieve optimum production and fruit size and color. High N/K ratios usually indicate that potassium supply is inadequate, while low ratios might indicate either that the nitrogen supply is too low or that the potassium supply is too high.

In addition to tree age and level of cropping, soil moisture supply and soil management practices affect leaf potassium status. If the soil potassium supply is adequate, moisture stress may limit availability of potassium and result in low leaf potassium levels. Soil management practices such as the use of clean-cultivation or herbicide strips along the tree row, or mulching generally result in higher leaf sample potassium. Any reduction in moisture stress and soil temperature favors uptake of potassium.

Calcium (Ca) content of leaf samples is considered adequate when in the range from 1.3 to 2.0 percent. Low leaf calcium is often, but not always, associated with low soil calcium supply and low pH, particularly in the subsoil. This usually reflects inadequate lime application prior to planting the orchard and/or failure to maintain an adequate liming program throughout the life of the orchard. When adequate soil calcium is available, low leaf calcium may be the result of boron deficiency and/or zinc deficiency. Normal applications of potassium or magnesium have little effect on calcium unless soil calcium supply is low.

Calcium in leaves is positively correlated with leaf nitrogen under normal growth conditions. This relationship exists because a large part of the calcium and nitrogen are taken into the tree and moved to the leaves as the result of water movement due to transpiration. Increasing nitrogen by increasing growth and leaf surface raises total transpiration. Excessively high nitrogen supplies, however, frequently promote development of a high leaf-to-fruit ratio that compounds the problems associated with low calcium in the fruit. This is particularly important when soil moisture is inadequate because calcium is removed from the fruit as water is moved from fruit to leaves under moisture stress conditions.

Magnesium (Mg) concentrations within the range of 0.35-0.50% are usually satisfactory, but Mg should be considered in relation to potassium (K). The requirement for magnesium increases as the potassium status of the tree increases. For practical purposes, a ratio of the percentages of K to Mg in the leaf sample of 4:1 or greater usually indicates that the magnesium supply is not adequate. Premature fruit ripening and accentuated preharvest fruit drop are often associated with magnesium deficiency. Blind wood, a lack of bud development, and weak, brittle spurs are also frequently associated with magnesium deficiency.

Boron (B) shortages frequently occur in orchards, particularly on coarse-textured soils and during dry seasons. Leaf concentrations of 30 to 50 ppm boron are required for normal tree performance. Low boron levels are often associated with calcium deficiency problems. Interpretation of leaf boron values must be done with past boron application practices kept in mind. If no foliar sprays of boron were used prior to leaf sample collection, a leaf level of 30 to 50 ppm usually indicates an adequate boron supply. However, if post petal-fall boron sprays were used, leaf levels in the 30 to 50 ppm range indicate a need to continue boron applications with a combination of soil and foliar treatments. Fruit analysis is considered to be the most reliable means of diagnosing boron status.

Zinc (Zn) is involved in the regulation of growth and fruiting and is an essential element in the production of growth-regulating hormones within the tree; it has also been shown to play a role in pollen tube growth. Zinc also influences calcium metabolism. Shortages of zinc are prevalent in the Northeast. Zinc has been shown to influence the degree of cold hardiness of trees and frost hardiness of flowers.

Interpretation of leaf zinc levels is complicated by zinc-containing materials in foliar applications and by interactions with phosphorus. If no foliar sprays containing zinc have been applied, levels of 35-50 ppm indicate adequate zinc; levels of 20-35 ppm indicate a low zinc status; levels less than 20 ppm indicate a zinc deficiency. Relying strictly on these levels to judge zinc status may be misleading for two reasons: 1) growth is reduced as zinc becomes limiting. This limited growth results in accumulation of zinc to higher concentrations than would occur with normal growth; and 2) high levels of phosphorus tend to reduce the availability of zinc within the tree as the result of the formation of inactive zinc phosphate precipitates. When zinc is limited, the reduced growth also tends to result in higher concentrations of phosphorus within the leaf tissue, making the problem even worse. An evaluation of the ratio of phosphorus to zinc in the leaf tissue provides a second means of determining relative zinc status. This ratio is calculated by dividing the ppm of phosphorus by the ppm of zinc. A P/Zn ratio of 150 or greater indicates that zinc is deficient, while 35 ppm or higher zinc levels with P/n ratios of 100 or less usually indicate an adequate supply of zinc.

Manganese (Mn) deficiency is found more frequently on high-pH soils and on coarse-textured soils. The primary effect of manganese deficiency is reduced photosynthesis. Manganese availability is strongly influenced by soil pH. Toxicity, measles in Delicious apple trees, occurs at low pH, usually near 5.0 or below, in soils not adequately limed. Manganese is usually more readily available in poorly drained soils where aeration is limited. For example, manganese availability may be excessive in a poorly drained soil at pH 5.5, but normal in a well-drained soil at the same pH. Necrosis of the phloem as a result of manganese toxicity is frequently confused with other problems such as oil spray damage, or deficiencies of copper or boron. Concentrations of 50 to 150 ppm of manganese indicate adequate amounts of this element in leaf samples from trees that have not been sprayed with manganese-containing materials. When excessively high manganese levels are found in leaf samples, it is advisable to verify that this is not related to a low pH problem.

Iron (Fe) content of leaf samples fluctuate over a considerable range, often in response to variations in soil and weather conditions and with contamination of samples by dust. Iron status of orchards in New York State is generally not a problem.

Copper (Cu) shortages can be a problem on coarser-textured soils and on soils with a pH 6.3 or higher. Levels of 7-12 ppm in leaf samples generally indicate a satisfactory copper level. Symptoms of copper deficiency are associated with leaf contents of Cu of 3.5 ppm or less.

Multiple deficiencies involving two or more elements are not uncommon. Potassium-magnesium, calcium-magnesium, boron-zinc, zinc-manganese, zinc-copper and other combinations have been encountered. In many such cases, tree growth is restricted and the levels of all elements in the leaf samples may be within the ranges considered to be satisfactory for normal tree performance. Visual examination of the trees, past performance, soil tests, and trial applications of the suspected problem elements may be necessary before the cause or causes of such problems can be determined. When the supplies of two or more elements are marginal, correction of one deficiency usually accentuates the appearance of symptoms associated with deficiencies of the other element(s)

Other factors such as the condition of the roots and conducting tissues, abnormal soil conditions, and damage to the roots from nematodes or diseases, may affect the results of leaf sample analysis and should be considered in the interpretation of results. Physical damage to limbs, trunks, or roots, whether by mechanical means or injury by rodents, or insect or disease problems may also affect nutrient uptake or translocation within the tree. Likewise, injuries to buds or foliage as a result of low temperature during winter, spring frosts, herbicides, or various pesticides can influence the growth and nutrient content of leaf samples.

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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*).

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

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 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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Micronutrient Management in Apple Orchards

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Micornutrients such as zinc, boron, and copper are often deficient in New York orchards. Cost–effective programs to improve micronutrient status of apples involve soil and foliar applications of boron and foliar applications of zinc and copper. Occasional problems with other micronutrients are often caused by low or high pH or poor soil drainage.

The quantities of individual micronutrient elements required to promote optimal performance of apple orchards are relatively small in comparison with calcium, potassium, nitrogen or magnesium. Estimates of actual amounts of individual micronutrients removed per acre from the orchard in a crop of apples include: boron - 120 grams; iron - 90 grams; zinc - 70 grams; copper - 30 grams; and manganese - 20 grams. However, it is the significant roles that these elements play in the physiology of the trees that makes them major factors in orchard nutrition management programs.

Both deficiency and toxicity problems must be considered in developing appropriate programs for managing micronutrients. Some of the more common problems contributing to deficiencies and toxicities of micronutrients are given in Table 1.

Boron

Boron is essential in the normal development of new tissues in shoot tips, flowers, fruit, and roots. Boron has long been essential in pollen development, pollination and fruit set. The boron content of unopened flower buds tends to be fairly high and as growth proceeds the boron content of the resulting tissues tends to decline. Leaf sample analysis and soil testing both provide information needed in evaluating boron status.

Although the most commonly recognized symptoms of deficiency occur in the form of various types of corking and cracking of the fruit, poor development of roots associated with boron deficiency is a significant factor that limits uptake and utilization of various other nutrients such as calcium and potassium.

Foliar applications of boron are effective in providing this element to the aboveground parts of the tree to which they are directly applied. Thorough coverage is essential with boron and it is suggested that these be applied as 1X to 3X tank mix concentrations if possible, and not over 6X to 8X.

Various forms of boron materials are available for use in foliar sprays, the most common being Solubor^{R} and Borosol^{R} at rates of one pound and one quart per 100 gallons dilute equivalent, respectively. Depending upon the boron content of leaf samples, boron sprays may be recommended at the tight-cluster to pink stage of development when the previous season's leaf analysis shows low (less than 35 PPM) B or when buds have been injured by cold weather. Pre-bloom sprays have been beneficial in improving bud development, pollination, fruit set, early season leaf and shoot growth, and in some cases have improved calcium uptake. Pre-bloom sprays generally do not have an appreciable effect on the boron content of leaf samples taken at the normal 60-70 days after petal fall timing.

Post-bloom sprays of boron are frequently needed to maintain adequate levels of boron to avoid development of deficiency problems in the fruit. These applications may be made at petal fall, first cover (7-10 days after petal fall) or third cover (approximately 30 days after petal fall). Applications of boron sprays later in the season should not be made because of the possibility of stimulating abnormal ripening and breakdown of the fruit.

Boron is not readily translocated within the woody tissues of the tree. Therefore, foliar sprays are not effective in supplying the boron needs of the roots. Annual soil applications of a suitable boron carrier are necessary to maintain an adequate supply in the root zone. The amount of boron needed in soil applications will vary with soil texture. Finer-textured soils have a higher buffering capacity and require higher concentrations of boron to meet crop requirements than those of coarser texture. Soil tests for boron should be used to determine actual rates of application needed. These rates may vary from none to as much as three pounds of actual B per acre, or even four pounds per acre per year on very fine-textured clayey soils.

Boron is soluble in water and can also be applied effectively through fertigation.

Zinc

Zinc deficiency is one of the most common nutrient deficiencies in tree fruit orchards. Zinc is not mobile within the soil and its availability for plant uptake is limited by high soil pH, high levels of phosphorus in the soil, high soil organic matter content, and low soil temperature. Movement of zinc into and through the tree can be limited by precipitation as insoluble zinc phosphate compounds on the root surfaces and in the conducting tissues of the trunks, shoots and leaves. An annual zinc spray program is usually necessary to obtain optimal performance of most orchards.

Zinc has been referred to as the "growth" element because of its role in hormone production in buds. Deficiency of zinc primarily affects the above ground portions of trees, resulting in poor leaf and shoot growth, reduced flowering and fruit set, and reduced size and coloring of fruit. Zinc is also important in the movement of calcium within the tree. Zinc, and potassium, have been shown to be significant factors in minimizing cold damage to flowers and woody tissues.

Soil application of various forms of zinc have been neither consistently nor sufficiently effective to be economical for use in orchards. Applications of various forms of zinc through fertigation have likewise been too inconsistent and/or too expensive for general recommendation.

Application of zinc sprays is the most consistent and cost effective method of applying this element in orchards. The most common methods for applying zinc include late-dormant sprays of zinc sulfate, summer application of zinc chelates or other materials, and post-harvest sprays. Zinc containing fungicides have been partially effective in established orchards, but have not met total requirements nor completely corrected a zinc deficiency.

Application of zinc sulfate (20 to 36 percent zinc) at dormant to silver-tip is effective in supplying part of the total zinc requirement. This material is applied at rates of approximately 3.5 to 5 pounds of actual zinc per 100 gallons of dilute spray, either alone or safened with fresh hydrated lime. This spray must be applied dilute or up to a 2X tank-mix concentration to obtain thorough coverage of buds and shoot surfaces. Oil sprays applied after the zinc sulfate spray increase penetration of the zinc sulfate into buds and spur tissues and have resulted in severe damage. Likewise, freezing weather (frosts) occurring within two to four days before or after the dormant spray has increased uptake of the zinc sulfate and resulted in killing of spurs. For these reasons, this method of applying zinc is not recommended.

There are numerous zinc materials available, but not all are equally effective for use in foliar sprays. NZN^R(10-0-0-5% Zn), basic zinc sulfate (zinc oxysulfate) and various chelated zinc products have been effective sources of zinc when used according to label directions. However, some zinc products, chelated and non-chelated, have caused injury when used as sprays while others, such as zinc oxide, have not been effective. In general, more frequent applications at low rates are preferred over less frequent applications at higher rates.

Approximately 20–25 percent of the zinc in various zinc-containing fungicides is available to the trees, but the remainder is present in or on leaves as an inactive contaminant. There appears to be little or no carryover of zinc from one season into the next. It is therefore necessary to ignore the zinc content of leaf samples and to proceed with an annual full-season zinc spray program.

TABLE 1

Contributing factors to micronutrient deficiency and toxicity symptoms

Micronutrient	Contributing Factors to Deficiency Symptoms
Boron	Coarse-textured soils, low soil B, dry soil conditions, leaching
Zinc	High soil pH, high phosphate levels, high soil organic matter
Copper	High soil pH, high phosphate levels, high soil organic matter
Manganese	High soil pH, highly leached soils
Iron	High soil pH, high phosphate levels, poor soil drainage
Molybdenum (seldom seen in apples)	Low soil pH
Micronutrient	**Contributing Factors to Toxicity Symptoms**
Boron	Application of excessive rates boron
Manganese	Low soil pH (below about 5.6), poor soil drainage
Aluminum	Low soil pH, poor soil drainage

TABLE 2

Foliar nutrient spray use suggestions – apples and pears. (Consult Cornell Cooperative Extension Information Bulletin 219 "Orchard Nutrition Management" for further details)

Nutrient	Green tip-1/4" green	Half-inch green	Tight cluster-Pink	Cover sprays	Comments
Copper (8-8-100 Bordeaux COCS Kocide	Apply from silver tip to 1/4" green and/or after harvest				Later applications or use during freezing temperatures will cause injury to apples.
Boron Solubor (1 lb/100 gal) Borosol (1qt/100 gal)		Assist recovery from winter injury	Improve fruit set and correct low boron levels in tissues.	7-10 day after petal fall and 20-25 days after petal fall	Do not mix with oil. Not compatible with water soluble packages.
Manganese				7-10 days after petal fall	
Zinc (1) EDTA-Zn chelae, NZN^R (10-00-0-5%Zn Basic zinc sulfate (zinc oxysulfate)		Assist recovery from winter injury	When leaf analysis shows deficient levels or symptoms of winter injury are evident.	2 to 4 cover sprays required to obtain adequate response	

Note (1) Some forms of zinc chelate have caused injury when applied as a sprays. These have included and EDTA-chelate in which the zinc sulfate was not adequately safened.

Copper

Copper is immobile within the soil. As with zinc, copper availability in the soil is frequently limited by high soil pH, high soil phosphorus, and high soil organic matter contents. Copper is involved in various enzyme reactions and processes related to photosynthesis. Symptoms of copper deficiency include abnormal and stunted leaf development, stunted shoot growth with dieback, reduced flowering and fruit set, and small fruit with poor color and quality. Toxicity of copper in the soil results in death of roots, but this has not been observed in New York State orchards.

Soil applications of copper, either to the soil surface or through fertigation, have not provided economically effective correction of deficiencies in apple orchards. Therefore, copper spray applications are the most efficient means for supplying copper to trees. Copper sprays can cause severe russeting of fruit if applied between the time that the florets are exposed in the opening flower clusters until after harvest. Several years of work have not resulted in finding a method for safening copper materials for use during this time period.

At present, the most efficacious method for supplying copper to apple trees is to apply copper fungicides according to the product directions for disease control. This may involve post-harvest and/or very early, not later than the 1/4-inch green stage, pre bloom sprays.

Manganese

Manganese is involved in processes related to photosynthesis and in enzyme reactions. The primary factor governing availability of manganese in most orchard soils is pH. Deficiency symptoms of manganese are frequently observed in orchards when soil pH exceeds approximately 6.3, particularly on coarse-textured soils that have received high rates of lime application. Detrimental effects of manganese deficiency are generally not apparent unless the leaves show chlorosis (loss of chlorophyll).

Although manganese can be effectively supplied through applications to the soil, this method is considered to be too expensive for general recommendation. Foliar sprays are the most cost effective means for supplying manganese to orchards. The manganese in mancozeb fungicides is apparently readily available to the trees. However, restrictions on the use of these materials has resulted in more frequent observations of manganese deficiencies and the need for application of supplemental sprays of other manganese products.

Usually, a single application of manganese sulfate at a dilute equivalent of 4 pounds per 100 gallons applied 7 to 10 days after petal fall is sufficient to prevent the appearance of deficiency symptoms.

Excessive amounts of available manganese associated with low soil pH (below about 5.6) results in "measles," a development of necrotic lesions in the bark of the trunks and limbs of apple trees. Correction of this problem generally requires applications of lime to raise soil pH, and installation of drainage systems, if needed, to improve internal soil drainage.

Iron

Iron is involved in various processes involved in photosynthesis and in enzyme systems in plants. Availability of iron in the soil decreases as soil pH increases. Excessive levels of phosphates or carbonates in the soil reduce iron availability through formation of insoluble iron compounds. Poor internal soil drainage can also result in reduced availability of iron. Organic matter is a source of iron and also complexes and chelates iron.

Iron deficiency is not generally a problem under most orchard conditions. Leaf chlorosis is sometimes seen, particularly on rapidly growing water sprouts but this is not generally a matter of serious concern. There are various proprietary products available for use in correcting iron deficiency. However, determination and correction of the problems that contribute to the occurrence of this condition should be emphasized rather than direct application of iron.

Aluminum

Although aluminum is not required for normal development and performance of apple trees, it is of concern because of the potential toxicity problems associated with its availability in excessive amounts in the soil. Excess aluminum results in root damage that interferes with uptake of the essential nutrient elements. Low soil pH and poor internal soil drainage are the primary factors associated with excess aluminum availability. Correcting these problems with liming to raise soil pH and avoiding soils with poor internal drainage, or installing adequate drainage systems, if feasible, should alleviate problems associated with excess aluminum.

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Fertigation of Apple Trees in Humid Climates

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Fertigation has several potential advantages over soil surface applications of fertilizers. These include: rapid application of precise amounts of essential plant nutrients directly to the root zone of the trees, application of nutrient at the exact time of year the tree needs them, and limiting nutrient leaching to ground water and nutrient run-off. An interesting additional benefit from fertigation is an increase in fruit size. With small fruited varieties like Empire and Gala this could greatly improve the economic benefit from fertigation.

Fertigation is the application of dissolved fertilizers through an irrigation system. Most commonly this is done through a drip or trickle irrigation system but it can also be done with under-tree micro-sprinklers or regular under-tree sprinklers. The macro nutrients, nitrogen, potassium, phosphorus and magnesium are the most common nutrients applied by fertigation, but micronutrients such as boron, zinc, iron, calcium manganese and copper can also be applied through the irrigation system.

The concept of applying fertilizers through the irrigation system was developed in arid climates like Israel and California where irrigation water is regularly applied. Increasingly in the more humid climate of the Northeastern US, growers who plant high-density orchards are adding trickle irrigation as an important component to ensure the success of the new planting. Thus, fertigation is increasingly being considered as a way to improve tree response.

Advantages of Fertigation

Fertigation has several potential advantages over soil surface applications of fertilizers. These include:

1. Rapidly applying precise amounts of essential plant nutrients directly to the root zone of the trees.
2. Applying nutrient at the exact time of the year when the tree needs them.
3. Limiting nutrient leaching to ground water and nutrient runoff.

Precise delivery of nutrients to the root zone. Fertigation uses the trickle irrigation water as a carrier for delivering small doses of dissolved fertilizer to the root zone frequently. The fertilizer generally remains in solution and travels with the water through macropores into the soil to the depth the water travels. If the amount of irrigation water is correctly calculated, the dissolved nutrients are delivered to the precise area of the soil where the tree roots are; the nutrients can then be directly absorbed by the roots from the soil solution or they can be adsorbed to the soil clay particles for later uptake by the plant. Since the nutrients are precisely and efficiently delivered to where the tree root zone is, this technique can substantially reduce the amount of fertilizer required to maintain plant nutritional status. Several investigators have estimated that fertilizer usage can be reduced by 50 percent if fertigation is properly done.

Delivery of nutrients at the proper time. Conventional ground applications of fertilizer at the beginning of the season results in high concentrations of fertilizer in the soil followed by lowered amounts as the season progresses. Fertigation allows delivery of what the plant needs nearly on a daily basis. It also allows different nutrients to be delivered to the root zone at different times of the season. As we learn more about which nutrients are involved at various times of the season in essential growth, flowering and fruit growth processes, fertigation programs can be tailored to give the desired plant response. It may be possible to stimulate rapid leaf area development and fruit growth in the spring with fertigation treatments high in nitrogen and then stimulate increased fruit color in the late summer and early fall by the application of other nutrients.

Reduced leaching and runoff of nutrients. With conventional ground applications of fertilizers, a significant portion of the applied fertilizer is lost when it is leached beyond the root zone. Leached nutrients contaminate the ground water or are lost in surface runoff where they contaminate surface water resources including streams, ponds and lakes. Fertigation, if done properly, can limit leaching and runoff of nutrients; however, the success of fertigation in reducing leaching and runoff depends on the precise application of the proper amount of water so that nutrients are not carried too deep in the soil profile. If too much irrigation water is applied it will carry the dissolved nutrients too deep in the soil profile where roots from dwarf apple trees cannot access it. Thus, the irrigation water amount and frequency of application are essential parts of fertigation strategies.

Irrigation in the Northeastern US

The need for irrigation. The root systems of dwarf apple trees and newly planted apple trees are small and do not occupy a large volume of soil. This often leads to water stress especially with newly planted trees. Much of the problem of poor tree growth of dwarf apple trees during the first few years can be traced to inadequate water supply. In an average growing season in the Northeast, rainfall is usually less than that required for optimal tree performance during critical periods of tree establishment and growth (Figure 1). Rainfall average from May-September is 5-6 inches less than evapotranspiration. In addition, in 3 years out of 10, severe water shortages occur during the months of June, July and/or August.

TABLE 1

Crop coefficient for apple that are used to calculate the amount of water needed by an apple orchard.

Month	K_C-pan with cover crop	K_C-pan without cover crop
May	0.68	0.48
June	0.92	0.68
July	1.00	0.80
August	1.00	0.80
September	0.96	0.76

Often during these months the shortfall can be 1.5-2.0 inches per week. Our research over the last 10 years has shown that early tree performance can be significantly improved by the addition of trickle irrigation. In general, our experiments have shown that trickle irrigation increases shoot growth and trunk cross-sectional area especially in the early years. The effect of irrigation is greater in years 1-3 when trees are developing a root system. However, in years 4-6, there continues to be a significant improvement in tree growth with irrigation. Even after 7 or 8 years, irrigated trees were up to 36 percent larger than the unirrigated controls. Ground fertilization did not generally increase tree growth in the first three years when no irrigation water was applied. In two of our experiments, the addition of ground-applied fertilizers to the unirrigated plots significantly reduced shoot growth in the first and second year, (when compared with unfertilized plots). However, with the addition of trickle irrigation water, ground fertilizers significantly improved tree growth compared to either the irrigated trees without fertilization or the unirrigated controls.

Trickle irrigation also has had a significant effect on yield. In one experiment, trickle alone had no effect on yield in years 2-4. But since irrigation increased tree growth during the early years, yields in later years were greater than controls. In a second experiment, there was a consistent improvement in yield in all years from the addition of trickle irrigation. Cumulative yield of irrigated trees has been consistently greater than the un-irrigated trees in all experiments. The addition of ground applied fertilizers without trickle irrigation in experiment one increased yield in the second year, but, because tree growth was reduced, there was no yield advantage in later years from ground fertilizers. However, if water was applied in conjunction with the ground fertilizer, yield was improved considerably.

Average fruit size was in most cases improved by trickle irrigation plus ground fertilizer or fertigation. When averaged over the first six cropping years of our second study, trickle irrigation alone or fertigation increased fruit size by 7-8 percent. This increase in fruit size would have translated into a significant economic difference in packout.

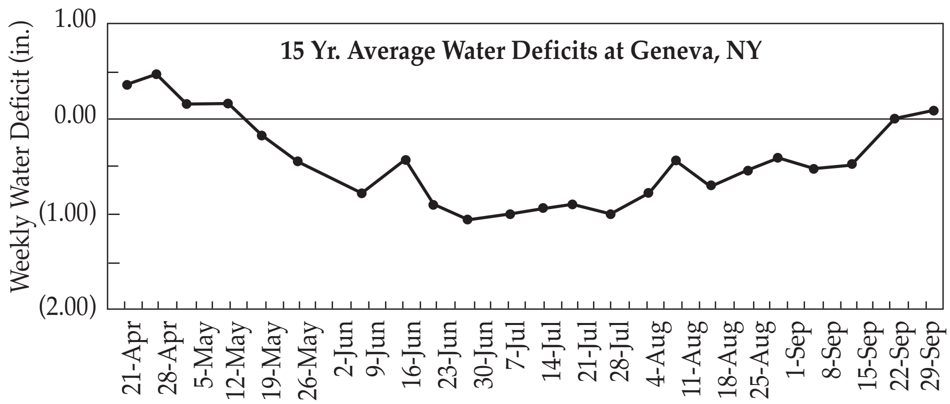

Figure 1. Average weekly water deficits at Geneva NY.

Estimating tree water requirements. Generally, mature apple orchards require approximately 1.5 to 2.0 acre-inches of water per week during periods of peak water use. Young orchards that do not yet fill their allotted space use significantly less. The water supply available to the trees varies with the water holding capacity of soils, the level of weed control during the early season, the amount of mulch and the rooting volume with dwarf apple trees. Mulch can act as a substitute for irrigation. The water holding capacity of the soil varies from as short as four days on sands to 11 days on sandy loams to 15 days on loams and 19 days on silt and clay loams. To calculate how much irrigation water to apply we use one of three methods:

A. Modified Kenworthy Rule: Apply 1 gallon water/tree/day/year of tree age reaching a maximum on the year the tree canopy fills the space between trees. With low-density Central Leader trees, canopies may not fill the space until year 10 resulting in 10 gallons per tree per day at maturity but with high density orchards canopies usually have filled the space by year five resulting in a maximum of five gallons per tree per day.

B. Tensiometers: Apply irrigation when tensiometers read 20 centibars. We suggest placing the tensiometers in the soil at an appropriate distance (usually 18-24") from the emitter in the root zone of the tree (8" deep).

C. Evapotranspiration Models: Calculate the amount of water to apply based on the daily water used by the tree. We use the simple formula:

$$\text{Amount of Irrigation Water (inches/acre/week)} = \frac{\text{Net Weekly Water Deficit (inches/week)} \times \text{Crop Coefficient}_{\text{pan}} (K_C\text{-pan})}{\text{Efficiency of irrigation system (fraction)}}$$

The Net Weekly Water Deficit = Inches of water evaporated per week from a Class A evaporator pan minus inches of rainfall per week. The SkyBit commercial weather forecasting company gives daily estimates of pan evaporation and rainfall. The Efficiency of an Irrigation System is commonly estimated at 0.60 to 0.70 for sprinkler irrigation and 0.90 for trickle irrigation. The Crop Coefficient $_{\text{pan}}$ values vary through the season depending on leaf area and canopy cover. Estimated values for apple orchard crop coefficients in Washington State are given in Table 1. Crop coefficient values with cover crops are where there is grass in the tractor alleys and irrigation water is applied to both the grass and the trees (flood or sprinkler). The values without cover crop are when irrigation water is applied only to the trees and the grass is not irrigated (trickle). In our work with trickle irrigation in New York we have used K_C-pan values of 0.80 in the heat of the summer because we do not irrigate the grass. For young orchards that do not yet fill the allotted space, reduce the crop coefficient proportionally to the percentage of ground covered compared to a mature tree. Never go below about 70 percent of the K_C-pan values listed above.

Fertigation Methods

Irrigation system requirements. The most important requirement of any irrigation system used for fertigation is that the system has good uniformity of distribution (i.e. ≤15 variation among emitters). If uniformity is low, some areas of the orchard will receive too much water and too much fertilizer while other areas will receive substantially less water and fertilizer. This can lead to significant variability in vigor and fruit quality in an orchard. Variability in topography can often cause pressure differences across an orchard. With trickle systems, pressure- compensating emitters allow uniform distribution on slopes and undulating terrain. Both in-line emitters and plug-in type emitters are currently being used, but the trend is toward the use of tubing with emitters built in at various spacings.

Various types of irrigation systems can be used to deliver water and nutrients to apple orchards in New York but nearly all fertigation systems use either trickle irrigation or microsprinklers.Traditional undertree sprinklers are designed to cover 100 percent of the land area on an acre with water. Microsprinklers are designed to cover 60-80 percent of the land area with water. These spread the dissolved fertilizer over too large an area making precise placement of the fertilizer over the tree root zone impossible. In contrast, trickle or drip-irrigation systems designed to cover only 25-40 percent of the land area with water are ideally suited for precise placement of dissolved fertilizers.

In New York State, one of the most serious limitations to a more widespread adoption of irrigation of orchards is the lack of adequate supplies of water for irrigation in many areas. Because trickle irrigation has an efficiency of >90 percent, and most sprinkler systems have efficiencies from 60-70 percent, most of the recent irrigation systems have been trickle systems. With this method growers can utilize limited water resources much more efficiently. One important limitation of trickle irrigation is that on coarse textured soils the lateral movement of water under a trickle emitter is limited and may require two trickle lines per row (one on each side of the tree).

Types of fertilizer injectors. Several types of fertilizer injectors are used, including bladder tanks, batch tanks, Venturi injectors and positive displacement pumps. With bladder tanks, irrigation-water pressure pushes fertilizer out of the bladder tank and into an irrigation line through a metering valve. The concentration of fertilizer remains the same from the beginning of the injection cycle until the tank is empty. A second system utilizes batch tanks in which the fertilizer to be injected is mixed in the tank and when the tank is closed, water flows through the tank and carries the dissolved fertilizer into the water stream. With this system the concentration of fertilizer is high at first then declines as the tank is diluted.

The Venturi injector systems utilize a venturi restriction in the water line to suck the fertilizer solution into the water stream and therefore they do not require electrical power. Venturi systems require a pressure drop across the injector to function. With Venturi systems the concentration of fertilizer in the water stream remains constant throughout the irrigation cycle. Lastly, positive displacement pumps accurately meter a constant amount of fertilizer into the irrigation water stream thus maintaining a constant concentration of fertilizer in the water stream throughout the irrigation cycle. They can operate with either electricity or water power. They are generally more accurate and easier to use than Venturi but are also more expensive. With positive displacement pumps and irrigation controllers the fertilizer injection process can be automated the relieving the grower of significant management time often associated with fertigation. With all fertilizer injection systems a back-flow prevention valve is essential to avoid contamination of the water source.

Fertilizers applied through fertigation. The most common nutrients applied through an irrigation system include nitrogen, potassium, phosphorus and magnesium but other nutrients including boron, zinc, iron, calcium, manganese and copper can also be applied through the irrigation system.

Nitrogen. Ammonium nitrate or potassium nitrate are preferred sources but rrea is also an alternative. Calcium nitrate has also been used but it has resulted in incompatibility problems if any phosphate or sulfate is present in the solution. Various combinations of urea and ammonium nitrate such as URAN 28 or URAN 32 have been formulated as liquid fertilizers. Such liquid formulations are often the nitrogen fertilizers of choice by many growers because of the ease of use. Bulk loads can be delivered by fertilizer dealers to tanks at the orchard site allowing automation of the fertigation process.

Phosphorus. Although various forms of water soluble phosphates might be used, application of phosphates through drip systems is not considered to be necessary with orchards. Our research to date has shown no beneficial response of apple trees to phosphorus applied through the drip irrigation system. A note of caution is that phosphates are incompatible with magnesium and calcium compounds. It appears that the best approach with apples is to incorporate phosphate during preplant-site preparation if soil tests indicate a need.

Potassium. Muriate of potash (KCl), potassium nitrate (KNO_3) and potassium sulfate (K_2SO_4) are the most common sources of potash used in fertigation. The primary limitation with potassium is its limited solubility. Liquid forms of potassium generally have low concentrations of potash.

Calcium. Calcium nitrate is readily soluble and can be used for both a nitrogen fertilizer and a calcium fertilizer; however the Ca content is too low to allow sufficient calcium without getting excessive amounts of nitrogen. In addition, calcium nitrate is incompatible with other phosphate or sulfate fertilizers.

Magnesium. Epsom salts ($MgSO_4$) or liquid formulations of Magnesium sulfate are the preferred sources. Magnesium sulfate is incompatible with phosphates due to precipitates.

Boron. Since boron is required in very small amounts, the preferred source is Solubor which is readily soluble. An alternative is boric acid or borax.

Zinc. Chelated forms of zinc have been effective in increasing leaf Zn levels in our research trials but the rates required are not economical when compared to foliar applications. Zinc sulfate has been used in greenhouse systems and may be of value in orchards but at much higher rates than chelated forms of zinc.

Copper. Chelated forms of copper have been used successfully in increasing leaf Cu levels in our research trials.

Manganese. Manganese sulfate or chelated forms of manganese are both possible sources for fertigation. Foliar applications may be more economical under most conditions.

Iron. Chelated forms of Iron are the most effective in increasing leaf Fe levels.

Potential application problems. The primary problem encountered with fertigation is the incompatibility of chemicals resulting in precipitates that clog emitters of trickle systems. Calcium, magnesium, iron, zinc and copper materials should not be mixed with phosphates or sulfates because insoluble precipitates are formed. Whenever phosphates are used, an acid should be injected into the trickle distribution system for 30 to 60 minutes at the end of the fertigation cycle to dissolve precipitates. Hydrochloric acid (muriatic) is generally suggested for this purpose. In some cases well water has a high iron content. To avoid incompatibility problems, apply incompatible materials separately being sure to flush the lines thoroughly between injecting each set of materials. Also use separate mixing tanks and injector heads for materials that may be incompatible, and then apply the materials sequentially.

Water that has more than 0.1 ppm iron content can be a problem. To avoid problems with iron precipitates, the water can be aerated to oxidize the iron into an insoluble form that can settle out. This requires a settling basin for water before it enters the trickle system. Alternatively, the water can be treated with chlorine (1 ppm per 0.7 ppm iron) and then the precipitates can be removed at the filter. This will require frequent back flushing of the filter. In addition the system should be treated with acid (muriatic, sulfuric, phosphoric or nitric acid) as described above.

Solubility of materials. Solubility of dry fertilizer materials in water is affected by water temperature. Therefore, problems may be encountered when trying to mix these in cold water. Some means of heating the water is usually necessary when formulating liquid fertilizer solutions. The salt-out temperature, (the temperature at or below which materials will precipitate from the solution) is an important consideration. Information on the solubility of various fertilizer materials is presented in Table 2.

Application strategies. In arid climates where fertigation was developed, the best strategy has been to apply a constant concentration of fertilizer in all irrigation water. Each time irrigation water is applied, fertilizer is also injected into the water. Thus the soil solution that the plant roots are exposed to has a constant concentration of the elements that are applied. With light textured soils, nitrogen is maintained at 100 ppm in the irrigation water for young developing trees and 50 ppm in the water is used for mature trees. For potassium, very little (10 ppm), is applied to young developing trees while 50 ppm is used for mature trees. With heavier, more fertile soils that supply substantial amounts of nitrogen through mineralization, the concentrations in the irrigation water can be reduced to 30-50ppm. This strategy of applying a constant dose of fertilizer in all irrigation water works well when the amount of water applied per week, month or season is predictable; this allows the advance programming of the total amount of each nutrient that will be applied each week, month or season. It also works best in light-textured soils that have low inherent fertility and daily doses of fertilizer help to maintain a constant nutrient supply available to the plant.

In humid climates where the amount of irrigation water needed is variable and depends on the amount of rainfall in any

TABLE 2

Solubility of common fertilizers used in fertigation.

Fertilizer		Solubility (pounds/gallon of water)
Nitrogen Sources	Ammonium Nitrate	9.8 @ 32°F
	Ammonium Sulfate	5.9 @ 32
	Calcium Nitrate	10.2 @ 64°F
	Magnesium Nitrate	3.5 @ 64°F
	Potassium Nitrate	1.1 @ 32°F
	Sodium Nitrate	6.1 @ 32°F
	Urea	5.9 @ 32°F
Potassium Sources	Potassium Chloride	2.9 @ 68°F
	Potassium Nitrate	1.1 @ 32°F
	Potassium Sulfate	1.0 @ 77°F
Phosphorus Sources	Phosphoric Acid	43.2 (liquid)
	Mono Potassium phosphate	2.75 @ 77°F
	Di-ammonium phosphate (DAP)	3.5 @ 32°F
	Mono ammonium phosphate (MAP)	1.9 @ 32°F
Calcium Sources	Calcium Nitrate	10.2 @ 64°F
Magnesium Sources	Epsom Salts (Magnesium Sulfate)	5.9 @ 32°F
	Magnesium Nitrate	3.5 @ 64°F
Boron Sources	Solubor	1.0 @ 32°F
	Boric Acid	0.5 @ 86°F
	Borax	3.8grams @ 32°F
Manganese Sources	Manganese Sulfate	8.7 @ 32°F
	Manganese Chelates	———
Iron Sources	Iron Chelates	———
	Ferrous Sulfate	1.3
Zinc Sources	Zinc Sulfate	8.0
	Zinc sulfate monohydrate	———
	Zinc Chelates	———
Copper Sources	Copper Sulfate	2.6 @ 32°F
	Copper Chelates	——

TABLE 3

Effect of irrigation and fertigation on tree growth and yield of 'Oregon Spur Delicious' /M.7 apple trees over the first 7 years.

Irrigation Treatment	Fertilizer nutrients and application method	Shoot Growth (m) Years 1-3	Shoot Growth (m) Years 4-6	Yield/ tree (kg) Years 2-4	Yield/ tree (kg) Years 5-7	Average Fruit Size (g) Years 2-7
		(% of Control)				
Unirrigated Control	Ground applied NKB	100 c[z]	100 b	100 b	100 b	100 a
Trickle Irrigation	Ground applied NKB	137 b	131 a	98 b	115 ab	101 a
Fertigation	Water applied NKB	171 a	140 a	124 a	127 a	104 a

[z] Means within years followed by the same letter are not significantly different (P=0.05 n=4).

TABLE 4

Effect of irrigation and fertigation on tree growth and yield of 'Redchief Delicious'/M.7, 'Mutsu'/M.9/MM.106 and 'Empire'/M.9/MM.106 apple trees over the first 6 years.

Irrigation Treatment	Fertilizer nutrients and application method	Shoot Growth (m) Years 1-3	Shoot Growth (m) Years 4-5	Yield/ tree (kg) Years 2-4	Yield/ tree (kg) Years 5-6	Average Fruit Size (g) Years 2-6
		(% of Control)				
Unirrigated Control	Ground applied NKB	100 b[z]	100 b	100 b	100 b	100 b
Trickle Irrigation	Ground applied NKB	160 a	139 a	145 a	160 a	107 a
Fertigation	Water applied NKB	153 a	134 a	140 a	135 a	108 a

[z] Means within years followed by the same letter are not significantly different (P=0.05 n=4).

TABLE 5

Effect of irrigation, fertilization, and fertigation on tree growth and yield of 'Empire' apple trees on M.9 and M.7 rootstock over the first 3 years.

Fertilization	Irrigation	TCA increase '92-'93	Total Shoot Length '92-'93	Yield 1994	Yield Eff. 1994	Fruit Size 1994
		(% of Control)				
Preplant Lime only (Control)	None	100	100	100	100	100
	Trickle	114	117	114	105	106
Preplant Lime + NPKB	None	105	103	108	103	106
	Trickle	116	115	117	107	105
Annual NKB	None	106	108	120	115	111
	Trickle	128	135	138	117	112
Annual NKB+FoliarMg,Cu,Zn	None	105	94	114	111	110
	Trickle	117	112	116	105	113
Fertigation	Trickle	115	129	116	107	110
LSD (0.05)		8[z]	16	18	16	5

[z] Least significant difference between means in a column (P=0.05 n=4).

given week, month or year, it becomes impossible to predict in advance the annual amount of fertilizer which will be applied. In wet years when little or no irrigation may be needed, very low rates of fertilizer will be applied; while in very dry years significant amounts of water may be needed and thus significant amounts of fertilizer. More commonly in humid climates such as New York, the total amount of fertilizer to be applied per year is divided by the number of weeks over which the nutrient is to be applied to obtain a weekly dose of each nutrient. The weekly dose is applied in one irrigation cycle on one day of the week. If additional water is needed later in the week it is applied without dissolved fertilizers.

In New York, many soils naturally produce 40-60 lbs. of nitrogen per year through mineralization. With young non-bearing apple trees we suggest an additional 40-60 lbs. of nitrogen per season. Utilizing the weekly application strategy for the first 10 weeks of the season will require 4-6 lbs. N per acre per week. With mature trees we suggest from 20-40 lbs. of nitrogen per season which would be 2-4 lbs. N per acre per week. With potassium we recommend annual rates of 60 lbs. K20 per acre on young trees. When spread over 15 weeks this would be 4 lbs. K20 per acre per week. Mature trees with heavy crops require substantially more potassium. We recommend 80-90 lbs. K20 per season; that would be 5.3-6 lbs. K20 per acre per week. The amount of nitrogen and potassium fertilizers listed above should only be used as guidelines. The actual amount applied to mature trees should be adjusted up or down depending on the levels of each nutrient measured in leaf samples.

Where leaf boron levels are low, small amounts of boron can be applied very effectively through fertigation. This element is efficiently taken up by this method. Our results indicate that 1.5 to 2 pounds of actual boron per acre per year appears to be an adequate maintenance amount. This would translate into 0.15 to 0.2 pounds of Boron per acre per week. Other elements such as magnesium, zinc and copper can be applied via fertigation but current methods cost more than foliar applications of these elements. We continue to recommend foliar sprays of those elements.

Results of Fertigation Research in New York

Results with young trees. Weekly fertigation over the first 10 weeks of the season had a positive effect on tree growth. Ammonium nitrate was the source of nitrogen, muriate of potash was the source of potassium, Epsom salt was the source of magnesium and Solubor was the source of boron. In most years, the fertigated trees had the greatest growth, but often there was little difference between the fertigated trees and the water plus ground fertilizer trees (Tables 3 5). It appears that it is important to have both water and fertilizers to obtain optimum tree growth but the method of fertilizer delivery was not consistently important. After six or seven years the fertigated trees were the largest being 53 percent and 30 percent larger than the unirrigated controls in experiments one and two respectively.

Fertigation also increased yield in both the early and later years. Cumulative yield over six or seven years was increased 25-28 percent by fertigation compared to the un-irrigated controls (Tables 3 and 4). In the early years, fertigation resulted in slightly improved yield compared to the ground-applied fertilizers plus irrigation treatment. However, cumulative yield from fertigation in all three experiments was not statistically greater than the irrigation plus ground fertilizer treatment. In experiment one the fertigation treatment had the greatest yield while in experiments two and three the irrigation plus ground fertilizer treatment had the greatest yield. This indicates that trickle irrigation aids in the utilization of applied fertilizers whether the fertilizers are soil applied or dissolved in the irrigation water (Tables 3-5).

Average fruit size was improved by fertigation. When averaged over the six cropping years of the second study, fertigation increased fruit size by 6-18 percent (Table 4). There was little benefit from supplemental irrigation on fruit size unless it was accompanied by fertigation or ground applied fertilizer.

Results with older trees. In a grower owned plot, sixteen weekly applications of potassium providing a total of 120 lbs. of potash (K20) per acre resulted in a significant fruit size increase. In a Geneva plot, the addition of potassium fertilizer in the trickle system reduced tree growth, and increased yield, fruit size and red color of mature Empire trees (Table 6). The source of potassium (KCl vs. KNO3) did not affect tree growth, yield, fruit size or fruit color. The method of application of the potassium fertilizer did not affect its response. The ground-applied method gave similar results as the fertigation method. The timing of potassium application affected tree growth and fruit size but not yield or red color (Table 7). If potassium was applied through fertigation in the last eight weeks of the season, it produced more tree growth than applications in the first eight weeks of the season. Fruit size was greatest if potassium was applied during the first eight weeks of the season.

Distribution of nutrients in the soil. In our trials, fertigation moved nitrogen deep in the soil to depths between 16 and 32 inches and in a narrow cylindrical pattern with a horizontal diameter of 32 inches. When nitrogen was applied to the soil surface as a dry fertilizer it was concentrated mostly in the top 16 inches of soil. Potassium was found only in the top 8 inches when it was spread on the soil surface but with fertigation, potassium was moved deeper in the soil to depths between 16 and 24 inches and with a horizontal diameter of 24 inches. Copper and zinc chelates were moved in the soil similarly to potassium.

An important deleterious effect of fertigation was found by measuring soil pH under the fertigation emitters. We found that fertigation with ammonium nitrate significantly reduced soil pH under the emitters in a pattern similar to the nitrogen distribution in the soil. After eight years the soil pH beneath the emitters was between 4 and 5. This indicates that liming materials should be banded in the herbicide treated strip along each tree row rather than broadcast over the entire orchard floor.

Conclusions

Taken together, the results of our studies indicate trickle irrigation in the Eastern US can improve tree performance in the first few years after planting. The addition of ground-applied fertilizer or fertigation will improve tree growth even more, and will result in larger trees with greater bearing capacity. The magnitude of the improvement in yields over the first six or seven years appears to justify the investment in trickle irrigation for humid climates such as the Northeastern US, especially in dwarf apple orchards where significant yields are expected in the 2nd-5th years. However, the economic benefit of fertigation versus ground applied fertilizer with trickle irrigation is less clear but still may be justified to improve fruit quality and reduce leaching and runoff of nutrients. An interesting additional benefit from fertigation is the increase in fruit size. With small-fruited varieties like Empire and Gala, this could greatly improve the economic benefit from fertigation.

The improvement in tree performance from trickle irrigation or fertigation can be expected to vary with soil type. With light textured soils, which are more droughty than heavier textured soils, a greater difference between un-irrigated trees and fertigated trees would be expected. Under heavier soil conditions additional irrigation may not be beneficial and may in fact result in excess water and poorer tree performance in wet years. The benefit of trickle irrigation may also depend on the amount and frequency of natural rainfall in any given year. Nevertheless, with high-density orchards the improvement in early tree performance will help ensure the financial benefits of planting high tree densities.

When considering the use of irrigation or fertigation in the Northeastern US, the following points can be gleaned from our experiences:

1) To maximize tree growth, trickle irrigation should be installed as soon after planting as possible. This is especially true with large caliper trees which have large tops relative to their root systems.
2) Trickle irrigation can significantly enhance the uptake and benefit of ground-applied fertilizers. We have shown that without supplemental irrigation there is no benefit derived from soil-applied fertilizers in the first few years if proper preplant land preparation is done. However with trickle irrigation, ground fertilization increased yield and tree growth.
3) Trickle irrigation and fertigation have their largest impact on tree growth and yield in years one-four so should be installed in the first year. If the trickle system is not installed in the first year the loss of potential tree growth will necessarily limit early yields.
4) The application of water for irrigation alone should begin about June 1 in a normal year. In very dry years like 1995, irrigation should begin in mid-May. If the application of water is delayed until drought symptoms develop later in the year much of the potential benefit of trickle irrigation will be lost. In very wet years irrigation should be delayed until late June.
5) When fertigation is used, water and fertilizer applications should begin on May 1. In wet years apply only enough water to get the fertilizer on, while in drier years apply enough water to replace that lost by the trees.
6) In New York, we suggest that nitrogen, and potassium can be applied effectively through the trickle system. Magnesium and boron can be effectively applied through the trickle system or foliarly while zinc and calcium are best applied foliarly. Nitrogen should be applied during the first half of the season while potassium can be applied over the whole season or just in the last half of the season. In either case, the total amount of nitrogen or potassium for the year should be divided into equal amounts each week for the period of time that the nutrient is being applied.
7) Irrigation frequency with trickle should be twice per week during the cooler periods of the growing season and daily during the warmer periods.

TABLE 6

Effect of irrigation and fertigation with Potassium fertilizers on tree growth and yield of mature 'Empire' apple trees on M.9.

Treatment	TCA increase '94-'97	Average Yield '94-'98	Average Fruit Size (g)	Fancy Grade '94-'98
Irrigation and Ground Applied NK	**4.32 z**	**776**	**164**	**65**
Fertigation NK	5.44 NS	785 NS	161 NS	63 NS
Nitrogen Only	5.67	746	159	61
Nitrogen and Potassium Fertilizers	4.63*	798*	166*	65*
KCl	4.59	777	164	65
KNO3	5.03 NS	769 NS	166 NS	63 NS

z Paired mean comparison by LSD (Means followed by * or NS are significantly different or Non Significant, P=0.05 n=4).

TABLE 7

Effect of timing of fertigation with Potassium fertilizers on tree growth and yield of mature 'Empire' apple trees on M.9.

Treatment	TCA increase '94-'97	Average Yield '94-'98	Average Fruit Size (g)	% Extra Fancy Grade '94-'98
Fertigation 16 weeks	**4.36 z**	**789**	**164**	**65**
Fertigation 8 weeks early	4.45	729	167	65
Fertigation 8 weeks late	5.72	743	161	64
Anova	*	**NS**	*	**NS**

z Mean comparison by LSD (Means followed by * or NS are significantly different or Non Significant, P=0.05 n=4).

With microsprinklers, irrigation frequency should be once per week during the cooler periods of the growing season and twice per week during the warmer periods.

8) Calculate how much irrigation water to apply by either the modified Kenworthy rule, tensiometers or evapotranspiration models.

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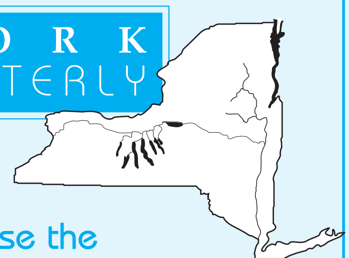

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