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Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida[1]

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Introduction

Improved fertilizer management for vegetables is important in view of today's need to reduce production costs, conserve natural resources, and minimize possible negative environmental impacts. These goals can be achieved through optimum management of the fertilizer applied. Understanding the crop nutrient requirements and using soil testing to predict fertilizer needs are keys to fertilizer management efficiency.

Plant tissue testing is another tool for use in achieving a high degree of precision in fertilizer management. Timely tissue testing can help diagnose suspected nutrient problems or can simply assist in learning more about fertilizer management efficiency.

This guide is provided to assist vegetable growers, Cooperative Extension Service personnel, and consultants in conducting a meaningful plant tissue testing program. Guidelines are provided for collecting samples, proper handling of the sample, and choosing an analytical lab. Information is also presented on basic plant nutrition so that the reader understands the nutrient requirements of each vegetable crop and the process of identifying nutrient deficiencies.

The final section of the guide presents the deficiency, sufficiency, and toxicity ranges for plant nutrient concentrations. This is the interpretation portion. Values presented in the tables have been drawn from research from many areas of the country with emphasis on research conducted in Florida. Missing values in the tables indicate areas of research need. The final section of the guide also presents recommendations for nutrient deficiency correction.

Plant Nutrition

Essential Elements

Plants require light, water, minerals, oxygen, carbon dioxide, and a suitable temperature to grow. These absolute growth requirements must be available within appropriate ranges and in balance with others for optimum growth to occur.

A total of 17 elements are known to be required for plants to grow and reproduce normally. The elements are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), boron (B), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), chlorine (Cl) and nickel (Ni).

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The atmosphere provides C and O, and H is provided by water. Together, these three elements are combined into simple organic compounds during the process of photosynthesis. The other 14 elements are supplied mostly from the soil, including native soil fertility, residual lime and fertilizer, or from current lime and fertilizer applications. Other less important sources of plant nutrients are well water (Ca, Mg, S, Fe) and the atmospheric deposition (S and N).

The macronutrients (N, P, K, Ca, Mg, S) are those found in comparatively high concentrations in plants and are measured in percent (%). Micronutrients (Fe, B, Mn, Cu, Zn, Mo, Cl) are present in comparatively minute concentrations in plants and are measured in parts per million (ppm).

Roles of Essential Elements in Plant Growth

Each of the essential elements has at least one specifically defined role in plant growth so that plants fail to grow and reproduce normally in the absence of that element. However, most of the essential elements have several functions in the plant. A basic summary of some of these functions follows:

Carbon, from carbon dioxide (CO_2) in the atmosphere, is assimilated by plants in the photosynthetic process. It is a component of organic compounds such as sugars, proteins, and organic acids. These compounds are used in structural components, enzymatic reactions, and genetic material, among others. The process of respiration degrades organic compounds to provide energy for various plant metabolic processes.

Oxygen, derived from CO_2, also is a part of organic compounds such as simple sugars. Atmospheric oxygen is necessary for all oxygen-requiring reactions in plants including nutrient uptake by roots.

Hydrogen derived from water (H_2O) also is incorporated into organic compounds in the photosynthetic process. Hydrogen ions are involved in electrochemical reactions and maintain electrical charge balances across all membranes.

Phosphorus is used in several energy transfer compounds in plants. A very important function for P is its role in nucleic acids, the building blocks for the genetic code material in plant cells.

Potassium plays a major role as an activator in many enzymatic reactions in the plant. Many enzymes responsible for cellular reactions require K as a co-factor. Another role for K in plants occurs in special leaf cells called guard cells found around the stomata. By regulating the turgor pressure in the guard cells, the degree of opening of the stomata is controlled and thus the level of gas and water vapor exchange through the stomata is regulated. Turgor is largely controlled by K movement in and out of guard cells.

Nitrogen is found in many compounds including chlorophyll (the green pigment in plants), amino acids, proteins, and nucleic acids. A large part of the plant body is composed of N-containing compounds.

Sulfur is a component of sulfur-containing amino acids such as methionine. Sulfur also is contained in the sulfhydryl group of certain enzymes.

Calcium is a component of calcium pectate, a constituent of cell walls. In addition, Ca is a co-factor of certain enzymatic reactions. Recently, it has been determined that Ca is involved in the intimate regulation of cell processes mediated by a molecule called calmodulin.

Magnesium plays an important role in plant cells since it appears in the center of the chlorophyll molecule. Certain enzymatic reactions require Mg as a co-factor.

Iron is used in the biochemical reactions that form chlorophyll and is a part of one of the enzymes that is responsible for the reduction of nitrate-N to ammoniacal-N. Other enzyme systems such as catalase and peroxidase also require Fe.

Boron functions in the plant are still not well understood. Boron seems to be important for normal meristem development in young plant parts, such as root tips.

Manganese functions in several enzymatic reactions that involve the energy compound adenosine triphosphate (ATP). Manganese also activates several enzymes and is involved in the processes of the electron transport system in photosynthesis.

Copper is a constituent of a protein, plastocyanin, involved in electron transport in chloroplasts, and copper is part of several enzymes, called oxidases.

Zinc is involved in the activation of several enzymes in the plant and is required for the synthesis of indoleacetic acid, a plant growth regulator.

Molybdenum is a constituent of two enzymes involved in N metabolism. The most important of these is nitrate

reductase, the enzyme involved in the reduction of nitrate-N to ammoniacal-N.

Chlorine plays a possible role in photosynthesis and might function as a counter ion for K fluxes involved in cell turgor.

Nickel is now recognized by plant scientists as an essential element for plants. It is involved in the enzyme urease and is a part of several other enzymes involved in plant metabolism.

Mobility of Essential Elements within the Plant

Approximately 80% of all nutrients absorbed by roots are translocated to the shoots. When nutrient supply is abundant, they are delivered directly to the shoots often within minutes of absorption. Accordingly, plants may absorb and accumulate essential elements in far greater quantities than are necessary for immediate use. These accumulated elements are available for use later in the plant life cycle when demands are high for fruit production and/or when nutrient supply from the soil is restricted. The ability of an element to move from one plant part to another is called mobility and the process is known as retranslocation. The mobility of the essential elements in plants is shown in Table 1.

The mobility of an element influences the location where deficiency symptoms (see the following section) are likely to be observed on the plant. For example, Mg deficiency symptoms occur on the oldest, generally lower leaves, because Mg is retranslocated to the younger leaves of the plant. Conversely, Ca deficiencies occur at the growing point or in storage organs like roots and fruits because Ca, being immobile, is not retranslocated to these sites during Ca stress conditions.

Nutrient Deficiency Symptoms

Vegetable plants exhibit deficiency symptoms that are characteristic for each element, and are, therefore useful for diagnostic purposes. However, in many cases, the symptoms may be masked by symptoms of other nutritional disorders, those caused by unfavorable environment, or stress caused by plant pests. In these situations, plant tissue analysis provides useful information to complement and confirm visual diagnosis. Nutritional disorders of vegetables rarely occur in well managed crops. The general symptoms associated with deficiencies and excesses of the essential elements follow:

Nitrogen is absorbed as NH_4^+ and NO_3^-. It is a mobile element in the plant and deficiency symptoms therefore show up first on the lower leaves. Symptoms consist of a general yellowing (chlorosis) of the leaves. On tomatoes, there might be some red coloration to the petioles and leaf veins. If the problem persists, lower leaves will drop from the plant.

Healthy plant leaves contain between 2.0 and 5.0% N on a dry weight basis. Deficiencies of N show up most often where errors are made in fertilizer management resulting in insufficient N supply to the crops. More often in commercial vegetable production, there is a problem from excess N application. Plants receiving excess N usually are lush and tender with larger and darker-green leaves. Excess N (especially in warm and sunny conditions) can lead to "bullish" tomato plants. These plants produce thick, leathery leaves that curl under in dramatic fashion producing compact growth.

Phosphorus is typically absorbed as $H_2PO_4^-$ by an active (energy-requiring) process. P is very mobile in the plant. Deficiencies therefore show up on the older leaves of the plant because P is translocated out of these leaves to satisfy the needs of new growth. P deficiency shows up as stunting and a reddish coloration resulting from enhanced display of anthocyanin color pigments. Deficient leaves will have only about 0.1% P in the dry matter. Normal, most-recently matured leaves of most vegetables, will contain 0.25 to 0.6% P on a dry weight basis. Excess P in the root zone can result in reduced plant growth probably as a result of P retarding the uptake of Zn, Fe, and Cu.

Potassium is absorbed in large quantities by an active uptake process. Once in the plant, K is very mobile and is transported to young tissues rapidly. Deficiency symptoms for K show up first on lower leaves as flecking or mottling on the leaf margins. Prolonged deficiency results in necrosis along the leaf margins and the plants can become slightly wilted. Deficient plant leaves usually contain less than 1.5% K. Deficiencies of K lead to blotchy ripening of tomatoes where fruits fail to produce normal red color in some areas on the fruit.

Calcium, unlike most elements, is absorbed and transported by a passive mechanism. The transpiration process of plants is important in the transport of Ca. Once in the plant, Ca moves toward areas of high transpiration rate, such as rapidly expanding leaves.

Most of the uptake of Ca occurs in a region on the root just behind the root tip. This has practical importance for

vegetable culture because it means that growers must keep healthy root systems with numerous actively growing root tips. Root diseases and nematodes may severely limit Ca uptake by the plant.

Calcium is immobile in the plant, therefore, deficiency symptoms show up first on the new growth. Deficiencies of Ca cause necrosis of new leaves or lead to curled, contorted growth. Examples of this are tipburn of lettuce and cole crops. Blossom-end rot of tomato also is a calcium-deficiency related disorder. Cells of the tomato fruit deprived of Ca break down causing the well-known dark area on the tomato fruit. Sometimes this breakdown can occur just inside the skin so that small darkened hard spots form on the inside of the tomato while the outside appears normal. On other occasions, the lesion on the outside of the fruit is sunken or simply consists of a darkening of tissue around the blossom area.

Since Ca movement in the plant is related to transpiration, environmental conditions that affect transpiration also affect Ca movement. Periods of high humidity can lead to tipburn of lettuce because the leaves are not transpiring rapidly enough to move adequate Ca to the leaf extremities.

Calcium concentrations in healthy, most-recently matured leaves will be from about 0.6 to 5.0%. Deficiencies, however, can occur temporarily given certain environmental conditions as previously discussed. Therefore, it is important to consider irrigation in the overall Ca fertilization program.

Magnesium is absorbed by the plant in lower quantities than Ca. Unlike Ca, Mg is highly mobile in the plant and deficiencies first appear on the lower leaves. Deficiency symptoms consist of an interveinal chlorosis, which can lead to necrosis of the affected areas. On tomato leaves, advanced Mg deficiency leads to a mild purpling of the affected areas.

Magnesium is usually found in concentrations of 0.2 to 0.8% in normal leaves. Conditions that lead to deficiency are usually related to poorly designed fertilizer programs that supply too little Mg, or when Ca and/or K compete with Mg for uptake.

Sulfur is absorbed mainly in the form of sulfate (SO_4^{-2}) by a mechanism that is not well understood. Sulfur is somewhat mobile in the plant so deficiency symptoms are fairly evenly distributed on the plant but mostly on the upper leaves. Deficiency symptoms consist of a general yellowing of the leaves. Deficiencies of N and S appear somewhat similar but N deficiency occurs on the lower leaves whereas S deficiency occurs in the upper part of the plant.

Plant leaves usually contain between 0.2 and 0.5% S on a dry weight basis. This range is similar to that for P. Plants can generally tolerate quite high concentrations of S in the growing media. This is one reason for the wide use of S-containing materials to supply nutrients such as Mg and the micronutrients, and explains why S deficiency is not very common in vegetable crops.

Iron is absorbed by an active process as Fe^{2+} or as iron chelates, which are organic molecules containing iron sequestered within the molecule. Uptake of Fe is highly dependent on the Fe form and adequate uptake depends on the ability of the root to reduce the pH nearby and reduce Fe^{3+} to Fe^{2+} for uptake. Iron chelates are soluble and aid in keeping Fe in solution for uptake. The uptake of the whole chelate molecule is low and usually Fe is removed from the chelate before uptake.

Iron is not mobile in plants and symptoms appear on the new leaves first. Symptoms consist of interveinal chlorosis that may progress to a bleaching and necrosis of the affected leaves. Usually, the chlorosis begins on the lower part of the leaflets and not at the tips. Normal leaves contain 30 to 150 ppm Fe on a dry-weight basis.

Conditions that lead to Fe deficiency are inadequate concentrations of Fe in the soil solution or basic soil conditions (pH above 7.0). Fe deficiency is corrected by adding Fe to the fertilizer or by foliar sprays of Fe. Usually one or two sprays of 0.5 ppm Fe solution will correct a temporary Fe deficiency.

Manganese is absorbed as Mn^{2+} ions and uptake is affected by other cations such as Ca and Mg. Manganese is relatively immobile in the plant and symptoms of deficiency first appear on the upper leaves.

Deficiency of Mn resembles that of Mg, however Mn deficiency appears on the upper leaves of the plant. Manganese deficiency consists of interveinal chlorosis; however, the chlorosis is more speckled in appearance compared to Mg deficiency. Manganese deficiency also slightly resembles Fe deficiency of tomato however Mn deficiency appears as chlorotic speckling over most of the leaf while Fe deficiency usually appears first on the lower part of the leaflets.

Critical concentrations of Mn in leaves ranges from 20 to 100 ppm for most plants. High levels of Mn can be toxic to plants. Toxicity appears as marginal leaf necrosis in many

plants. Concentrations of Mn on the order of 500 to 800 ppm can result in toxicity in many crops. Excess Mn in the soil solution can reduce uptake of Fe by the plant.

Situations that lead to deficiency are mostly related to inadequate Mn supply in the soil solution, from basic soil conditions, or to competition effects of other ions. Toxicity can occur from excess Mn supply especially when plants are in acidic soil. Solubility of Mn in the soil solution is increased by low pH.

Zinc uptake is thought to be by an active process and can be negatively affected by high concentrations of P in the media. Zinc is not highly mobile in plants. Deficiency of Zn results in young leaves with interveinal chlorosis. Sometimes Zn deficiency will lead to plants with shortened internodes.

Healthy leaves contain about 25 to 150 ppm Zn. High levels of Zn can lead to toxicity where root growth is reduced and leaves are small and chlorotic. Zinc deficiency may occur in cold, wet soils, or in soil with a very high pH where Zn is rendered unavailable to the plant.

Copper is absorbed by plants in very small quantities. The uptake process appears to be an active process and it is adversely affected by high Zn concentrations. Copper is not highly mobile in plants but some Cu can be translocated from older to newer leaves. The normal level of Cu in plants is on the order of 4 to 20 ppm.

Copper deficiency on young leaves leads to chlorosis and some elongation of the leaves. Excess Cu, especially in acidic soil may be toxic to plants.

Molybdenum is absorbed as molybdate (MoO_4^{-2}) and the uptake can be suppressed by sulfate. Normal tissue concentrations of Mo are usually less than 1 ppm.

A deficiency of Mo first appears on leaves that are intermediate in age and older. The leaves become chlorotic and the margins roll. Unlike other micronutrients, Mo deficiency occurs in acidic soil conditions.

Boron uptake by plants is not well understood. Boron is not mobile in the plant and seems to have many uptake and transport characteristics in common with Ca.

Boron deficiency affects the young growing points first, e.g., buds, leaf tips and margins, and root tips. Buds develop necrotic areas and leaf tips become chlorotic and eventually die. Tomato leaves and stems become brittle. Healthy leaves contain 20 to 100 ppm B; levels higher than 150 ppm may lead to toxicity. Cole crops, beets, and celery have rather high B requirements, otherwise only small amounts of B are needed by plants and supplying excessive B from fertilizer or from foliar sprays can lead to toxicity.

Chlorine is supplied for plant nutrition as the chloride ion and is required in very small amounts for normal plant growth. Chloride is involved in photosynthesis and functions as a counter-ion in maintaining turgor pressure in cells. Chlorine deficiency symptoms are not common but include wilting. The chloride ion is very common in the environment and is often found as a constituent in fertilizers; therefore, deficiency symptoms are rare. High concentrations of chloride in the nutrient solution can be toxic to plants in hydroponic culture.

Nickel is required in small amounts by plants, 0.5 to 5.0 ppm Ni. Nickel is common in soil, and truly deficient soils have not be found. Deficiency symptoms include chlorosis similar to that of iron deficiency. Nickel deficiency also can be similar to zinc deficiency. These similarities in deficiencies make it difficult to diagnose true Ni deficiency in plants. A buildup of urea in leaf tips may occur in Ni-deficient plants.

Key to Nutritional Disorders of Vegetable Crops

The key in Table 2 can be used to assist in diagnosis of visual symptoms of nutrient disorders. Color photographs, available in many books (see general reference list at the end of this publication) may be useful in conjunction with the key.

Critical Concentrations

As reported in the section on nutrient deficiency symptoms, there is a general concentration range for each essential element that results in normal plant growth. This is called the adequate or sufficient nutritional concentration range (Fig. 1). Plant growth remains relatively constant within the range of concentrations found in the zone of sufficiency.

The so-called critical concentration occurs at the point where growth is reduced 10% because of a shortage of the element in question. The critical concentration is in the transition zone, which is the borderline between elemental sufficiency and deficiency. Critical concentrations for an element can be different depending on stage of growth and plant part used for the reference tissue.

The zone of sufficiency (level part of the graph) is the area where an increase in tissue nutrient concentration is not accompanied by an increase in growth (Fig. 1). This is the range in nutrient concentrations in which the grower should attempt to control the fertilizer program. The objective is to maintain tissue nutrient concentrations on the lower side of the range with good fertilization techniques. Managing plant nutrient concentrations on the right of the zone indicates over fertilization and resulting luxury consumption of nutrients by the plant.

The deficient zone occurs at tissue elemental concentrations lower than those in the transition zone and is accompanied by a drastic restriction in growth. Plants show deficiency symptoms as the nutrient concentration falls within this zone. This is the vertical portion of the curve (Fig. 1).

At the other end of the scale is the toxicity zone where tissue elemental concentrations are greater than those in the adequate zone. A gradual decrease in plant growth occurs in the toxicity zone. As the tissue concentration rises further, toxicity symptoms, often necrosis, begins (Fig. 1).

The curve shown in Fig. 1 is obtained by growing plants at a wide range of concentrations of the element being studied. Meanwhile, other nutrients and factors influencing growth are held constant so that changes in growth can be attributed solely to the nutrient being studied. Either greenhouse or field experiments may be designed to generate the data necessary to develop the relationship between plant growth and tissue concentrations of a particular element.

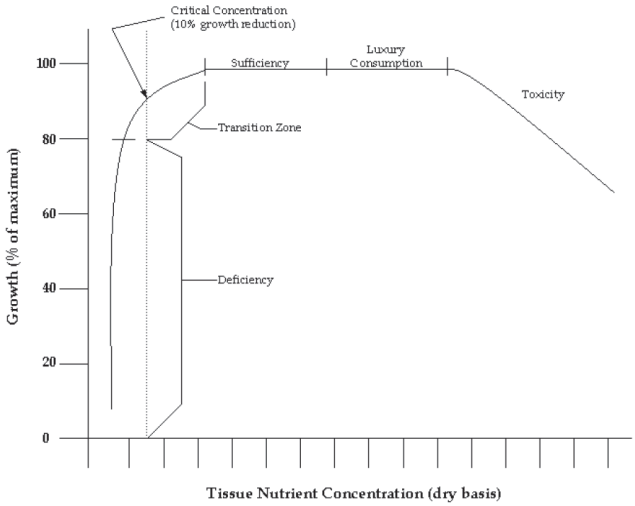

Figure 1. Crop growth in relation to concentration of a nutrient in the diagnostic tissue sample.

Application of Plant Analysis

Plant analysis assists in diagnosing nutritional problems or potential problems in the crop from which the samples are taken, i.e., the current crop. Potential problems can be circumvented, particularly if they are discovered early in the crop (before bloom) cycle by routine leaf analyses. For example, young cabbage plants that appear normal might have a very low N concentrations for that stage of growth. When checking fertilizer application records, it is found that an error was made, and only 1/10 of the intended rate was applied. Additional N can be applied and the crop can be saved, whereas if symptoms of N deficiency had developed before diagnosis, the crop may have been lost or there may have been a substantial yield reduction. With micro-irrigated or fertigated (drip) crops, the nutritional status of the crop can be monitored continuously, and fertigation adjustments can be made as needed.

Plant analysis results also have application for fertilizer management of the same crop grown in subsequent seasons. Fertilizer rates can be increased or decreased based on tissue test results and yields of previous crops. Given certain conditions, plant analysis results can be used to manage timing of supplemental sidedress or topdress fertilizer applications.

Results of plant tissue analysis along with results of soil analysis provide useful tools for the grower in managing the rate and timing of fertilizer applications for vegetables. However, each has limitations and they should not be used for purposes not intended.

Tissue testing is not recommended if the crop has received foliar sprays containing nutrients, especially micronutrients. There is no way to completely remove residues from leaf surfaces and these residues result in higher test results than actually in the plant tissue.

Sample Collection, Preparation, and Handling

Why Sample

There are two main reasons to test plant tissue for nutrient status. The first reason is to monitor the nutrient within the plants during the growing season. This technique is a good management strategy so long as the grower has a means of regulating nutrition in field conditions, for example, addition of nutrients through the micro irrigation system.

The second reason for tissue testing is to diagnose a suspected nutritional deficiency or toxicity. This diagnostic sampling is usually only done after a problem has been detected. In the case of deficiencies, the sampling should only be undertaken if the grower has enough time to apply

extra fertilization AND the addition will actually enhance production. Too often, supplemental fertilization at the end of the season does not result in higher production, but only in greener foliage. With toxicities, information obtained on the current stressed crop can only be used to make management decisions that may benefit subsequent crops. For example, diagnosis of copper toxicity can only be treated by liming the field for the next crop.

The most frequent use of leaf tissue analysis is to diagnose a suspected nutrient deficiency. It is best to perform this analysis as soon as possible after the symptoms are evident. Once a deficiency manifests itself, the optimum yield may have already been lost. Losing the market window in shortseason crops due to a nutrient deficiency is devastating. The loss of market value due to poor leaf color in greens, for example, is also a consideration. Therefore, routine tissue sampling and analysis at the proper time(s) in the season can pay dividends for the grower.

When to Sample

A grower wishing to develop a routine program of tissue sampling to ensure proper nutrition for his or her crop throughout its growth cycle should begin shortly after the crop emerges from the soil (first true leaf) and continue at weekly or biweekly intervals. By means of a routine sampling and analysis program, the grower can fine-tune his fertilization program. Tissue analysis can serve as an indicator as to which nutrients are in adequate, deficient, or high concentrations. If a grower believes the nutritional status of his crop is satisfactory, he may benefit from a single sample taken just before fruit set and perhaps a second sample during mid-production. These samples would bracket that period when a deficiency would be most detrimental to optimum yield.

For routine sampling, a 'reference' tissue (most often leaves) is used to index plant nutritional status. Samples are collected on the basis of physiological age of the plant (not on calendar date) such as prebloom, tasseling, midgrowth, or heading.

What to Sample

There are several types of vegetable plant reference tissues including petiole, leaf, but rarely fruits. Some work has been done with vegetable plant petioles for nitrates in greenhouse crops and some field vegetable crops, but the standard vegetable reference tissue is the leaf. It is essential to use the same plant part as the one used to develop the interpretative data.

It is not practical to harvest and prepare entire plants for chemical analysis. Therefore, a plant part is used for convenience. However, it is essential that the plant part selected for chemical analysis accurately represents the nutritional status of the plant during its entire life cycle. For many vegetable crops, the most-recently-matured leaf (MRML) provides the most sensitive indicator of the nutritional status of the plant, sometimes only the petiole of this leaf is used for plant analysis. Specific plant parts for sampling each vegetable crop are specified in the section on sampling.

For most crops, and for many nutrients, mature, physiologically active leaves should be sampled. This is often referred to as "the most-recently-matured leaf" (MRML) including the blade and its petiole. The MRML is the leaf that has turned from a light-green juvenile color to a darker-green color and has reached full size. The exception to the rule of the MRML is the analysis of Ca, Cu, B, and S, which are relatively immobile in the plant. Therefore, an analysis of the mature leaves in this case may not reveal the Ca, B, Cu, or S deficiency in the younger leaves. When a nutrient deficiency of this nature is suspected, young (not fully expanded) leaf tissue is needed for analysis.

How to Sample

The sample is a whole leaf sample and it should not contain any root or stem material. For sweet corn or onions, the leaf is removed just above the attachment point to the stalk or bulb. For compound leaves (carrots, peas, tomatoes, etc.), the whole leaf includes the main petiole, all the leaflets and their petioliules. For heading vegetables, it is most practical to take the outermost whole wrapper leaf. When sampling particularly young plants, the whole above-ground portion of the plant may be sampled.

A proper leaf sample should consist of about 25 to 100 individual leaves. The same leaf (i.e., physiological age and position) should be removed from each sampled plant. Plants damaged by pests, diseases, or chemicals should be avoided when trying to monitor the nutrient status of the crop.

Individual plants, even side-by-side, may have a considerably different nutrient status. Therefore, by sampling a sufficiently large number of plants, the error due to this variability can be minimized. Figure 2 indicates the potential sampling error due to varying sample sizes. More accuracy in determining the actual nutrient status is derived from a larger sample size.

For a nutrient deficiency diagnosis, one composite tissue sample should be collected from the area exhibiting the disorder and a second sample from otherwise "normal" plants for comparison. Both samples should be of similar physiological age and from the same cultivar. The "disorder" sample and the "normal" sample must be properly separated from each other so a valid comparison can be made after analysis.

It is advisable to include a corresponding soil sample when submitting a diagnostic tissue sample. This practice is particularly important when the sample taken is from an area where a nutrient deficiency is suspected. The soil sample may indicate other factors, such as pH or nematodes, that may have a negative effect on crop growth and nutrient availability.

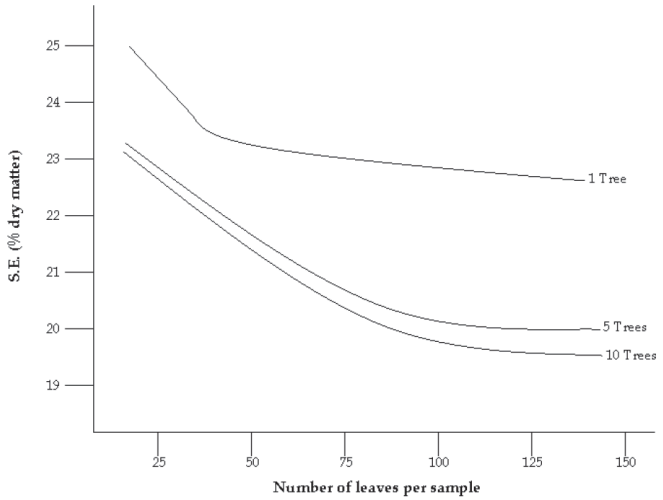

Figure 2. Nitrogen leaf sampling errors for different sampling sizes (Holland et al., 1967).

Contaminants

Samples are often contaminated by fungicides, nutrient sprays, soil, or dust. Data obtained from contaminated leaf samples will be misleading. Decontamination of some dust or soil is best accomplished by quickly rinsing in a dilute non-phosphate detergent solution (2%) followed by two distilled water rinses. Tap water should not be used because it can be high in certain nutrients such as Ca, Fe, Mg, or S. Leaf samples should be washed quickly to minimize the leaching of certain nutrients (especially K) from the leaves. When testing for Fe, it is always necessary to wash the tissue as described above. It is not likely that contamination from chemical or nutrient sprays can be effectively removed from the leaf surface.

Preparation for Shipping

Following rinsing, the sample should be blotted dry with absorbent paper. The samples should be air-dried for several hours before shipment. If a plant analysis mailing kit is not available, the samples should be wrapped in fresh absorbent paper and placed in a large envelope (plastic bags must not be used). The sample should be mailed immediately to the soil and plant analysis laboratory. An air-dried sample, if loosely packed to avoid rotting, will last two to three days before decomposition begins.

If the samples must be held for any length of time before shipping, they should be dried at 150°F in a ventilated oven (leave the door ajar) until dry weight is constant. Once dried, the sample can be placed in a plant analysis mailing kit or a large envelope. This ensures the integrity of the sample until shipping is possible.

Considerations for Choosing a Laboratory

Tissue testing can be a valuable tool for monitoring nutrients within a growing crop. Tissue samples must be collected from the field, shipped to the laboratory, and analytical results with appropriate interpretations returned to the grower. Armed with this information, the grower can make a knowledgeable decision regarding possible additions of fertilizers to the crop. The time for this cycle to be completed must be held to a minimum. A reasonable time frame for this process is 3 to 5 working days for most vegetables, for diagnostic samples. For some short season crops, and for deficiency diagnosis, next-day service is needed.

Laboratory Location

Because of the need for short turnaround from sampling to receipt of the results, the best approach is to select a reliable laboratory close to the production area. However, if the producer is equipped with electronic mail or FAX instruments, delays for return of results can be greatly reduced. Priority mailing of tissue samples can further reduce the turnaround time. Thus, the need for the laboratory to be located relatively close to the production site is somewhat reduced, but the grower should still consider the physical problems of mailing as a factor in selecting a laboratory for tissue testing.

Since several tissue samples will be needed throughout the season, it is often advisable to make prior arrangements with the laboratory for all of the expected samples. Some laboratories offer a "package" for selected crops that includes a discount for a specified number of sampling dates.

The Land Grant University laboratories in the southeast region have been exchanging standardized plant samples for many years [Southern Region Information Exchange Group (SRIEG) 18 Work Group] and have found good agreement among the participating university laboratories. However, both laboratory procedures and methodology can influence tissue results, so it is usually advisable to continue testing with the same laboratory throughout the season and years to avoid possibly significant differences among laboratories.

Interpretation of Laboratory Results

While many laboratories do an excellent job of reporting the concentrations of nutrients in plant tissue, a few laboratories also provide accurate interpretations and recommendations based upon those results. That interpretations and recommendations may be provided with the report is no indication of their value for efficient crop production. Information (such as that contained in this circular) must be based upon research in local field conditions to be of use in interpreting laboratory results. Some laboratories might report the tissue results, compared with the average value for that crop and nutrient, observed by the lab in previous years. This average value might not be the critical concentration the grower is looking for because the average value includes results from crops of variable nutrient status or varieties. In other words, one needs the true critical concentration. Sometime the lab's "low", "medium", and "high" interpretation are simply a placement of the results relative to what is observed on average by the laboratory. Interpretations of this sort are misleading and of little help when making nutrient management decisions. A discussion concerning the procedure used for interpreting concentrations can assist with laboratory selection.

Diagnostic Tissue Testing

By its very nature, diagnostic tissue testing is only undertaken after a problem has been recognized. Often, the grower will see some visual clue that the crop is not as it should be. At this point, information to help make a diagnosis is needed, one component of which may be tissue analysis. Other information, such as soil testing, climatic data, pesticide, and fertilizer records, will often be needed besides nutrient status of the crop before the problem is correctly identified.

All of the considerations discussed with respect to nutrient monitoring pertaining to laboratory selection and location apply equally to diagnostic sampling. However, sample turnaround time may be the most important, since prompt reaction to some nutrient deficiencies is needed to avoid loss of yield and/or fruit quality.

Interpretations and recommendations of diagnostic samples should be a two-step process. The first interpretation should be based solely on the concentrations of nutrients found in the tissue sample. In short, do the nutrient levels represent deficiency or toxicity? The information in this circular can help with the answer to this question.

Secondly, results of samples from the affected area should be compared with those taken from an unaffected area: so-called "normal" and "disorder" areas. The samples should be taken at the same time so that a valid comparison can be made. The distance between the two composite samples should also be as small as possible.

This comparison will greatly aid in proper diagnosis. Often, a nutrient may be found to be at the lower level of the sufficiency range in the "disorder" sample, immediately making that nutrient suspect. However, comparison between "normal" and "disorder" levels may reveal that the nutrient is of similar magnitude in both samples, indicating that the symptoms may be caused by other factors.

Plant-Analysis Methods

The method used by the laboratory may greatly affect the meaning of the reported results. Many laboratory procedures, all radically different in approach, have been developed for plant analysis. For example, tests for P, K, etc., range from exotic neutron magnetic resonance (NMR) techniques to field quick-test kits. However, growers should patronize laboratories offering agricultural tests. These methods usually require destructive sampling, either by dry ashing the sample or by dissolving the sample in one or more acids. For small sample sets, some laboratories may employ microwave digestion in acids, but most laboratories will digest samples using a controlled temperature oven or heating apparatus. Testing of the resulting solutions by specific ion electrode methods is usually considered less accurate than colorimetric or spectrophotometric methods.

Methods that analyze the plant sap are usually only semi-quantative measurements. Most field kits use this approach. While some of these kits are appropriate for field use by the grower for certain nutrients, the bulk of these procedures are not as precise as laboratory methods.

All reputable laboratories will monitor the accuracy and precision of test results. This process is usually referred to as a quality assurance program. It is this process that insures that numbers from the various tests are actually

within acceptable accuracy ranges. A short discussion with the laboratory about their quality assurance program is good insurance against choosing the wrong laboratory. In all chemical and physical testing, it is agreed that an active quality assurance program has to be in place if any credence is to be given the results of the laboratory effort. Laboratories actively participating in the North American Proficiency Testing program meet or exceed plant tissue quality standards.

A common misconception is that two laboratories should be able to report the same, exact figures on split samples. Selection of methods and possibly different units of measure often cloud such expected agreement. For plant tissue analyses, the analytical results of split samples should be similar. For example, if one lab reports 4.8% N on one sample from a split-sample of tomato leaves, then the second lab results should be the same. In the final analysis however, the actual laboratory answer is but one step to making accurate interpretations and recommendations. It is the accuracy of the recommendation and subsequent positive crop response that is of value to the grower.

Listing of Commercial Laboratories for Agricultural Testing

The University of Florida (IFAS) Extension Soil Testing Laboratory (ESTL) offers only limited plant tissue testing to the public. Services for blueberry and pecan leaves are available. County extension faculty may request diagnostic testing of other plant samples, but this service is not offered directly to the public. Therefore, a discussion with the local county extension faculty is recommended before any samples are sent to the ESTL.

The listing in Table 3 of commercial laboratories may be of use to the reader. This listing is not exhaustive. http://www.naptprogram.org/

Plant-Sap Quick Test for Nutrient Analysis

Much of the diagnostic information presented in this publication deals with analysis of dried plant material (whole leaves, leaf blades, or petioles). The time period from sampling to recommendations for problem correction can be excessive for many situations involving deficiencies. Cost of routine sampling and analysis that involves many samples might be too high for many growers. However, the cost of tissue testing should be compared to the crop value at stake. Costs are often cited as hindrances to routine use of tissue testing in a fertilizer management program. Growers like the idea of tissue testing but may be reluctant to use it in a routine and timely fashion.

An alternative, for certain nutrients, to traditional laboratory analysis is a nutrient determination made on the fresh plant sap. Procedures for plant sap analysis have been available for years, but recently the techniques have been improved to make them more accurate and easier to use in the field. Most of these in-field plant sap "quick tests" should be used in conjunction with periodic laboratory analysis done on dried whole leaves.

Plant sap analysis kits are available in a range of sophistication from simple, hand-held "colorimeters" and ion-specific electrodes to sophisticated portable laboratory units that can test for a multitude of nutrients and chemicals. Growers interested in plant sap testing should evaluate their goals and purchase the equipment needed to meet the needs and avoid unneeded equipment. Often a $50 kit will suffice, but some growers who have the personnel, could benefit from larger, more diverse testing kits.

Plant sap kits can test for several plant nutrients but the user needs to evaluate the need for speed versus accuracy for the nutrients to be determined. For example, a sap test kit may not have the desired accuracy for certain micronutrients compared to traditional laboratory analyses using whole leaves.

Currently, plant sap test kits appear to have most utility for the mobile nutrients such as N, P, and K. These elements, particularly N and K, make up the bulk of nutrients applied as fertilizers to vegetable crops and also are the ones most often managed during the growing season, which makes plant sap testing particularly attractive for these elements. A good example is N management through the season with micro-irrigation. The routine use of a calibrated plant sap quick test could help a micro-irrigation manager make decisions regarding N scheduling for the crop. Proper management of N could reduce the overall fertilizer applications to that crop.

Recent studies in the University of Florida, Institute of Food and Agricultural Sciences (IFAS), have provided calibration data for commercially available nitrate and K quick tests. The kits, described below, have been adapted to determine nitrate and K concentrations of fresh plant sap from petioles of most-recently-matured leaves. The initial work was conducted for tomato, although some work also has been done for other crops (cantaloupe, broccoli, cucumber, squash, and collards). The kits calibrated for use in Florida are described in Table 4.

Plant sap test kits are easy to use and result in rapid evaluations of plant sap for nitrate and potassium.

For sap testing, petioles collected from MRML are used for analyses. Most-recently-matured leaves (MRML) are leaves that have essentially ceased to expand and have turned from a juvenile light-green color to a darker-green color. A random sample of a minimum of 25 petioles should be collected from each "management unit" or "irrigation zone." Management units larger than 20 acres should be subdivided into 20-acre blocks. Leaves with obvious defects or with diseases should be avoided. Sampling should be done on a uniform basis for time of day (best between 10 AM and 2 PM), and for interval after rainfall or fertilization.

For tomatoes, the sample is usually the fifth or sixth leaf from the tip. Whole leaves are collected from the plant and the leaf blade tissue and leaflets are then stripped from the petiole. For tomatoes, a petiole of six to eight inches in length remains. Petioles are chopped into about one-half inch segments. If analysis is not to be conducted immediately in the field, then whole petioles should be packed with ice and analyzed within a few hours of collecting. Given more extreme environmental field conditions (high temperature and bright sun), more dependable results are obtained by making measurement in the lab or office than outdoors.

Chopped petiole pieces are mixed and a random subsample (about 1/4 cup) is crushed in a garlic press, lemon press, or hydraulic press (obtainable from HACH Co., Table 4). Expressed sap is collected in a small beaker or juice glass and stirred.

Early in the season, when sap nitrate-N concentrations are high, the sap might need to be diluted. Dilution makes it possible to read the nitrate-N levels within the scales of some test kits. Dilution also will minimize the interference of the green chlorophyll color of the sap on the reading of colorimetric testing systems. Some users have reported success with charcoal-filtered sap. This procedure is particularly good for dark sap that does not need to be diluted. Slightly different results will be obtained with filtered and unfiltered sap and users should standardize procedures with one method. With tomatoes, a dilution of 50 or 60 parts deionized or distilled water to one part sap is needed. Later in the season, a dilution of 20 to 1 will usually suffice. Diluting can be accomplished by using a laboratory pipette and graduated cylinder or less precisely, with an eyedropper. The pipette method is recommended for highest accuracy. Diluted sap is stirred completely prior to use in the test kits.

For the Quant strip test, a test strip is removed from the container (keep strips cool when not in use) and dipped for a second into the diluted sap. Following 60 seconds, the pink or purple color developed on the test pad on the end of the strip is compared to the calibrated color chart provided with the kit. Interpolation will be needed for readings between any two color blocks on the chart. An alternative is to use a newly developed strip color reader. This reflectometer provides for more quantitative evaluation of the color on the strip. Readings are made in parts per million (ppm) nitrates which can be converted into ppm nitrate-N by dividing by 4.45.

For the HACH colorimeter, two viewing tubes are filled with diluted sap. One tube is placed in its slot in the "comparator." Contents of one powder reagent pillow are emptied into the second diluted sap sample and the tube mixed for one minute. After mixing, the tube is placed in its slot in the "comparator" and left for one minute. After one minute, the colors in the viewing slots are matched by rotating the color wheel, and the resulting ppm of nitrate-N read from the dial.

For the Cardy meters, plant sap is pressed from the petioles and a drop is placed on the Cardy meter, covering both electrode spots on the meter. The meter must be calibrated with standard ion solutions before measuring ion concentration in the sap and again between every 6 or 8 measurements. There are specific meters for nitrate-N and K.

Current interpretations for these test kits for several vegetables are presented in Table 5. Work is continuing to provide data for additional crops and for other nutrients. Details on use and care of these sap measuring systems are presented in the publication "Plant Petiole Sap-Testing Guide for Vegetable Crops". Fla. Coop. Ext. Circ. 1144. (http://edis.ifas.ufl.edu/cv004).

Correcting Nutrient Deficiencies

Nutrient deficiencies, if directly related to lack of fertilizer, must be corrected in timely fashion to avoid reduced yield and quality. It is best to avoid deficiencies by well executed soil-based nutrient programs, however, deficiencies if detected early enough can be corrected. Depending on the situation and cultural system used, several means of applying the needed fertilizer can be employed.

For open bare-ground culture, the deficient nutrient can be top dressed over the crop or banded along side of the row if the crop is not too large. Care must be taken to avoid soluble-salt damage to the crop or mechanical damage to

the crop from the fertilizing equipment. For most macronutrients (N, P, K, Ca, Mg, S), a sidedressing of 30 to 40 lb. of element (P and K are in oxide form) per acre will correct a deficiency (Table 6).

Where polyethylene mulch is used, the nutrients must be applied to the root zone by manually punching holes in the mulch, with a liquid injection wheel, or through the micro-irrigation tubing, if that system is in place. Applying fertilizer in the alleys between the beds is not as effective as placing the fertilizer in the soil in the bed.

Foliar applications of macronutrients (N, P, K, Ca, Mg, or S) are not recommended due to inherent inefficiency. Too much nutrient is needed to overcome deficiencies in a short time period, which results in a high risk of foliar damage from soluble salt burn. Leaves are not well adapted for absorbing large amounts of nutrients in a short period due to the waxy cuticle and the inability to achieve uniform covering without soluble salt damage. These deficiencies are more effectively corrected by drenching or banding the needed nutrient in the root zone.

Micronutrient (Mn, Cu, Fe Zn, B, and Mo) deficiencies can be corrected by application of small amounts of the deficient nutrient (Table 6). Foliar application of the deficient micronutrient can be an effective means of correction if adequate leaf coverage is obtained. Micronutrients can be toxic in small amounts so care must be exercised to apply the recommended rates. For crops with waxy leaves, coverage can be improved by use of a spreader-sticker adjuvant in the spray tank.

Table of Deficient, Adequate, and Excessive Nutrient Concentrations for Vegetables

The following tables of nutrient concentrations were developed for vegetables from research conducted on vegetable nutrition. Tables 7 through 18 contain data for macronutrients N, P, K, Ca, Mg, and S and Tables 19 through 29 contain data on micronutrients Fe, Mn, Zn, B, Cu, and Mo. Much of these data were derived from fertilizer response research conducted in the United States with special emphasis on Florida. In these studies, researchers evaluated crop yield (and sometimes quality) response to varying rates of fertilizer nutrients on soils that contributed minimally to the crop nutrient requirement. Plant tissue nutrient concentrations from plants from those fertilizer treatments producing optimum yield and quality were selected as indicating adequate nutrition for a specific nutrient. Optimum fertilizer treatments were those fertilizer amounts above which no further increase in yields or quality resulted. Therefore, the corresponding tissue nutrient values would fall on the lower side of the sufficiency range.

Deficient nutrient values were those from fertilizer treatments that yielded significantly less than with the optimum treatments. These levels might not result in deficiency symptoms but are likely to result in reduced yields and quality.

In some situations, the dividing line between deficient and adequate values is not as clear as the table would indicate. For example, 2.0% and 2.1% might not be different from each other. For these "gray zone" values, one must use a common-sense approach to the interpretation.

The concentrations representing the adequate range (sufficiency range) are those nutrient concentrations to be found in plants that have adequate nutrients available to them. Plants with nutrient concentrations in the high range are indicative of over fertilization. Reduced yields and poor quality could result if the fertilizer rates are not reduced for these plants. For the micronutrients plant nutrient concentrations maintained in the high range could lead to phytotoxicity.

The reference tissues in Tables 5-29 are usually the MRML. This tissue is the whole leaf (blade plus petiole). This reference tissue is the most widely used plant part for most crops. However, for some crops, most of the interpretive research has been conducted for other plant parts (e.g., petioles).

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Table 1. Mobility of essential elements in plants. Mobility reflects the ability of an element to be relocated within the plant under deficient supply.

Relative Mobility in the Plant		
High	**Intermediate**	**Low**
Nitrogen (NO_3- or NH_4+)	Iron	Calcium
Phosphorus	Manganese	Boron
Potassium	Zinc	
Magnesium	Copper	
Sulfur	Molybdenum	
Chlorine		
Nickel		

Table 2. Key to Nutritional Disorders of Vegetable Crops.

	Symptoms of Nutritional Disorder	**Diagnosis of Deficiency**
A.	Symptoms on leaves, stems, or petioles	B
	Flowering or fruiting affected	M
	Storage organs affected	N
	Variable plant growth throughout the field. Some plants appear normal, some show severe marginal leaf necrosis, while others are stunted. Determine soil pH.	Acidic or Alkaline Soil Complex
B.	Youngest leaves affected first.	C
	Entire plant affected or oldest leaves affected first.	I
C.	Chlorosis appears on youngest leaves.	D
	Chlorosis is not a dominant symptom. Growing points eventually die and storage organs are affected.	H
D.	Leaves uniformly light green, followed by yellowing and poor, spindly growth. Most common in areas with acidic, highly leached, sandy soils low in organic matter.	Sulfur
	Uniform chlorosis does not occur.	E
E.	Leaves wilt, become chlorotic, then necrotic. Onion bulbs are undersize and outer scales are thin and lightly colored. May occur on acidic soils, on soils high in organic matter, or on alkaline soils.	Copper
	Wilting and necrosis are not dominant symptoms.	F
F.	Distinct yellow or white areas appear between veins, and veins eventually become chlorotic. Symptoms rare on mature leaves. Necrosis usually absent. Most common on calcareous soils ("lime induced chlorosis").	Iron
	Yellow/white areas are not so distinct, and veins remain green.	G
G.	Chlorosis is less marked near veins. Some mottling occurs in interveinal areas. Chlorotic areas eventually become brown, transparent, or necrotic. Symptoms may appear later on older leaves. In peas and beans, the radical and central tissue of cotyledons of ungerminated seeds become brown ("marsh spot"). Most common on soils with pH over 6.8	Manganese
	Leaves may be abnormally small and necrotic. Internodes are shortened. Beans, sweet corn ("white bud" of maize), and lima beans most affected; potatoes, tomatoes, and onion somewhat affected; uncommon with pea, asparagus, and carrots. Reduced availability in acidic, highly leached, sandy soils, in alkaline soils, and in organic soils.	Zinc
H.	Brittle tissues. Young, expanding leaves may be necrotic or may be short, especially at shoot terminals. Stems may be rough, cracked, or split along the vascular bundles (hollow stem or crucifers, cracked stem of celery). Most likely on highly leached, acidic soils and on organic soils with free lime.	Boron
	Brittle tissues not a dominant symptom. Growing points usually damaged or dead ("dieback"). Margins of leaves developing from the growing point are first to turn brown or necrotic, expanding corn leaf margins are gelatinous and necrotic, expanding cruciferous seedling leaves are cupped and have necrotic margins; old leaves remain green. Common on acidic, highly leached, sandy soils. May result from excess Na, K, or Mg from irrigation waters, fertilizer or dolomitic limestone. (Celery blackheart, brown heart of escarole, lettuce tipburn, internal tipburn of cabbage, internal browning of brussels sprouts, hypocotyl necrosis of snapbeans.)	Calcium
I.	Plant exhibits chlorosis.	J
	Chlorosis is not a dominant symptom.	L
J.	Interveinal or marginal chlorosis.	K

	General chlorosis. Chlorosis progresses from light green to yellow. Entire plant becomes yellow under prolonged stress. Growth is immediately restricted and plants soon become spindly and drop older leaves. Most common on highly leached soils or with high organic matter soils at low temperatures. Soil applications of N show dramatic improvements.	Nitrogen
K.	Marginal chlorosis or chlorotic blotches which later merge. Lower leaves show yellow chlorotic interveinal tissue on some species, reddish purple progressing to necrosis on others. Younger leaves affected with continued stress. Chlorotic areas may become necrotic, brittle, and curl upward. Symptoms usually occur late in growing season. Most common on acidic, highly leached, sandy soils or on soils with high K or high Ca.	Magnesium
	Interveinal chlorosis, with early symptoms resembling N deficiency (Mo is required for nitrate reduction); older leaves chlorotic or blotched with veins remaining pale green. Leaf margins become necrotic and may roll or curl. Symptoms appear on younger leaves as deficiency progresses. In Brassicas, leaf margins become necrotic and desintegrate, leaving behind a thin strip of leaf ("whiptail"), especially of cauliflower. Common on acidic soils or highly leached alkaline soils.	Molybdenum
L.	Leaf margins tanned, scorched, or have necrotic spots (may be small black dots which later coalesce). Margins become brown and cup downward. Growth is restricted and dieback may occur. Mild symptoms appear first on recently matured leaves, then become pronounced on older leaves, and finally on young leaves. Symptoms may be more common late in the growing season due to translocation of K to developing storage organs. Most common on highly leached, acidic soils and on organic soils due to fixation.	Potassium
	Leaves appear dull, dark green, blue-green, or red-purple, especially on the underside, and at the midrib and veins. Petioles may also exhibit purpling. Restriction in growth may be noticed. Availability reduced in acidic and alkaline soils, and in cold, dry, or organic soils.	Phosphorus
	Terminal leaflets wilt with slight water stress. Wilted areas later become bronzed, and finally necrotic. Very infrequently observed.	Chlorine
M.	Fruit appear rough, cracked, or spotted. Flowering is greatly reduced. Tomato fruits show open locule, internal browning, blotchy ripening, or stem-end russeting. Occurs on acidic soils, on organic soils with free lime, and on highly leached soils.	Boron
	Cracking and roughness are not dominant symptoms. Fruits exhibit water-soaked lesions on blossom end, later become sunken, dark or leathery (blossom end rot of tomato, pepper, and watermelon). Common on acidic, highly leached soils.	Calcium
N.	Internal or external necrotic or water soaked areas of irregular shape (hollow stem of crucifers, internal browning of turnip and rutabaga, canker or blackheart of beet, water core of turnip). May occur on acidic soils, on alkaline soils with free lime, or on highly leached soils.	Boron
	Cavities develop in the root phloem, followed by collapse of the epidermis, causing pitted lesions. (Cavity spot of carrots or parsnips.) Common on acidic, highly leached soils.	Calcium

Table 3. Partial listing of commercial laboratories offering agricultural testing services to Florida growers. Not all laboratories offer all services. Some laboratories do not provide interpretations or recommendations with test results. Clients should contact the laboratory before submitting samples. This listing does not imply a recommendation of these laboratories by the authors or IFAS.

ABC Research Corporation
3437 SW 24th Avenue
Gainesville, FL 32607
(352) 372-0436

A & L Agricultural Laboratories
1301 W. Copans Road Bldg. D, Suite 8
Pompano Beach, FL 33064
(954) 972-3255

Flowers Chemical Laboratory
481 Newberry Port Ave
Winter Park, FL 32789
(407) 339-5984

Agro Services International, Inc.
215 E. Michigan Avenue
Orange City, FL 32763
(904) 775-6601

Thornton Laboratories
1145 E. Cass Street
Tampa, FL 33602
(813) 223-9702

Bionomics Laboratory, Inc.
4310 Anderson Road
Orlando, FL 32812
(407) 851-2560

Technical Services, Inc.
2901 Danese Street
Jacksonville, FL 32206
(904) 353-5761

Table 4. Nitrate-nitrogen (and potassium) quick-test kits for use in petiole sap nitrate-N (and potassium) determinations.

1.	**Hach colorimeter** - HACH Company, PO Box 389, Loveland, CO, 80539. Kit determines nitrate-N directly from a small hand-held "comparator" or colorimeter. There is a range in test-kit sophistication available from HACH and test kits for several other plant nutrients are available. http://www.environmental-expert.com/
2.	**Merckoquant test strips** - EMD Chemicals, Analytics & Reagents, 480 South Democrat Rd, Gibbstown, NJ 08027. Kit tests for total nitrates in test solution by comparison of color developed on test strip with a color chart. Available also is a "reflectometer" to assist in more quantitative reading of the color developed on the strips. http://www.emdchemicals.com/
3.	**Cardy Meters** - Spectrum Technologies, Inc. 12010 S. Aero Dr., Planfield IL 60544. Ion-specific, hand-held meters for nitrate-N or potassium ions. Measure ion concentrations in undiluted plant sap with digital read-out. http://www.specmeters.com/Nutrient_Management/Cardy_Plant_Nutrient_Meters.html

Table 5. Adequate nitrate-N and K concentrations in fresh petiole sap of most recently matured leaves for several vegetable crops at various periods in the season using the Hach or Quant-strip methods, or Cardy meter.

Crop	**Stage of Growth**	**Fresh Petiole Sap Concentration (ppm)**	
		K	**NO_3-N conc.**
Cucumber	First blossom	N/A	800 to 1000
	Fruits three inches		600 to 800
	First harvest		400 to 600
Broccoli and Collards	Six-leaf stage	N/A	800 to 1000
	Just prior to harvest		500 to 800
	At first harvest		300 to 500
Eggplant	First fruit (two-inches long)	4500 to 5000	1200 to 1600
	First harvest	4000 to 5000	1000 to 1200
	Mid harvest	3500 to 4000	800 to 600
Muskmelon (Cantaloupe)	First blossom	4000 to 5000	1000 to 1200
	Fruits 2 inches	3500 to 4000	800 to 1000
	First harvest	3000 to 3500	700 to 800
Pepper	First flower buds	3200 to 3500	1400 to 1600
	First open flowers	3000 to 3200	1400 to 1600
	Fruits half-grown	3000 to 3200	1200 to 1400
	First harvest	2400 to 3000	800 to 1000
	Second harvest	2000 to 2400	500 to 800
Potato	Plants 8 inches tall	4500 to 5000	1200 to 1400
	First open flowers	4500 to 5000	1000 to 1400
	50% flowers open	4000 to 4500	1000 to 1200
	100% flowers open	3500 to 4000	900 to 1200
	Tops falling over	2500 to 3000	600 to 900
Squash	First blossom	N/A	900 to 1000
	First harvest		800 to 900
Strawberry (in Florida)	November	3000 to 3500	800 to 900
	December	3000 to 3500	600 to 800
	January	2500 to 3000	600 to 800
	February	2000 to 2500	300 to 500
	March	1800 to 2500	200 to 500
	April	1500 to 2000	200 to 500
Tomato (Field)	First buds	3500 to 4000	1000 to 1200
	First open flowers	3500 to 4000	600 to 800
	Fruits one-inch diameter	3000 to 3500	400 to 600
	Fruits two-inch diameter	3000 to 3500	400 to 600
	First harvest	2500 to 3000	300 to 400
	Second harvest	2000 to 2500	200 to 400
Tomato (Greenhouse)	Transplant to 2nd fruit cluster	4500 to 5000	1000 to 1200
	2nd cluster to 5th cluster	4000 to 5000	800 to 1000
	Harvest season (Dec-Jun)	3500 to 4000	700 to 900
Watermelon	Vines 6-inches in length	4000 to 5000	1200 to 1500
	Fruits 2-inches in length	4000 to 5000	1000 to 1200
	Fruits one-half mature	3500 to 4000	800 to 1000
	At first harvest	3000 to 3500	600 to 800

Table 6. Recommendations for correction of crop nutrient deficiencies.

Nutrient	Fertilizer	Method	Application Rate (nutrient)lb. per acre
Nitrogen (N)	Ammonium nitrate	T,S,D,W[2]	30 to 40
	Calcium nitrate	T,S,D,W	30 to 40
Phosphorus (P_2O_5)	Ammonium phosphates	T,S,D,W	20
	Triple, normal superphosphate	T,S	20
	Phosphoric acid	S,D	20
Potassium (K_2O)	Potassium chloride	T,S,D,W	30
	Potassium nitrate	T,S,D,W	30
Calcium (Ca)	Calcium nitrate	T,S,D,W	30
	Calcium chloride	D,W	30
Magnesium (Mg)	Magnesium sulfate	T,S,D,W	20
	Magnesium nitrate	D,W	20
	Potassium magnesium sulfate	T,S	10
Boron (B)	Borax, Solubor[1]	D,F	0.1 to 0.2
Copper (Cu)	Copper sulfate	D,F	0.1 to 0.2
Iron (Fe)	Ferrous sulfate, chelated iron	D,F	0.2 to 0.5
Manganese (Mn)	Manganous sulfate	D,F	0.5 to 1.0
Molybdenum (Mo)	Sodium molybdate	D,F	0.01 to 0.05
Zinc (Zn)	Zinc sulfate, chelated zinc	D,F	0.1 to 0.2

[1] Mention of a trade name does not imply a recommendation compared to similar materials.

[2] T,S,D,W,F are topdress, sidedress, drip irrigation, injection wheel, and foliar, respectively.

Table 7. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	N	P	K	Ca	Mg	S
				---------- % ----------					
Beets (Table)	Leaf blades	5 weeks after seeding	Deficient	<3.0	0.2	2.0	1.5	0.25	-
			Adequate	3.0	0.3	2.0	1.5	0.25	0.6
			range	5.0	0.4	6.0	2.0	1.0	0.8
			High	>5.0	0.4	6.0	2.0	1.0	-
			Toxic (>)	-	-	-	-	-	-
	Leaf blades	9 weeks after seeding	Deficient	<2.5	0.2	1.7	1.5	0.3	-
			Adequate	2.6	0.2	1.7	1.5	0.3	0.6
			range	4.0	0.3	4.0	3.0	1.0	0.8
			High	>4.0	0.3	4.0	3.0	1.0	-
			Toxic (>)	-	-	-	-	-	-
Brussel Sprouts	MRM leaf	At early sprouts	Deficient	<2.2	0.2	2.4	0.4	0.2	0.2
			Adequate	2.2	0.2	2.4	0.4	0.2	0.2
			range	5.0	0.6	3.5	2.0	0.4	0.8
			High	>5.0	0.6	3.5	2.0	0.4	0.8
Broccoli	MRM leaf	Heading	Deficient	<3.0	0.3	1.1	0.8	0.23	-
			Adequate	3.0	0.3	1.5	1.2	0.23	0.2
			range	4.5	0.5	4.0	2.5	0.4	-
			High	>4.5	0.5	4.0	2.5	0.4	-
Cabbage	MRM leaf	5 weeks after transplanting	Deficient	<3.2	0.3	2.8	0.5	0.25	-
			Adequate	3.2	0.3	2.8	1.1	0.25	0.3
			range	6.0	0.6	5.0	2.0	0.6	-
			High	>6.0	0.6	5.0	2.0	0.6	-
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	8 weeks after transplanting	Deficient	<3.0	0.3	2.0	0.5	0.2	-
			Adequate	3.0	0.3	2.0	1.5	0.25	0.3
			range	6.0	0.6	4.0	2.0	0.6	-
			High	>6.0	0.6	4.0	2.0	0.6	-
	Wrapper leaf	Heads 1/2 grown	Deficient	<3.0	0.3	1.7	0.5	0.25	-
			Adequate	3.0	0.3	2.3	1.5	0.25	0.3
			range	4.0	0.5	4.0	2.0	0.45	-
			High	>4.0	0.5	4.0	2.0	0.45	-
	Wrapper leaf	At harvest	Deficient	<1.8	0.3	1.2	0.5	0.25	-
			Adequate	1.8	0.3	1.5	1.5	0.25	0.3
			range	3.0	0.4	1.5	1.5	0.25	0.3
			High	3.0	0.4	3.0	2.0	0.45	-

Table 8. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	%					
				N	P	K	Ca	Mg	S
Collards	Tops	Young plants	Deficient	<4.0	0.3	3.0	1.0	0.4	-
			Adequate	4.0	0.3	3.0	1.0	0.4	-
			range	5.0	0.6	5.0	2.0	1.0	-
			High	>5.0	0.6	5.0	2.0	1.0	-
	MRM leaf	Harvest	Deficient	<3.0	0.3	2.5	1.0	0.35	-
			Adequate	3.0	0.3	2.5	1.0	0.35	-
			range	5.0	0.5	4.0	2.0	1.0	-
			High	>5.0	0.5	4.0	2.0	1.0	-
Carrots	MRM leaf	60 days after seeding	Deficient	<1.8	0.2	2.0	1.0	0.15	-
			Adequate	1.8	0.2	2.0	2.0	0.2	-
			range	2.5	0.4	4.0	3.5	0.5	-
			High	>2.5	0.4	4.0	3.5	0.5	-
	MRM leaf	Harvest	Deficient	<1.5	0.2	1.0	1.0	0.25	-
			Adequate	1.5	0.2	1.4	1.0	0.4	-
			range	2.5	0.4	4.0	1.5	0.5	-
			High	>2.5	0.4	4.0	1.5	0.5	-
Cauliflower	MRM leaf	Buttoning	Deficient	<3.0	0.4	2.0	0.8	0.25	0.6
			Adequate	3.0	0.4	2.0	0.8	0.25	0.6
			range	5.0	0.7	4.0	2.0	0.6	1.0
			High	>5.0	0.7	4.0	2.0	0.6	-
	MRM leaf	Heading	Deficient	<2.2	0.3	1.5	1.0	0.25	-
			Adequate	2.2	0.3	1.5	1.0	0.25	-
			range	4.0	0.7	3.0	2.0	0.6	-
			High	>4.0	0.7	3.0	2.0	0.6	-
Celery	Outer petiole	6 weeks after transplanting	Deficient	<1.5	0.3	6.0	1.3	0.3 -	-
			Adequate	1.5	0.3	6.0	1.3	0.3 -	-
			range	1.7	0.6	8.0	2.0	0.6 -	-
			High	>1.7	0.6	8.0	2.0	0.6 -	-
	Outer petiole	At maturity	Deficient	<1.5	0.3	5.0	1.3	0.3 -	-
			Adequate	1.5	0.3	5.0	1.3	0.3 -	-
			range	1.7	0.6	7.0	2.0	0.6 -	-
			High	>1.7	0.6	7.0	2.0	0.6 -	-
Chinese Cabbage (Heading)	Oldest undamaged leaf	8 leaf stage	Deficient	<4.5	0.5	7.5	4.5	0.35 -	-
			Adequate	4.5	0.5	7.5	4.5	0.35 -	-
			range	5.0	0.6	8.5	5.0	0.45	-
			High	>5.0	0.6	8.5	5.0	0.45	-
	Oldest undamaged leaf	At maturity	Deficient	<3.5	0.3	3.0	3.7	0.4	-
			Adequate	3.5	0.3	3.0	3.7	0.4	-
			range	4.0	0.6	6.5	6.0	0.5	-
			High	>4.0	0.6	6.5	6.0	0.5	-

Table 9. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	%				
				N	P	K	Ca	Mg	S
Cucumber	MRM leaf	Before bloom	Deficient	<3.5	0.3	1.6	2.0	0.58	0.3
			Adequate	3.5	0.3	1.6	2.0	0.58	0.3
			range	6.0	0.6	3.0	4.0	0.7	0.8
			High	>6.0	0.6	3.0	4.0	0.7	0.8
	MRM leaf	Early bloom	Deficient	<2.5	0.3	1.6	1.3	0.3	0.3
			Adequate	2.5	0.3	1.6	1.3	0.3	0.3
			range	5.0	0.6	3.0	3.5	0.6	0.8
			High	>5.0	0.6	3.0	3.5	0.6	0.8
			Toxic (>)	-	-	-	-	-	-
Eggplant	MRM leaf	Early fruit set	Deficient	<4.2	0.3	3.5	0.8	0.25	0.4
			Adequate	4.2	0.3	3.5	0.8	0.25	0.4
			range	5.0	0.6	5.0	1.5	0.6	0.6
			High	>6.0	0.6	5.0	1.5	0.6	0.6
Endive	Oldest undamaged leaf	8 leaf stage	Deficient	<4.5	0.5	4.5	2.0	0.25	-
			Adequate	4.5	0.5	4.5	2.0	0.25	-
			range	6.0	0.8	6.0	4.0	0.6	-
			High	>6.0	0.8	6.0	4.0	0.6	-
	Oldest undamaged leaf	Maturity	Deficient	<3.5	0.4	4.0	1.8	0.3	-
			Adequate	3.5	0.4	4.0	1.8	0.3	-
			range	4.0	0.6	6.0	3.0	0.4	-
			High	>4.0	0.6	6.0	3.0	0.4	-
Escarole	Oldest undamaged leaf	8 leaf stage	Deficient	<4.2	0.5	5.7	1.7	0.25	-
			Adequate	4.2	0.5	5.7	1.7	0.25	-
			range	5.0	0.6	6.5	2.2	0.35	-
			High	>5.0	0.6	6.5	2.2	0.35	-
	Oldest undamaged leaf	Maturity	Deficient	<3.0	0.4	5.5	2.0	0.25	-
			Adequate	3.0	0.4	5.5	2.0	0.25	-
			range	4.5	0.5	6.5	3.0	0.35	-
			High	>4.5	0.5	6.5	3.0	0.35	-
Romaine	Oldest undamaged leaf	8 leaf stage	Deficient	<5.0	0.4	5.0	2.0	0.25	-
			Adequate	5.0	0.4	5.0	2.0	0.25	-
			range	6.0	0.8	6.0	3.0	0.35	-
			High	>6.0	0.8	6.0	3.0	0.35	-
	Oldest undamaged leaf	Maturity	Deficient	<3.5	0.4	5.0	2.0	0.25	-
			Adequate	3.5	0.4	5.0	2.0	0.25	-
			range	4.5	0.6	6.0	3.0	0.4	-
			High	>4.5	0.6	6.0	3.0	0.4	-

Table 10. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	N	P	K	Ca	Mg	S
				---------- % ----------					
Lettuce	MRM leaf	8 leaf stage	Deficient	<4.0	0.4	5.0	1.0	0.3	-
			Adequate	4.0	0.4	5.0	1.0	0.3	0.3
			range	5.0	0.6	7.0	2.0	0.5	-
			High	>5.0	0.6	7.0	2.0	0.5	-
	Wrapper leaf	Heads 1/2 size	Deficient	<2.5	0.4	4.5	1.4	0.3	-
			Adequate	2.5	0.4	4.5	1.4	0.3	0.3
			range	4.0	0.6	8.0	2.0	0.7	-
			High	>4.0	0.6	8.0	2.0	0.7	-
	Wrapper leaf		Deficient	>2.0	0.3	2.5	1.4	0.3	-
			Adequate	2.0	0.3	2.5	1.4	0.3	0.3
			range	3.0	0.5	5.0	2.0	0.7	-
			High	>3.0	0.5	5.0	2.0	0.7	-
Cos	Oldest undamaged leaf	8 leaf stage	Deficient	<4.0	0.5	4.0	1.7	0.3	-
			Adequate	4.0	0.5	4.0	1.7	0.3	-
			range	5.0	0.6	6.0	2.0	0.7	-
			High	>5.0	0.6	6.0	2.0	0.7	-
	Oldest undamaged leaf	Maturity	Deficient	<3.0	0.4	4.0	1.7	0.3	-
			Adequate	3.0	0.4	4.0	1.7	0.3	-
			range	4.0	0.6	6.0	2.0	0.7	-
			High	>4.0	0.6	6.0	2.0	0.7	-
Boston Lettuce	Oldest undamaged leaf	8 leaf stage	Deficient	<4.0	0.4	5.0	1.0	0.4	-
			Adequate	4.0	0.4	5.0	1.7	0.4	-
			range	6.0	0.6	6.0	2.0	0.6	-
			High	>6.0	0.6	6.0	2.0	0.6	-
			Toxic (>)	-	-	-	-	-	-
	Oldest	Maturity	Deficient	<3.0	0.4	5.0	1.0	0.3	-
			Adequate	3.0	0.4	5.0	1.7	0.3	-
			range	4.0	0.5	6.0	2.0	0.6	-
			High	>4.0	0.5	6.0	2.0	0.6	-
			Toxic (>)	-	-	-	-	-	-
Muskmelon (Cantaloupe)	MRM leaf	12 inch vines	Deficient	<4.0	0.4	5.0	3.0	0.35	-
			Adequate	4.0	0.4	5.0	3.0	0.35	0.2
			range	5.0	0.7	7.0	5.0	0.45	-
			High	>5.0	0.7	7.0	5.0	0.45	-
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	Early fruit set	Deficient	<3.5	0.3	1.8	1.8	0.3	-
			Adequate	3.5	0.3	1.8	1.8	0.3	0.2
			range	4.5	0.4	4.0	5.0	0.4	-
			High	>4.5	0.4	4.0	5.0	0.4	-
			Toxic (>)	-	-	-	-	-	-

Table 11. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling		%					
			Status	N	P	K	Ca	Mg	S
Okra	MRM leaf	30 days after seeding	Deficient	<3.5	0.3	2.0	0.5	0.25	-
			Adequate	3.5	0.3	2.0	0.5	0.25	-
			range	5.0	0.6	3.0	0.8	0.5	-
			High	>5.0	0.6	3.0	0.8	0.5	-
	MRM leaf	Prior to harvest	Deficient	<2.5	0.3	2.0	1.0	0.25	-
			Adequate	2.5	0.3	2.0	1.0	0.25	-
			range	3.0	0.6	3.0	1.5	0.5	-
			High	>3.0	0.6	3.0	1.5	0.5	-
Sweet Onions	MRM leaf	Just prior to bulb initiation	Deficient	<2.0	0.2	1.5	0.6	0.15	0.2
			Adequate	2.0	0.2	1.5	0.6	0.15	0.2
			range	3.0	0.5	3.0	0.8	0.3	0.6
			High	>3.0	0.5	3.0	0.8	0.3	0.6
			Toxic (>)	-	-	-	-	-	-
Pepper	MRM leaf	Prior to blossoming	Deficient	<4.0	0.3	5.0	0.9	0.35	0.3
			Adequate	4.0	0.3	5.0	0.9	0.35	0.3
			range	5.0	0.5	6.0	1.5	0.6	0.6
			High	>5.0	0.5	6.0	1.5	0.6	0.6
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	First blossoms open	Deficient	<3.0	0.3	2.5	0.9	0.3	0.3
			Adequate	3.0	0.3	2.5	0.9	0.3	0.3
			range	5.0	0.5	5.0	1.5	0.5	0.6
			High	>5.0	0.5	5.0	1.5	0.5	0.6
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	Early fruit set	Deficient	<2.9	0.3	2.5	1.0	0.3	0.3
			Adequate	2.9	0.3	2.5	1.0	0.3	0.3
			range	4.0	0.4	4.0	1.5	0.4	0.4
			High	>4.0	0.4	4.0	1.5	0.4	0.4
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	Early harvest	Deficient	<2.5	0.2	2.0	1.0	0.3	0.3
			Adequate	2.5	0.2	2.0	1.0	0.3	0.3
			range	3.0	0.4	3.0	1.5	0.4	0.4
			High	>3.0	0.4	3.0	1.5	0.4	0.4
			Toxic (>)	-	-	-	-	-	-

Table 12. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling		%					
			Status	N	P	K	Ca	Mg	S
Potato	MRM leaf	Plants 8 to 10 inches tall	Deficient	<3.0	0.2	3.5	0.6	0.3	0.3
			Adequate	3.0	0.2	3.5	0.6	0.3	0.3
			range	6.0	0.8	6.0	2.0	0.6	0.5
			High	>6.0	0.8	6.0	2.0	0.6	0.5
	MRM leaf	First blossom	Deficient	<3.0	0.2	3.0	0.6	0.25	0.2
			Adequate	3.0	0.2	3.0	0.6	0.25	0.2
			range	4.0	0.5	5.0	2.0	0.6	0.5
			High	>4.0	0.5	5.0	2.0	0.6	0.5
	MRM leaf	Tubers 1/2 grown	Deficient	<2.0	0.2	2.5	0.6	0.25	0.2
			Adequate	2.0	0.2	2.5	0.6	0.25	0.2
			range	4.0	0.4	4.0	2.0	0.6	0.5
			High	>4.0	0.4	4.0	2.0	0.6	0.5
	MRM leaf	At tops-down	Deficient	<2.0	0.2	1.5	0.6	0.2	0.2
			Adequate	2.0	0.2	1.5	0.6	0.2	0.2
			range	3.0	0.4	3.0	2.0	0.5	0.5
			High	>3.0	0.4	3.0	2.0	0.5	0.5
Radish	MRM leaf	At harvest	Deficient	<3.0	0.3	1.5	1.0	0.3	-
			Adequate	3.0	0.3	1.5	1.0	0.3	-
			range	4.5	0.4	3.0	2.0	0.5	-
			High	>4.5	0.4	3.0	2.0	0.5	-
			Toxic (>)	-	-	-	-	-	-
Snapbean	MRM trifoliate leaf	Before bloom	Deficient	<3.0	0.3	2.0	0.8	0.25	0.2
			Adequate	3.0	0.3	2.0	0.8	0.25	0.2
			range	4.0	0.5	3.0	1.5	0.45	0.4
			High	>4.1	0.5	3.1	1.6	0.45	0.4
			Toxic (>)	-	-	-	-	-	-
	MRM trifoliate leaf	Full bloom	Deficient	<3.0	0.3	2.0	0.8	0.25	0.2
			Adequate	3.0	0.3	2.0	0.8	0.26	0.2
			range	4.0	0.5	3.0	1.5	0.45	0.4
			High	>4.1	0.5	3.1	1.6	0.45	0.4
			Toxic (>)	-	-	-	-	-	-
	MRM trifoliate leaf	Full bloom	Deficient	<2.5	0.2	1.5	0.8	0.25	0.2
			Adequate	2.5	0.2	1.6	0.8	0.26	0.2
			range	4.0	0.4	2.5	1.5	0.45	0.4
			High	>4.1	0.4	2.5	1.6	0.45	0.4
			Toxic (>)	-	-	-	-	-	-
Squash (summer)	MRM leaf	Early fruit	Deficient	<3.0	0.3	2.0	1.0	0.3	0.2
			Adequate	3.0	0.3	2.0	1.0	0.3	0.2
			range	5.0	0.5	3.0	2.0	0.5	0.5
			High	>5.0	0.5	3.0	2.0	0.5	0.5

Table 13. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	%					
				N	P	K	Ca	Mg	S
Pumpkin	MRM leaf	5 weeks from seeding	Deficient	<3.0	0.3	2.3	0.9	0.35	0.2
			Adequate	3.0	0.3	2.3	0.9	0.35	0.2
			range	6.0	0.5	4.0	1.5	0.6	0.4
			High	>6.0	0.5	4.0	1.5	0.6	0.4
	MRM leaf	8 weeks from seeding	Deficient	<3.0	0.3	2.0	0.9	0.3	0.2
			Adequate	3.0	0.3	2.0	0.9	0.3	0.2
			range	4.0	0.4	3.0	1.5	0.5	0.4
			High	>4.0	0.4	3.0	1.5	0.5	0.4
Southern Pea	MRM leaf	Before bloom	Deficient	<3.5	0.3	2.0	1.0	0.3	-
			Adequate	3.5	0.3	2.0	1.0	0.3	-
			range	5.0	0.8	4.0	1.5	0.5	-
			High	>5.0	0.8	4.0	1.5	0.5	-
	MRM leaf	First bloom	Deficient	<2.5	0.2	2.0	1.0	0.3	-
			Adequate	2.5	0.2	2.0	1.0	0.3	-
			range	4.0	0.4	4.0	1.5	0.5	-
			High	>4.0	0.4	4.0	1.5	0.5	-
Spinach	MRM leaf	30 days after seeding	Deficient	<3.0	0.3	3.0	0.6	1.0	-
			Adequate	3.0	0.3	3.0	0.6	1.0	-
			range	4.5	0.5	4.0	1.0	1.6	-
			High	>5.0	0.5	4.0	1.0	1.6	-
	MRM leaf	Harvest	Deficient	<3.0	0.3	2.5	0.6	1.0	-
			Adequate	3.0	0.3	2.5	0.6	1.0	-
			range	4.0	0.5	3.5	1.0	1.6	-
			High	>4.0	0.5	4.0	1.0	1.6	-

Table 14. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	%					
				N	P	K	Ca	Mg	S
Strawberry	MRM leaf	Tranplants	Deficient	<2.8	0.3	1.5	0.3	0.3	-
			Adequate	2.8	0.3	1.5	0.3	0.3	-
			range	3.5	0.4	3.0	1.5	0.6	-
			High	>3.5	0.4	3.0	1.5	0.6	-
	MRM leaf	Initial flower	Deficient	<3.0	0.2	1.5	0.4	0.25	-
			Adequate	3.0	0.2	1.5	0.4	0.25	-
			range	4.0	0.4	3.0	1.5	0.5	-
			High	>4.0	0.4	3.0	1.5	0.5	-
	MRM leaf	Initial flower	Deficient	<3.0	0.2	1.5	0.4	0.25	-
			Adequate	3.0	0.2	1.5	0.4	0.25	-
			range	3.5	0.4	2.5	1.5	0.5	-
			High	>3.5	0.4	2.5	1.5	0.5	-
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	Midseason	Deficient	<2.8	0.2	1.1	0.4	0.2	0.8
			Adequate	2.8	0.2	1.1	0.4	0.2	0.8
			range	3.0	0.4	2.5	1.5	0.4	1.0
			High	>3.0	0.4	2.5	1.5	0.4	1.0
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	End of season	Deficient	<2.5	0.2	1.1	0.4	0.2	-
			Adequate	2.5	0.2	1.1	0.4	0.2	-
			range	3.0	0.3	2.0	1.5	0.4	-
			High	>3.0	0.3	2.0	1.5	0.4	-

Table 15. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	%					
				N	P	K	Ca	Mg	S
Sweet Corn	Whole seedlings	3 leaf stage	Deficient	<3.0	0.4	2.5	0.6	0.25	0.4
			Adequate	3.0	0.4	2.5	0.6	0.25	0.4
			range	4.0	0.5	4.0	0.8	0.5	0.6
			High	>4.0	0.5	4.0	0.8	0.5	0.6
			Toxic (>)	-	-	-	-	-	-
	Whole seedlings	6 leaf stage	Deficient	<3.0	0.3	2.5	0.5	0.25	0.4
			Adequate	3.0	0.3	2.5	0.5	0.25	0.4
			range	4.0	0.5	4.0	0.8	0.5	0.6
			High	>4.0	0.5	4.0	0.8	0.5	0.6
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	30 inches tall	Deficient	<2.5	0.2	2.5	0.5	0.2	0.2
			Adequate	2.5	0.2	2.5	0.5	0.2	0.2
			range	4.0	0.4	4.0	0.8	0.4	0.4
			High	>4.0	0.4	4.0	0.8	0.4	0.4
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	Just prior to tassel	Deficient	<2.5	0.2	2.0	0.3	0.15	0.2
			Adequate	2.5	0.2	2.0	0.3	0.15	0.2
			range	4.0	0.4	3.5	0.6	0.4	0.4
			High	>4.0	0.4	3.5	0.6	0.4	0.4
			Toxic (>)	-	-	-	-	-	-
	MRM leaf (ear leaf)	Tasseling	Deficient	<1.5	0.2	1.2	0.3	0.15	0.2
			Adequate	1.5	0.2	1.2	0.3	0.15	0.2
			range	2.5	0.4	2.0	0.6	0.4	0.4
			High	>2.5	0.4	2.0	0.6	0.4	0.4

Table 16. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling		%					
			Status	N	P	K	Ca	Mg	S
Sweet Potato	MRM leaf	Early vining	Deficient	<4.0	0.3	2.5	0.8	0.4	0.2
			Adequate	4.0	0.3	2.5	0.8	0.4	0.2
			range	5.0	0.5	4.0	1.6	0.8	0.6
			High	>5.0	0.5	4.0	1.6	0.8	0.6
	MRM leaf	Midseason -before root enlargment	Deficient	<3.0	0.2	2.0	0.8	0.25	0.2
			Adequate	3.0	0.2	2.0	0.8	0.25	0.2
			range	4.0	0.3	4.0	1.8	0.5	0.4
			High	>4.0	0.3	4.0	1.8	0.5	0.4
	MRM leaf	Root enlargement	Deficient	<3.0	0.2	2.0	0.8	0.25	0.2
			Adequate	3.0	0.2	2.0	0.8	0.25	0.2
			range	4.0	0.3	4.0	1.6	0.5	0.6
			High	>4.0	0.3	4.0	1.6	0.5	0.6
	MRM leaf	Just before harvest	Deficient	<2.8	0.2	2.0	0.8	0.25	0.2
			Adequate	2.8	0.2	2.0	0.8	0.25	0.2
			range	3.5	0.3	4.0	1.6	0.5	0.6
			High	>3.5	0.3	4.0	1.6	0.5	0.6

Table 17. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling		%					
			Status	N	P	K	Ca	Mg	S
Tomato	MRM leaf	5 leaf stage	Deficient	<3.0	0.3	3.0	1.0	0.3	0.3
			Adequate	3.0	0.3	3.0	1.0	0.3	0.3
			range	5.0	0.6	5.0	2.0	0.5	0.8
			High	>5.0	0.6	5.0	2.0	0.5	0.8
	MRM leaf	First flower	Deficient	<2.8	0.2	2.5	1.0	0.3	0.3
			Adequate	2.8	0.2	2.5	1.0	0.3	0.3
			range	4.0	0.4	4.0	2.0	0.5	0.8
			High	>4.0	0.4	4.0	2.0	0.5	0.8
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	Early fruit set	Deficient	<2.5	0.2	2.5	1.0	0.25	0.3
			Adequate	2.5	0.2	2.5	1.0	0.25	0.3
			range	4.0	0.4	4.0	2.0	0.5	0.6
			High	>4.0	0.4	4.0	2.0	0.5	0.6
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	First ripe fruit	Deficient	<2.0	0.2	2.0	1.0	0.25	0.3
			Adequate	2.0	0.2	2.0	1.0	0.25	0.3
			range	3.5	0.4	4.0	2.0	0.5	0.6
			High	>3.5	0.4	4.0	2.0	0.5	0.6
	MRM leaf	During harvest period	Deficient	<2.0	0.2	1.5	1.0	0.25	0.3
			Adequate	2.0	0.2	1.5	1.0	0.25	0.3
			range	3.0	0.4	2.5	2.0	0.5	0.6
			High	>3.0	0.4	2.5	2.0	0.5	0.6

Table 18. Critical (deficiency) values, adequate ranges, high values, and toxicity values for macronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling		%					
			Status	N	P	K	Ca	Mg	S
Turnip Greens	MRM leaf	Hypocotyl 1-inch diameter	Deficient	<3.0	0.3	2.5	0.8	0.25	0.2
			Adequate	3.0	0.3	2.5	0.8	0.25	0.2
			range	5.0	0.8	4.0	1.5	0.6	0.6
			High	>5.0	0.8	4.0	1.5	0.6	0.6
Watermelon	MRM leaf	Layby (last cultivation)	Deficient	<3.0	0.3	3.0	1.0	0.25	0.2
			Adequate	3.0	0.3	3.0	1.0	0.25	0.2
			range	4.0	0.5	4.0	2.0	0.5	0.4
			High	>4.0	0.5	4.0	2.0	0.5	0.4
			Toxic (>)	-	-	-	-	-	-
	MRM leaf	First flower	Deficient	<2.5	0.3	2.7	1.0	0.25	0.2
			Adequate	2.5	0.3	2.7	1.0	0.25	0.2
			range	3.5	0.5	3.5	2.0	0.5	0.4
			High	>3.5	0.5	3.5	2.0	0.5	0.4
	MRM leaf	First fruit	Deficient	<2.0	0.3	2.3	1.0	0.25	0.2
			Adequate	2.0	0.3	2.3	1.0	0.25	0.2
			range	3.0	0.5	3.5	2.0	0.5	0.4
			High	>3.0	0.5	3.5	2.0	0.5	0.4
	MRM leaf	Harvest period	Deficient	<2.0	0.3	2.0	1.0	0.25	0.2
			Adequate	2.0	0.3	2.0	1.0	0.25	0.2
			range	3.0	0.5	3.0	2.0	0.5	0.4
			High	>3.0	0.5	3.0	2.0	0.5	0.4

Table 19. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	ppm					
				Fe	Mn	Zn	B	Cu	Mo
Table Beets	Leaf blades	5 weeks after seeding	Deficient	<40	30	15	30	5	0.05
			Adequate	40	30	15	30	5	0.2
			range	200	200	30	80	10	0.6
			High	-	-	-	80	10	-
			Toxic (>)	-	-	-	650	-	-
	Leaf blades	9 weeks after seeding	Deficient	-	-	15	30	5	0.1
			Adequate	-	70	15	60	5	0.6
			range	-	200	30	80	10	-
			High	-	-	-	80	10	-
			Toxic (>)	-	-	-	650	-	-
Brussel Sprouts	MRM leaf	At early sprouts	Deficient	<50	20	20	20	4	0.0
			Adequate	50	20	20	30	5	0.2
			range	150	200	80	70	10	0.2
			High	>150	200	80	70	-	-
Broccoli	MRM leaf	Heading	Deficient	<40	20	25	20	3	0.0
			Adequate	40	25	45	30	5	0.0
			range	300	150	95	50	10	0.2
			High	>300	150	100	100	10	-
Cabbage	MRM leaf	5 weeks after transplanting	Deficient	<30	20	30	20	3	0.3
			Adequate	30	20	30	20	3	0.3
			range	60	40	50	40	7	0.6
			High	>100	40	50	40	10	-
	MRM leaf	8 weeks after transplanting	Deficient	<30	20	30	20	3	0.3
			Adequate	30	20	30	20	3	0.3
			range	60	40	50	40	7	0.6
			High	>100	40	50	40	10	0.6
	Wrapper leaf	Heads 1/2 grown	Deficient	<20	20	20	30	4	0.3
			Adequate	20	20	20	30	4	0.3
			range	40	40	30	50	8	0.6
			High	>100	40	40	50	10	-
	Wrapper leaf	At harvest	Deficient	<20	20	20	30	4	0.3
			Adequate	20	20	20	30	4	0.3
			range	40	40	30	50	8	0.6
			High	>100	40	40	50	10	-

Table 20. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	ppm					
				Fe	Mn	Zn	B	Cu	Mo
Collards	Tops	Young plants	Deficient	<40	40	25	25	5	-
			Adequate	40	40	25	25	5	-
			range	100	100	50	50	10	-
			High	>100	100	50	50	10	-
	MRM leaf	Harvest	Deficient	<40	40	20	25	5	-
			Adequate	40	40	20	25	5	-
			range	100	100	40	50	10	-
			High	>100	100	40	50	10	-
Carrots	MRM leaf	60 days after seeding	Deficient	<30	30	20	20	4	-
			Adequate	30	30	20	20	4	-
			range	60	60	60	40	10	-
			High	>60	100	60	40	10	-
	MRM leaf	Harvest	Deficient	<20	30	20	20	4	-
			Adequate	20	30	20	20	4	-
			range	30	60	60	40	10	-
			High	>60	100	60	40	10	-
Cauliflower	MRM leaf	Buttoning	Deficient	<30	30	30	30	5	-
			Adequate	30	30	30	30	5	-
			range	60	80	50	50	10	-
			High	>100	100	50	50	10	-
	MRM leaf	Heading	Deficient	<30	50	30	30	5	-
			Adequate	30	50	30	30	5	-
			range	60	80	50	50	10	-
			High	>100	100	50	50	10	-
Celery	Outer petiole	6 weeks after transplanting	Deficient	<20	5	20	15	4	-
			Adequate	20	5	20	15	4	-
			range	30	10	40	25	6	-
			High	>100	20	60	25	-	-
	Outer petiole	At maturity	Deficient	<20	5	20	20	1	-
			Adequate	20	5	20	20	1	-
			range	30	10	40	40	3	-
			High	>100	20	60	40	3	-
Chinese Cabbage (Heading)	Oldest undamaged leaf	8 leaf stage	Deficient	<-	8	30	15	5	-
			Adequate	-	14	30	15	5	-
			range	-	20	50	25	10	-
			High	>-	20	50	25	10	-
	Oldest undamaged leaf	At maturity	Deficient	<-	7	20	30	4	-
			Adequate	-	13	20	30	4	-
			range	-	19	40	50	6	-
			High	>-	20	40	50	6	-

Table 21. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	ppm					
				Fe	Mn	Zn	B	Cu	Mo
Cucumber	MRM leaf	Before bloom	Deficient	<40	30	20	20	5	0.2
			Adequate	40	30	20	20	5	0.3
			range	100	100	50	60	20	1.0
			High	>100	100	50	60	20	2.0
	MRM leaf	Early bloom	Deficient	<40	30	20	20	5	0.2
			Adequate	40	30	20	20	5	0.3
			range	100	100	50	60	20	1.0
			High	>100	100	50	60	20	2.0
			Toxic (>)	-	900	950	150	-	-
Eggplant	MRM leaf	Early fruit set	Deficient	<50	50	20	20	5	0.5
			Adequate	50	50	20	20	5	0.5
			range	100	100	40	40	10	0.8
			High	>100	100	40	40	10	0.8
Endive	Oldest undamaged leaf	8 leaf stage	Deficient	<-	15	30	25	5	-
			Adequate	-	15	30	25	5	-
			range	-	25	50	35	10	-
			High	>-	25	50	35	10	-
	Oldest undamaged leaf	Maturity	Deficient	<-	15	20	30	5	-
			Adequate	-	15	20	30	5	-
			range	-	20	40	40	10	-
			High	>-	20	40	40	10	-
Escarole	Oldest undamaged leaf	8 leaf stage	Deficient	<-	15	30	20	4	-
			Adequate	-	15	30	20	4	-
			range	-	25	50	30	6	-
			High	>-	25	50	30	6	-
	Oldest undamaged leaf	Maturity	Deficient	<-	15	20	30	4	-
			Adequate	-	15	20	30	4	-
			range	-	25	50	45	6	-
			High	>-	25	50	45	6	-
Romaine	Oldest undamaged leaf	8 leaf stage	Deficient	<-	15	20	30	5	-
			Adequate	-	15	20	30	5	-
			range	-	25	50	45	10	-
			High	>-	25	50	45	10	-
	Oldest undamaged leaf	Maturity	Deficient	<-	15	20	30	5	0.1
			Adequate	-	15	20	30	5	0.1
			range	-	25	50	45	10	0.4
			High	>-	25	50	45	10	-

Table 22. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling		---------- ppm ----------					
			Status	Fe	Mn	Zn	B	Cu	Mo
Lettuce	MRM leaf	8 leaf stage	Deficient	<50	20	25	15	5	-
			Adequate	50	20	25	15	5	-
			range	150	40	50	30	10	-
			High	>150	40	50	30	10	-
	Wrapper leaf	Heads 1/2 size	Deficient	<50	20	25	15	5	-
			Adequate	50	20	25	15	5	-
			range	150	40	50	30	10	-
			High	>150	40	50	30	10	-
	Wrapper leaf	Maturity	Deficient	<50	20	25	15	5	-
			Adequate	50	20	25	15	5	-
			range	150	40	50	30	10	-
			High	>150	40	50	30	10	-
Cos	Oldest undamaged leaf	8 leaf stage	Deficient	<40	10	40	20	5	-
			Adequate	40	10	40	20	5	-
			range	100	20	60	40	10	-
			High	>100	20	60	40	10	-
	Oldest undamaged leaf	Maturity	Deficient	<20	10	20	20	5	-
			Adequate	20	10	20	20	5	-
			range	50	20	40	40	10	-
			High	>50	20	40	40	10	-
Boston Lettuce	Oldest undamaged leaf	8 leaf stage	Deficient	<50	10	40	15	5	0.1
			Adequate	50	10	40	15	5	0.1
			range	100	20	60	25	10	0.2
			High	>100	20	60	25	10	0.4
			Toxic (>)	-	250	-	100	-	-
	Oldest undamaged leaf	Maturity	Deficient	<50	10	20	15	5	0.1
			Adequate	50	10	20	15	5	0.1
			range	100	20	40	25	10	0.2
			High	>100	20	40	25	10	0.4
			Toxic (>)	-	250	-	100	-	-
Muskmelon	MRM leaf	12 inch vines	Deficient	<40	20	20	20	5	0.6
			Adequate	40	20	20	20	5	0.6
			range	100	100	60	80	10	1.0
			High	>100	100	60	80	10	1.0
			Toxic (>)	-	900	-	150	-	-
	MRM leaf	Early fruit set	Deficient	<40	20	20	20	5	0.6
			Adequate	40	20	20	20	5	0.6
			range	100	100	60	80	10	1.0
			High	>100	100	60	80	10	1.0
			Toxic (>)	-	900	-	150	-	-

Table 23. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling		---------- ppm ----------					
			Status	Fe	Mn	Zn	B	Cu	Mo
Okra	MRM leaf	30 days after seeding	Deficient	<50	30	30	25	5	-
			Adequate	50	30	30	25	5	-
			range	100	100	50	50	10	-
			High	>100	100	50	50	10	-
	MRM leaf	Prior to harvest	Deficient	<50	30	30	25	5	-
			Adequate	50	30	30	25	5	-
			range	100	100	50	50	10	-
			High	>100	100	50	50	10	-
Sweet Onions	MRM leaf	Just prior to bulb initiation	Deficient	<-	10	15	10	5	-
			Adequate	-	10	15	10	5	-
			range	-	20	20	25	10	-
			High	>-	20	20	25	10	-
			Toxic (>)	-	-	-	100	-	-
Pepper	MRM leaf	Prior to blossoming	Deficient	<30	30	25	20	5	-
			Adequate	30	30	25	20	5	-
			range	150	100	80	50	10	-
			High	>150	100	80	50	10	-
			Toxic (>)	-	-	-	350	-	-
	MRM leaf	First blossoms open	Deficient	<30	30	25	20	5	-
			Adequate	30	30	25	20	5	-
			range	150	100	80	50	10	-
			High	>150	100	80	50	10	-
			Toxic (>)	-	1000	-	350	-	-
	MRM leaf	Early fruit set	Deficient	<30	30	25	20	5	-
			Adequate	30	30	25	20	5	-
			range	150	100	80	50	10	-
			High	>150	100	80	50	10	-
			Toxic (>)	-	-	-	350	-	-
	MRM leaf	Early harvest	Deficient	<30	30	25	20	50	0.1
			Adequate	30	30	25	20	5	0.1
			range	150	100	80	50	10	0.2
			High	>150	100	80	50	10	-
			Toxic (>)	-	-	-	350	-	-

Table 24. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	ppm					
				Fe	Mn	Zn	B	Cu	Mo
Potato	MRM leaf	Plants 8 to 10 inches tall	Deficient	<40	30	30	20	5	0.1
			Adequate	40	30	30	20	5	0.1
			range	150	60	60	60	10	0.2
			High	>150	60	60	30	10	-
	MRM leaf	First blossom	Deficient	<40	30	30	20	5	0.1
			Adequate	40	30	30	20	5	0.1
			range	150	100	60	30	10	0.2
			High	>150	100	60	30	10	-
	MRM leaf	Tubers 1/2 grown	Deficient	<40	20	30	20	5	0.1
			Adequate	40	20	30	20	5	0.1
			range	150	100	60	30	10	0.2
			High	>150	100	60	30	10	-
	MRM leaf	At tops-down	Deficient	<40	20	30	20	5	0.1
			Adequate	40	20	30	20	5	0.1
			range	150	100	60	30	10	0.2
			High	>150	100	60	30	10	-
Radish	MRM leaf	At harvest	Deficient	<30	20	30	15	3	0.1
			Adequate	30	20	30	15	3	0.1
			range	50	40	50	30	10	2.0
			High	>50	40	50	30	10	2.0
			Toxic (>)	-	-	-	85	-	-
Snapbean	MRM trifoliate leaf	Before bloom	Deficient	<25	20	20	15	5	-
			Adequate	25	20	20	15	5	0.4
			range	200	100	40	40	10	-
			High	>200	100	40	40	10	-
			Toxic (>)	-	1000	-	150	-	-
	MRM trifoliate leaf	First bloom	Deficient	<25	20	20	15	5	-
			Adequate	25	20	20	15	5	-
			range	200	100	40	40	10	0.4
			High	>200	100	40	40	10	-
			Toxic (>)	-	1000	-	150	-	-
	MRM trifoliate leaf	Full bloom	Deficient	<25	20	20	15	5	-
			Adequate	25	20	20	15	5	-
			range	200	100	40	40	10	0.4
			High	>200	100	40	40	10	-
			Toxic (>)	-	1000	-	150	-	-
Squash (summer)	MRM leaf	Early fruit	Deficient	<40	40	20	25	5	0.3
			Adequate	40	40	20	25	5	0.3
			range	100	100	50	40	20	0.5
			High	>100	100	50	40	20	0.5

Table 25. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	ppm					
				Fe	Mn	Zn	B	Cu	Mo
Pumpkin	MRM leaf	5 weeks from seeding	Deficient	<40	40	20	25	5	0.3
			Adequate	40	40	20	25	5	0.3
			range	100	100	50	40	10	0.5
			High	>100	100	50	40	10	-
	MRM leaf	8 weeks from seeding	Deficient	<40	40	20	20	5	0.3
			Adequate	40	40	20	20	5	0.3
			range	100	100	50	40	10	0.5
			High	>100	100	50	40	10	-
Southern Pea	MRM leaf	Before bloom	Deficient	<30	30	20	15	5	-
			Adequate	30	30	20	15	5	-
			range	100	100	40	25	10	-
			High	>100	100	40	25	10	-
	MRM leaf	First bloom	Deficient	<30	30	20	15	5	4.0
			Adequate	30	30	20	15	5	4.0
			range	100	100	40	25	10	6.0
			High	>100	100	40	25	10	6.0
Spinach	MRM leaf	30 days after seeding	Deficient	<-	50	50	20	5	0.1
			Adequate	-	50	50	20	5	0.1
			range	-	100	70	40	7	1.0
			High	>-	100	70	40	7	1.0
	MRM leaf	Harvest	Deficient	<-	30	50	20	5	0.1
			Adequate	-	30	50	20	5	0.1
			range	-	50	70	40	7	1.0
			High	>-	80	70	40	7	1.0

Table 26. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling		---------- ppm ----------					
			Status	Fe	Mn	Zn	B	Cu	Mo
Strawberry	MRM leaf	Transplants	Deficient	<50	30	25	25	5	-
			Adequate	50	30	25	25	5	-
			range	100	100	40	40	10	-
			High	>100	100	40	40	10	-
	MRM leaf	Initial flower	Deficient	<50	30	20	20	5	-
			Adequate	50	30	20	20	5	-
			range	100	100	40	40	10	-
			High	>100	100	40	20	10	-
	MRM leaf	Initial harvest	Deficient	<50	30	20	20	5	-
			Adequate	50	30	20	20	5	-
			range	100	100	40	40	10	-
			High	>100	100	40	40	10	-
			Toxic (>)	-	800	-	-	-	-
	MRM leaf	Midseason	Deficient	<50	25	20	20	5	0.5
			Adequate	50	25	20	20	5	0.5
			range	100	100	40	40	10	0.8
			High	>100	100	40	40	10	0.8
			Toxic (>)	-	800	-	-	-	-
	MRM leaf	End of season	Deficient	<50	25	20	20	5	-
			Adequate	50	25	20	20	5	-
			range	100	100	40	40	10	-
			High	>100	100	40	40	10	-

Table 27. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	ppm					
				Fe	Mn	Zn	B	Cu	Mo
Sweet Corn	Whole seedlings	3 leaf stage	Deficient	<50	40	30	10	5	0.1
			Adequate	50	40	30	10	5	0.1
			range	100	100	40	30	10	0.2
			High	>100	100	40	30	10	0.2
			Toxic (>)	-	-	-	100	-	-
	Whole seedlings	6 leaf stage	Deficient	<50	40	30	10	5	0.1
			Adequate	50	40	30	10	5	0.1
			range	100	100	40	30	10	0.2
			High	>100	100	40	30	10	0.2
			Toxic (>)	-	-	-	100	-	-
	MRM leaf	30 inches tall	Deficient	<40	40	25	10	4	0.1
			Adequate	40	40	25	10	4	0.1
			range	100	100	40	30	10	0.2
			High	>100	100	40	30	10	0.2
			Toxic (>)	-	-	-	100	-	-
	MRM leaf	Just prior to tassel	Deficient	<30	30	20	10	4	0.1
			Adequate	30	30	20	10	4	0.1
			range	100	100	40	20	10	0.2
			High	>100	100	40	20	10	0.2
			Toxic (>)	-	-	-	100	-	-
	MRM leaf (ear leaf)	Tasseling	Deficient	<30	20	20	10	4	0.1
			Adequate	30	20	20	10	4	0.1
			range	100	100	40	20	10	0.2
			High	>100	100	40	20	10	0.2

Table 28. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	ppm					
				Fe	Mn	Zn	B	Cu	Mo
Sweet Potato	MRM leaf	Early vining	Deficient	<40	40	25	20	5	-
			Adequate	40	40	25	20	5	-
			range	100	100	50	50	10	-
			High	>100	100	50	50	10	-
	MRM leaf	Midseason -before root enlargment	Deficient	<40	40	25	25	5	-
			Adequate	40	40	25	25	5	-
			range	100	100	40	40	10	-
			High	>100	100	40	40	10	-
	MRM leaf	Root enlargment	Deficient	<40	40	25	20	5	-
			Adequate	40	40	25	20	5	-
			range	100	100	50	50	10	-
			High	>100	100	50	50	10	-
	MRM leaf	Just before harvest	Deficient	<40	40	25	20	5	-
			Adequate	40	40	25	20	5	-
			range	100	100	50	50	10	-
			High	>100	100	50	50	10	-
Tomato	MRM leaf	5 leaf stage	Deficient	<40	30	25	20	5	0.3
			Adequate	40	30	25	20	5	0.2
			range	100	100	40	40	15	0.6
			High	>100	100	40	40	15	0.6
	MRM leaf	First flower	Deficient	<40	30	25	20	5	0.2
			Adequate	40	30	25	20	5	0.2
			range	100	100	40	40	15	0.6
			High	>100	100	40	40	15	0.2
			Toxic (>)	-	1500	300	250	-	-
	MRM leaf	Early fruit set	Deficient	<40	30	20	20	5	0.2
			Adequate	40	30	20	20	5	0.2
			range	100	100	40	40	10	0.6
			High	>100	100	40	40	10	0.6
			Toxic (>)	-	-	-	250	-	-
	MRM leaf	First ripe fruit	Deficient	<40	30	20	20	5	0.2
			Adequate	40	30	20	20	5	0.2
			range	100	100	40	40	10	0.6
			High	>100	100	40	40	10	0.6
	MRM leaf	During harvest period	Deficient	<40	30	20	20	5	0.2
			Adequate	40	30	20	20	5	0.2
			range	100	100	40	40	10	0.6
			High	>100	100	40	40	10	0.6

Table 29. Critical (deficiency) values, adequate ranges, high values, and toxicity values for micronutrients for vegetables (most-recently-matured whole leaf plus petiole (MRM leaf) unless otherwise noted).

Crop	Plant Part	Time of Sampling	Status	ppm					
				Fe	Mn	Zn	B	Cu	Mo
Turnip Greens	MRM leaf	Hypocotyl 1-inch diameter	Deficient	<30	30	20	20	5	-
			Adequate	30	30	20	20	5	-
			range	100	100	40	40	10	-
			High	>100	100	40	40	10	-
Watermelon	MRM leaf	Layby (last cultivation)	Deficient	<30	20	20	20	5	-
			Adequate	30	20	20	20	5	-
			range	100	100	40	40	10	-
			High	>100	100	40	40	10	-
			Toxic (>)	-	800	-	-	-	-
	MRM leaf	First flower	Deficient	<30	20	20	20	5	-
			Adequate	30	20	20	20	5	-
			range	100	100	40	40	10	-
			High	>100	100	40	40	10	-
	MRM leaf	First fruit	Deficient	<30	20	20	20	5	-
			Adequate	30	20	20	20	5	-
			range	100	100	40	40	10	-
			High	>100	100	40	40	10	-
	MRM leaf	Harvest period	Deficient	<30	20	20	20	3	-
			Adequate	30	20	20	20	3	-
			range	100	100	40	40	10	-
			High	>100	100	40	40	10	-