13

Mineral Nutrition

R. Scott Johnson and K. Uriu

For normal growth and optimum production, fruit trees require 13 essential nutrients in varying amounts (table 13.1). Those needed in relatively large amounts are termed macronutrients – nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Those needed in smaller concentrations are called micronutrients – chlorine (Cl), iron (Fe), manganese (Mn), zinc (Zn), boron (B), copper (Cu), and molybdenum (Mo).

Growers must learn to manage these nutrients for optimum growth and production and to minimize adverse environmental effects. Most important is balancing the nutrients – when one element is deficient, its absence can negatively affect plant processes and thereby inhibit optimum uptake, utilization, or distribution of other elements. On the other hand, an excess of any element may be toxic to trees, thus affecting the availability of other nutrients in the soil.

Besides the great variation in amounts of different nutrients needed by plants, concentrations of nutrients in individual organs and at different times during the season also differ substantially. For instance, the calcium content of leaves can be 10 to 30 times higher than that in the fruit (table 13.1). Also, the percentage of leaf calcium steadily increases over the season, while leaf nitrogen content declines. Therefore, efficient nutrient management calls for supplying the right nutrient to the right organ at the right time. Most of the elements essential to trees need not be supplied in a regular fertilizer program because (1) many elements are abundant (and available) enough in most soils to provide an adequate supply; (2) perennial trees recycle a substantial portion of some nutrients from the leaves back into the tree structure before leaf fall, and (3) for some nutrients (i.e., phosphorus), very little is removed in the crop, leaves, and prunings. Because of the last two reasons, nutrients like phosphorus are not needed in nearly the quantities that they are in certain annual crops. Generally, nitrogen is the only macronutrient that must be consistently supplied to fruit trees in California. Under certain conditions, other nutrient deficiencies can develop. Toxicities can also become a problem. These will be discussed in the sections for individual nutrients.

Nutrient problems (deficiencies and excesses) can often be identified visually, but it is advisable to chemically analyze leaf samples to confirm the problem and quantify its severity. Even without obvious problems, leaf samples should be taken to check the effectiveness of one's nitrogen fertilization program and to watch for gradual changes in nutrient levels. Leaf samples should be taken in June or July when nutrient levels are relatively stable. For peach and nectarine, basal to midshoot leaves on moderately vigorous fruiting shoots (10 to 20 inches long) are sampled. For plum, the standard is nonfruiting spur leaves. Each sample should include 60 to 100 leaves taken randomly from within the orchard. The leaves are washed, dried at 150° to 160°F (66° to 72°C), and sent to a chemical laboratory for analysis. Optimum leaf concentrations for each element are shown in table 13.1.

Nitrogen (N)

In soil

In soil, nitrogen can exist in several forms. Its conversion from one form to another must be understood to manage nitrogen efficiently so that as much as possible is available to the plant.

In soil, nitrogen can exist in a soil organic form, or as an ammonium ion (NH_4^+), nitrite ion (NO_2^-), or nitrate ion (NO_3^-). In most soils, more than 90

Table 13.1. Nutrient elements in stone fruit

	Level in leaves								
	Peaches and Nectarines			Plums					
Element	Deficient below	Optimum range	Toxic over	Deficient below	Optimum range	Toxic over	Range in mature fruit	Mobility* in plant	Occurrence of deficiency in California
	%	%	%	%	%	%	%		
N	2.3	2.6–3.0	–†	–	2.3–2.8	–	1.0–1.5	Med.	Common
P	–	0.1–0.3	–	–	0.1–0.3	–	0.1–0.3	High	Rare
K	1.0	Over 1.2	–	1.0	Over 1.1	–	1.5–2.5	High	Occasional
Ca	–	Over 1.0	–	–	Over 1.0	–	.05–.15	Low	Unknown
Mg	0.25	Over 0.25	–	0.25	Over 0.25	–	.05–.15	High	Occasional
Cl	–	–	0.3	–	–	0.3	–	High	Unknown
S	–	–	–	–	–	–	–	Low	Unknown
	ppm	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*	*ppm*		
Fe	60‡	Over 60‡	–	–	–	–	20–80	Low	Common
Mn	20	Over 20	–	20	Over 20	–	5–10	Med.	Occasional
Zn	15	Over 20	–	18	Over 18	–	10–20	Low	Common
B	18	20–80	100	25	30–60	80	20–50	Low	Rare
Cu	–	Over 4	–	4	Over 4	–	5–10	Low	Rare
Mo	–	–	–	–	–	–	–	Med.	Unknown

*Indicates ability to move from older leaves to developing leaves and fruit.
†Data unavailable.
‡Leaf samples need to be taken in April or May.

percent of the nitrogen is in the soil in organic form, tied up in living organisms and decaying matter. Under natural conditions, this form breaks down slowly into ammonium ions. About 2 to 3 percent of organic nitrogen is converted each year, an amount usually insufficient to sustain vigorous plant growth – so fertilizer nitrogen must be added.

The next step in the conversion of soil nitrogen, from the ammonium form to the nitrate form, occurs in two distinct steps involving two groups of bacteria. The first step is from ammonium to nitrite and the second step from nitrite to nitrate.

$$NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$$

These two steps, referred to as nitrification, occur rapidly (within 2 weeks) under most soil and environmental conditions. Both nitrite and ammonium can be toxic to plants, so it is necessary to understand the nitrification processes. (Actually, the ammonium ion itself is not toxic, but it can be partially converted to ammonia gas, which is toxic.)

Nitrification can be affected by temperature, soil water conditions, soil pH, and the carbon-to-nitrogen ratio in the soil. Optimum conditions for nitrification occur at soil temperatures of 80° to 90°F (27° to 32°C), moderate soil water status, and a pH of 6 to 7. The process is inhibited for a time when the carbon-to-nitrogen ratio of the soil is high, as when straw or wood shavings are applied.

Nitrogen can be lost from the soil as a gas in several different forms: ammonia gas, elemental nitrogen, and nitrous oxides. When ammonium fertilizers are applied on the soil surface, the ammonium ion can be readily converted to ammonia gas and lost to the atmosphere. Therefore, after application, ammonium fertilizers must be quickly incorporated. It is also advisable to avoid using ammonium fertilizers on alkaline soils. Under high pH conditions a greater conversion of ammonium ions to ammonia gas occurs, leading to a greater loss of nitrogen. Furthermore, nitrite can build up because ammonium ions inhibit the second step of nitrification. Not only is nitrite toxic to plants but it can also be readily converted to various forms of nitrogen gas and lost from the soil.

A second source of nitrogen loss in gaseous form is termed denitrification. Here, nitrates are converted to elemental nitrogen and nitrous oxides. Although the process occurs naturally in soil, it is enhanced under anaerobic conditions since the bacteria involved use nitrates for an oxygen source when oxygen gas (O_2) is limited. Therefore, denitrification is much higher under waterlogged and other anaerobic soil conditions.

Another source of nitrogen loss is through leaching. Generally, soil particles are negatively charged.

Therefore, positive ions (cations) are attracted to and held by the soil and are not readily leached out with water. Negatively charged ions (anions), however, are repelled by soil particles and leach out easily. For this reason, ammonium ions that are positively charged do not move far into the soil, even with heavy irrigations or rainfall. On the other hand, nitrates move readily with water and can be leached from the root zone in substantial amounts, especially in sandy soils.

All of these processes combined can account for significant losses of soil nitrogen. Even with good management, losses of 25 to 50 percent of applied nitrogen have been reported. Therefore, careful attention must be paid to each process mentioned to minimize loss and environmental contamination. A well-managed, low-volume irrigation system can help reduce nitrogen losses. First, water is applied more uniformly to the field, thus reducing losses to deep drainage and runoff. Second, nitrogen can be portioned out in small amounts over a period of time and consequently taken up much more efficiently by the tree.

In the tree

Nitrogen exists in many different forms in fruit trees; each has a separate function and each exists in widely varying amounts. Nitrogen is mostly taken up in nitrate form by roots. Some uptake occurs in ammonium form but is probably small in fruit trees. Uptake of nitrate requires energy; therefore, the roots must be supplied with carbohydrates. Once in the plant, nitrate is reduced to the ammonium form and then incorporated into amino compounds. These compounds, which include amino acids, amines, and amides, are the form in which nitrogen is stored and moved around the plant. Arginine, the most common amino acid in peach trees, is the principal storage form in the dormant season. Amino compounds constitute about 5 percent of the total nitrogen in the plant.

Most nitrogen in a growing plant is found in proteins and nucleic acids. An estimated 10 percent exists as nucleic acids and 80 to 85 percent as proteins. These compounds play key roles in essentially all the active processes occurring in plants. Proteins function mainly as enzymes for such plant processes as nutrient uptake, photosynthesis, carbohydrate movement, and cell division. The nucleic acids, in RNA and DNA molecules, constitute the genetic material of plants. Obviously, nitrogen is vital to plant growth, development, and reproduction.

Nitrogen is needed most where plant growth is actively occurring, especially in those processes involving cell division. Large quantities are also needed in seeds where nitrogen materials are synthesized, moved around, and stored. Therefore, when various plant parts are analyzed, nitrogen content tends to be high in growing shoot tips, growing leaves, young fruits, and seeds. It is also fairly high in mature leaves, since photosynthesis requires a large quantity of enzymes. It is important to note that nitrogen is not particularly high in woody tissues or in the flesh of fruit tissues near harvest. Fruits can be expanding rapidly near harvest, but this is mostly a function of cell expansion from water uptake, which does not require as much enzymatic activity as the cell division stage of growth. Therefore, large quantities of nitrogen applied to trees near harvest would not be expected to directly affect fruit size.

Nitrogen is very efficiently remobilized in senescing leaves. Approximately 50 percent is transported out of the leaves before they abscise. This nitrogen is then stored as arginine and other amino acids in the shoots, branches, and roots. In spring, this stored nitrogen is very important for the initial flush of growth.

Deficiency, excess, and correction

Nitrogen is the only major element that must be added regularly to typical stone fruit orchards in California. Because detrimental effects can result from either insufficient or excess amounts, only the optimum amount necessary in a regular maintenance program should be applied.

Deficiency symptoms are similar for peach and plum showing pale green leaves near the terminal of the shoot and yellow leaves at the base. In peach and nectarine, leaf midribs and stems are characteristically red (fig. 13.1). As the season progresses, red and brown spots develop in leaves (fig. 13.2). Shoot growth and leaf size are reduced, but not nearly to the extent of zinc deficiency. Premature leaf drop often occurs. Fewer flower buds are produced and the resulting fruits are smaller and more highly colored.

Correction is easily achieved with any nitrogen-containing fertilizer (table 13.2). The form of fertilizer makes little difference in terms of supplying nitrogen to the tree. Instead, the choice of material should be based more on other considerations. For instance, ammonium fertilizers are usually the least expensive but are not available for root uptake until converted to nitrate. They also lower the pH of the soil and are subject to volatilization if not incorporated immediately. Nitrate fertilizers offer the advantage of being immediately available for uptake by the plant. Manure and other organic fertilizers improve soil structure and water penetration by flocculating

Table 13.2. Nitrogen-containing fertilizers

Fertilizer	Formulation	Nitrogen (%)	Equivalent acidity or basicity (in lb $CaCO_3$) Acid	Base
Ammonium nitrate	NH_4NO_3	33.5–34	62	
Ammonium sulfate*	$(NH_4)_2SO_4$	21	110	
Anhydrous ammonia	NH_3	82	148	
Aqua ammonia	NH_4OH	20	36	
Calcium ammonium† nitrate solution	$Ca(NO_2)_2 \cdot NH_4NO_3$	17	9	
Calcium nitrate	$Ca(NO_3)_2$	15.5		20
Manure (dry)‡		1–3		
Sodium nitrate§	$NaNO_3$	16		29
Urea	$CO(NH_2)_2$	45–46	71	
Urea ammonium† nitrate solution	$NH_4NO_3 \cdot CO(NH_2)_2$	32	57	

*Will acidify the soil when used exclusively over a period of time.
†Often injected through low volume irrigation systems.
‡Also improves soil structure but can contain high levels of salt.
§Not recommended in San Joaquin Valley because of sodium salt content.

This table was prepared from information in the Western Fertilizer Handbook.

soil particles. However, these materials are slower than commercial fertilizers in terms of releasing nitrogen for uptake, and they may add undesirable salts to soil. With any fertilizer, one should take into account the potential beneficial and detrimental effects of the other nutrients making up the fertilizer material. Foliar application of fertilizers cannot supply sufficient nitrogen to correct a deficiency.

Time the application for late summer, after harvest. Early spring applications are also effective. For sandy soils, split the application to minimize leaching losses. Little nitrogen is taken up when leaves are

Fig. 13.1. Nitrogen deficiency in peach, showing characteristic reddening of stem and leaf midrib.

Fig. 13.2. Severe nitrogen deficiency in peach. Leaves are very chlorotic and have developed typical brown spots.

absent from the tree, so a dormant application is inefficient due to leaching, volatilization, and denitrification losses. Late spring and summer applications are too late for the cell division phase of fruit growth and tend only to stimulate additional vegetative growth. With low-volume irrigation systems, the recommended timing does not change, but toxicity can occur if the full rate is applied at one time through the system. Therefore, apply in smaller amounts over an extended period.

A rate of 100 to 150 pounds actual nitrogen per acre (112 to 168 kg per ha) is usually adequate for maintaining trees at an optimum level. This rate may vary considerably with tree status, soil type, ground cover, variety, and irrigation method. With severely deficient trees, more may be needed initially. On the other hand, overly vigorous trees should be left unfertilized for a year or two to allow the nitrogen level to drop to a more optimum range. Soil types can vary in their natural fertility levels and the ground cover can either add to or compete for nitrogen, depending on how it is managed. Generally, early season varieties should receive less nitrogen than mid- and late season varieties. Not only is there less removal in the crop, but it is also desirable to prevent excessive postharvest vegetative growth. Substantial amounts of nitrogen can be found in many wells in the San Joaquin Valley. Since this can contribute a substantial portion of the tree's requirements, wells used for irrigation should be tested for nitrates (1 ppm $NO_3^-{-}N = 2.7$ lb N/acre-foot) and accounted for in the fertilization program. Studies with nitrogen fertilizers applied through low volume irrigation systems indicate much greater uptake efficiency. Therefore, to get the same response as with broadcast fertilization under flood irrigation, usually about half the recommended rate is sufficient.

Rather than relying on a standard application rate each year and trying to account for all of the above factors, growers should monitor the nutrient status of trees with a yearly leaf sampling program. Leaf nitrogen levels should be maintained between 2.6 and 3.0 percent N for peaches and nectarines and between 2.3 and 2.8 percent N for plums.

Detrimental effects can result at high nitrogen levels. These include a delay in fruit maturity, decreased red coloration on the fruit, and excessive vegetative growth resulting in shading out and eventual death of lower fruiting wood. Sometimes, yield and fruit size are decreased.

At very high rates of nitrogen, fertilizer burn can occur. Symptoms of this disorder include leaf burn and defoliation and dark discoloration in the xylem but not in the phloem. It can be severe enough to kill the tree.

Phosphorus (P)

In soil

The chemistry of phosphorus in soil is complicated and not fully understood. Nevertheless, several principles tend to hold true. (1) Phosphorus readily reacts with numerous elements in soil to form insoluble compounds. (2) These reactions are pH dependent. At a low pH, certain reactions dominate and the phosphorus is tied up in insoluble compounds containing iron, aluminum, and magnesium. Likewise, at high pH values, other reactions dominate and phosphorus becomes tied up in calcium phosphates. Usually, a pH of 6 is considered optimum for phosphorus availability to plants. Even at this level, only a small amount of the total phosphorus exists in a soluble form that is readily available to plants. By some estimates, only a third of a crop's immediate requirements for phosphorus exists in readily available form. However, this readily available form is in equilibrium with less available forms so that as plants take up phosphorus it is quickly replenished in the soil solution. When commercial fertilizers containing phosphorus are added to soils, these chemical reactions quickly render most of the phosphorus unavailable to plants. Even though this phosphorus will slowly become available over time, there is typically only a 5 to 20 percent recovery of fertilizer phosphorus in the year of application. However, there is minimal leaching loss of phosphorus from the soil because it exists predominately in these insoluble forms.

In the tree

Even though phosphorus levels in plants are low compared with those of other macronutrients, they are essential to many plant processes. Three principal forms of phosphorus in plants are: in RNA and DNA molecules, in cell membranes, and in ATP molecules. The last form, ATP, is a molecule that stores the energy from photosynthesis and the breakdown of sugars. It is very mobile and can therefore be transported to sites requiring a great deal of energy such as expanding shoots, leaves, and fruits. When phosphorus is deficient, this last form is particularly depleted, so developing shoots and fruits are especially sensitive.

Deficiency and correction

In California, phosphorus deficiency has seldom been observed in stone fruits, possibly because: (1) Phosphorus is very efficiently recycled in senescing peach leaves. Estimates of 70 percent recovery have been reported. (2) Phosphorus levels in fruit tissues are not very high; thus, minimal amounts are removed in harvest. (3) Plants generally deal with soil phosphorus unavailability by exuding organic substances from their roots that help solubilize this nutrient. (4) Certain soil fungi, called mycorrhizae, exist in association with tree roots. This relationship increases the uptake of phosphorus into the roots.

The first two points suggest that not much phosphorus is required from the soil each year. In fact, annual requirements of fruit trees in general range from 5 to 10 lb/acre (6 to 11 kg/ha), which is much lower than for many field crops.

On the other hand, deficiencies of phosphorus in the field have been reported in the U.S., including California. Leaves on deficient peach and nectarine trees are dark green, eventually turning bronze and developing a leathery texture. A purple or red coloration appears on the leaves, petioles, and young shoots. Leaf size may be reduced and premature defoliation may occur, beginning with basal leaves. Yield and fruit size are reduced. The fruit are more highly colored and ripen earlier but exhibit surface defects and poor eating quality.

Potassium (K)

In soil

In California, potassium exists in large quantities in most stone fruit orchard soils. More than 90 percent of it is relatively unavailable to the tree, being tied up, or "fixed," by clay particles or in micas and other minerals. Its predominant, more available form is a positively charged ion (cation). Only a small proportion of these potassium ions is actually in solution at any given time; the remainder is adsorbed on negatively charged clay or humus particles. These different forms are in equilibrium with each other. Therefore, as potassium ions in solution are depleted by plant uptake, they are quickly replaced by adsorbed ions, which are then gradually replaced by weathering of more unavailable forms. This provides a tremendous storage of potassium so that trees can usually be amply and continuously supplied without adding any fertilizer.

Potassium tends to be more concentrated near the soil surface (top 6 to 8 inches) in most California stone fruit orchards. Therefore, deficiencies are more likely to occur where scraping has occurred for land leveling or topsoil removal.

In the tree

Potassium exists in large quantities in both leaf and fruit tissues. Although one of its functions is to activate enzymes, most potassium ions are not tied up in complex molecules, but are used in the ionic form by cells as a solute to help maintain turgor. This includes both young, actively growing cells and also guard cells, which control the opening and closing of stomates. Potassium, therefore, is mobile, readily moving in and out of cells and from one part of the plant to another. At the same time, potassium is not retrieved efficiently from senescing leaves. A 30 percent retrieval for peaches has been reported. Also, potassium is apparently not stored extensively over the dormant period; most potassium in the plant, therefore, is derived through active soil uptake. Potassium uptake appears to be proportional to vegetative growth, reaching its maximum in early summer. Potassium accumulates substantially in fruit tissues and appears to have a role there in fruit growth, since potassium-deficient trees have been shown to have greatly reduced fruit sizes. On low potassium soils, a heavy crop load can induce deficiency symptoms.

Deficiency and correction

Potassium deficiency is sometimes found in peaches, plums, and nectarines in California, although it is not nearly as much a problem as it is in prunes. Symptoms first develop in early summer on midshoot leaves, which exhibit a pale color similar to that of nitrogen deficiency. Leaves show a characteristic curling or rolling, especially in peaches (fig. 13.3). Leaf margins

Fig. 13.3. Potassium deficiency (*right*) compared with normal peach shoots (*left*). Note pale color and leaf-rolling symptoms.

become chlorotic and then necrotic, leading to a marginal scorch that is particularly evident in plums. This necrosis eventually extends inward, leading to cracks, tears, and necrotic spots. Terminal leaves are least affected and defoliation of older leaves may or may not occur. Both shoot growth and leaf size are reduced. Fewer flower buds are produced and the resulting fruit are definitely smaller. Fruit color in peaches is poor, either lacking color or having a dull, dirty looking, orange color.

Correction can be obtained with a soil application of potassium sulfate shanked in to a depth of 6 to 8 inches. Five to 10 pounds (2.3 to 4.5 kg) of fertilizer per tree will bring about correction for several years in sandy soils. In many fine-textured California soils, higher rates are required since a large portion of the potassium is "fixed" by minerals and clay particles. Potassium chloride and potassium nitrate can also correct deficiency symptoms. However, potassium chloride is not recommended in the San Joaquin Valley because of chloride's detrimental effects. The nitrogen component must be accounted for when applying potassium nitrate. Heavy applications may supply more nitrogen than is desirable for good fruit quality.

Potassium sulfate can also be applied through a low-volume irrigation system to correct potassium deficiency. Research on prunes indicates that correction can be achieved with approximately half the recommended rates for conventional irrigation systems. The fertilizer can be applied at one time or metered out through the season with no apparent difference in response.

Calcium (Ca)

In soil

Calcium, abundant in most soils, exists in several forms, including insoluble compounds and as Ca^{++} ions. The ionic form accounts for a substantial amount of the total calcium, either as adsorbed ions on negatively charged soil particles (exchange sites) or dissolved in the soil solution. As many as 80 percent of the exchange sites in a typical soil can be occupied by calcium ions. As these adsorbed ions are in equilibrium with the ions in solution, calcium is generally available to plants.

Having a substantial portion of the calcium in ionic form also makes it subject to leaching. Although it has a double positive charge and is, therefore, bound tightly to negatively charged soil particles, it can still be replaced by hydrogen ions (H^+) or other cations (Mg^{++}, K^+, Na^+). Applications of acids or salts to soils can therefore increase calcium leaching due to acidification of the soil. Highly weathered soils with low pH are generally low in calcium.

Adsorbed Ca^{++} is important for soil structure by promoting the aggregation of soil particles. This improves water and root penetration through the soil and maintains the stability of soil particles.

In the tree

Where it is abundant in the soil, calcium is abundant in leaves, since it is taken up passively by growing roots (not requiring an energy source). Apparently, only the region just behind the tips of a growing root is capable of calcium uptake (unlike potassium and phosphorus), so factors inhibiting root growth also inhibit its uptake. Calcium moves almost exclusively in the xylem with very small concentrations being found in the phloem. Therefore, once in an organ (such as a mature leaf), calcium is not readily transported out, even during senescence. Fruit calcium levels are low, since nutrients in fruit tissues are supplied mostly by the phloem. For this reason, fruit and leaf calcium levels are poorly correlated, meaning leaf samples cannot be used to determine the fruit's calcium status.

Calcium is involved in many plant processes, including cell elongation, cell division, germination, pollen growth, and senescence. One of its most important functions is the maintenance of membrane permeability and cell integrity. When it is deficient, cells become "leaky" and lose control over the import and export of nutrient elements, leading to tissue breakdown. Due to its immobility, deficiency symptoms first appear in young tissues. This sort of tissue breakdown also occurs commonly in fruit tissues, since calcium levels are naturally low. In fact, more than 35 calcium-related disorders have been identified in fruits and vegetables. These disorders often develop with poor root growth rather than because of inadequate calcium supplies. Such disorders among fruit crops have mostly been related to apple and have not been verified for peach, plum, and nectarine.

Deficiency

Calcium deficiency in peach, plum, and nectarine has never been documented in California. From sand culture experiments and a few field reports from other states, deficiency symptoms have been described. These include reduced shoot growth, due to shortened internodes, followed by twig dieback and defoliation. Chlorotic patches often develop on leaves before abscission occurs.

Magnesium (Mg)

In soil

Most magnesium in soil exists as various minerals in a nonexchangeable form. However, exchangeable Mg^{++} is usually the second most abundant cation, occupying from 4 to 20 percent of the cation exchange sites. Also, like calcium, there is a fairly high concentration in the soil solution. It can, therefore, easily be leached from the soil, especially with the addition of other cations. Magnesium is also subject to competition by other cations. Reports of magnesium deficiency due to heavy applications of potassium and ammonium fertilizer have been cited for some crops. The effect is apparently a result of Mg^{++} being replaced on the cation exchange sites by K^+, NH_4^+, and H^+.

In the tree

Levels of magnesium in the tree are generally less than either calcium or potassium – calcium is more abundant in soil and potassium is taken up actively by the plant. Magnesium functions as an activator of many important enzyme reactions and as a major component of the chlorophyll molecule. However, as much as 70 percent of the magnesium in the plant is associated with diffusible anions; thus, it is very mobile. Deficiency symptoms, therefore, are first seen in older leaves.

Fig. 13.4. Magnesium deficiency in peach leaves, showing the typical, inverted, green "V" around the midrib. Healthy leaf is far *right*.

Deficiency and correction

Magnesium deficiency, rare in California orchards, is usually caused by high potassium in soil rather than by naturally low magnesium levels. Trees are usually vigorous, despite the deficiency, and yield, fruit size, and leaf size are not affected. The characteristic pattern on the leaf is a marginal chlorosis, leaving an inverted green "V" around the midrib (fig. 13.4). These symptoms appear first on the most basal leaves and develop sequentially up the shoot. As the season progresses, the chlorotic area increases and develops into necrosis. Eventually, the whole leaf is affected and then abscises from the shoot. Thus, the lower part of the shoot becomes devoid of leaves.

As mentioned, magnesium deficiency in California usually does not damage yield and therefore no treatment is required. Nevertheless, when correction is desired, soil applications of magnesium sulfate, magnesium oxide, and dolomite have proved effective.

Sulfur (S)

In soil

The most abundant reservoir of sulfur in soil is in the organic form, such as lipids, amino acids, and proteins. These compounds are broken down by microorganisms to inorganic sulfates ($SO_4^=$). At any given time, a substantial amount of the total sulfur exists in this form, which is readily available to plants and actively taken up by the roots. Orchard soils in California are rarely deficient in sulfur, partly because it is added in many different ways including fertilizers (i.e., ammonium sulfate), gypsum ($CaSO_4 \cdot 2H_2O$), manure, and other organic matter, and atmospheric SO_2, which is carried into the soil by rain.

In the tree

Sulfur's uptake and availability is not influenced by soil pH and is thus taken up readily over a range of orchard soil conditions. In the tree, it is incorporated into certain amino acids (cysteine, methionine) and subsequently becomes part of certain enzymes, vitamins, and oils. Once in these complex molecules, sulfur is not easily mobilized within the plant. Deficiency symptoms, therefore, occur in young tissues before older ones.

Senescing leaves efficiently retrieve sulfur. As complex molecules are broken down, sulfur is converted into $SO_4^=$, which is readily transported out of the leaf and into the rest of the plant.

Sulfur is also taken up by leaves in gaseous form as SO_2. In heavily industrialized areas, SO_2 concentrations can be high enough to be toxic to plants. However, under most conditions, the normal SO_2 level of the atmosphere can supply a significant portion of the needed sulfur for trees without detriment.

Deficiency and correction

Sulfur deficiency in stone fruit has never been documented in California. The reasons for this probably include the abundance and availability in the soil and atmosphere, the efficient recycling in senescing leaves, and the minimal removal by the crop and prunings.

If a deficiency were ever to occur, one would expect symptoms similar to nitrogen deficiency. In other plants there is uniform yellowing over the leaf. In contrast to nitrogen deficiency, symptoms generally occur on young leaves first, since sulfur is not easily remobilized from older leaves. The deficiency is easily corrected with applications of ammonium sulphate, gypsum, or elemental sulfur.

Iron (Fe)

In soil

Iron, one of the most abundant minerals in the soil, constitutes about 5 percent of the weight of the earth's crust. Despite this abundance, iron deficiency is common because of its unavailability to plants or because of utilization problems. Most iron exists as insoluble minerals. Only a very small amount exists in the soluble form as $Fe(OH)_2^+$, $FeOH^{++}$, Fe^{+++}, and Fe^{++}. The first three forms dominate under aerobic conditions, while Fe^{++} prevails in anaerobic situations. The concentration of these soluble forms is pH dependent, reaching a maximum at a low value (pH 3) and a minimum at a pH of about 6.5 to 7.5. Unfortunately, this is about the optimum pH for most other nutrients and accounts for some iron deficiency.

At pH values higher than 4.5, soluble iron levels in the soil are less than 1 percent of that required by plants. Many plants have mechanisms for dealing with this so that iron deficiency does not become a problem, as discussed in the next section.

In the tree

Iron is absorbed only by root tips, so continual development of new roots is important. It is taken up in the form of Fe^{++} or iron chelates. Because concentration of Fe^{++} is extremely low in well-aerated soils and natural chelates are also rare, the roots actively carry out several processes to improve uptake. (1) Hydrogen ions (H^+) are exuded from the roots, thus lowering pH in the immediate root vicinity. (2) Various morphological and physiological changes occur at the root surface which allow for reduction of Fe^{+++} to Fe^{++}. (3) Roots have been shown to excrete chelates, which combine with iron molecules and greatly improve their availability to the plant. Different plants and rootstocks vary in their ability to carry out these processes.

Iron complexes with proteins to form important enzymes in the plant. However, this only accounts for a small percentage of the total iron. Most of this nutrient is associated with chloroplasts, where it has some role in synthesizing chlorophyll. In this role, it is not very mobile within the plant and explains why deficiency symptoms first appear in young leaves.

Deficiency and correction

A symptom of iron deficiency is loss of chlorophyll, leading to chlorotic leaves. However, in early stages, only the interveinal areas of the leaf are affected; thus, veins remain dark green (fig. 13.5). Young leaves are the first to show symptoms. As the severity increases, leaves can become almost white as chlorophyll completely disappears (fig.13.6). Eventually the leaves

Fig. 13.5. Iron deficiency in peach. Veins remain green while the rest of the leaf turns chlorotic.

turn necrotic and abscise, leaving the terminal half of the shoot bare.

Iron deficiency results from several conditions that can be grouped into three categories: (1) insufficient amounts in the soil, (2) sufficient but unavailable supplies, and (3) sufficient and available supplies that are not properly utilized within the plant. The first category is rare, especially in California orchard soils; therefore, it will not be discussed further. The second category is common and may result from trees growing in a high pH soil, outcompeting of iron by other cations (Mn^{++}, Cu^{++}, Ca^{++}, Mg^{++}, K^{+}, and Zn^{++}), or an inability of roots to carry out the processes mentioned previously.

The third category, commonly called lime-induced chlorosis, is the most common form of iron deficiency in California orchards. It results when high levels of HCO_3^- occur in the soil. Usually sufficient iron is taken up by the tree, but it is somehow immobilized by HCO_3^-, thus inhibiting its utilization. High levels of CO_2 in the soil are required to build up HCO_3^-. Therefore, iron chlorosis is often observed under conditions of poor soil aeration, where CO_2 produced by root respiration cannot escape. It follows that correction of this disorder can often occur by simply preventing waterlogging and overirrigation or by improving soil aeration through various cultural techniques. It often helps to irrigate more frequently, using shorter runs and lower quantities of water.

Applying inorganic iron to the soil seldom corrects the deficiency, since conversion to insoluble

Fig. 13.6. Increasing iron deficiency (*right* to *left*) in peach. With severe deficiency the leaf turns almost white.

minerals occurs rapidly. Synthetic iron chelates applied to soil or foliage have been effective, but results are often short lived and may not be cost effective. Also, one must be careful with soil applications, especially in situations of lime-induced chlorosis. With less stable chelates, calcium or other cations can displace iron, thus creating calcium chelate and insoluble iron, which is then unavailable to the plant.

With lime-induced chlorosis, applications of sulfur to lower the soil pH are sometimes effective. The effect may be more a direct effect of H^+ ions neutralizing HCO_3^- rather than increased solubility of iron at the lower pH. Unfortunately, the amount of sulfur needed to neutralize all of the HCO_3^- in the full root zone is often prohibitive. However, recent studies acidifying a portion of the root zone have shown promise.

Finally, one other promising approach is to inject or place materials into holes drilled in the trunk. Materials that have shown correction of symptoms include ferric phosphate, iron citrate, ferric ammonium oxalate, ferrous sulfate, and ferric ammonium citrate.

Manganese (Mn)

In soil

The total amount of soil manganese varies widely from one soil to another. However, there is usually an adequate amount to supply the limited requirements of fruit trees. The most important form for uptake by roots is Mn^{++}, but it is also commonly found as oxides of Mn^{+++} and Mn^{++++} (Mn_2O_3, MnO_2, etc.). The interconversion of these various forms is controlled by oxidation-reduction reactions in soil. Therefore, such factors as pH, organic matter, and soil moisture strongly influence manganese availability. For instance, manganese deficiency is often found on high pH soils with a high organic matter level.

In the tree

High levels of other cations in soil can inhibit uptake of manganese. Magnesium ions are especially effective in this cation competition. Also, in heavily limed soils, manganese uptake may be reduced by both high pH and competition with calcium ions.

Manganese in the plant participates in several important processes including photosynthesis and nitrogen and carbohydrate metabolism. It is generally considered to be somewhat immobile in the plant, but it is preferentially supplied to young growing tissue.

Fig. 13.7. Manganese deficiency symptoms in peach leaves, showing characteristic "herringbone" pattern. Healthy leaf is *upper left*.

Deficiency and correction

Leaf deficiency symptoms in peach, plum, and nectarine include an interveinal chlorosis extending from midrib to margin. Relatively wide bands around the major veins remain green, giving a "herringbone" pattern (fig. 13.7). In contrast to many other plants, stone fruits show symptoms first on older basal leaves. Although the whole tree usually looks pale, the terminal leaves often appear more green. Unless the deficiency becomes severe, shoot growth, leaf size, and yield are not seriously affected.

To correct deficiency, foliar sprays of about 3 to 5 lb/100 gal (0.4 to 0.6 kg/100 l) of manganese sulfate have proved effective. Applying the same material to the soil is often ineffective, since manganese (Mn^{++}) is quickly oxidized to less available forms. If the deficiency problem is induced by high soil pH, lowering the pH with sulfur is generally effective. Temporary deficiency symptoms often are observed in spring when poor root growth may be induced by cold temperatures or dry soil.

Zinc (Zn)

In soil

Most zinc in soil is found in different minerals with only a small percentage being adsorbed in ionic form on soil and organic matter exchange sites. Even less is solubilized in the soil solution, although it is considered more soluble than other heavy metals. This is influenced by pH, however, so zinc solubility is especially low at high pH and even lower when $CaCO_3$ is present.

Zinc also complexes with organic matter, which can either increase or decrease its availability to plants. Some complexes render zinc unavailable to trees, which may partially explain zinc deficiency often observed on trees in old corral sites or with heavy applications of manure. Trees grown on sandy soils are also more prone to zinc deficiency than those grown on heavier soils.

In the tree

Although zinc is needed in small amounts in the tree, it has been identified as a component of almost 60 enzymes; therefore, it has a role in many plant functions. Of particular interest is its role as an enzyme in producing the growth hormone IAA. This is the most probable explanation for the shortened internodes and small leaves observed with zinc deficiency. It also accumulates and plays an important role in seed development, which may explain the sensitivity of fruit growth to zinc deficiency. The mobility of zinc in the tree ranges from low to high, depending on several factors. With adequate supplies, zinc moves readily from old leaves to developing tissues. However, under zinc deficiency, little zinc moves out of the old leaves.

Deficiency and correction

Stone fruit are particularly sensitive to zinc deficiency, as is often observed in California. There is rootstock and variety variability, especially in plum. The disorder has often been called "little leaf" because of the small pointed leaves produced (figs. 13.8 and 13.9). These leaves occur in rosettes on the tips of the

Fig. 13.8. Zinc deficiency (*left*) compared to healthy plum shoot (*right*). The most typical symptom: small, pointed leaves.

shoots and young spurs because of shortened internodes (fig. 13.10). The affected leaves become chlorotic with an interveinal mottling. Leaf margins are often crinkled or wavy, especially in peach and nectarine. These symptoms along with delayed foliation often occur early in spring. Defoliation eventually follows, beginning with basal leaves. Production is drastically affected, since formation of fruit buds is inhibited and fruit produced are small, elongated, and misshapen.

Because this deficiency is so common, a zinc spray is routine for most fresh shipping fruit orchards in California, even before symptoms appear. To prevent or correct the deficiency, treatments can be put on at several different times. Zinc sulfate (36 percent metallic zinc) applied at a rate of about 10 to 15 lb/acre (11 to 17 kg/ha) from mid-October (or about 50 percent leaffall) through the dormant season is very effective. The dormant spray should not be applied with or within several weeks of dormant oil spray. Neutral or basic zinc (52 percent metallic zinc), also at a rate of about 10 to 15 lb/acre (11 to 17 kg/ha), is effective when applied in spring or summer. However, it may leave spray deposits on fruit and cause leaf burn and defoliation if rain occurs shortly after application. This material can also be applied with dormant pesticide sprays for a maintenance treatment to prevent mild zinc deficiency development the following growing season. Zinc EDTA corrects the deficiency when applied in spring.

For chronic problems, soil applications can be helpful. Applications of zinc sulfate trenched into the soil at least 6 inches deep have been effective. The rate is highly variable and depends on soil type, tree age, and severity of the deficiency.

Fig. 13.9. Zinc deficiency (*right*) compared with healthy peach shoot (*left*).

Fig. 13.10. Zinc deficiency in a plum tree. Rosetting on shoots occurs due to shortened internodes and small, pointed leaves.

Boron (B)

In soil

Most boron in soils is unavailable to plants. The soluble form is primarily boric acid ($B(OH)_3$). In neutral to acid soils, boric acid has no charge and can, therefore, be easily leached. At higher pH values, conversion to $B(OH)_4^-$ occurs. The resulting negative charge on the molecule causes its absorption by soil particles. Thus, it is less easily leached but also less available to plants.

In the tree

Boron is involved in several processes within the plant, including protein synthesis, transport of sugars, and the metabolism of plant hormones. Because these functions are vital to meristematic tissues, boron deficiency is particularly damaging to actively growing shoot and root tips. Boron moves almost exclusively with the transpiration stream in the xylem. Like calcium, it is virtually absent from the phloem and is thus relatively immobile within the plant.

Deficiency and correction

Boron deficiency is seldom observed on stone fruit in California, since typical orchard soils are usually adequately supplied with boron and are within the appropriate pH range. Reportedly, peaches, compared with other fruit trees, are not very sensitive to boron deficiency.

Other areas report initial deficiency symptoms occur at the shoot tips, leading to terminal dieback. This may then lead to development of many side branches. New leaves that follow are small, thick, misshapen, and brittle. Defoliation often occurs, starting with terminal leaves and moving down the shoot. Sunken, necrotic spots have been reported on apple and apricot fruit, but peach and Japanese plum are apparently less sensitive to this disorder.

Deficiency has been corrected with soil applications of ¼ to ½ lb/tree (100 to 200 g) of borax. Applications of boric acid to foliage or soil have proved effective on other crops. However, one must be cautious since boron toxicity can easily result from overapplication.

Toxicity

Boron can be toxic to plants at levels slightly higher than normal requirements. Therefore, overfertilization with boron materials can lead to toxicity symptoms. Also, soils derived from marine sediments in arid regions can often be naturally high in boron. Many sites on the western side of the San Joaquin Valley exhibit this characteristic. In such areas, one must pay particular attention to irrigation water. Boron levels as low as 1 ppm can induce toxicity symptoms.

The symptoms of peach and nectarine, considered two of the most sensitive crops to boron toxicity, include small necrotic spots on the underside of the midrib. Also, cankers may develop along the midrib, on petioles, and on young twigs. In severe cases, leaf yellowing, defoliation, twig dieback, and gumming can occur. The fruit is distorted with sharp sunken areas and kernel development is poor. Correction is achieved by leaching boron out of the root zone. This is a slow process, more easily achieved in neutral to acid soils than in alkaline soils.

Copper (Cu)

In soil

Copper exists mainly as a divalent cation (Cu^{++}) and is bound tightly to soil exchange sites; its concentration in the soil solution is low and it does not move readily through the soil with leaching. However, it can be replaced from exchange sites by hydrogen ions (H^+) and is therefore more available in low pH soils. Plant deficiencies often occur in alkaline soils.

Copper is also bound strongly by soil organic matter. This often has the effect of increasing the

Fig. 13.11. Midsummer copper deficiency symptoms in plum showing small, chlorotic, and malformed young leaves. Older leaves are more normal in size and color.

Fig. 13.12. Marginal leaf burn in peach caused by excessive chloride ions in the leaf.

availability of this nutrient if the complex can be taken up by plants. However, certain complexes are apparently less available, probably because of being too large for uptake. In fact, plants growing in peat and muck often develop copper deficiency.

In the tree

Very small amounts of copper are needed by the tree. When adequately supplied, it moves easily from old to new leaves. When deficient, however, it becomes immobile so that young leaves first exhibit deficiency symptoms. More than half of the copper in trees is located in the chloroplasts and participates in photosynthetic reactions. It is also found in other enzymes involved with protein and carbohydrate metabolism.

Deficiency, toxicity, and correction

Copper deficiency in California is rare in peach and nectarine but is occasionally seen in plum. Symptoms in plum include terminal dieback after about 2 months of normal growth in spring (fig. 13.11). Terminal leaves turn yellowish. Rough bark accompanied by gumming also occurs. The initial symptoms on peach and nectarine include interveinal chlorosis on young leaves, followed by development of small, malformed leaves. Eventually cessation of terminal growth and terminal dieback occurs. Finally, there is rosette formation due to multiple bud growth.

Correction of the deficiency has been obtained with soil applications of 0.25 to 2 lb/tree (0.1 to 0.9 kg) of copper sulfate. This greatly exceeds plant needs, but it is necessary due to the large amount that is quickly and tightly bound to soil-exchange sites. Correction can also be expected with foliar chelate or Bordeaux sprays in early spring or soil applications of copper chelate. Aggravation of copper deficiency has been observed with high applications of nitrogen, phosphorus, or zinc fertilizers.

Copper toxicity has never been observed in California, but it can occur in soils naturally high in copper or where Bordeaux sprays have been continuously used over many years.

Chlorine (Cl)

Abundant in nature, chlorine is mobile in soil, being taken up easily and in relatively large amounts by plants. Since the tree's physiological requirement for this element is only a few ppm, it is rarely deficient. Symptoms induced in sand culture on some crops have included wilting and chlorotic leaves.

The more serious problem with chlorine is an excess of the element. Indeed, peach, plum, and nectarine are three crops very sensitive to an excess of chloride salts. The characteristic symptom of this disorder is a marginal leaf burn (fig. 13.12). Leaves will start showing the symptom when chloride levels reach about 0.3 percent on a dry weight basis. Sodium levels and symptoms are very similar except that the marginal burn is often striated. If the problem of excess salt is not corrected, trees will readily die. Because chlorine is so mobile within the soil, the problem can be alleviated easily by leaching.

Molybdenum (Mo)

The amount of molybdenum in the soil can vary widely, but such small amounts are needed by plants that deficiencies are seldom encountered. In the few cases reported (not in fruit trees), soil pH was low. Since molybdenum availability is strongly influenced by pH, liming has usually solved the problem.

Molybdenum is known to be an essential component of two enzymes involved with nitrogen metabolism. Therefore, deficiency symptoms sometimes resemble nitrogen deficiency. In stone fruit, the deficiency has never been documented in the field. However, it has been induced on myrobalan plum in sand culture. Symptoms included dwarf leaves, diffuse mottling on some leaves, and irregular areas of dead tissue on tips and margins of leaves.

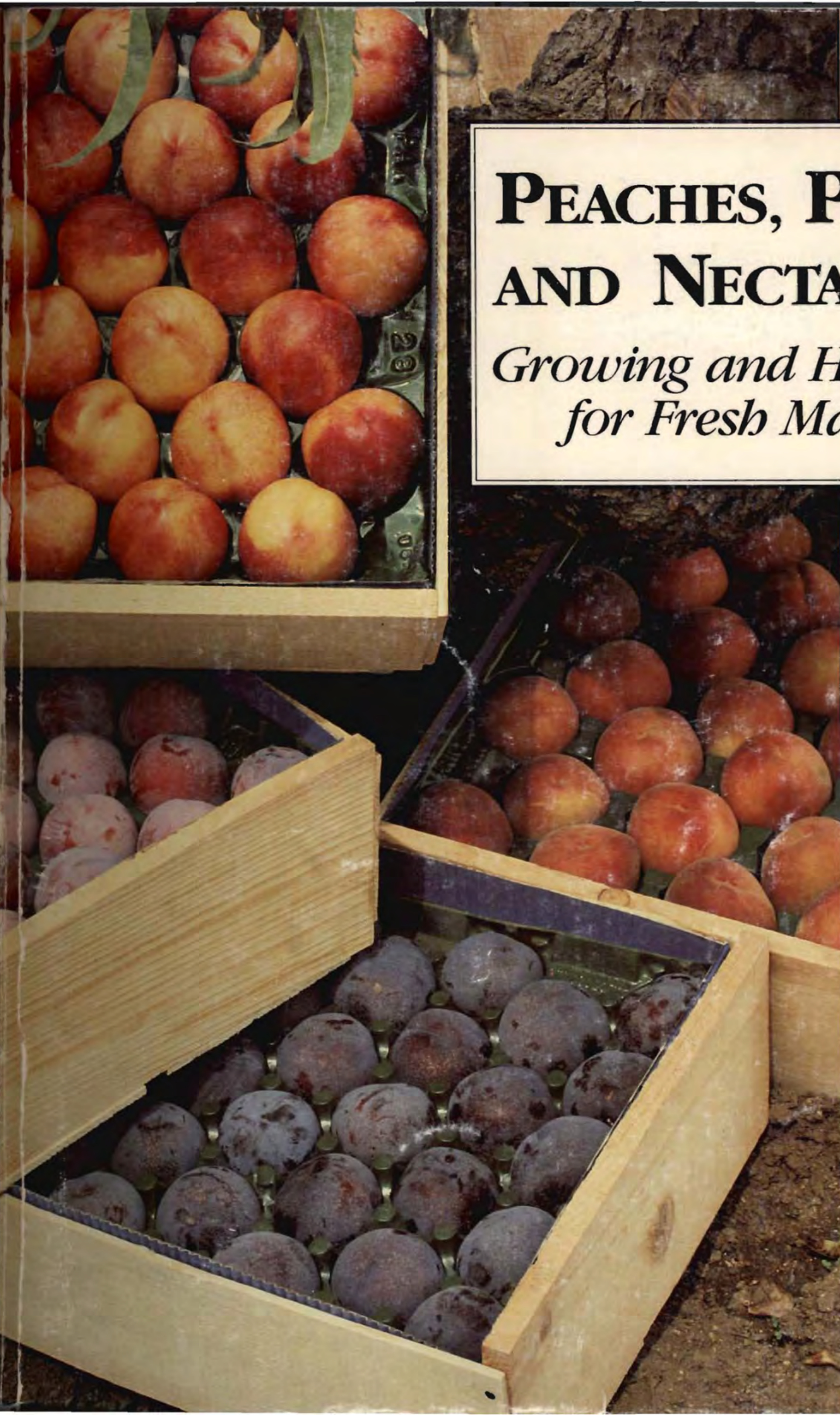
Additional Reading

Ayers, R. S., and 30 co-authors. 1983. Soil and Plant Tissue Testing in California. University of California Bulletin 1879, Berkeley.

Chapman, H. C., editor. 1973. Diagnostic Criteria for Plants and Soils. Department of Soils and Plant Nutrition, University of California, Riverside.

Mengel, K., and E. A. Kirby. 1982. Principles of Plant Nutrition. International Potash Institute, Bern, Switzerland.

Shear, C. B., and M. Faust. 1980. Nutritional Ranges in Deciduous Tree Fruits and Nuts. Horticultural Reviews 2:142-163.



PEACHES, PLUMS, AND NECTARINES

Growing and Handling for Fresh Market

Technical Editors:
James H. LaRue
R. Scott Johnson

Cooperative Extension

University of California

Division of Agriculture and Natural Resources

Publication 3331