Horticultural Reviews
Edited by Jules Janick

8

Foliar Nutrition of Fruit Crops

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I. INTRODUCTION

A. Scope of This Review

Growing costs of fertilizers and increasing concern about groundwater pollution resulting from indiscriminate or excessive soil fertilization are problems that may be solved by more efficient fertilizer technologies. Foliar nutrition is one possibility for minimizing this environmental hazard. However, we have to learn how to maximize the absorption of minerals by aboveground plant parts and direct the absorbed nutrients into specific plant organs. Introduction of herbicides into orchard soil management in the last decade decreased fertilizer requirements for N and K but at the same time aggravated Ca and P nutritional problems of fruit. This may open new challenges for foliar nutrition. For this reason, we believe that a new era of foliar nutrition is yet to come. This prompted us to review the subject.

Different aspects of foliar nutrition have been reviewed previously (Boynton 1954; Wittwer and Teubner 1959; Jyoung and Wittwer 1965; Wittwer *et al.* 1967; Franke 1967; Haynes and Goh 1977; Slowik and Swietlik 1978; Kannan 1980). The literature on foliar nutrition is voluminous; consequently, it was necessary to restrict this review to foliar nutrition of fruit trees. However, in reviewing basic aspects of the problem, we have included information obtained with other plants when we felt that it contributed to clarification of the subject.

Except for the historical outline, we reviewed publications that have appeared since the late 1940s. The information presented on application of foliar nutrients was based on Extension Service recommendations;

data on commercially available foliar fertilizers were obtained from manufacturers.

B. History of Foliar Nutrition

The entire surface of aquatic plants has the ability to assimilate carbon dioxide and absorb mineral nutrients and water. Plants that adapted to terrestrial habitats during the course of evolution formed specialized organs performing specific functions. However, the aboveground parts retained the ability to absorb water, minerals, and other chemical compounds. This was recognized in 1789 by Forsyth in England (see Ticknor 1957), who noted increased growth of trees following bark treatment with a mixture of manure, wood ashes, lime, and urine. Griss (1844) reported the use of iron sprays to control chlorosis in what was probably the first published report on foliar absorption of mineral nutrients. This was followed by those of Mayer (1874) and Bohm (1877), as reported by Wittwer and Teubner (1959). Downing (1869) noted the effect of dormant K sprays on promoting growth of fruit trees. Ballard and Volck (1914), in California, and Lewis in 1915 (see Ticknor 1957), in Oregon, successfully used sodium nitrate sprays applied during dormancy to increase the yield of apple trees.

In 1916 and 1924, Johnson applied foliar sprays of iron sulfate to control Fe chlorosis in pineapples (see Boynton 1954). In the 1930s, Parker (1934, 1935, 1937) and Fudge, Askew, and Chittenden (see Boynton 1954) showed that Zn, Cu, or B sprays were effective in controlling deficiency symptoms of these elements in apple and citrus trees. In the early 1940s, foliar sprays were found effective in controlling Mg, K, and Mn deficiencies (Burrel *et al.* 1942; Boynton *et al.* 1943, Parker and Southwick 1941; Southwick and Smith 1945). Based on new research findings, foliar nutrition became a more popular practice in commercial fruit growing during the 1940s. Woodhams (see Tukey 1953) estimated that in southern California about 402,000 citrus trees were sprayed with zinc salts, 35,000 with copper salts, and 10,000 with magnesium salts in 1945.

Trunk injection of chemicals, another technique for applying nutrients to the aboveground part of trees, was also studied very early. Mineral salts were injected into tree trunks by the Polish entomologist Mokrzecki at the beginning of this century, and studies of this type were continued by Czyzewski and others during the 1930s (Czyzewski 1974). Trunk injections of iron and zinc were reported by Bennett in 1931 (see Tukey 1953) and Chandler *et al.* (1933) as effective measures for overcoming deficiency symptoms of these elements in fruit trees.

Hamilton *et al.* (1943) were the first to recognize that apple leaves may absorb nitrogen in appreciable quantities. This finding was followed by extensive research on the use of foliar urea sprays on apple and other fruit trees. During the next decade, Boynton (1954) and Fisher (1952) attempted to supply the total N needs of apple trees by spring and summer urea sprays but had difficulty in achieving this goal. Oland (1960, 1963) used autumn urea sprays and reported beneficial responses. Following his lead, Shim *et al.* (1972, 1973a,b), Titus (1976), and Titus and Kang (1982) provided valuable information on the metabolism of foliar-applied N and N recycling within the tree. Their findings explained Boynton's and Fisher's difficulties and Oland's success.

Beginning in the early 1950s, scientists in numerous laboratories pursued research on the mechanism of absorption of foliar-applied minerals and growth regulators. The employment of radioisotopes and development of new laboratory techniques allowed the separation of the penetration process into its components. Penetration of ions through the cuticle and absorption by the mesophyll cells could be studied as individual processes. Such studies also provided knowledge on epicuticular waxes and leaf cuticles as barriers to penetration and on the relationship between leaf metabolism and ion absorption. It is not possible to mention here all those who contributed to this body of knowledge. Nevertheless, S.H. Wittwer, M.J. Bukovac, and W. Franke are the most outstanding pioneers in this area of study and must be mentioned.

Foliar application of nutrients was also being studied as a means of supplying nutrients to the fruit. Calcium and P sprays, especially, are used extensively to reduce the occurrence of physiological disorders of the fruit. Recently, it has been recognized that root uptake must be maximized in order to obtain the most benefit from foliar sprays.

Foliar nutrition is accepted by fruit growers worldwide. The two decisive factors in its favor are the reliability and rapidity of tree responses to foliar sprays.

II. UPTAKE OF FOLIAR-APPLIED NUTRIENTS

According to Franke (1967) mineral nutrient uptake by leaves involves three steps. After mineral nutrients are deposited on the leaf surface they (1) penetrate the cuticle and epidermal walls by means of diffusion; (2) are adsorbed on a surface of the plasmatic membranes, and (3) pass through the plasma membranes and enter the cytoplasm.

A. Penetration Through the Cuticle

1. Structure of the Cuticle. The first, and most limiting, barrier to foliar uptake of nutrients is the cuticle (Leece 1978), which consists of two layers. The outer layer is made almost entirely of cutin covered by surface (epicuticular) waxes. The inner layer is composed of cellulose and pectic substances and is encrusted with cutin. Pockets of cuticular (embedded) waxes are also present in the second layer. The entire cuticular membrane is separated from the underlying epidermal cell wall by a pectic layer (Norris and Bukovac 1968; Martin and Juniper 1970).

The epicuticular wax is the outermost and most hydrophobic component of the leaf surface on which foliar sprays are deposited. The cutin, consisting of polyesterified hydroxy fatty acids (Martin and Juniper 1970) is more hydrophylic due to the presence of polar groups attracting water through hydrogen bonds (Van Overbeek 1956; Hall and Donaldson 1963). Other components of the cuticle (pectinaceous substances and proteins) have a great ability to absorb water and thus may serve as polar pathways for water and solutes.

2. Pathways for Nutrient Penetration Through the Cuticle. Views on possible conducting channels through the cuticle have changed with time. Roberts *et al.* (1948) reported that in the leaves of 'McIntosh' apple pectinaceous substances form a continuum across the cuticle. Norris and Bukovac (1968) noted pectic substances in pear cuticles, although those substances did not appear to reach the outer cuticular surface. More recently Hoch (1979) showed that polysaccharide microfibrils in apple leaf cuticle form a continuum from the outer surface to the epidermal cell wall and serve as a pathway for polar transport. He concluded that due to the staining and microscopic techniques used by Roberts *et al.* (1948) and Norris and Bukovac (1968), it is doubtful that the pectinaceous substances they found represented microfibrils in the cuticle. Instead, he proposed that these materials represented the pectinaceous substances of anticlinal epidermal cell walls. Reed and Tukey (1982b) confirmed the existence of polysaccharide microfibrils in apple leaf cuticle, although the extension of these microfibrils to the outer surface of the cuticle was not confirmed. In addition to polysaccharides, cutin may also serve as a penetration pathway for water and solutes since it is not totally impermeable.

The existence of polar pathways in the cuticle may be demonstrated by the formation of black precipitates after leaf fixation in Gilson solution (Schonherr and Bukovac 1970a). Mercury precipitates are usually found under the cuticle overlying trichomes, anticlinal epidermal cell walls, periclinal walls above veins, and guard cell walls (Norris and Bukovac 1968; Schonherr and Bukovac 1970a, 1972; Leece 1978). Polar pathways may also be observed in areas where epicuticular waxes are removed or disrupted (Schonherr and Bukovac 1970a). Polar pathways are more abundant on the abaxial (lower) than adaxial (upper) surface, corresponding with more rapid absorption through the abaxial surface, at least in hypostomatous leaves (Leece 1978).

Miller (1982) showed that pores and canals were present in apple fruit cuticle. The lack of success in demonstrating cuticular canals in many other investigations may be attributed to inadequate microscopic methods (Miller 1982) and/or to the fact that they occur only in some species. Whether transcuticular canals serve as polar or nonpolar pathways is not known. Schonherr (1976) postulated the existence of transcuticular canals lined with carboxyl groups in citrus leaf cuticle. These canals were proposed to serve as polar pathways for penetration. Depending upon dissociation and hydration of carboxyl groups, the canals may swell or shrink and, thus, become opened or closed for diffusion of water and solutes. According to Schonherr (1976), the small diameter of the canals (0.46–0.45 nm) makes it impossible to view them directly with presently available techniques, but the dependence of penetration on the size of the diffusing molecules indicates their existence indirectly.

Besides directly penetrating through the outer leaf cuticle, nutrients may enter a leaf through stomatal pores. This route does not bypass the cuticular barrier, since stomatal openings are cuticular invaginations and not cuticular perforations (Norris and Bukovac 1968). However, the cuticle covering the stomatal cavity is hydrated and wax-free (Wittwer *et al.* 1967; Norris and Bukovac 1968; Leece 1978). Thus, stomatal infiltration by liquids should greatly enhance leaf absorption. For an aqueous solution to bypass the stomatal pore, the contact angle formed by the solution on the stomatal walls must be less than the wall angle of the pore (Schonherr and Bukovac 1972). Wall angle may approach zero due to the presence of stomatal ledges as demonstrated in plum leaves (Leece 1978). In this case stomatal penetration will occur if complete wetting of the leaf surface is achieved.

Trichomes may serve as another portal of entry for foliar-applied nutrients. The importance of this pathway for overall leaf absorption of nutrients depends on the extent and localization of trichome cutinization, which is a function of leaf maturity and plant species (Hull *et al.* 1975).

3. Importance of Waxes. The outer wax layer is an effective barrier to the cuticular channels through which ions may penetrate. The amount, distribution, and chemical composition of these waxes correlate well with foliar absorption in orange, apple, plum, and peach (Leece 1976, 1978). In contrast, cuticular penetration was rather poorly correlated with cuticle thickness in the leaves of various fruit trees and other plant species (Norris and Bukovac 1968; Norris 1974; Leece 1976). Physical disruption of surface waxes enhanced foliar absorption in plum, apricot, and peach (Bukovac 1965; Leece and Kenworthy 1972; Leece 1978). Penetration of 2,4-D through the cuticle of nine plant species (six of which were fruit trees) increased substantially when cuticles were dewaxed (Norris 1974). The magnitude of the increases in penetration did not correspond with the amount of wax removed, but the waxes were not fractionated into epicuticular and cuticular waxes. Cuticular waxes are viewed as less effective barriers to penetration than epicuticular waxes (Bukovac and Norris 1967). Cuticular waxes are deposited in pockets in the cuticle and probably do not interfere with polar pathways (Norris and Bukovac 1968). Additionally, cuticular waxes were found to be more polar than surface waxes (Baker and Bukovac 1971).

The wettability of a leaf depends on the distribution of surface waxes and is a function of which chemical groups are exposed on the surface (Holloway 1969, 1970; Schonherr and Bukovac 1972; Leece 1978). Wettability is related to the contact angle formed between the liquid droplets and the leaf surface. Contact angles less than 90° indicate that surface waxes may be discontinuous; those in a range of 90–110° indicate that the leaf may be covered by an amorphous continuous sheet of waxes; and angles greater than 110° are indicative of substantial surface roughness superimposed on the amorphous wax layer in the form of a secondary structure of wax ridges (Holloway 1969; Leece 1978).

The greater the contact angle, the more difficult it is to wet the leaf surface. The determination of critical surface tension of the abaxial surface of plum leaves suggests that methyl groups are exposed on the surface of epicuticular waxes (Leece 1978). Wettability could not explain the greater foliar absorption by orange leaves than by apple leaves since apple leaves were wetted more readily than orange leaves (Leece 1976). However, on the basis of wettability, apple leaves should be more efficient in foliar absorption than peach leaves (Leece 1976). This parallels well with the lower effectiveness of N sprays in peach than in apple.

The structure of the wax covering the surface of the fruit is very important. Amorphous wax apparently cracks more easily than the platelet-type wax (Faust and Shear 1972a). Cracks open the path to penetration of spray-applied nutrients into the young fruit, causing slight injury and resulting in russeting in apple (Faust and Shear 1972b).

Heavy buildup of surface waxes over structures that may serve as major penetration routes could prevent absorption. In plum and peach, guard cells, which are important sites of foliar entry (Franke 1964), are covered with waxes, which may contribute to poorer leaf absorption in these species compared with apple or orange. In the latter, the guard cells are relatively wax-free.

The composition of surface waxes may also play a significant role in penetration. Hydrocarbons were found to be the least permeable, followed by triterpenoids, alcohols, fatty acids, and esters (Baker and Bukovac 1971). On this basis, apple wax should be the most permeable followed by orange and peach waxes (Leece 1976).

4. Diffusion Through the Cuticle. Penetration of substances through the cuticle is a diffusive process influenced by temperature and especially by concentration gradient (Darlington and Circulis 1963). Penetration of water and solutes takes place through stomatous and astomatous cuticles (Darlington and Circulis 1963; Yamada *et al.* 1964; McFarlane and Berry 1974; Schonherr and Huber 1977; Chamel and Gambonnet 1980). The penetration of cations through the cuticle, which is inversely related to the radius of the hydrated ion, is in the following order, from highest to lowest: Cs^+, Rb^+, K^+, Na^+, Li^+, Mg^{2+}, Sr^{2+}, Ca^{2+} (Haile-Mariam and Wittwer 1965; Wittwer *et al.* 1965; McFarlane and Berry 1974). Kannan (1969) reported that penetration of organic molecules across the cuticle of *Euonymus japonicus* was inversely related to their molecular weights, and that $FeSO_4$ diffused more readily than FeEDDHA (Fe Na ethylene-diamine di-O-hydroxy-phenylacetate). Penetration through stomatous cuticles is usually more rapid than through astomatous cuticles (Goodman and Addy 1962; Haile-Mariam and Wittwer 1965; Kannan 1969; Chamel 1980), although results for citrus cuticle show the opposite (Basiouny and Biggs 1976).

Yamada *et al.* (1964) reported that the diffusion of cations and anions from the outer toward the inner cuticle surface was more rapid than their diffusion in the opposite direction. They proposed that the greater binding of ions on the inner surface facilitated inward diffusion; however, such an explanation could not apply in the case of urea diffusion (Yamada *et al.* 1965b). Other results indicate more rapid diffusion from the inner toward the outer surface (Goodman and Ady 1962). Differences in the techniques for isolating cuticles and the use of different plant materials may account for these discrepancies. In a more recent study, Schonherr and Huber (1977) found no charge gradients across the leaf cuticles of apricot, citrus, and pear.

Cuticles are 10 to 20 times more permeable to urea than to inorganic ions (Yamada *et al.* 1965b). This agrees with the observation that absorption of urea by intact leaves is more rapid than absorption of any other mineral nutrient (Wittwer and Teubner 1959). Urea facilitates the penetration of other nutrients through isolated cuticles and into intact leaves (Yamada *et al.* 1965a; Kannan and Wittwer 1965). The hypothesis that urea may rearrange chemical bonds in the cuticle, thus facilitating penetration, is doubtful since Kannan (1969) reported reduced iron penetration through the cuticle in the presence of urea.

On the basis of a study with apricot leaf cuticle, McFarlane and Berry (1974) developed a model of the cuticular membrane that assumed the presence of cuticular pores lined with positive charges. This model is contradictory to other findings showing that more cations than anions bind on cuticular membranes (Yamada *et al.* 1964; Yamada *et al.* 1966) and that this cuticle is usually more permeable to cations than to anions (Yamada *et al.* 1964). Thus, the model of the leaf cuticle proposed by Schonherr and Huber (1977) on the basis of citrus, pear, and apricot studies appears to be more acceptable. They measured the electric potential across the cuticle and found the isoelectric point (the point at which the cuticle does not carry a net charge) to be around pH 3. Above pH 3, cuticles carried a net negative charge and were more permeable to cations, whereas below pH 3 they had a net positive charge and were more permeable to anions. Positive charges in cuticles are donated by basic amino acids and the negative charges by acidic amino acids, polygalacturonic acid, and nonesterfied carboxyl groups of the cutin polymer.

B. Absorption Pathways Subsequent to Cuticular Penetration

The cell walls of leaves form a continuum, which may serve as a pathway for free-space (apoplastic) movement of minerals. It was estimated that free space occupies 3–5% of the volume of leaf tissue (Crowdy and Tanton 1970), but this value may vary depending on plant species (Smith and Fox 1975). Our knowledge of the physiological pathways of foliar absorption subsequent to cuticular penetration is rather limited. Several possible pathways were discussed by Haynes and Goh (1977). One of them involves translocation of ions along free space to vascular tissue where, after energy-dependent phloem loading, they are transported out of the leaf or fruit. This pathway is probably followed by divalent cations such as Ca^{2+} and Mg^{2+} (Haynes and Goh 1977). However, as will be shown later, little Ca is transported out of the leaf. Recent data by Ferguson and Watkins (1981) showed that Ca uptake into the free space of apple cortical tissue constituted 80% of total Ca uptake. This indicates that little Ca was transported across the plasmalemma into the cells. There is probably little, if any, apoplastic movement of anions since the negative charges of cell walls repel them (Van Steveninck and Chenoweth 1972).

The other two possible physiological pathways of foliar absorption involve active transport of nutrients across the plasmalemma to the leaf cells, where they may be involved in synthesis of organic compounds (Haynes and Goh 1977). Further transport of cell-absorbed nutrients may proceed through the symplastic pathway to the vascular tissues, or nutrients may leave the cells and enter the free space from which they are subsequently loaded into the sieve tubes (Haynes and Goh 1977). There is convincing evidence of involvement of foliar-applied nitrogen, phosphorous, and sulphur in organic synthesis in leaves and fruits (Wittwer and Teubner 1959; Haynes and Goh 1977; Watkins and Ferguson 1981). Thus these elements are accumulated in the leaf or fruit cells and may follow the above-mentioned two pathways of foliar absorption. Watkins and Ferguson (1981) showed that P uptake by apple tissue was positively correlated with metabolic activity of the fruit during the growing season.

1. Penetration Through the Epidermal Cell Wall. After passing through the cuticle, water and solutes must pass through the outer wall of the epidermis. Because of its cellulosic nature, the cell wall is recognized as a lesser barrier to absorption than are cuticular membranes (Schonherr and Bukovac 1970a). Threadlike structures were detected in the cell wall (Schumacher, cited in Franke 1971). The role of disfusion pathways was later assigned to these structures, which were designated ectodesmata or ectocythodes (Franke 1971). Ectodesmata are not plasmatic structures (Franke 1964). They are visualized by fixation in Gilson solution as a black mercury precipitate. This precipitate is formed by reduction of mercuric chloride by a reductant (speculated to be ascorbic acid) excreted by epidermal protoplasts to the cell wall (Schonherr and Bukovac 1970b). Distribution of ectodesmata in the epidermal cell wall of the onion leaf coincides with the binding sites of ions and urea in the overlying cuticle (Yamada *et al.* 1966; Franke 1969). Therefore the concept was developed that ectodesmata are cell-wall extensions of the polar pathways extending through the cuticle. Schonherr and Bukovac (1970a) questioned the existence of ectodesmata as definable cell-wall structures and showed that their appearance and localization are determined by the existence of permeable sites in the cuticle and not by the presence of specialized structures in the cell wall. According to these authors, mercury precipitates (ectodesmata) may be demonstrated wherever $HgCl_2$ can penetrate the cuticle. Franke (1971), although agreeing that ectodesmata are not true morphological structures, defends the existence of ectodesmata as polar pathways in the cell wall. He demonstrated that $HgCl_2$ does not diffuse in all directions in the cell wall after passing the cuticle, but forms precipitates in the shape of threads, ribbons, or cones with a tip toward the plasma membrane, contrary to what is expected if diffusion in all directions was involved.

reported a positive correlation between the number of ectocythodes, the amount of ascorbic acid in the cell wall (reductant), and the quantity of 2,4-D absorbed by the leaves.

2. Ion Uptake into the Cells. Nutrient absorption by leaf cells closely resembles absorption by root cells (Kannan 1980). Absorption of Rb^+, K^+, Cu^{2+}, Zn^{2+}, Mn^{2+}, Fe^{2+}, Cl^-, and PO_4^{3-} by intact leaves, leaf slices, or enzymatically isolated leaf cells is metabolically dependent (Jyung and Wittwer 1964; Rains 1967, 1968; Kannan and Wittwer 1967; Bowen 1969; Robinson and Smith 1970; Kholdebarin and Oertli 1972). Inhibitors of oxidative phosphorylation decreased the absorption of Rb^+, K^+, Cu^{2+}, Zn^{2+}, Mn^{2+}, Cl^-, and PO_4^{3-} by leaf tissue of various plant species (Jyung and Wittwer 1964; Jyung *et al.* 1965b; Rains 1968; Bowen 1969; Robinson *et al.* 1970). Energy sources such as succinate or ATP increased the absorption of Rb^+ by isolated leaf cells (Jyung *et al.* 1965b). However, succinate at high concentrations diminished dramatically the absorption of Cu^{2+}, Zn^{2+}, and Mn^{2+} by sugarcane leaf tissue (Bowen 1969). The above results indicate that absorption of mineral nutrients by leaf cells is an energy-dependent process and is coupled to oxidative phosphorylation. In the light, energy for leaf absorption may be alternatively supplied by photophosphorylation (Jyung *et al.* 1964; Rains 1968; Robinson and Smith 1970; Kholdebarin and Oertli 1972).

Absorption of PO_4^{3-} and Rb^+ by intact bean leaves and isolated tobacco cells was inhibited by chloramphenicol (Jyung *et al.* 1964; Jyung *et al.* 1965a), indicating that metabolism in general and protein synthesis in particular have a significant role in foliar absorption. A strong relationship between absorption of Rb^+ and PO_4^{3-} and metabolism in intact bean leaves, as well as the dependence of leaf absorption on temperature, oxygen level, and pH, the accumulation against a concentration gradient, and the irreversibility of absorption, all support the hypothesis that foliar absorption of these ions is an active process (Jyung and Wittwer 1964).

III. FACTORS AFFECTING ABSORPTION OF FOLIAR-APPLIED NUTRIENTS

A. Light, Temperature, and Relative Humidity

Environment may affect leaf absorption by affecting cuticle development and/or by influencing physiological processes that are linked with the active uptake mechanism (Flore and Bukovac 1982).

The amount of cuticle, cutin matrix, or cuticular wax (μg/cm^2) was reported to be greater in high than in low light intensities in *Brassica oleracea*, *Eucalyptus*, cereal crops, and carnation (Tribe *et al.* 1968; Macey 1970; Hallam 1970; Reed and Tukey 1982a). However, low light caused the production of thicker cuticles (μm) in brussels sprouts, but light did not influence the cuticular thickness in carnations (Reed and Tukey 1982a). Leece (1978) suggested that the seasonal build-up and development of secondary wax structure on the abaxial surface of plum leaves is related to increasing light intensities as the season progresses. Thus, he concluded, foliar absorption should be maximal in the spring when abaxial waxes are not fully developed. Contrary to that, light intensity did not affect the amount or chemical composition of epicuticular waxes in apple leaves (Darnell and Ferree 1983).

Light may affect the absorption process itself. It enhanced absorption of urea by apple leaves, of K^+ by corn leaves, and of Rb^+ and PO_4^{3-} by bean leaves (Jyung *et al.* 1964; Rains 1968; Shim *et al.* 1972). Plants in these experiments were grown in the same environment and light was differentiated during the time of absorption only.

High temperature increased deposition of surface waxes in the leaves of tobacco (Skoss 1955) and velvet mesquite (Hull 1958). In contrast, Leece (1978) found more surface waxes and more dense secondary wax structure on plum leaves that developed under low temperatures. High temperature increases both leaf expansion and wax production. However, leaf expansion at high temperatures is faster than wax extrusion, thus the wax per unit surface area is less. Leece (1978) concluded that high temperatures during leaf expansion in spring would have a positive effect on leaf absorption. Similar conclusions can be drawn from the data reported by Reed and Tukey (1982a,c), although they pointed out that the permeability of the cuticle did not depend on a single cuticular parameter but was a result of interaction among several factors. No effect of temperature was found on the amount of surface waxes in apple leaves, although higher temperature (25° versus 20°C) increased the proportion of alkanes and esters in the wax (Darnell and Ferree 1983). Hull *et al.* (1975) indicated that the effect of temperature on cuticle development is probably strongly dependent on plant species.

Temperature also affects absorption by leaves that have developed in the same environment. In studies where drying of the solution was not a limiting factor, increasing temperatures elevated absorption of Rb^+ and PO_4^{3-} by bean leaves (Jyung *et al.* 1964). Cook and Boynton (1952), on the contrary, showed greater urea absorption by apple leaves at low temperatures. Since low temperatures are usually associated with low air-moisture deficits, their results might reflect slower drying of urea solution on leaf surfaces. Bukovac and Wittwer (1959) showed that the amount of phosphate absorbed by bean leaves was doubled when the treated surface was kept moist, compared with similar treatments in which leaf surfaces were allowed to dry. Drying also decreased the absorption of Cu^{2+} and Mg^{2+} by apple leaves (Allen 1970) and phosphate uptake by chrysanthemum leaves (Reed and Tukey 1978). In contrast, rapid drying of droplets increased the speed of absorption of α-naphthaleneacetic acid (NAA) by pear leaves (Greene and Bukovac 1971) and Ca^{2+} [from $Ca(NO_3)_2$] by apple fruits (Van Goor 1973). In both cases, increased penetration due to drying was related to the increase in concentration as droplets dried and consequently increased the concentration gradient for diffusion. The rate of Ca^{2+} uptake into apple fruit from postharvest dips in $CaCl_2$ solution was greatest at 87% relative humidity (Lidster *et al.* 1977). Higher (94%) as well as lower (80% or 75%) relative humidity decreased the rate of Ca^{2+} uptake. These results suggest that high humidity (94%), by preventing the droplets from drying, kept the concentration gradient unchanged for a long period of time. At a relative humidity of 87% the droplets dried enough to increase the concentration gradient; $CaCl_2$ could still remain in solution due to the hygroscopic property of $CaCl_2$ salt.

B. Leaf Age, Leaf Surface, and Plant Species

Hull *et al.* (1975) related the higher resistance of old leaves to 2,4-D injuries to their more complete cuticle development compared with young leaves. Cook and Boynton (1952) showed that terminal leaves of 'McIntosh' apple absorbed almost twice as much urea than did basal leaves within a 2-hour period. Similarly, P absorption by young apple leaves was greater than absorption by old leaves (Fisher and Walker 1955). Greater penetration of NAA into young leaves of pear (Greene and Bukovac 1971), 3-chlorophenoxypropionic acid in peach (Bukovac 1965), and 2,4-D in bean (Sargent and Blackman 1962) have been reported. It is probable that both the waxes and the cuticle of young leaves in these studies were not completely developed, thus allowing higher penetration rates. However, Leece (1978) showed that the wax deposition on plum leaves did not depend on the physiological age of the leaf but on the time of the growing season. Leaves of similar physiological age that developed later in the season had more abaxial waxes than did those that developed early in the season.

Swietlik and Slowik (1981), using ^{15}N-labeled urea, found that the leaves of apple and sour cherry treated with a 4 or 8% urea solution during autumn absorbed more of the applied nitrogen than did leaves treated five times with a 0.5% urea solution in late spring and early summer of the following year. The total amounts of urea applied per tree were the same in all treatments. However, the total leaf area receiving urea was less in autumn than in spring because of new spring growth. The amount of urea absorbed per g of leaf dry weight was two to three times greater in autumn than in the spring–early summer period. These results do not necessarily show that leaf age was responsible for the different rates of urea absorption since the higher concentration of urea used in autumn could have accelerated absorption. Shim *et al.* (1972) found that senescing (about 4 months of age) apple leaves were able to absorb 75% of the foliar-applied urea from a 5% urea solution within 24 hours. This compares well with the study by Cook and Boynton (1952) in which apple leaves, described as 1–3 months old, absorbed 80% the applied urea from a 1% urea solution.

Miller (1983) determined both wax deposition and cuticle thickness in fruit of a wide range of species. He reported that both increase as the season progresses. If wax or cuticle thickness is the sole factor in absorption, then mature fruit should absorb much less nutrients than young fruit.

Lower surfaces of leaves absorb urea more rapidly than upper surfaces in apple (Cook and Boynton 1952); plum (Leece 1978); banana (Freiberg and Payne 1957); coffee and cacao (Cain 1956). Absorption by the lower surface of the apple leaf is very rapid within the first 24 hours and then levels off, whereas the upper surface absorbs urea more steadily. Within 7 days after urea application, total absorption by both surfaces may not differ greatly (Boynton *et al.* 1953). Similar data were reported by Rodney (1952).

Among fruit tree species, *Prunus* leaves are regarded as less efficient in foliar absorption than are apple or citrus leaves (Norton and Childers 1954; Impey and Jones 1960; Leece 1978). Peach, plum, and sour cherry trees responded poorly, as measured by leaf N level, to foliar N application (Weinberger *et al.* 1949; Bullock *et al.* 1952; Eckert and Childers 1954; Norton and Childers 1954; Walker and Fisher 1955; Wlodek *et al.* 1959; Leece and Kenworthy 1972; Leece and Dirou 1977; Swietlik 1980). In contrast, urea sprays applied to apple trees resulted in significant increases in leaf N (Rodney 1952; Oland 1963). Nevertheless, peach, plum, and cherry leaves were shown to be able to absorb N from foliar urea or KNO_3 sprays (Holubowicz 1974; Weinbaum and Newmann 1977; Leece 1978; Swietlik and Slowik 1981). However, comparative data on the absorption rates of different species are lacking. From the data presented by Swietlik and Slowik (1981), it may be calculated that apple leaves are able to absorb about two to three times more N per unit of dry leaf weight from foliar urea application than are sour cherry leaves. This comparison is rather tentative since the growing conditions were different for apples and cherries and the dose of urea per unit of leaf area was not the same.

Urea is rapidly absorbed by the leaves of banana, coffee, and cacao (Cain 1956; Freiberg and Payne 1957).

Differences in absorption rates may exist between cultivars. Van Goor (1973) showed that 'Cox's Orange Pippin' apple absorbed five times more Ca than did 'James Grieve' within a 7-day absorption period.

C. Nutritional Status of the Plant

Cook and Boynton (1952) reported that apple leaves high in N absorbed more urea than did those low in N. Forshey (1959) showed that $MgSO_4$ sprays satisfactorily alleviated Mg-deficiency symptoms in apple trees that were adequately supplied with N. Subsequent studies (Forshey 1963b) revealed that high N status of the plant stimulated Mg absorption by both leaves and roots.

Carbohydrate level in apple trees as affected by different light preconditioning did not influence urea absorption by apple leaves (Cook and Boynton 1952). Sprays with sucrose decreased foliar absorption of urea and decreased the magnitude of leaf injuries in apple and plum caused by high urea concentrations (Cook and Boynton 1952).

D. Chemical Formulation, Concentration, pH, and Presence of Urea

Sprays containing 2600 ppm N in the form of urea, $Ca(NO_3)_2$, or $(NH_4)_2SO_4$ increased apple leaf N to the same extent, implying that the form of N did not influence the rate of leaf absorption of this element (Rodney 1952). However, $Ca(NO_3)_2$ and $(NH_4)_2SO_4$ sprays at this concentration caused leaf damage, whereas urea did not. The use of $NaNO_3$, $(NH_4)_2SO_4$, or $Zn(NO_3)_2$ on peaches did not show any superiority over urea (Norton and Childers 1954). Since the nitrate and sulfate salts especially $Zn(NO_3)_2$, caused leaf injuries, their use instead of urea is not justified.

Different chemical forms of P have dramatically different effects upon leaf absorption of this element. Results of Fisher and Walker (1955) and Yogaratnam *et al.* (1981) for apple and Reed and Tukey (1978) for chrysanthemum showed that H_3PO_4 is absorbed more rapidly than other P compounds. According to Yogaratnam *et al.* (1981), the absorption rate of H_3PO_4 is followed in descending order by K_2HPO_4, NaH_2PO_4, KH_2PO_4, and $Ca(H_2PO_4)_2$ and according to Fisher and Walker (1955) by $NH_4H_2PO_4$, KH_2PO_4, and $Mg(H_2PO_4)_2$. Phosphoric acid and K_2HPO_4 produced leaf injuries; therefore their use as sprays is not recommended. Increasing concentrations of KH_2PO_4 from 0.5 to 2% proportionally increased P concentration in the apple leaf 24 hours after treatment (Yogaratnam *et al.* 1981). Earlier, Allen (1970) observed a similar proportional relationship between the concentration of applied $MgCl_2$ and $CuSO_4$ and the amount of Mg^{2+} and Cu^{2+}, respectively, taken up by apple leaves.

Different Mg compounds were absorbed at different rates by apple leaves (Fisher and Walker 1955). After a 24-hour absorption period, leaves absorbed up to 71% of applied Mg from $Mg(NO_3)_2{\cdot}6H_2O$; 66% from $MgCl_2{\cdot}6H_2O$; 32% from $(CH_3COO)_2Mg{\cdot}H_2O$; 8% from $MgSO_4{\cdot}7H_2O$; and 4% from $Mg(H_2PO_4)_2$. The concentrations of all solutions were equivalent to the Mg content of 5% $MgSO_4{\cdot}7H_2O$. At this concentration, $Mg(NO_3)_2{\cdot}6H_2O$ caused leaf injury. Allen (1970) reported that apple leaves were able to take up 90% of foliar-applied $MgCl_2$. Magnesium chloride is a deliquescent salt and remains in solution when relative humidity exceeds 30%, whereas $MgSO_4$ requires 80% relative humidity to remain in solution (Allen 1970). This may explain the greater effectiveness of $MgCl_2$ in increasing leaf Mg levels compared with $MgSO_4$.

The chelated forms of mineral nutrients are extensively used for foliar applications, especially Fe chelates. Their effectiveness is probably related to their increased mobility within the plant compared with inorganic salt sources of Fe, since chelation of Fe with EDTA (ethylene-diamine tetraacetic acid) or EDDHA (ethylene-diamine di-O-hydroxy-phenylacetic acid) decreased absorption of Fe by leaves compared with $FeSO_4$ (Kannan and Wittwer 1965). Neumann and Prinz (1975) observed that FeEDDHA spray was less effective than $FeSO_4$ spray in alleviating chlorosis in bean plants when an organosilicone surfactant, L-77, was added to both forms of Fe. More recently, Basiouny and Biggs (1976) reported greater Fe uptake by citrus leaves from FeEDTA than from $FeCl_3$.

Absorption of certain mineral nutrients by leaves and fruits has been found to be pH dependent. Absorption of urea by apple leaves is highest at pH 5.4 and 6.6, intermediate at pH 8.0, and lowest at pH 7.3 (Cook and Boynton 1952). Bukovac and Wittwer (1959) reported a 30% reduction in absorption of Ca^{2+} by bean leaves when the solution pH was lowered from 5 to 4, but increasing the pH from 5 to 6 did not affect Ca^{2+} absorption. The optimum pH for Ca^{2+} absorption by sweet cherry fruit from $CaCl_2$ solution has been reported to be 7 (Lidster *et al.* 1979).

Reed and Tukey (1978) demonstrated that chrysanthemum leaves absorbed P most rapidly at pH 2, but a necrosis of the leaf tissue occurred at this pH. In the range of pH between 3 and 10, maximum P absorption occurred with sodium phosphate at pH 3–6 and potassium phosphate at pH 7–10. The pH had no effect on P absorption from ammonium phosphate or from calcium phosphate over the range between 3 and 5.

The addition of urea to the spray solution was reported to increase the effectiveness of foliar sprays containing P, Mn, S, Mg, and Fe in different plant species (Horsfall 1956; Bar-Akiva and Hewitt 1959; Okuda and Yamada 1962; Watson 1962; Labanouskas and Puffer 1964). However, the addition of urea to the spray solution failed to increase uptake of Mg or P by apple leaves (Fisher and Walker 1955). Conversely, the presence of $MgSO_4 \cdot 7H_2O$ in the spray solution consistently reduced the absorption of urea by apple leaves (Fisher and Walker 1955).

E. Growth Regulators

The data on the effect of growth regulators on ion absorption by leaves are very limited. Gibberellic acid (GA_3) fed to the roots of bean plants increased Rb^+ absorption by the leaves (Halevy and Wittwer 1965). Kannan and Mathew (1970) showed that treatment of the trifoliate leaf of bean with GA_3 or (2-chloroethyl)-trimethylammonium chloride (chlormequat, CCC) enhanced absorption of Fe by the primary leaf. Triiodobenzonic acid (TIBA) did not influence Fe absorption by citrus leaves (Bar-Akiva and Hewitt 1959). Dimethylsulfoxide, a compound with multiple effects, increased Fe penetration into maize leaves (Chamel 1972).

F. Surfactants

Employment of surfactants may greatly improve wetting of the leaf by lowering the surface tension and consequently reducing the contact angle between the liquid and leaf surface (Leece 1976). Complete wetting is achieved when the contact angle is zero. The liquid surface tension at which the contact angle is zero is termed *critical surface tension* (Schonherr and Bukovac 1972). Critical surface tension was estimated to be 25–30 mN/m for the leaves of *Zebrina purpusii* and 22–24 mN/m for the leaves of plum (Schonherr and Bukovac 1972; Leece 1978). Such a low surface tension will also facilitate stomatal infiltration. Surface tensions of aqueous solutions of selected surfactants are given in Table 8.1. Stomatal infiltration by solutions containing different surfactants was reported by several authors (Dybing and Currier 1961; Schonherr and Bukovac 1972; Greene and Bukovac 1974; Grieve and Pitman 1978). The number of stomata infiltrated was inversely related to the surface tension of the solution (Greene and Bukovac 1974).

TABLE 8.1. SURFACE TENSION OF AQUEOUS SOLUTIONS OF SELECTED SURFACTANTS[1] REFERRED TO IN TEXT

Surfactant	Ingredient	Concentration (%v/v)	Surface tension (mN/m)	Manufacturer[2]	Reference
Aerosol OT (anionic)	Carbohydrate base	0.3	28.2	6	Neumann and Prinz 1974a
Agral 90 (nonionic)	Not given	0.1	28.7	4	Beauchamp and Lean 1973
Atlox 209 (nonionic)	Not given	0.5	31.4	2	Beauchamp and Lean 1973
Baysilon603 (nonionic)	Silicone block copolymer	0.3	30.1	3	Neumann and Prinz 1974a
F.C. 128 (anionic)	Fluoracarbon polymer	0.1	16.3	10	Neumann and Prinz 1974a
L-77 (nonionic)	Silicone block copolymer	0.05	20.0	12	Neumann and Prinz 1974a
		0.05	22.0	12	Leece 1978
MONFLOR51 (nonionic)	Fluorocarbon polymer	0.05	23.6	8	Neuman and Prinz 1974a
Multi-Film X-77 (nonionic)	Alkylaryl polyethoxy ethanol and free fatty acids	0.01	30.9	Not given	Schonherr and Bukovac 1972
PEG1000MO (nonionic)	Not given	0.1	36.2	1	Beauchamp and Lean 1973
PM 4894 (nonionic)	Not given	1	31.6	12	Beauchamp and Lean 1973
R-11	Not given	0.1	28.0	Not given	Beauchamp and Lean 1973

Triton X100 (nonionic)	Octyl phenoxy polyethoxy ethanol	0.05	30.1	11	Neumann and Prinz 1974a
Tween 20 (nonionic)	Polyoxyethylene sorbitan monolaurate	0.01	36.6	5	Schonherr and Bukovac 1972
Tween 80 (nonionic)	Polyoxyethylene sorbitan monooleate	0.3	32.8	5	Neumann and Prinz 1974a
Vatsol OT (nonionic)	Dioctyl ester of sodium sulfosuccinic acid	0.3	25.5	Not given	Schonherr and Bukovac 1972
X-77 (nonionic)	Alkyl aryl polyethoxy-ethanol, free fatty acids, anad isopropanol	0.01	33.2	9	Leece 1976
Zonyl A (nonionic)	Not given	0.1	24.8	7	Beauchamp and Lean 1973

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[1] This table was prepared from the publications quoted as references. The incompleteness of the listing is realized by the reviewers. For more information, readers should contact manufacturers.

[2] Codes for Manufacturers: 1=Armour Chemicals Ltd., Canada; 2=Atlas Power Co., USA; 3=Bayer A.G., West Germany; 4=Chipman Chemical, Canada; 5=City Chemical Corp., USA; 6=Cyanamid Corp., USA; 7=E.I. duPont de Nemours Co., Canada; 8=ICI Ltd., Great Britain; 9=Lane Ltd., Sydney, Australia; 10=3M Co., USA; 11=Rohm Haas Co., USA; 12=Union Carbide Co., USA.

The use of some surfactants along with foliar nutrients might not be advantageous for various reasons. Some surfactants, such as Aerosol OT, Triton X 100, and Monflor 51, may damage cellular membranes (Wallihan *et al.* 1964; Neumann and Prinz 1974a); others, such as FC 128 and Aerosol OT, may precipitate inorganic salts.

Addition of L-77, an organosilicone surfactant, to $FeSO_4$ sprays not only eliminated Fe chlorosis in citrus trees and beans (Neumann and Prinz 1974a, 1975) but also eliminated the leaf damage caused by $FeSO_4$ sprays alone. This surfactant lowers surface tension sufficiently to promote stomatal infiltration (Table 8.1), which may be the reason for its effectiveness. It also increases the initial absorption of P and Fe by bean leaves (Neumann and Prinz 1974b) and NO_3^- by prune leaves (Weinbaum and Neumann 1977). However, Leece and Dirou (1977) were unable to increase plum leaf N levels with urea sprays containing L-77 under field conditions. They attributed this to increased run-off from the leaf surface when L-77 was used. This is in agreement with Mason's (1979) data that indicated reduced retention of $CaCl_2$ solution on apple fruit surface in the presence of surfactant. According to Greene and Bukovac (1974), stomatal penetration was not an important pathway for liquid entry into pear leaves when the surfactant Vatsol OT was used, since only 4–5% of stomata were infiltrated.

Beauchamp and Lean (1973) and Greene and Bukovac (1974) concluded that the surface tension of a surfactant solution may not be a useful characteristic in determining surfactant effectiveness in promoting leaf absorption. Hull *et al.* (1975) reported that the ethylene oxide content and hydrophile/lipophile balance (HLB) of a surfactant are useful measures of effectiveness, although predicting surfactant effect on leaf absorption with certainty is difficult. High HLB values usually indicate that a surfactant will strongly promote leaf absorption (Hull *et al.* 1975). However, Norris' (1973) data showed an inverse relationship between 2,4-D penetration through pear leaf cuticle and HLB values. Hull *et al.* (1975) suggested that different HLB may be needed to optimize leaf absorption when different pathways of penetration into the leaf are used. Moreover such factors as the pH of the solution, the type of chemical compound applied along with a surfactant, and the properties of the leaf surface interact with a surfactant and affect its effectiveness.

Tween 80 (0.1%) or Tween 20 (0.01%) doubled the absorption rate of urea by apple leaves during absorption periods of 2–5 hours (Cook and Boynton 1952). However, surfactants Wesco 93X, Petrol BP, Multifilm, or X-77 reduced Ca absorption by apple and sweet cherry fruits (Mason *et al.* 1974a; Lidster *et al.* 1979). Addition of thickeners such as Kelzan, Keltrol, arrowroot thickener, or cornflour increased Ca absorption by apple and cherry fruits (Mason *et al.* 1974a; Mason 1976, 1979; Lidster *et al.* 1979; Johnson 1979). It is believed that thickeners increase liquid retention on the treated surface and, in addition, probably extend the period of solution drying. Recently Mason (1979) and Lidster *et al.* (1979) reported that surfactant added to a solution containing $CaCl_2$ plus thickener further increased Ca penetration into fruit above the rate of Ca uptake from a solution containing $CaCl_2$ and thickener only. Surfactants L-77 and X-77 had a positive effect on infiltration of $CaCl_2$ solution into apples when temperature differentials were used (Lee and Dewey 1981).

IV. METABOLISM OF FOLIAR-ABSORBED NITROGEN

In contrast to most other nutrients, leaf-absorbed N must be metabolized in the plant before it is utilized. The metabolism involves several reactions such as hydrolysis of urea, reduction of nitrate, and incorporation of ammonium into amino acids. Following these steps, transamination, protein synthesis, and eventually protein breakdown follow. There is no evidence that N metabolism of root-absorbed and leaf-absorbed N are different. Yet there are special considerations that apply to leaf-absorbed N.

Urease activity has been detected in a wide spectrum of woody and herbaceous plants (Tukey *et al.* 1952; Hinsvark *et al.* 1953; Kuykendall and Wallace 1954; Dilley and Walker 1961a,b; Shim *et al.* 1973a,c). However, no urease activity was found on the leaf surface (Cook and Boynton 1952; Hinsvark *et al.* 1953; Impey and Jones 1960), thus ammonium loss from foliar urea sprays should not occur.

Hinsvark *et al.* (1953) proposed that the hydrolysis of urea to ammonium and CO_2 is a first step in the utilization of foliar-absorbed urea and formulated a concept that the rate of urea hydrolysis in the leaves is a limiting factor for absorption of this compound in some plant species. They concluded that those plants with leaves that hydrolyzed urea rapidly would be most likely to benefit from urea sprays. Urease activity may be so high in leaves of citrus that it would never limit urea assimilation (Kuykendall and Wallace 1954). Other authors reported that urea absorption may be more rapid than its hydrolysis (Boynton *et al.* 1953). The lack of urease activity in banana leaves did not prevent absorption of 65% of foliar-applied urea within 25 min (Freiberg and Payne 1957). The most convincing evidence that a lack of or low urease activity was not responsible for the lack of response of peach trees to urea sprays was provided by Dilley and Walker (1961b). In their study, urea labeled with ^{14}C and ^{15}N was fed through the leaf petiole in order to avoid the cuticular barrier to leaf absorption. Urea hydrolysis proceeded to a greater extent in peach than in apple. Also, assimilation of $^{14}CO_2$ and ^{15}N into organic compounds proceeded efficiently in the peach leaves. Thus, difficulty in foliar absorption of urea rather than in its subsequent metabolism is the reason for the lack of response to urea sprays in peach.

Absorbed urea may be hydrolyzed within the leaves (Dilley and Walker 1961b) and/or transported out of the leaves and hydrolyzed in other plant organs (Freiberg and Payne 1957). Especially active export of N from urea-treated leaves was observed in banana (Cain 1956).

Translocation and/or hydrolysis of foliar-absorbed N is reflected by a steady decrease in the urea content of leaves following application of foliar urea sprays (Boynton *et al.* 1953; Cain 1956). Boynton *et al.* (1953) reported an increase in amino-N, amide-N (exclusive of urea), and ammonium-N in apple leaves sprayed with urea. They stressed the importance of glutamine, glutamic acid, and alamine as the recipients of urea nitrogen. Cain (1956) found that asparagine and, to a smaller extent, glutamic acid increase in coffee and banana following foliar urea application. Dilley and Walker (1961b) reported that ^{15}N derived from urea hydrolysis in peach and apple leaves was predominantly incorporated into aspartic and glutamic acids and their amides into alanine. Urea sprays may increase proteolysis in the leaves of apple (Boynton *et al.* 1953) and of coffee, cacao, and banana (Cain 1956). However, after an initial decrease in leaf proteins in apple following spraying with urea, protein content of leaves increased again reaching higher values than during the pretreatment period (Boynton *et al.* 1953).

Hinsvark *et al.* (1953) proposed that ammonium accumulation may have caused leaf injury when an excessive concentration of urea was used. Boynton *et al.* (1953) concluded, however, that accumulation of urea rather than ammonium was responsible for leaf injury in apple leaves sprayed with 3% urea solution.

Reports from Washington (Benson 1953) and New York (Walker and Fisher 1955) described the yellowing and premature drop of cherry leaves sprayed with urea. Walker and Fisher (1955) have proposed that a high biuret content was responsible for these symptoms. Similar symptoms were observed occasionally by D. Swietlik on the sour cherry cultivar 'Shattenmorelle' sprayed with urea in early summer. These reports seem to suggest that cherry trees might be especially susceptible to biuret toxicity.

Tests for nitrate reductase in leaves of apple trees have often been negative (Eckerson 1931; Sanderson and Cocking 1964; Dirr *et al.* 1972). In general, nitrate reductase has only been detected in buds and in adjacent bark (Thomas 1927; Eckerson 1931), without inducing the leaf enzyme.

Beevers and Hageman (1969) considered nitrate reductase an inducible enzyme. Titus and Ozorol (1966) detected nitrate reductase in apple leaves when trees received a high rate of nitrate nutrition through the soil. Frith (1972) demonstrated that ammonium inactivated root nitrate reductase by feedback inhibition and suppressed the enzyme to about one-sixth of that in the absence of ammonium. Once the nitrate reductase was inhibited, NO_3^- could move up in the xylem and induce nitrate reductase in the aerial parts of the tree. Under such conditions nitrate reductase has been detected in leaves of apple, apricot, sour and sweet cherry, plum, and grape, but not in peach (Klepper and Hageman 1969; Leece *et al.* 1972; Perez and Kliever 1978). Leece *et al.* (1972) demonstrated that the leaf enzyme of nitrate reductase in apricot leaves is indeed substrate-inducible.

No specific information is available on induction of nitrate reductase when NO_3^- is applied to the leaf from the outside rather than transported into the leaf through the xylem. Weinbaum and Neumann (1977) were able to show that prune leaves metablized foliar-applied $^{15}NO_3^-$ and that the ^{15}N label was in the alcohol-insoluble fraction of the leaf. We believe that regardless of the mode of entry of NO_3^- into the leaf, a high NO_3^- level will induce nitrate reductase and this enzyme cannot be considered as a limiting step in the metabolism of foliar-absorbed NO_3^-.

Nitrate reductase and urease activity by themselves are of little significance unless followed by ammonium assimilation into organic form. Titus and Kang (1982) reviewed assimilation of NH_4^+ into organic forms. They consider glutamate dehydrogenase (GDH) which catalyzes the reductive amination of α-ketoglutarate, to be the major enzyme only when ammonium is in excess. In any case, this enzyme could produce the initial glutamate, which then becomes the substrate of glutamine synthetase (GS). Once glutamine is synthesized the formation of glutamate proceeds from glutamine in the presence of glutamate synthesase (GOGAT). In this system, GS functions in conjunction with GOGAT. The important of the GS/GOGAT system is that GS is responsible for ammonium assimilation and two molecules of glutamate are then formed in the presence of GOGAT. Kang and Titus (1980, 1981a,b) characterized these two enzymes in both apple bark and leaf tissues. Concomitant transamination from glutamine can explain the appearance of foliar-applied N in the various amino acids listed previously.

The functioning of the GS/GOGAT enzyme system requires specific carbohydrate derivatives such as α-ketoglutarate and cofactors such as

ATP and NADPH. However, these compounds are not considered limiting for assimilation of ammonium in actively photosynthesizing leaves. A more important consideration is the mixture of N forms in foliar sprays. Several formulations contain all three forms of N: urea, NO_3^-, and NH_3^+. Considering the feedback control of NH_4^+ on nitrate reductase it is likely that NO_3^- is not utilized by the leaves until all absorbed NH_4^+ is assimilated. Ammonium, at the same time, is also rapidly generated from urea. If ammonium is at a high level in the leaf, it must be detoxified (Givan 1979). The rate of assimilation at which the GS/GOGAT and/or the GDH/GS can function becomes of the utmost importance; however, no data are available on this subject.

Oland (1960) recognized the normal autumnal migration of leaf N to storage tissues in the tree. He suggested that N might be efficiently introduced into the tree by postharvest sprays, and he found that higher concentrations of urea were readily absorbed by apple leaves and broken down by urease. The N is then incorporated into amino acids and proteins (Shim *et al.* 1973a,b). The proteins in turn are converted to amino acids, transported to the storage tissues, and reassembled into proteins. These experiences point to the fact that N is efficiently metabolized when applied through foliar sprays.

V. TRANSLOCATION OF FOLIAR-ABSORBED NUTRIENTS

Bukovac and Wittwer (1957) classified foliar-absorbed mineral nutrients into three groups: mobile, partially mobile, or immobile. According to these authors, mobile nutrients are K (Rb), Na, P, Cl and S; partially mobile ones are Zn, Cu, Mn, Fe and Mo; and immobile ones are Ca, (Sr and Ba). Later, Mg was classified as immobile (Bukovac and Wittwer 1959), although it may not be completely immobile when Mg deficiency develops. Magnesium is transported from old leaves to new leaves and fruit. According to the results of Forshey (1963a), 37% of the Mg absorbed by 'McIntosh' apple leaves was exported to permanent woody tissues and roots. Very little is known about the mobility of foliar-absorbed boron. Chamel *et al.* (1981) found that 24 hours after foliar application of boron (as $H_3^{10}BO_3$) to radish, 78 to 98% of absorbed B was still present in the treated leaf, 4.5 to 7% had migrated to the epicotyl, and 2.5 to 17.7% had migrated to the hypocotyl. Considering these data, B may also be regarded as a partially immobile nutrient when foliar-applied.

The immobility of Ca has perhaps the most practical importance. Many physiological disorders of fruits are associated with low Ca levels (Shear 1975). Limited translocation of Ca to the fruit, as well as lack of

Ca migration from leaves, makes it difficult to elevate its concentration in fruit either by soil or foliar application (Perring 1979; Sharples 1980). To increase fruit Ca by sprays, Ca must directly penetrate the fruit. Consequently, spray droplets must be deposited on the fruit to be effective in decreasing the occurrence of physiological disorders (Ford 1979).

In early experiments, 2,3,5-triiodobenzoic acid (TIBA) and to a lesser extent maleic hydrazide induced downward transport of foliar-absorbed ^{45}Ca in apple and tomato (Kessler and Moscicki 1958; Bukovac and Wittwer 1959). Exposure of leaves to ether vapors also induced downward transport of foliar-applied ^{45}Ca in bean plants (Bukovac *et al.* 1956). These findings led to the formulation of a hypothesis that the lack of Ca migration from leaves, under normal conditions, is caused by the polarity of Ca movement. TIBA and ether were believed to eliminate this polarity. Biddulph *et al.* (1959) rejected this hypothesis on the basis that ^{45}Ca migration from leaves induced by ether took place in the xylem, not in the phloem. In addition, the effect of TIBA on ^{45}Ca migration from the leaves could only be demonstrated in samples taken from intact-dried plants. They suggested that injury from ether or TIBA enabled entrance of ^{45}Ca into the xylem and that the subsequent back flow of water caused by ether or drying transported ^{45}Ca out of the leaf. Later Taylor *et al.* (1961) reported that drying of intact plants *per se* induced export of foliar-applied ^{45}Ca, independent of TIBA pretreatment. Faust and Shear (1973) studied Ca transport in apple in detail and showed that Ca is transported in the xylem by ion exchange and that this transport is concentration dependent. The reason that Ca is not transported from the leaves to the rest of the plant is that the concentration gradient of root-absorbed Ca is toward the leaf. They also demonstrated that back transport is possible if the midrib is cut and a Ca concentration gradient is set up in such a way that the leaf-applied Ca represents the highest concentration. Wieneke (1976) reported that Ca is transported from the leaf to other parts of the plant in the late fall. It is conceivable that when, during senescence, the internal structures of the leaf are disorganized, Ca is freed and could be high enough in concentration to change the concentration gradient. This, of course, would happen only in yellowing leaves in late fall. Hanger (1979) summarized the conditions accompanying the export of foliar-applied Ca. Most of the conditions he mentions could fit the above criteria. His conditions for Ca transport from the leaf are as follows: leaf injury, high air humidity, high concentration of Ca in spray solution, addition of other divalent cations to spray solutions, Ca chelation, and a volume of spray solution exceeding the volume transpired during foliar uptake.

Alternatively, the possibility that Ca is transported through the phloem cannot be completely dismissed (Hanger 1979; Ringoet *et al.* 1968). However, the lack of Ca migration from the leaves is explained by the inability of this element to move freely in symplastic pathways. Movement through the phloem would involve such a pathway; therefore, it is unlikely to occur (Ferguson 1979, 1980).

The early TIBA work raises many questions. Even if TIBA increases movement of Ca from the leaves, the overall effect of this hormone on Ca levels of the fruit is unfavorable. TIBA diminishes the level of Ca in apple fruit (Stahly and Benson 1970, 1976) and in peppers (Marcelle *et al.* 1981). Therefore, it defeats the main purpose of foliar application of Ca, which is to increase fruit Ca.

As already mentioned, it is difficult to increase fruit Ca. One of us (MF) calculated that only about 15 % of the total Ca needed in apple can be supplied through sprays applied directly to the fruit. Thus, for sprays to be effective in decreasing physiological disorders, the tree must supply at least 85% of the need. Agrotechniques that maximize Ca uptake through the root and Ca transport to the fruit must be adjusted concurrently with sprays for the sprays to be effective (Kirkby 1979).

The high mobility of spray-applied P to the leaves or bark of apple and cherry trees has been reported by Eggert *et al.* (1952), Bukovac and Wittwer (1959), and Yogaratnam and Greenham (1982a). The data of Yogaratnam *et al.* (1981) for apple trees showed that foliar-absorbed P started to migrate from leaves within the first 24 hours following foliar treatment and continued for at least 6 more days. Under conditions of equal application, the amount of foliar-absorbed P exported from the leaf of bean was 750-fold greater than that of Ca (Biddulph *et al.* 1959). Eggert *et al.* (1952) and Yogaratnam *et al.* (1981) reported that translocation of foliar-absorbed P in apple trees depended on the chemical form of P applied to the leaves. However, they measured only ^{32}P in the target organ in one study and P concentration in the absorbing leaf in another study. Thus, differences resulting from foliar application of different P compounds may have been caused by different absorption rates and/or different translocation rates.

Bukovac and Wittwer (1957) classified Fe as a partially mobile nutrient; however, Eddings and Brown (1967) reported that as much as 60% of foliar-absorbed ^{59}Fe (from ^{59}FeCl$_3$) might be translocated out of the leaf within 50 hours in sorghum. In other species studied (tomato and white bean) the transport was not as efficient but involved at least 25% of leaf-absorbed ^{59}Fe. Kessler and Moscicki (1958) noted that TIBA promoted the mobility of foliar-absorbed Fe. Data by Bukovac and Wittwer (1959) and Kannan and Mathew (1970) for bean plants and

Bar-Akiva and Hewitt (1959) for citrus did not confirm this finding. According to Kannan and Mathew (1970), translocation of foliar-applied Fe may be enhanced by chelation and by treatments with GA_3 and kinetin (6-furfurylamino purine).

The auxin α-naphthalenacetic acid (NAA) enhanced the mobility of foliar-applied Zn in bean plants (Bukovac and Wittwer 1959). Abscisic acid, 2-chloroethyl phosphonic acid (ethephon), gibberellic acid (GA_3), indoleacetic acid (IAA), 2,4-dichlorophenoxy-acetic acid (2,4-D), and 6-benzylamino purine (BAP) were reported in the recent review by Kannan (1980) to affect the direction of movement of foliar-absorbed Rb, P, and S.

The rate of translocation of urea from the leaves of apples to other parts of the tree has caused some controversy throughout the years. Boynton *et al.* (1953) reported that about 50% of the urea N absorbed by apple leaves, attached to actively growing or nongrowing shoots, was translocated out of the absorbing leaves within 24 hours. Within the same time interval, 92%, 70%, and 18% of leaf-absorbed urea N was exported from the absorbing leaves of banana, coffee, and cacao plants, respectively (Cain 1956). Substituting ammonium sulfate for urea did not change the amount of foliar-absorbed N translocated out of apple leaves (Boynton *et al.* 1953). Boynton *et al.* (1953) and Cain (1956) reported high mobility of foliar-absorbed urea N in woody plants, irrespective of shoot growth. However, they did not specify destinations of translocation of foliar-absorbed N. Forshey (1963b) reported rather limited translocation of foliar-absorbed urea N. His study showed poorer translocation of N to permanent structures of apple trees when this element was supplied via the leaves as compared to soil application. From the data presented by Forshey (1963b) we have calculated that under conditions of equal root and leaf absorption of N, 48% and 63%, respectively, of absorbed N accumulated in the leaves by the end of August. Forshey (1963b) observed that supplying N exclusively via sprays resulted in low levels of N in the bark but maintained adequate levels of N in the leaves. He suggested that this distribution explained the low vigor and productivity of trees exclusively supplied with N via sprays. We must note, however, that Forshey's data showed total N distribution rather than actual movement of leaf- or root-absorbed N, since it was not possible to differentiate between newly absorbed N and N present in the trees before the initiation of the treatments. When ^{15}N was supplied via foliage or soil to sour cherry (Swietlik and Slowik 1981) and apple trees (Hill-Cottingham and Lloyd-Jones 1975) the percentage of absorbed N found in leaves in August was only 7 to 10% greater in leaf- than in soil-supplied trees. In these experiments the amount of N absorbed constituted only a modest portion of total tree N, whereas in Forshey's (1963b) experiment it constituted almost 50% of total tree N.

Weinbaum and Neumann (1977) suggested that metabolism and translocation of foliar-absorbed N from ^{15}N-labeled potassium nitrate spray applied to prune trees were enhanced by the nonionic organosilicone surfactant L-77. However, Regulaid, a carbohydrate-based nonionic surfactant, did not produce such an effect.

The amount of foliar-absorbed N subsequently exported to other parts of woody plants may differ according to the physiological stage of growth. During senescence, 23 to 70% of initial apple leaf N is reabsorbed by the tree (Oland 1963; O'Kennedy *et al.* 1975; Shim *et al.* 1972, 1973b). Oland (1960) was the first to show that N migration might be significantly increased by urea sprays applied 3–4 weeks before leaf abscission. Later studies by Shim *et al.* (1973b) and O'Kennedy *et al.* (1975) confirmed this finding. Shim *et al.* (1973b) established that N absorbed by senescing apple leaves is exported to the tree as amino acids and urea. However, only 5% of urea C was found in permanent tissues at the end of leaf abscission, indicating that urea sprays are a rather poor supplier of C. More recently, Swietlik and Slowik (1981) reported that in sour cherry trees as much as 80–87% of leaf-absorbed N from autumn application of ^{15}N-urea migrated to the rest of a tree before abscission. Depending on the year of study, 49 to 64% of fertilizer N reabsorbed from the leaves was found in the roots during dormancy. Using ^{15}N techniques, Hill-Cottingham and Lloyd-Jones (1975) found that about 62% of leaf-absorbed N from autumn application of foliar urea to apple trees was recovered in permanent tissues during dormancy and that this N was evenly distributed among root and stem tissues of the stock and scion. The chemical form of stored N and the storage sites for N derived from senescing leaves were recently discussed in detail by Titus and Kang (1982).

These data indicate that N absorbed by leaves during senescence is highly mobile in fruit trees. The translocation of N from the leaves in fall may depend on temperature. If the temperature is such that leaves senesce slowly most of the N is translocated. However, N application in late fall also increases the rate of photosynthesis of leaves and they stay green longer. This increases the possibility that they may be killed by frost before the N is translocated to the tree.

VI. EFFECT OF FOLIAR SPRAYS ON PHOTOSYNTHESIS, STOMATAL CONDUCTANCE, AND TRANSPIRATION

Few efforts have been made to associate the nutrient content of leaves, regardless of its origin, with net photosynthesis (Pn). Absolute leaf N levels were positively correlated with Pn in apple, peach, and tung trees; however, P and K concentrations in the leaf had much less effect on Pn (Childers and Cowart 1935; DeJong 1982; Loustalot *et al.* 1950). Increasing doses of the N, P, and K when applied as fertilizers, also incrased diurnal Pn rates in apples (Shatkovskii 1979). While nutrients that may be involved in the synthesis of proteins have a positive effect on Pn, their deficiency causes a decrease in Pn. Copper and Zn deficiencies reduced Pn in tung trees (Loustalot *et al.* 1945).

Heinicke (1934) was the first to indicate that healthy green foliage of apple trees in autumn is essential for synthesis of carbohydrates utilized in autumn root growth (Heinicke 1935) and for deposition of carbohydrate reserves that enhance early spring growth. Application of N fertilizers to apple trees in later summer increased Pn rates in the leaves and prolonged their photosynthetic activity till the late autumn (Heinicke 1934). Urea sprays have been reported to delay leaf abscission (Norton and Childers 1954; Leece and Kenworthy 1971) and to increase the N level in the leaves in autumn (Oland 1963; O'Kennedy *et al.* 1975). Thus it seems reasonable to suggest that autumn urea sprays may elevate not only N reserves in the trees (Oland 1963) but also carbohydrate reserves.

It is often assumed that foliar application of nutrients increases Pn, especially when the applied nutrients are at or near deficiency levels in the tree. The fact that urea sprays increased dry matter production in apple (Hansen 1980) and pretreatments with four foliar urea sprays helped apple seedlings to recover from water stress as measured by photosynthesis (Swietlik *et al.* 1982d) support this assumption.

One must note that there is a very limited number of papers reporting Pn rates following application of foliar nutrient sprays. Swietlik *et al.* (1982a) showed that spraying apple seedlings with a complete nutrient solution reduced Pn, stomatal and mesophyll conductances, and transpiration on the day of spray treatments. Further studies on apple seedlings (Swietlik *et al.* 1984) revealed that $CaCl_2$ was the component of the sprays that had the most pronounced negative effect on stomatal conductance. Sprays containing $CaCl_2$ also reduced the Pn rate, although full recovery was usually observed 1 day following treatment. It was concluded that mesophyll and not stomatal conductance was responsible for the observed decrease in Pn. The effects of $CaCl_2$ were not associated with visible leaf injuries. The decrease in Pn due to nutrient sprays was unexpected but by no means unique for trees. Decreases in Pn and stomatal conductance were also observed following application of N–P–K–S sprays to maize plants (Harder *et al.* 1982). There was a 17% reduction in the Pn one day following foliar fertilizer application; however, almost full recovery was noted by the second day. In studies on soybeans, Pn rates increased slightly 6 days after spraying with N–P–K–S fertilizers (Boote *et al.* 1978). No attempt was made to measure Pn at shorter intervals after spraying. The limited experiments with apples and corn indicate that some foliar sprays may stress plants resulting in reduced Pn. The same experience also indicates that the stress is temporary and recovery occurs in days. The nature of the stress is not defined at present, but does not appear to be associated with visually observable injury.

Other studies by Swietlik *et al.* (1982b) showed that K_2SO_4 sprays reduced Pn, stomatal conductance, and transpiration in apple seedlings exposed to mild water stress. These effects were not observed when K_2SO_4 sprays were applied to unstressed seedlings. When the level of stress was increased, unsprayed seedlings started to wilt while sprayed plants did not. It was proposed that earlier stomatal closure of K-sprayed plants, at a low level of stress, allowed the seedlings to escape water depletion when the stress level was elevated.

In one study, KCl sprays increased stomatal conductance (Swietlik *et al.* 1982d) and lowered leaf water potentials in apple seedlings (Swietlik *et al.* 1982c). However, in another study (Swietlik, Bunce, and Miller, 1984) wider stomatal opening could not be induced by KCl sprays.

VII. EFFECT OF FOLIAR SPRAYS ON HORTICULTURAL CHARACTERISTICS

A. Vegetative Growth

Applying foliar urea sprays in spring and/or autumn to apple trees as a substitute or supplement to soil N dressing has been reported to increase the amount of shoot growth (Fisher *et al.* 1948; Fisher and Cook 1950; Rodney 1952; Titus 1972; Shim *et al.* 1972; Holewinska 1974; Szafranek 1974; Hansen 1980). However, when the N status of experimental trees was high, growth responses to urea sprays were not obtained (Greenham and White 1959; Ford *et al.* 1965; Little *et al.* 1966; Hennerty *et al.* 1980).

There are conflicting reports in the literature as to the relative efficiency of soil vs. foliar N for promoting apple tree growth. Shim *et al.* (1972) reported more shoot growth on apples fertilized with a 5% urea spray in fall than on those fertilized through the soil in spring, even though a four times greater N dose was used for the soil treatment. Contrary to this finding, Little *et al.* (1966) showed that additional soil N in spring stimulated increases in trunk girth, whereas the same dose of additional N applied in the autumn as a foliar spray had no effect.

Holewinska (1974) found no differences in the amount of shoot and trunk growth between soil- and foliar-treated apple trees, despite the fact that 50% less N was used for foliar than soil N applications. Blasberg (1953) reported that four urea sprays applied to apple trees in spring induced more shoot growth than did soil N dressing in spring, but the sprays supplied 62% more N than did the soil treatment. The results of Fisher *et al.* (1948) and Fisher and Cook (1950) are conflicting. Fisher *et al.* (1948) reported that 3 pounds of urea applied per apple tree as spring urea sprays induced less shoot growth than did an identical dose applied to the soil in early spring. Fisher and Cook (1950) indicated equal effectiveness of foliar and soil N dressing. Later, Fisher (1952) reported that spring urea sprays resulted in smaller increases in trunk girth than did soil N dressing. Similar observations were made by Forshey (1963b). Fisher (1952) related this effect to a decrease in leaf N during summer in foliar-treated trees and claimed that urea sprays had only a temporary effect on leaf N status. However, even when urea sprays maintained an adequate leaf N level, the vigor of trees was low (Forshey 1963b). This was explained by poor translocation of foliar-absorbed N to permanent tree parts (Forshey 1963b). From the results of Fisher (1952) and Forshey (1963b) the general conclusion emerges that spring urea sprays might not be adequate to maintain tree vigor unless the trees have sufficient N reserves or the soil can provide some of the tree's N needs. A similar conclusion may be derived from the data of Hansen (1980) for potted apple trees. With application of soil N in late autumn plus foliar urea sprays in spring, the amount of shoot growth was much less than expected from leaf N concentrations. Since the uptake of soil N in late autumn is poor due to unfavorable temperatures, it may be assumed that these trees had rather low N reserves. In trees that were treated with N from August till late autumn, and thus had an opportunity to increase N reserves, urea sprays applied the following spring increased shoot growth in proportion to leaf N increases.

Urea or KNO_3 sprays had small or no effects on vegetative growth in peach and sour cherry (Weinberger *et al.* 1949; Eckert and Childers 1954; Norton and Childers 1954; Walker and Fisher 1955; Leece and Kenworthy 1971; Wierszyllowski 1974; Banna *et al.* 1981). However, autumn application of foliar urea sprays to sour cherry trees that also received soil N dressing in spring, tended to increase trunk thickness (Swietlik 1980). Applying urea sprays to pear, plum, and apple trees in a nursery increased the percentage of successful budding by prolonging activity of the cambium (Byszewski *et al.* 1974).

Despite the high effectiveness of Mg sprays in controlling deficiency symptoms of this element in apple trees, growth responses are inconsistent, indicating a complex relationship between deficiency symptoms and growth (Ford 1958, 1968; Ford *et al.* 1965; Greenham and White 1959). Ford (1966) concluded that reduction of growth due to Mg deficiency might occur if the ratio of photosynthesizing to respiring surface area on the trees decreased to a critical level. This might explain the lack of growth reduction in Mg-deficient apple trees in some cases (Greenham and White 1959; Beyers and Terblanche 1971f). Growth responses of Mg-deficient apple trees to Mg sprays were reported to depend on the rootstock and variety (Ford 1968). Sprays containing $MgSO_4$ were found to be more effective in increasing growth than were those containing $MgCl_2$, even though both sprays controlled Mg-deficiency symptoms equally well (Ford *et al.* 1965).

There is little information on the effect of other mineral nutrient sprays on the growth of temperate-zone fruit trees. Correction of various mineral deficiencies by means of foliar sprays may be expected to stimulate growth if one of the deficiencies is retarding growth. Dixon *et al.* (1973) reported that when B is deficient in apple fruit, applying sprays with this element to apple trees did not affect trunk girth increases. In contrast, Potapova (1974) reported 33% and 41% increases in leaf area and dry weight, respectively, in Antonovka seedlings sprayed with H_3BO_3. She also reported increased root growth after spraying with $ZnSO_4$.

B. Yield

The first reports on spring urea sprays applied to apple trees indicated that they might be equally or more effective in improving fruit set, fruit size, and yield than were soil N applications at comparable doses (Fisher and Cook 1950; Fisher 1952). Under poor conditions for fruit set, an early spray program commencing before bloom was more advantageous than one commencing at petal fall (Fisher *et al.* 1948). Early sprays were also shown to increase the proportion of flowering spurs (Blasberg 1953). These results were obtained in relatively short-term experiments conducted for 2 to 3 years. Later observations revealed that prolonged reliance on foliar urea sprays as the exclusive external source of N for apple trees resulted in unsatisfactory flowering and fruit set (Forshey 1963b). However, urea sprays as a supplement to soil N application proved to be an efficient means for increasing fruit set and/or yield of apple (Greenham and White 1959; Ford *et al.* 1965; Szafranek 1974; Cahoon and Donoho 1982) when the original N status of trees was not too high (Wlodek *et al.* 1959; Vang-Petersen 1975; Stang *et al.* 1978). Recently, preblossom urea sprays applied to high N apple trees were reported to improve initial fruit set, although sprays failed to affect fruit yield (Yogaratnam and Greenham 1982b).

In the early 1960s, Oland, in Norway, pioneered in the use of autumn urea sprays on apple trees. Trees treated with a single postharvest spray had increased amounts of N reserves (Oland 1960) and 50% higher fruit set and yield compared with the control or soil fertilized trees (Oland 1963). Fruit size on sprayed trees was either bigger or did not differ from that in other treatments. Shim *et al.* (1972) showed that urea sprays in autumn produced similar or greater increases in yield or fruit set, respectively, than did soil N dressing in spring. The amount of N applied in the urea sprays was only 25% of that applied to the soil. Holewinska (1974) reported a tendency toward higher yield of apple trees treated with autumn urea sprays compared with those fertilized with soil-applied N.

Increases in fruit set following autumn urea sprays indicate the high effectiveness of this method for building up tree N reserves, which are critical for tree development in early spring. These reserves were shown to have beneficial effects on flower bud development, increasing the longevity of ovules and enhancing the degree of self-fertilization in some apple cultivars (Hill-Cottingham 1963; Williams 1963, 1965; Hill-Cottingham and Williams 1967; Delap 1967). However, when tree N status was high, autumn urea sprays were ineffective in improving fruit set and yields of apples (Little *et al.* 1966; Wilson 1966; Terblanche and Strydom 1973; Hansen and Christensen 1980; Hennerty *et al.* 1980).

Urea sprays applied in spring or autumn as an exclusive or additional N treatment had no effect on fruit set, fruit size, or yield in peach, pear, plum, and sour cherry trees (Weinberger *et al.* 1949; Walker and Fisher 1955; Wlodek *et al.* 1959; White and Glenn 1967; Leece and Dirou 1977; Wierszyllowski 1974; Holubowicz 1976; Ystaas 1980; Banna *et al.* 1981). In other experiments, spring or autumn urea sprays applied in addition to soil N dressing increased the yield of 'Shattenmorelle' sour cherry (Slowik and Swietlik 1978; Swietlik 1980) and the fruit set of 'Nefris' sour cherry (Wierszyllowski 1976). Khattab *et al.* (1981) reported that autumn urea sprays applied to pear trees increased the flower-bud burst and number of flowers per spur the next spring but had no effect on fruit set.

Generally, $MgSO_4$ sprays do not affect cropping of fruit trees that are low but not deficient in Mg (Ford 1968; Yogaratnam and Greenham 1982b). In some instances, corrective $MgSO_4$ sprays applied to apple trees showing Mg-deficiency symptoms also did not affect yield (Forshey 1963a). In English experiments, however, postblossom $MgSO_4$ sprays applied to apple trees showing severe Mg deficiency increased the yield by increasing fruit set and fruit size and reducing fruit drop later in the season (Greenham and White 1959; Ford *et al.* 1965; Ford 1968).

Boron plays a significant role in pollen germination and pollen tube growth in deciduous fruit trees (Thompson and Batjer 1950). Batjer and Thompson (1949) were the first to report increased fruit set in pear after treatment with B sprays at bloom, even though the control trees did not express deficiency symptoms and fruit and leaf boron at harvest were high. The authors speculated that trees could experience temporary B insufficiency during bloom, which was not reflected by leaf and fruit analysis. Degman (1953) concluded that B sprays might improve fruit set only when deficiency symptoms were present. Later reports seem to support this idea (Horsfall and Shear 1950; Dixon *et al.* 1973; Rogers *et al.* 1976). In contrast, Bramlage and Thompson (1962) found that when B was adequate for normal functioning of the trees, B sprays applied to naturally poorly setting 'Stayman' apple trees increased fruit set but did not have an effect on the more heavily setting cultivars 'Jonathan' and 'Golden Delicious.' Most recently, Chaplin *et al.* (1977) and Westwood and Stevens (1979) reported increased fruit set and yield resulting from fall B sprays applied to non-B-deficient prune and cherry trees. This effect was interpreted as a direct involvement of B in the reproductive physiology of the tree. It was also suggested that B absorbed from fall sprays was metabolized and available for flowers in early spring in suitable chemical form (Chaplin and Westwood 1980). There is no direct evidence to support this suggestion, although earlier research by Johnson *et al.* (1955) consistently showed postharvest B sprays to be more advantageous than spring sprays. The research to date has failed to answer precisely under what conditions B sprays would result in beneficial responses in fruit set and fruit yield. This task is complicated by the fact that availability of soil B is strongly dependent on soil conditions and as a consequence is subject to rapid changes. Thorough knowledge of B requirements at different stages of tree growth is essential. Excess of B resulting from unnecessary sprays may cause negative effects, i.e., premature fruit senescence especially on early cultivars (Yogaratnam and Greenham 1982b; Yogaratnam and Johnson 1982).

The appearance of deficiency symptoms of Zn, Mn, Fe, or Cu coincides with a deterioration in the productivity of fruit trees (Beyers and Terblanche 1971a). Thus, correction of deficiency symptoms by mineral foliar sprays or other means increases the productivity of the trees (Labanauskas and Puffer 1964; Mochecki 1978; Navrot and Banin 1982). Very little is known about the effect of micronutrient sprays on the yield of fruit trees that do not show deficiency symptoms. Increases in yields of apple trees after treatment with Mn or Zn sprays were reported by some authors (Stojkovska *et al.* 1975; Eliyeva 1975). However, the nutritional status of the trees in these studies was not reported.

Stang *et al.* (1978) observed no effect on fruit set by Zn sprays applied to dormant apple trees with high leaf levels (117 ppm) of Zn. Applying zinc sulfate sprays to 'Cox's Orange Pippin' apple trees with Zn leaf concentrations judged to be marginal (12–13 ppm), but without deficiency symptoms, did not affect the number of flower buds, fruit set, and yield (Yogaratnam and Greenham 1982b). 'Discovery' apple trees, containing twice as much Zn in the leaves as 'Cox's Orange Pippin,' responded to Zn sprays with increased number of flower buds the following spring. However, no yield increases were noted since the increased number of flowers was offset by reduced fruit set. Nevertheless, the results show that Zn sprays may affect generative processes in apple trees that do not show deficiency symptoms of this element.

C. Fruit Quality

DeLong (1936) was the first to relate low Ca level in apple fruit with the occurrence of bitter pit. Forty years later, inadequacy of Ca in fruits was related to many other physiological disorders: cork spot, cracking, internal breakdown, low temperature breakdown, senescence breakdown, watercore, superficial scald, softening in storage, cracking of cherries, surface pitting of cherries, cork spot of pears, alfalfa greening of pears, and cracking of prunes (Shear 1971, 1972, 1975; Lidster *et al.* 1975, 1979; Bramlage *et al.* 1979, 1980; Raese *et al.* 1979; Perring 1980; Sharples 1980; Terblanche *et al.* 1980; Wills and Scott 1981). Shear (1974) showed that the N/Ca ratio in the fruit is more closely related to bitter pit and cork spot than is the Ca level alone. Other authors have stressed the importance of K/Ca and Mg/Ca ratios in the occurrence of bitter pit (Faust and Shear 1968; Sharples 1980) and the K/Ca ratio in the incidence of breakdown (Wills and Scott 1981). These findings may explain the increased incidence of bitter pit in apples following application of Mg or K sprays (Anon. 1980; Sadowski 1974; Yogaratnam and Sharples 1982).

Terblanche *et al.* (1980) concluded that the only practical way to elevate the resistance of apples to bitter pit is through maximizing their Ca concentration. However, the goal of maximizing fruit Ca level is not easily attained. Although several techniques have been developed, we will discuss only those that are related to direct Ca application to the fruit surface.

Preharvest Ca foliar sprays were reported to reduce the incidence of bitter pit, cork spot, breakdown, watercore, and scald in apples (Stiles 1964; Dixon *et al.* 1973; Sadowski 1974; Martin *et al.* 1976; Drake *et al.* 1979; Greene and Smith 1979; Mason 1979; Sharples 1980; Swietlik and

Slowik 1980; Terblanche *et al.* 1980; van der Boon 1980; Weis *et al.* 1980). The sprays were also found to be effective in controlling surface pitting of cherries and cork spot of pears (Lidster *et al.* 1979; Richardson and Lombard 1979). Perring (1979) noted that five applications of sprays containing $Ca(NO_3)_2$ or $CaCl_2$ may increase apple Ca level by 1 mg per 100 g of fresh fruit weight. Similar responses were reported by Terblanche *et al.* (1980). The data of Drake *et al.* (1979) and Greene and Smith (1979), when standardized to five applications and expressed on a fresh weight basis, would probably indicate an increase of only 0.5 mg Ca per 100 g of fruit fresh weight. Contrary to Perring's procedure, Drake *et al.* and Greene and Smith excluded the peel from the fruit analysis; the peel may be expected to gain more Ca from the sprays than would the flesh. A single preharvest spray with a massive dose of $CaCl_2$ (84 kg/ha) elevated apple Ca by 0.7–1 mg per 100 g of fresh weight (Looney 1977). Large increases in Ca concentrations (30–120 ppm flesh dry weight) were also reported by Weis *et al.* (1980) following a similar type of spray applied to apple trees. Excessive leaf and fruit injury observed in this study leave serious doubt about the practicality of this technique.

Postharvest dips in 4% $CaCl_2$ solution is another practical means of increasing fruit Ca level. Immersion of single fruits in $CaCl_2$ was reported to elevate Ca levels in apple flesh by 60–120 ppm on a dry-weight basis (Mason *et al.* 1974a,b; Mason 1976; Betts and Bramlage 1977) or by 1.2 mg per 100 g of fruit fresh weight (Johnson 1979). This is slightly more than can be expected after five treatments with preharvest foliar sprays. When a thickener is added to the $CaCl_2$ solution, apples gained as much as 500 ppm Ca on a dry-weight basis (Mason *et al.* 1974a; Mason 1976) or 4.4 mg per 100 g of fresh fruit weight (Johnson 1979). Some apple cultivars (for example, 'Jonathan') develop skin injury after dipping in $CaCl_2$ solution. Postharvest dips of apples in $CaCl_2$ solution were shown to decrease the incidence of bitter pit, breakdown, and fruit softening in storage (Mason *et al.* 1974b; Mason 1976; Betts and Bramlage 1977; Scott and Wills 1977, 1979). The dips were also found effective in controlling surface pitting of cherries (Lidster *et al.* 1979) but did not control cork spot in pears, since cork spot develops prior to harvest (Richardson and Lombard 1979).

Postharvest vacuum or pressure infiltration of Ca into apples was shown to be very effective in controlling bitter pit, breakdown, and fruit softening (Scott and Wills 1977, 1979; Poovaiah and Shekhar 1978; Poovaiah *et al.* 1978; Johnson 1979). However, such treatment often results in extensive internal fruit damage that limits its practicality. Nevertheless, there is hope that this technique might be suitable for apple varieties with closed calyxes (Scott and Wills 1979).

Lee and Dewey (1981) proposed a new technique—cooling warm apples in a $CaCl_2$ solution—for infiltrating Ca into apple fruit. The reduction in temperature of the submerged fruit decreases the gas pressure in the intercellular spaces and forces the $CaCl_2$ solution into the fruit. An increase in fruit Ca concentration of 3.7 mg per 100 g of fresh fruit weight was obtained by cooling warm fruit at 22.5°C in a 4% $CaCl_2$ solution at −0.5°C for 1 hour. When surfactant (L-77) was added to the $CaCl_2$ solution, fruit gained as much as 4.8 mg Ca per 100 g of fresh weight within 10 minutes.

It has been shown that the susceptibility of apples to low temperature breakdown (LTB) is negatively correlated with fruit P (Perring 1968). Sharples (1980) indicated that the level of P in the fruitlets in July was more critical to LTB development than was the level of P in fruit at harvest. Spraying with different P compounds during the growing season increased fruit P and decreased the incidence of senescence and low temperature breakdowns in fruit of 'Cox's Orange Pippin' and 'Bramley's Seedling' (Johnson and Yogaratnam 1978; Yogaratnam and Sharples 1982). Sprays applied from mid-June to mid-July were most effective, whereas those applied later had a negligible effect, although they also elevated fruit P level (Yogaratnam and Sharples 1982). This points out the importance of high P level during the early stages of fruitlet development. Phosphorous sprays are a useful method of increasing the storage life of apples grown on trees insufficiently supplied with P. However, the prospect of decreasing recommended storage temperatures by raising fruit P concentration does not appear feasible (Johnson and Yogaratnam 1978; Johnson 1980; Yogaratnam and Sharples 1982).

Unlike bitter pit, the incidence of apple breakdown is negatively correlated with fruit Mg level (Perring 1968; Wills and Scott 1981). Sprays containing Epsom salt ($MgSO_4 \cdot 7H_2O$) applied to apple trees, judged to be at a low Mg nutritional level, decreased the incidence of low temperature and senescence breakdowns in storage (Yogaratnam and Johnson 1982). This effect is related to the accelerated fruit ripening of apples low in Mg. The background skin color of apples remained green longer in storage when the trees were sprayed with Mg salts during the growing season (Sadowski 1974).

Boron deficiency causes cracking and internal and external cork development in fruit. Confusion between B-deficiency symptoms and bitter pit and cork spot probably led to many misinterpretations as to the effect of B sprays on the occurrence of bitter pit and cork spot (Faust and Shear 1968). In addition to relieving B-deficiency symptoms, B applications may affect fruit quality through its effect on fruit Ca nutrition. Application of B to apple trees low in B was shown to increase the mobility of Ca in the trees (Shear and Faust 1971a). Shear (1980) concluded that a steady supply of B at the time of greatest demand by the fruit for Ca is essential for adequate fruit Ca concentration at harvest and consequently for fruit storage quality. In fact, when B was insufficent, B sprays increased fruit Ca levels; however, no decreases in bitter pit incidence were noted, although fruit cracking was significantly reduced (Dixon *et al.* 1973; Shorrocks and Nicholson 1980). In other studies, B sprays were reported to reduce the incidence of cork spot on apples (Dunlap and Thompson 1959; Stiles 1964; Shear and Faust 1971b; Greene and Smith 1979). Martin *et al.* (1976) concluded that B sprays may affect fruit Ca nutrition only when the trees suffer from B insufficiency. Excessive levels of B in apples, resulting from B sprays, was reported to accelerate fruit maturation, enhance red color development, and increase the incidence of breakdown and core flush in storage (Bramlage and Thompson 1962; Martin *et al.* 1976; Yogaratnam and Johnson 1982).

The reports in the literature concerning the effect of Zn sprays on apple fruit quality are inconclusive. Kolesnik and Tserevitinov (1966) showed a beneficial effect of Zn sprays on Ca, Mg, and P concentrations in apples. The data of Schmitz and Engle (1973) also indicated a positive effect of Zn sprays on fruit Ca that resulted in less bitter pit. However, the results of other investigations did not confirm these findings (Martin *et al.* 1976; Yogaratnam and Johnson 1982).

VIII. TECHNOLOGY AND GENERAL RECOMMENDATIONS FOR FOLIAR NUTRIENT APPLICATION

The technology of foliar application of nutrients must consider the time of application, most commonly used effective concentration, dose per acre, dilute vs. concentrated application, mixability with pesticide sprays, and, finally, pesticides as a source of foliar nutrients. Several of these factors have been addressed throughout this review. Others are considered here. In general, little information is available on the mixability and the effectiveness of foliar nutrients applied as concentrates in low-volume applications.

The Cooperative Extension Service in several states recommend the application of nutrients as sprays. These recommendations have evolved through growers' practice, observations, and the inability to correct certain nutrient insufficiencies or deficiencies through soil application of nutrients. We present a general listing of these recommendations in Table 8.2 based on those of California (J.A. Beutel personal communication), Massachusetts (Lord 1983), Michigan (Kenworthy 1968; Kenworthy *et al.* 1975), New York State (Stiles *et al.* 1983), Ohio (Williams *et*

TABLE 8.2. GENERAL RECOMMENDATIONS FOR FOLIAR APPLICATION OF NUTRIENTS

				Dose per unit area[2]		Concentration for dilute spray[3]		
Nutrient	Time of spray	Purpose	Materials[1]	U.S.	Metric	U.S.	Metric	Remarks
Boron	Prepink, pink, first cover	Maintenance	Solubor	2.5 pa	2.8 kh	0.5 pg	0.06 kl	Do not apply over 5 lbs per acre per year.
	Foliar	Maintenance	Solubor	2.5 pa	2.8 kh	0.5 pg	0.06 kl	Do not apply over 5 lb per acre per year.
	Prepink	Correct deficiency	Solubor	5 pa	5.6 kh	1 pg	0.1 kl	Do not apply over 5 lb per acre per year. Best applied after harvest or before bloom on pears.
	Foliar	Correct deficiency	Solubor	5 pa	5.6 kh	1 pg	0.1 kl	Do not apply over 5 lb per acre per year.
	Dormant	Correct deficiency	Solubor	4–6 pa	4.5–6.0 kh			
Calcium	Foliar	Reduce bitter pit and storage breakdown	$CaCl_2$	12–18 pa	13.5–20.4 kh	3 pg	0.35 kl	Make 3 or more applications as needed from mid-June to harvest.
			$Ca(NO_3)_2$	20–30 pa	22.5–34 kh	5 pg	0.6 kl	
	Foliar	Prevent fluoride injury	$CaCl_2$	15 pa	17 kh	3–4 pa	0.4–0.5 kl	Make 3 applications 10 days apart starting 2 weeks after pit hardening.
	Foliar	Reduce cork spot	$CaCl_2$	18.24 pa	20.4–27.2 kh	1–1.5 pg	0.1–0.18 kl	Do not use $Ca(NO_3)_2$. Apply in 1–7 cover sprays.
Iron	Foliar	Control lime-induced chlorosis	Fe chelate or organic complex					Follow mfg's directions.

(Continued)

TABLE 8.2. *(Continued)*

Nutrient	Time of spray	Purpose	Materials[1]	Dose per unit area[2]		Concentration for dilute spray[3]		Remarks
				U.S.	Metric	U.S.	Metric	
Magnesium	Foliar	Correct deficiency	$Mg(NO_3)_2$ 13.5% crystals	20–40 pa	22.5–45.3 kh	4–5 pg	0.5–0.6 kl	Apply in June. Repeat in July if necessary. Do not apply after August 1.
	Foliar	Correct deficiency	$Mg(NO_3)_2$, 0.4 lb/gal LC[4]	6–12 ga	56.7–113.4 lh	1.55 gg	1.5 ll	
			Epsom salts (magnesium sulfate)	40–80 pa	45.3–90.6 kh	10 pg	1.2 kl	
Manganese	Dormant	Correct deficiency	$MnSO_4$	2 pa	2.2 kh	0.5 pg	0.06 kl	Apply when leaf Mn level are less than 35 ppm for apple or 120 ppm for peach.
Nitrogen	Foliar	Correct deficiency	Urea	2–10 pa	2.2–11.2 kh	1–2 pg	0.1–0.2 kl	Not recommended when Ca-deficiency problems occur. Not effective on pear or stone fruits.
Potassium	Foliar	Correct deficiency	KNO_3	20 pa	22.5 kh	7 pg	0.8 kl	Usually needed on prunes in California.
Zinc	Dormant	Maintenance	$ZnSO_4$ 36% crystals	6 pa	4.5 kh	1.5 pg	1.5 ll	
	Dormant	Maintenance	$ZnSO_4$, 47 g/l (1.2 lb/gal)LC[4]	2 ga	18.9 lh	0.5 gg	0.5 ll	

Dormant	Maintenance	Zn chelate or organic complex					Follow mfg's suggestions.
Post-harvest	Maintenance	$ZnSO_4$ 36% crystals	6–25 pa	6.8–28.3 kh	0.7–4 pg	0.1–0.8 kl	
Post-harvest	Maintenance	$ZnSO_4$, 47 g/l (1.2 lb/gal)LC[4]	2 ga	18.9 lh	0.25–0.5 gg	0.25–0.5 ll	
Post-harvest	Maintenance	Zn chelate or organic complex					Follow mfg's instructions.
Dormant	Correct deficiency	$ZnSO_4$ 36% crystals	40 pa	45.3 ka	10 pg	1.2 kl	
Dormant	Correct deficiency	$ZnSO_4$, 47 g/l (1.2 lb/gal)LC[4]	12 ga	113.4 lh	3 gg	3 ll	
Dormant	Correct deficiency	Zn chelate or organic complex					Follow mfg's suggestions.
Foliar	Correct deficiency	Zn chelate or organic complex					Can cause injury particularly on stone fruits. Follow mfg's recommendations.
Post-harvest	Correct deficiency	$ZnSO_4$ 36% crystals	27 pa	30.5 kh	3–6 pg	0.3–0.7 kl	Do not apply before Oct 1.
Post-harvest	Correct deficiency	$ZnSO_4$, 47 g/l (1.2 lb/gal)LC[4]	7 ga	66.1 lh	1–1.5 gg	1–1.5 ll	Do not apply on apricot.

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[1] Use any one of the listed materials or listed combinations.

[2] ga = gal per acre; kh = kg per ha; lh = liters per ha; pa = pounds per acre.

[3] gg = gal per 100 gal; kl = kg per 100 liters; ll = liters per 100 liters; pg = pounds per 100 gal.

[4] LC = liquid concentrate.

al. 1983), Pennsylvania (Ritter 1980), Washington (Young 1983), and West Virginia (Stump 1981; Young *et al.* 1983), combined with the experience of scientists in other countries and our own.

A. Boron

Boron deficiency is common throughout the Pacific Northwest where it manifests itself in poorly developed stamens, blast of pear blossoms, inadequate fruit set, bark necrosis of apple, corking in the fruit, and cracking of fruit. In the Northeast, B deficiency is observed through its effect on Ca uptake. Symptoms of this are cork spot and cracking of fruit, both Ca-related disorders. Flatness of fruit is also often attributed to B insufficiency. When leaf B levels are in the range of 20–25 ppm (desired is 35 ppm) on a dry-weight basis, supplemental B is needed. Boron is taken up from the soil only at higher soil temperatures than are other elements. Late bud break and small spur leaves in apple may be signs of incipient B insufficiency, and B sprays may be useful in such cases. To improve the B status of the tree in early spring, B must be applied in late fall or early spring before bloom. Too frequent spraying with B after bloom may cause fruit drop, fruit breakdown of apples in storage, and possibly B toxicity (dieback of shoots and veinal chlorosis).

Most growers prefer annual B sprays to soil application of borax. They apply B in the first and/or second spray after petal fall in New York (Stiles *et al.* 1983). Soil application of B, especially on sandy soils, may easily induce toxicity symptoms since the safety margin for soil application is very narrow (Beyers and Terblanche 1971d).

Experience has indicated that B sprays can be concentrated up to eight times with satisfactory results. Solubor may be mixed with most nonoil base sprays (Travis 1983), but it cannot be applied with $CaCl_2$ (Williams *et al.* 1983).

B. Calcium

Calcium is applied principally to prevent major fruit disorders (e.g., cork spot and bitter pit) in apple, to improve storage quality of fruit, and to prevent fluoride injury (the so-called soft suture) in peaches. In the case of apples, the choice of the form of Ca and the time of application depend on the disorder the sprays are intended to correct. Cork spot develops early, soon after bloom. The choice here is $CaCl_2$, and the applications should be made in or coinciding with early cover sprays. Bitter pit and storage breakdown are primarily storage disorders; thus, later sprays after cessation of shoot growth are recommended. In this case, $CaCl_2$ or $Ca(NO_3)_2$ can be used. As mentioned earlier, the tree must deliver the maximum amount of Ca to the fruit. Nitrogen from $Ca(NO_3)_2$, if applied early, may increase shoot growth depending on the N status of the tree. Since shoots compete with fruit for Ca, $Ca(NO_3)_2$ sprays may actually decrease fruit Ca and increase cork spot (Stiles 1964). However, $Ca(NO_3)_2$ can be used effectively after both shoot growth and Ca uptake to the fruit have stopped (Quinlan 1969). Where Ca uptake continues throughout the summer, the advisability of late $Ca(NO_3)_2$ sprays is questionable (Rogers and Batjer 1954; Woodbridge 1971). Calcium nitrate sprays should not be used on cultivars that are sensitive to nitrate injury, i.e., 'Delicious' and 'York' (Stiles *et al.* 1983; Young *et al.* 1983). Thus the general choice for Ca sprays is $CaCl_2$.

The experience of several growers' groups indicates that $CaCl_2$ can be mixed with pesticide sprays. However, the combination of Captan or Guthion and $CaCl_2$ may increase foliar burn (Drake and Bramlage 1982). As mentioned before, $CaCl_2$ cannot be combined with B solutions. It appears more effective in increasing fruit Ca when concentrated up to 10 times than in diluted solutions (Drake and Bramlage 1983). The initial pH of $CaCl_2$ in water is around 10.3. This high pH may reduce the effectiveness of some pesticides. It is recommended that when combined with pesticides, the solution be acidified to lower the pH to about 6 (Drake and Bramlage 1983). High pH may be one of the reasons for the occasional leaf injury caused by concentrated sprays of $CaCl_2$ (Stump 1981; Young *et al.* 1983). When cork spot is a serious problem, $CaCl_2$ is recommended in every cover spray (Anon. 1980).

Fluoride injury to stone fruits can occur when orchards are located near aluminum smelters. Three applications of $CaCl_2$ are usually effective in preventing this type of injury (Benson 1959). Spraying at 10-day intervals beginning with pit hardening is recommended.

C. Copper

Copper deficiency or "wither tip" occasionally has been observed in orchards. Terminal leaves on part of the tree may wither and fall. Application of copper sulfate usually corrects this symptom. Copper deficiency can also be readily corrected with Bordeaux mixture (Ritter 1980). This mixture contains 8 pounds of copper sulfate plus 8 pounds of spray lime in 100 gal of water (1 kg each/100 l). Naturally, Bordeaux mixture also acts as a fungicide. Applying Cu may cause severe russeting of fruit, especially Anjou pears and apples. The best time for spray application to bearing trees is after harvest or immediately after bud break (Young 1983).

Copper deficiency in nonbearing apple and pear trees may be controlled with copper oxychloride or copper oxysulfate sprays in the spring

(Beyers and Terblanche 1971c). In the case of peach and plum, addition of hydrated lime is necessary to prevent leaf injury.

In addition to the materials already mentioned, there are some others that may serve a dual purpose as fungicides and suppliers of nutritional Cu. Nutra-Spray ZMC is primarily recommended as a copper fungicide, but it also supplies Zn and Mn. It is compatible with insecticides, but it should not be used in strongly acidic mixtures (Leffingwell 1981). Nutra-Spray COPOPHOS is a similar copper fungicide, which also supplies P and Zn. It is compatible with insecticides and miticides (Leffingwell 1981). Both Nutra-Sprays, ZMC and COPOPHOS, are recommended for application by air, low-volume, and conventional dilute sprayers. Nutra-Spray CB22, Nutra-Spray CB12, and Nutra-Spray BCC are all used as copper-containing pesticides. CB22 is compatible with most insecticides; BBC is compatible with organic phosphate and carbamate pesticides but it should not be used with Morestan and in mixtures that are strongly acidic since injury may occur from excessive solubility. Both are recommended as dilute sprays. CB12 is recommended for both low-volume and dilute applications and is used especially to control septoria and brown rot on citrus (Leffingwell 1981).

Excessive use of Cu sprays may induce toxicity resembling Fe chlorosis in plants due to excessive accumulation of this element in the soil (Beyers and Terblanche 1971c).

D. Iron

Lime-induced or bicarbonate-induced chlorotic leaves are usually recommended to be sprayed with Fe chelates twice during the growing season. The first spray is recommended about 4 weeks after bloom and the second spray 3 weeks later. These sprays are temporary measures at best and provide rather disappointing results (Wallihan *et al.* 1964; Beyers and Terblanche 1971e). Addition of a surfactant, Vatsol OT or L-77, to the Fe spray solution helped significantly to improve control of iron chlorosis; however, the use of Vatsol OT caused leaf injury (Wallihan *et al.* 1964; Neuman and Prinz 1974a). Trunk implantation of ferrous sulfate or ferrous citrate was reported to correct lime-induced Fe chlorosis in apples (Mochecki 1978). The best way to correct lime-induced Fe chlorosis is soil application of Fe-EDDHA chelate (Fe Na ethylenediamine di-O-hydroxyphenylacetate) (Beyers and Terblanche 1971e).

Low levels of Fe are rarely noted in most eastern orchards. In Pennsylvania, however, Fe chlorosis often occurs in blueberries, and it can be corrected with Ferbam (fungicide) sprays (Ritter 1980).

E. Magnesium

Magnesium deficiency is often most severe on fruiting trees. Usually two to five sprays with 2% Epsom salts are recommended to correct this deficiency. The first spray should be applied in June and the next spray at 2-week intervals (Ford 1968; Beyers and Terblanche 1971f). Since residual effects from Mg sprays in the next year are negligible, soil applications of dolomitic lime are essential for long-term correction of Mg deficiency. However, due to the slow movement through the soil and low absorption rates by the roots, the effects of soil applications of Mg become visible only after several years. However, fall application of a sulfate form of Mg gives response next season. Foliar applications of $MgCl_2$ or $Mg(NO_3)_2$ were found to be more effective than that of $MgSO_4$ in controlling Mg deficiency (Ford *et al.* 1965; Beyers and Terblanche 1971f), although the risk of leaf injury is higher when $MgCl_2$ is employed. Epsom salts have been applied to apple trees in a low-volume spray at concentrations up to 92% without leaf injury (Greenham and White 1959).

Epsom salt sprays are compatible with most pesticides up to 15 times concentrated, and Mg-EDTA is also amenable to concentrate applications (Stiles 1982). In general, Epsom salt is not recommended for mixing with lead arsenate.

F. Manganese

Manganese deficiency on fruit trees can be easily corrected with manganese sulfate sprays at petal fall and 4–6 weeks later if necessary. Spraying with the fungicides Dithane M-45 or Dikar was found very effective in increasing leaf Mn levels (Beyers and Terblanche 1971b; Stang *et al.* 1978). Such pesticides should be applied at petal fall and in the first and second cover spray to correct Mn deficiency (Lord 1983; Young 1983).

Application of manganese sulfate to the soil to control Mn deficiency is not effective on alkaline or heavily limed soils.

G. Potassium

Potassium sprays are recommended to decrease severe K deficiency in prunes on certain clay soils. The recommended dose is 0.84 kg KNO_3/100 liters of water (7 lb/100 gal) applied at 16.8–22.4 kg KNO_3/ha (15–20 lb/acre). Application is recommended at 2, 4 and 6 weeks after bloom. It will not completely correct the deficiency on soils with high K-fixing ability. However, in addition to K application through a drip irrigation system, this is the only treatment that effectively increases the K status of the plant (Uriu *et al.* 1980; Stebbins 1977).

H. Urea

Urea sprays may be used on apple and citrus trees to supplement soil application of N. They are not effective on stone fruits or on pear. Recommendations range from 0.5 to 1.2 kg urea per 100 liter of water (4–10 lb/100 gal). Applications are recommended before or after bloom or after harvest when leaves are still in good condition. In the case of postharvest sprays, the concentration of urea may be raised to 5 kg/100 liters (42 lb/100 gal).

Application after the second cover spray may decrease red color development in red apples or retain green color in yellow apples. Fall applications should be made only after the shoots have stopped growing, otherwise the tree will not develop the desired hardiness. Some N formulations (Tables 8.3 and 8.4) contain 1–9% ammonium. In our experience, ammonium sprays greatly reduce shoot growth of apple. Whether the ammonium ion in the complex spray would act this way is not known.

Urea is incompatible with Morocide; mixing of urea is not advised with Cyprex, Dodine, Karathane, Dikar, Omite or Comite (Leffingwell 1981).

I. Zinc

Low levels of Zn and Zn deficiency, as signified by small thin leaves, perhaps pale yellow leaves, and rosette-type growth, are often observed, especially in the West. The first symptoms on 'Delicious' apples may be a limited number of small leaves, poor fruit set, and small fruit. Soil applications of Zn are effective only when made prior to planting and last only for 3 to 5 years. Thus foliar applications become a necessity. Depending on the Zn status of the plants, Zn sprays may be applied as maintenance sprays or for correcting deficiency. High rates of Zn application may cause severe injury to shoots, buds, leaves, or fruit. Various Zn chelates and organic complexes are available that reduce the potential of foliar injury. The fungicides Dithane M-45 and Zineb contain Zn in a form that is not phytotoxic (Beyers and Terblanche 1971a). During the dormant season, higher rates of Zn compounds can be applied. Injury from spring applications has been associated with oil sprays and/or cool temperatures at the time of application. Zinc sulfate is not recommended for application within 3 days before or after applying oil. Some Zn

TABLE 8.3. COMPOSITION AND RECOMMENDED DOSE OF COMMERCIAL FOLIAR FERTILIZERS AVAILABLE IN THE UNITED STATES

Product	Composition											Recommended dose[1]		Mfg[2]	Remarks
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (%)	Fe (%)	Zn (%)	Cu (%)	Mn (%)	U.S.	Metric		
Allied NFE	16	—	—	—	—	—	—	4	—	—	—	0.5–1.3 ga	5–12 lh	1	Urea and $(NH_4)NO_3$
Allied NMG	14	—	—	—	4	—	—	—	—	—	—	1–10 ga	9.4–94 lh	1	Urea and $(NH_4)NO_3$
Allied NZN	15	—	—	—	—	—	—	—	5	—	—	0.1–2.0 ga	1.2–19 lh	1	Urea and $(NH_4)NO_3$
Leaf Life 3	10	12	—	—	—	—	—	0.5	2	—	1	0.5 ga	4.7 lh	11	Urea with buffering agent
Leaf Life 7	6	—	—	—	—	—	—	1	3	—	1	0.5 ga	4.7 lh	11	Urea, Zn, Fe, Mn chelated with EDTA
Leaf Life 8	—	13	17.4	—	—	—	—	0.5	1	—	—	0.5 ga	4.7 lh	11	Fe, Zn chelated with EDTA
Leaf Life 20–10–30	20	10	30	—	—	—	—	0.1	1.2	0.1	0.1	2–10 pa	2.3–11.3 kh	11	Urea and KNO_3
Leaf Life 22	—	—	—	—	4	12.5	—	2	14	3.2	4	12–16 pa	13.6–18 lh	11	
Leaf Life 102	11.6	2.2	35.2	—	—	—	—	0.1	7.7	—	1	3–10 pg	0.4–1.19 kh	11	KNO_3 and $(NH_4)_2HPO_4$
Leaf Life Boron Nutr. Spray	—	4	6	—	—	—	1.1	—	1	—	—	0.5–1 ga	4.7–9.4 lh	11	Zn chelated with EDTA
Leaf Life Chelated Fe	—	—	—	—	—	—	—	5	—	—	—	0.25 gg	0.25 ll	11	Fe chelated with EDTA
Leaf Life Chelated K-Zinc	—	—	—	—	—	—	—	—	8.4	—	—	0.25 gg	0.25 ll	11	ZN chelated with EDTA
Leaf Life Chelated Mn	—	—	—	—	—	—	—	—	—	—	6	0.5 gg	0.5 ll	11	Mn chelated with EDTA
Leaf Life NPKS	8	8	2	—	—	1.5	—	—	2	—	1	0.5 ga	4.7 lh	11	Urea with buffering agent
Leaf Life Chelated Zn	—	—	—	—	—	—	—	—	9	—	—	0.5 ga	0.5 ll	11	
Leaf Life Zn-Cu	—	—	—	—	—	—	—	—	19	19	—	6–9 pg	0.7–1.1 kh	11	
Nutra-Phos 3–15	—	15	—	7.5	—	3	—	—	15	—	15	15–45 pa	17–51 kh	4	
Nutra-Phos 10	—	10	—	10	—	—	—	—	14	—	7	20–50 pa	28–56 kh	4	
Nutra-Phos 12	—	12	—	11	—	—	—	—	25	—	—	10–35 pa	11–40 kh	4	
Nutra-Phos 24	—	24	—	20	—	6	—	—	12	—	—	10–30 pa	11–34 kh	4	
Nutra-Phos Fe	3	27	—	—	—	3	—	21	—	—	—	20–30 pa	26–34 kh	4	$(NH_4)_2HPO_4$
Nutra-Phos IMC	—	4	9	—	—	8	—	—	10	6	10	10–25 pa	11–28 kh	4	
Nutra-Phos K	—	16	16	—	—	—	—	—	31	—	—	10–25 pa	11–28 kh	4	
Nutra-Phos Mg	—	25	—	10	5.5	—	—	—	5.5	—	—	10–35 pa	11–40 kh	4	
Nutra-Phos N	20	12	—	5	2	—	1	1	2	—	—	8–20 pa 3–5 pg	9–26 kh 0.3–0.6 kl	4	Urea and $(NH_4)_2HPO_4$

(Continued)

TABLE 8.3. *(Continued)*

Product	N	P	K	Ca	Mg	S	B	Fe	Zn	Cu	Mn	Recommended dose[1]		Mfg[2]	Remarks
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	U.S.	Metric		
Nutra-Phos Super K	7	13	34	—	—	—	—	—	12	—	—	10–40 pa	11–45 kh	4	KNO_3
Nutra-Spray BCC	—	—	—	—	—	—	—	—	—	51	—	4–5 pg	0.5–0.6 kl	4	Primarily used as fungicide
Nutra-Spray CB12	—	—	—	—	—	—	—	—	—	12.5	—	4–6 pg	0.5–0.7 kl	4	Primarily used as fungicide
Nutra-Spray CB22	—	—	—	—	—	—	—	—	—	22	—	3–10 pg	0.3–1.2 kl	4	Primarily used as fungicide
Nutra-Spray COPOPHOS	—	10.8	—	—	—	—	—	—	5.4	14.5	—	15–20 pa 3–7 pg	17–28 kh 0.3–0.8 kl	4	Primarily used as fungicide
Nutra-Spray Mn 35	—	—	—	—	—	—	—	—	—	—	35	25–30 pa 3–5 pg	28–34 kh 0.3–0.6 kl	4	
Nutra-Spray ZM 18–7	—	—	—	—	—	—	—	—	18.5	—	7	20–50 pa 5–10 pg	28–50 kh 0.6–1.2 kl	4	1 pound/each 1% oil emulsion
Nutra-Spray ZM 25–25	—	—	—	—	—	—	—	—	25	—	25	15–30 pa 4 pg	17–34 kh 0.5 kl	4	1 pound/each 1% oil emulsion
Nutra-Spray ZMC 7–4	—	—	—	—	—	—	—	—	7.5	4	4	20–40 pa 5–10 pg	26–45 kh 0.6–1.2 kl	4	
Nutra-Spray ZMC 12–10	—	—	—	—	—	—	—	—	12	10	2	15–30 pa 3–5 pg	17–56 kh 0.3–0.6 kl	4	Primarily used as fungicide
Nutra-Spray Zn 50	—	—	—	—	—	—	—	—	50	—	—	5–15 pa 2–3 pg	6–17 kh 0.2–0.4 kl	4	
Peters CHFE	—	—	—	—	—	—	—	10	—	—	—	40 pg	4.7 kl	3	
Peters CHMn	—	—	—	—	—	—	—	—	—	—	12	—	—	3	
Solubor	—	—	—	—	—	—	20.5	—	—	—	—			10	See Table 8.2 for dosages
Sorba-Spray Ca	?	—	—	8	—	—	—	—	—	—	—	2–4 ga	19–38 lh	4	$Ca(NO_3)_2$
Sorba-Spray CaB	?	—	—	5	—	—	0.5	—	—	—	—	2–4 ga	19–38 lh	4	$CA(NO_3)_2$
Sorba-Spray Cu	—	10	—	—	—	1	—	—	1	4	—	1–2 ga	10–19 lh	4	
Sorba-Spray Mg	—	10	—	—	3	3	—	—	1	—	—	2–4 ga	19–38 lh	4	
Sorba-Spray MIP	—	10	—	—	—	2.5	—	2	—	—	2	2–4 ga	19–38 lh	4	
Sorba-Spray Mn	—	12	—	—	—	2	—	—	2	—	2	2–4 ga	19–38 lh	4	
Sorba-Spray ZBK	1	—	6	—	—	—	1	—	1	—	—	2–4 ga	19–38 lh	4	KNO_3
Sorba-Spray ZIP	—	8	—	—	—	2	—	3	1	—	—	2–4 ga	19–38 lh	4	
Sorba-Spray ZKP	—	16	9	—	—	—	—	—	1	—	—	2–4 ga	19–38 lh	4	
Sorba-Spray ZNP	10	12	—	—	—	1	—	—	2	—	—	2–4 ga	19–38 lh	4	1.5% NH_3, 8.5% urea

[1] ga = gal per acre; gg = gal per 100 liters; kh = kg per ha; kl = kg per 100 liters; lh = liters per ha; ll = liters per 100 liters; pa = pounds per acre; pg = pounds per 100 gal.

[2] Codes for manufacturers: 1 = Allied Chem.; 3 = Grace and Company; 4 = Leffingwell; 10 = U.S. Borax; 11 = PureGro. See Literature Cited for addresses and references.

TABLE 8.4. COMPOSITION AND RECOMMENDED DOSE OF COMMERCIAL FOLIAR FERTILIZERS AVAILABLE IN THE UNITED STATES

	Composition													Recommended dose[1]			
Product	N	P	K	Ca	Mg	S	B	Fe	Zn	Cu	Mn	Co	Mo			Mfg[2]	Remarks
	(%)	(%)	(%)	(%)	(%)	(%)	(parts per thousand)					(ppm)	(ppm)	U.S.	Metric		
Complesal	11	8	5	—	—	—	—	—	—	—	—	—	—	1–1.5 ga	9.5–14 lh	2	2.26% NO_3^-, 3.63% NH_3, 5.11% urea
NutriLeaf	20	20	20	—	—	—	0.2	1.0	0.5	0.5	0.5	—	5	2 pg	0.2 kl	5	6.2% NO_3^-, 6.2% NH_3, 7.6% urea
Peters Acid Spec.	21	7	7	—	0.05	—	0.07	1.5	0.03	0.03	0.03	—	10	2 pg	0.2 kl	3	9% NH_3, 11.9% urea
Peters Foliar Feed	27	15	12	—	—	—	0.2	1.2	0.6	0.6	0.6	6	6	2–7 pa 5 pg	2.3–8 kh 5 kl	3	3.7% NO_3^-, 3% NH_3, 20.2% urea
Peters Spray Feed	30	10	10	—	0.05	—	0.07	0.5	0.02	0.03	0.03	—	10	2–5 pg	0.2–0.5 kl	3	3.1% NO_3^-, 2.1%NH_3, 24.7% urea
Plantex 15–15–30	15	15	30	—	—	—	0.2	1.0	0.5	0.5	0.5	—	5	6–13 pa	6.8–14.7 kh	7	8.8% NO_3^-, 2.9% NH_3, 3.2% urea
Plantex 15–30–15	15	30	15	—	—	—	0.2	1.0	0.5	0.5	0.5	—	5	6–13 pa	6.8–14.7 kh	7	4.4% NO_3^-, 5.9% NH_3, 4.7% urea
Plantex 20–5–30	20	5	30	—	—	—	0.2	1.0	0.5	0.5	0.5	—	5	5–10 pa	5.7–11 kh	7	8.8% NO_3^-, 1% NH_3, 10.2% urea
Plantex 20–20–20	20	20	20	—	—	—	0.2	1.0	0.5	0.5	0.5	—	5	1–2 pg	0.1–0.2 kl	7	5.9% NO_3, 3.8% NH_3, 10.2% urea
Plant Marvel	25	15	10	—	—	4	0.2	1.0	0.5	0.5	0.5	—	9	No dose recommended.		6	22% NH_3, 3% NO_3^-
Prontogro	20	20	20	—	—	—	0.2	1.0	0.5	0.5	0.5	—	5	No dose recommended.		8	5.98% NO_3^-, 5.58% NH_3, 8.4% urea
This Ca	—	—	—	6	—	—	—	—	—	—	—	—	—	1–2 pg		9	Chelated from $CaCl_2$
This Cu + S	—	—	—	—	—	4	—	—	—	50	—	—	—	0.2 gg	0.2 ll	9	Salt of phenolic acid
This Fe	—	—	—	—	—	4	—	50	—	—	—	—	—	0.2 gg	0.2 ll	9	Salts of phenolic acid
This Mn	—	—	—	—	—	4	—	—	—	—	50	—	—	0.2gg	0.2 ll	9	Salts of phenolic acid
This Tree Mix	—	—	—	—	1	4	—	10	30	—	10	—	—	0.2 gg	0.2 ll	9	Salts of phenolic acid
This Zn	—	—	—	—	—	4	—	—	70	—	—	—	—	0.2 gg	0.2 ll	9	Salts of phenolic acid
Xylex	12	6	6	—	—	—	0.2	1.0	0.5	0.5	0.5	5	5	1.0 gg	1.0 ll	9	12% urea, salts of phenolic acid

[1] ga = gal per acre; gg = gal per 100 liters; kh = kg per ha; kl = kg per 100 liter; lh = liters per ha; ll = liters per 100 liters; pa = pounds per acre; pg = pounds per 100 gal.

[2] Codes for manufacturers: 2 = American Hoechst; 3 = Grace and Company; 5 = Miller Chemical; 6 = Plant Marvel; 7 = Plantco; 8 = Pronto; 9 = Stoller Chemical. See Literature Cited for addresses and references.

formulations can be applied in oil as shown on the label. Foliar applications are recommended especially for peach and all the other crops if necessary at 0.18–0.48 kg $ZnSO_4$ per 100 liters (1.5–4 lb/100 gal), 3–4 weeks after petal fall. The use of zinc oxide and zinc oxysulfate is recommended under South African conditions (Beyers and Terblanche 1971a). Fall application after harvest, when the leaves are still in good condition, is recommended for apricots, plums,and pears in California, is not recommended for apricots in Washington State. If a high concentration of 1.2 kg $ZnSO_4$ per 100 liters (10 lb/100 gal) is applied in the fall, as in California, the spray will burn the leaves, but it penetrates into the wood and acts almost like a dormant spray. The lower dose of 0.36–0.72 kg/100 liters (3–6 lb/100 gal) applied at 30 kg/ha (24 lb/acre) after October 1 in Washington State will not have a leaf-burning effect, but its effectiveness is reduced. Nevertheless, it may be needed in severe deficiency cases combined with spring application. Both spring and fall applications may be necessary for cherry. Symptoms of Zn deficiency very often mask those of Mn. Therefore, addition of Mn to sprays usually provides better tree responses to Zn sprays (Beyers and Terblanche 1971a). The same applies to addition of urea, which probably improves Zn absorption.

IX. COMMERCIALLY AVAILABLE FOLIAR FERTILIZERS

There is a relatively large number of foliar fertilizers on the market. Each of these fertilizers is formulated either for specific purposes or for general use. Tables 8.3 and 8.4 list the foliar fertilizers available in the United States and their compositions. Commercially available fertilizers can be divided into two large groups: (1) those containing major nutrients and very low concentrations of trace elements, and (2) those formulated for corecting special nutrient deficiencies or to overcome nutrient insufficiencies, which contain a relatively high percentage of the specific nutrient. We know very little about these specially formulated foliar nutrients. The information including rates of recommended dose in Tables 8.3 and 8.4 are supplied by the manufacturers. The Cooperative Extension Service usually refers to the manufacturer's recommendations for usage of specially formulated nutrients.

X. CONCLUSION

Foliar application of nutrients can supply essential elements directly to the foliage and fruit at times when rapid responses may be desired.

This method of application, with few exceptions, should be considered as a temporary measure that supplements soil applications (Stiles 1982). Certain organs of a tree may require more of a particular nutrient than does the entire tree (Faust 1980). Fruits of apple and pear, for example, require more Ca than the plant can supply even though the tree as a whole may have enough Ca. Spurs should be high in N to assure good fruit set, but high N is not desired later. Boron is especially needed during early spring when the roots may not be able to absorb it from the cool soil. Nutrient sprays, then, can be looked at as a fine-tuning technique to satisfy special needs at particular times or in special organs of the tree.

Foliar application of B, Cu, Mg, Mn, and Zn for controlling deficiencies of these elements in fruit trees have advantages over soil application. Those advantages are high effectiveness, rapid plant responses, convenience, and elimination or reduction of toxicity symptoms brought about by excessive soil accumulation of a given element. The disadvantage of foliar nutrition is that the effects of sprays are temporary and are not transmitted into the next year. Thus, annual sprays are necessary. In the case of Cu and Zn another disadvantage of foliar nutrition is the danger of leaf and/or fruit injury. By proper timing, injury can be avoided but there is need for better means of supplying these elements to fruit trees (Navrot and Banin 1982).

Efforts have been made to supply the entire N requirement of apple through sprays. Research has shown that this is possible in citrus, although the efficiency of foliar application does not exceed that of soil application (Embleton and Jones 1974). Based on limited testing in apples, it seems much better if the trees are supplied with adequate soil N and the temporary early-spring requirement is met by sprays applied in the late fall or early spring (Forshey 1963b). The increased use of herbicides in the soil management of orchards in the last decade has diminished fertilizer requirements for N (Atkinson and White 1980). In these new circumstances, the amount of N supplied by urea sprays might be sufficient to maintain high productivity of the trees. More long-term research is needed on this subject.

Fall application of N delays senescence and maintains green leaves longer for an extended period of photosynthesis. This may be very important for creating additional photosynthates for root growth and early-spring growth, as well as for deposition into the woody parts of the tree for increased winter hardiness. Thus the fall application of N sprays, in addition to supplying the early-spring N needs of the tree, may promote essential activities in the tree that would not occur or would occur to a lesser degree.

A new role for foliar nutrients emerges from preliminary experiments. Foliar sprays may regulate the water use of the tree and may prepare the tree for periods of drought (Swietlik *et al.* 1982a,b,c) and salinity stress (Malakondaiah and Rajeswararao 1979). If this is indeed the case in orchard conditions—that is, if nutrient sprays can be used to regulate water use and still maintain photosynthetic activity of trees—nutrient sprays will be used more often in the future than at present. As our knowledge of the nutrient requirements of fruit trees increases, we see an increasing role for foliar application in "fine tuning" tree nutrition.

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