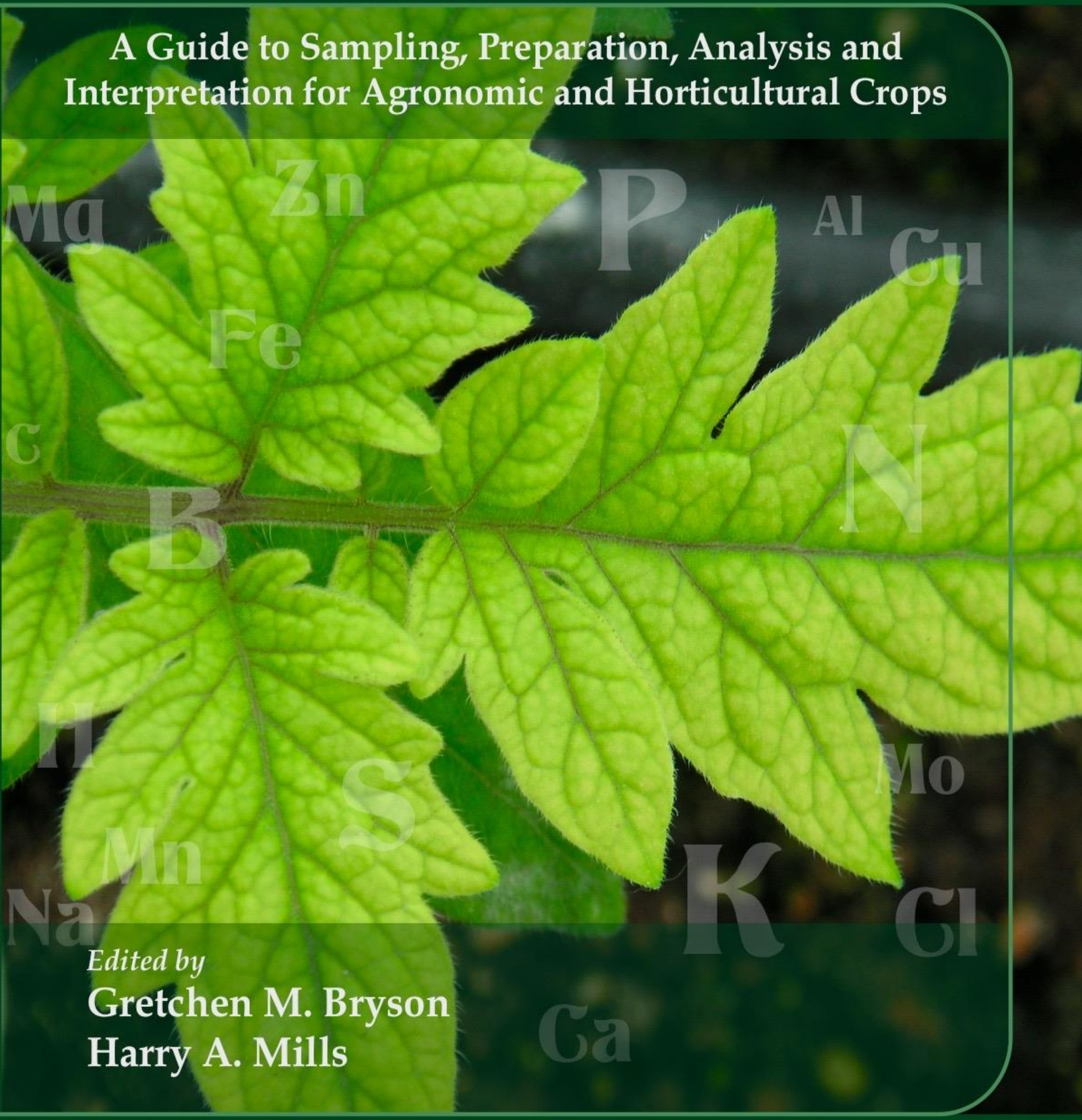
Plant Analysis Handbook IV

A Guide to Sampling, Preparation, Analysis and Interpretation for Agronomic and Horticultural Crops



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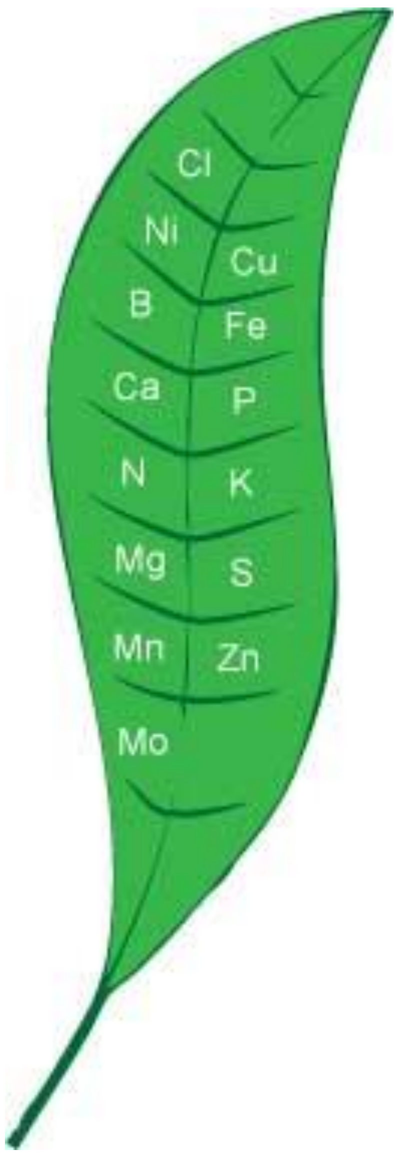

Plant Analysis Handbook IV e-Edition

A guide to plant nutrition and interpretationof plant analysis for agronomic and horticultural crops.

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Preface

The science of plant nutrition was established on ***Observation*** and ***Comparison*** of plant growth characteristics. ***Everything*** in crop production either influences plant nutrition or is influenced by plant nutrition. Everyone, whether a scientist, consultant, grower or student, involved in crop production and the science and practice of plant nutrition needs a working knowledge of plant physiology, soil science, environmental science, microbiology, plant pathology, weed science and water quality to properly identify a plant nutritional causation disorder. The genetics of a plant, the stage of maturity, soil moisture, sunlight, insect damage, hail damage, soil chemistry, soil pH, soil microbiology, and diseases all influence plant nutrition, and require a plant nutritionist to be well versed in these disciplines to help with causation of plant maladies and solutions to solve these growth issues. Though it has long been recognized that plant nutrition plays a critical role in plant growth and development of all plants, the link to improper plant nutrition role in plant disease is now well established. All cultural practices, including seed (genetic) selection and pesticide applications, have an influence on plant nutrition and the overall health and performance of a crop. For food crops, the nutritional status of crops directly influences human nutrition and health. Similarly, crops grown for feed and forage for animals also indirectly influences human nutrition and health through the meat, dairy, eggs and other human food products derived from animals eating these crops. It is clear that plant nutrition goes far beyond just determining how much N-P-K to apply. Understanding and then using the principles and science of plant nutrition is essential to achieve a successful crop production program. Optimum yield and crop performance can only be achieved consistently by adjusting the essential plant nutrients that the crop requires, as determined through ***plant analysis***, into the sufficiency range for that crop.

The ***Plant Analysis Handbook IV*** is a comprehensive overview of the use of plant analysis including principles, methodology and applications of plant nutrient analysis, and includes nutritional standards for over 1400 individual agronomic, horticultural and plantation crops. The current edition is designed to have multiple functions. For professional plant nutritionist, researchers and analytical laboratories, it serves as a handy reference for nutritional standards and nutrient interactions. For growers, agronomists, horticulturists, and nutrient suppliers, it is designed to help them do a better job of providing the nutritional needs of crops whether the crops are grown in the field, greenhouse, hydroponics, plantation, or elsewhere. A new chapter has been added on practical methods to use tissue analysis results to refine fertilizer programs to meet the nutritional needs of crops. Finally, for students of plant nutrition and crop production in general, the handbook explains the role and function of each essential plant nutrient within the plant, its interactions in the soil and growing media, fertilizers and forms that the plant takes up.

Plant Analysis Handbook IVe-Edition now allows electronic access to the information in the laboratory, field, or office. Color photographs of deficiencies and toxicities have been incorporated into the e-Edition. The Plant Analysis III printed edition is still in use throughout the world as the primary reference for plant tissue nutritional standards and plant nutrients role in the plant.

Every entry of the over 1400 individual agronomic, horticultural and plantation crops listed in the new edition has been reviewed to ensure the most current and accurate information has been included. These nutrient element concentration values, presented in tabular form, were obtained from the authors' own research data, from published data, and from the accumulation of plant analysis data by MicroMacro International, Inc.

Two different types of values are presented and noted for each nutrient entry:

Sufficiency Values—nutrient element concentrations for plants where deficiency, sufficiency, and toxicity levels have been established through scientific evaluation over a broad range of growing conditions

Survey Values—nutrient element concentrations that have not been clearly identified as being either at deficient or toxic levels covering a broad range of growing conditions. However, in the authors' opinion, Survey Values approximate the critical values for deficiency or toxicity, even though additional research data is required to verify this assumption under a wide range of growing conditions.

Tissue sampling procedures and preparing a plant tissue sample for laboratory elemental analysis are given, as well as factors influencing the interpretation of plant analysis results. Genetic, environmental and cultural factors all influence the concentration of plant nutrients, and each of these factors are presented from a practical viewpoint designed to aid decision making related to fertilizer application and plant utilization of essential plant nutrients. All of the information presented in this handbook is designed to assist those usingplant analysis results for determining the nutrient elemental status of crops, and then use these results to improve the nutritional status, and thus the performance and profitability of the crops.

Plant Analysis Handbook IVis a resource of information for students, growers, consultants, and professionals engaged in evaluating the nutrient element status of a crop plant to use for years to come.

The authors express their appreciation to Dr. Robert J. Kremer, Dr. Bruce Wood and Paul Milham for their contribution to the ***Plant Analysis Handbook IV***.

"The Sin of All Sins is to make Fertility Recommendations Without the Benefit of Plant Analysis"

Chapter 1

Introduction

Growers and scientists for generations have used abnormalities in the appearance of plants as the first indicator of nutrient deficiencies or toxicity. The association between plant appearance and nutrient status is usually based on one's experience, observation and comparison, or on photographs of nutrient deficient crops. However, using visual symptoms alone is often inadequate to understand the true nutritional status of a plant or crop. Often the application of the proposed deficient nutrient does not result in the correction of the observed visual symptoms. Essential nutrients do not operate independently of each other, or independently of the health and growing conditions that the crop is in. In the above example, another nutrient may limit or interfere with the uptake or utilization of the proposed deficient nutrient causing the visual deficiency symptoms of that nutrient to appear. Also, as long as this other nutrient continues to interfere with or limit uptake or utilization of the proposed deficient nutrient, then the application of the this nutrient will do little to correct the observed nutrient deficiency symptom.

Further, complicating the use of visual symptoms to identify a nutrient problem is that plants differ in their visual expression of nutrient deficiency symptoms. Not only between different types of plants, but also at different stages of development in the same plant. In addition cultural and environmental conditions can influence the expression of deficiency symptoms. This complexity limits the ability to diagnose many nutritional disorders based on visual symptoms. Consider Figure 1-1, which shows Mondo grass with leaf symptoms. The symptoms on the tips of the leaves could be caused by a deficiency or iron, boron or calcium, or a toxicity of chloride. That is, even with experience in identifying the symptoms of nutrient disorders a chemical analysis of the plant leaf would be needed to identify the element causing these symptoms.

Figure 1-1. Mondo grass showing yellowing and necrosis on the tip of the leaf.

These visual symptoms on the tip of the leaves could be iron deficiency, boron deficiency or toxicity; chloride toxicity and calcium deficiency also may cause the same visual symptoms. This clearly shows that even with experience in identifying nutrient deficiencies and toxicities, it is a guess at best without a laboratory plant analysis to confirm element causing the visual symptoms.

Several plants conditions can influence the appearance of visual nutrient deficiencies including poor root growth and development, low carbohydrate status for active nutrient uptake, low production of organic acids secretions by roots which help solubilize soil nutrients, and stage of plant maturity and genetic factors. These factors all influence nutrient uptake by the plant and the appearance of visual symptoms. Cultural factors include fertilizer composition and chemistry, fertilizer application rate, method and timing, tillage system used, pesticides used (especially herbicides and fungicides), soil pH and liming, use of irrigation, and pH and nutrient composition of irrigation water. Environmental conditions include soil and air temperature, air humidity (effect on passive nutrient uptake by transpiration), soil moisture, soil texture and cation exchange capacity, soil pH (effect on nutrient availability), soil salinity, competing nutrient concentrations (e.g., sodium and aluminum), microbial populations and activity (effect on nutrient mineralization, nutrient oxidation states, and nutrient uptake competition), weed growth (effect on competition for nutrients and water), and diseases and insects (effect on ability of roots and tissue to take up nutrients).

Use of soil testing during the cropping season to predict the quantity of fertilizer nutrients needed to properly supply sufficient nutrient levels to a crop is helpful, but provides only part of the information needed ensure the crop has all essential nutrients and in proper balance to produce high yields and high quality crops. Soil testing can show if sufficient nutrients exist in the soil to be “potentially” taken up by the plant. However, just because nutrients are in the soil does not guarantee that these nutrients are available for uptake and utilization by the plant.

Today many growers and fertilizer suppliers rely only on soil test results to determine the nutrients to apply to a crop during the cropping season. This practice is the “Sin of All Sins” in agriculture and can lead to crop failure for the grower and even legal action against the fertilizer company utilizing only soil test results to predict the amount of fertilizer to apply to a crop. Many laboratories perpetuate this “Sin of All Sins” by including the amount of fertilizer, based on the soil test results that a grower should apply to his crop. This practice can lead to erroneous conclusions about the nutritional requirement of the plant growing on the tested soil. A real world example of this improper practice can be demonstrated by the analysis of boron in the soil, a highly mobile nutrient in the soil. At the time of the soil test, the level of boron is low and the laboratory recommends the addition of boron to this crop area. However, analysis of the plant growing on this soil can show excessive levels of boron in the tissue that accumulated before a rainfall or irrigation leached the boron out of the root zone. Following the recommendations of the soil laboratory without confirming that the plant is also low in boron, the grower can over supply the boron needs of the crop to a toxic level that results in crop damage or failure.

Additional examples are calcium and boron that move into the new growth of the plant primarily by transpiration of water from the leaf, pulling water containing calcium and boron up to the growing points of the plant. Under conditions of moisture stress, low moisture or high relative humidity, transpiration from the leaf is reduced, and so is the movement of these essential nutrients into the new growth areas of the plant. Though a soil test may confirm adequate levels of these two nutrients in the soil, a deficiency in the plant may occur due to factors such as low soil moisture and high relative humidity. These conditions reduce the uptake of these nutrients by the plant and movement into the new growth areas of the plant potentially causing visual deficiency symptoms. Additions of fertilizers containing these nutrients may have little effect on these visual deficiency symptoms.

Another example, phosphorus is not mobile in the soil and requires the root to grow to new soil areas to mine soluble phosphorus for plant uptake. Anything that limits root growth can potentially reduce phosphorus mining and uptake. This limitation could be root damage due to fertilizer burn, root rots and diseases, nematode or insect damage. Plant analysis would show inadequate (deficient) phosphorus concentrations in the leaf tissue, not because of insufficient phosphorus in the soil, but due to other factors that influenced the uptake of this essential nutrient.

Another concern is that soil test results are based on a single point in time, often weeks, months or even years before the crop is planted. Changes in concentrations of soil nutrients may vary over time from crops grown (and crops harvested) and cropping systems used, fertilizers and liming materials applied, chemical and microbial mineralization and nutrient tie up, and many other factors. Changes in soil nutrients can also change over short periods of time as well such as from excessive rain or normal irrigation leaching nutrients out of the soil making soluble nutrients unavailable, increased by fertilizer or soil amendment (e.g., lime, compost or manure) application. While soil tests do give valuable information, but when soil tests are used alone, there is an unwritten and unspoken, but very real assumption that the concentration in the plant is directly related to the nutrient test results in the soil. The concentration in the plant tissue nutrient availability in the soil is dynamic, and just because a nutrient is high or low in a soil test does not guarantee that corresponding levels of the nutrient will occur in the plant tissue.

With all plants and crops regarding their nutritional status, *"The Plant is the Final Judge"*, and the only way to know for sure what the nutritional status of plant is to use tissue analysis to confirm the nutrient level inside the plant. The success of crop fertility programs is measured by the quantity and quality of yield of a harvested crop, and by the health, growth and quality of the plants not harvested. To achieve these goals, it is necessary to go beyond the soil (or growing media) and look at the plant nutrition and crop fertility from what is going on inside the plant, and not merely what is applied to the soil or growing media. A good fertility program will meet the nutritional needs of the plants, without the expense and environment impact of excessive fertilization beyond the needs of the crop. Furthermore, it is becoming more and more recognized by growers that micronutrients and secondary nutrients are just as important as N-P-K in plant nutrition and fertility programs.

All Essential Nutrients are Required for Proper Plant Growth

Table 1-1. Essential Nutrients Needed in Plant Analysis Tests

Macronutrients	Micronutrients
Nitrogen	Iron
Phosphorus	Zinc
Potassium	Copper
Calcium	Manganese
Magnesium	Molybdenum
Sulfur	Nickel
	Boron
	Chlorine (seldom needed)

In addition to the components of organic matter [carbon (C), hydrogen (H), and oxygen (O_2)], there are at present 14 nutrient elements considered to be essential for all higher plants (Table 1-1). Other nutrients such as sodium (Na), silicon (Si), vanadium (V), cobalt (Co), and titanium (Ti) have shown beneficial effects on some plants, but to date have not been accepted as essential for all plants. Of these, vanadium is the leading candidate as the next element to be established as an essential plant nutrient.

Based on the "Law of the Minimum" or "Law of Limiting Factor," one would expect only a single factor to limit yield at a time. For plant growth, this factor could be water, sunlight, or a nutrient. Assuming that non-nutrient factors such as water and sunlight are not limiting plant growth AND nutrients are limiting plant growth, then the nutrient MOST deficient would be the one limiting the plant's growth. Many times this deficient essential nutrient will limit growth while other nutrients might still accumulate in the tissue. These other nutrients can accumulate at sufficient or higher concentrations in the plant, and the nutrient that is deficient will still prevent growth from occurring.

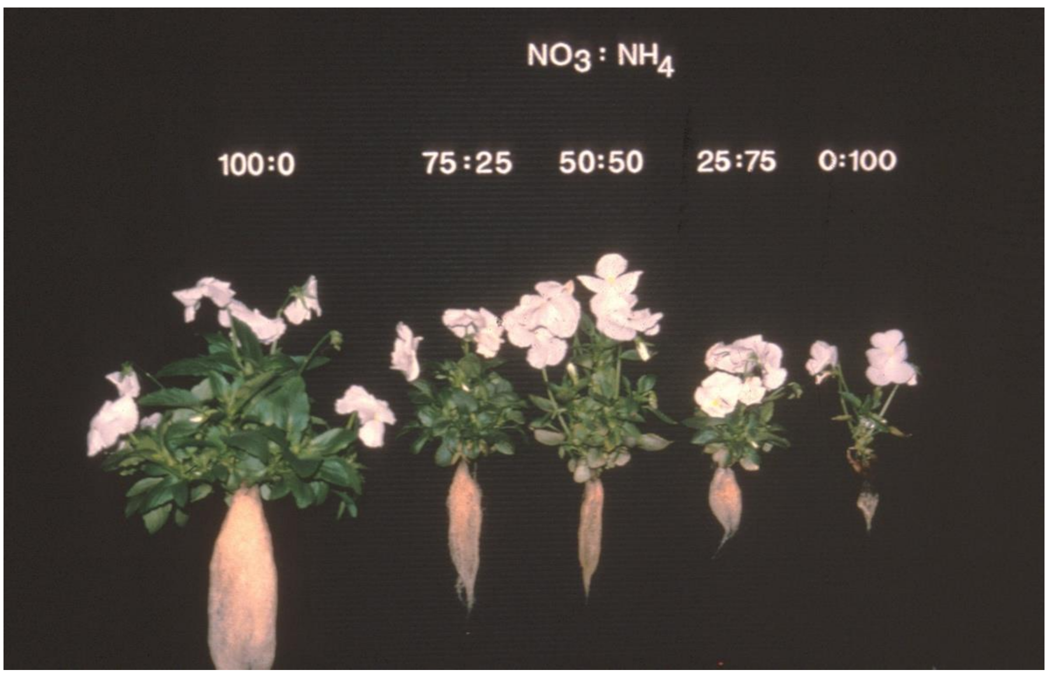
In some cases, plants can sustain limited growth to the extent that the limiting nutrient can support cell function, but the overall growth rate of the plant is reduced. When this occurs, visual deficiency symptoms are not always apparent. The plant may appear relatively normal, but growth is reduced and so is crop yield. This condition is sometimes referred to as *"hidden hunger."* It is called "hidden" because the plant can maintain cell functioning, and deficiency symptoms are not readily visible. But in the absence of deficiency symptoms, the plant still needs the limiting nutrient(s) to grow at a normal rate and to be healthy and productive. If the supply of the limiting nutrient(s) is increased, the concentration in the plant tissue will increase, then plant growth will resume, and new tissue will be produced. As the plant grows and becomes larger, the concentration of the nutrients in the tissue may become less (more diluted). When this action happens, new growth will slow and ultimately cease, as a nutrient once again becomes the most limiting factor (the nutrient could be same or another nutrient that limits growth). And this event is even after the original limiting nutrient or nutrients have been applied to correct the problem. This is called the dilution effect. However, often another nutrient or factor will become the limiting factor when corrective fertilization is used to offset a nutrient deficiency. Understanding the concentration of each nutrient in plant tissue that limits new plant growth, sometime called the "hidden hunger" nutrient level or concentration, is important to understand and evaluate tissue analysis data. Tissue analysis data (along with tissue nutritional standards contained in this text) help to determine which nutrient or nutrients need to be applied to eliminate these as limiting factors to plant growth. Plant tissue analysis is the only method to identify and correct the most-limiting nutrients to plant growth.

Besides the interrelationship between nutrient accumulation and dilution in tissue with growth stimulation and accumulation in plants, there are also physiological relationships between plant nutrients that affect their relative concentrations in plant tissues. For example, some pairs of nutrients are known to have either antagonistic or synergistic relationships regarding their uptake by plant roots.

For example, the positive-charged nutrients, potassium and ammonium, are believed to compete for the same uptake sites on root tissue membranes. Consequently, an abundance of one of these nutrients may reduce the uptake of the other nutrient, thereby causing a deficiency of the other in plant tissue. This action may be one reason that using ammoniacal fertilizers seems to increase (contribute to) potassium deficiency in some crops. Similarly, when plants take up nitrogen as nitrate, a negative-charged nutrient, the plant either export other anions out of the plant cell or import cations in order to maintain electron-charge balance inside the plant cell. This effect can result in the stimulation of potassium uptake where nitrate fertilizer is used.

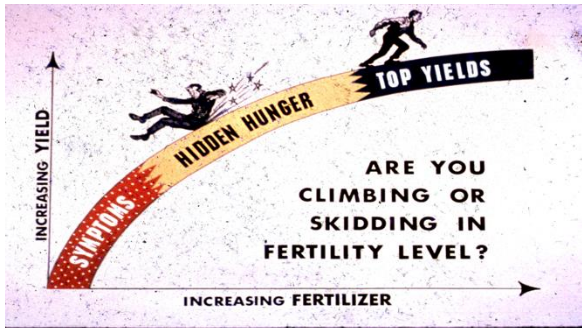
Based on balancing uptake based on chemical charges, it would appear that ammonium (positive-charge) uptake would stimulate nitrate (negative-charge) uptake. However, free ammonium inside the plant tissues is toxic. Consequently, the plant preferentially detoxifies ammonium by forming amino acids, and in the process consumes available carbon in the tissue. The result is a simultaneous depletion of surplus carbon, which is needed to supply the energy required for nitrate uptake. When the surplus carbon is exhausted in detoxifying the free ammonium, then carbon used for growth of roots and leaves, flowers and fruit is significantly reduced. Unlike ammonium, nitrate is not very toxic in the plant. Once inside the plant cell, nitrate can be stored in the vacuole of the cell and does not require carbon to detoxify this form of nitrogen prior to its incorporation into nitrogen compounds in the plant and thus does not compete for carbon utilized in the growth processes. Nitrate incorporation into nitrogen containing compounds in the plant is regulated by series of enzyme-mediated conversions beginning with nitrate reductase. Under field conditions, much of the applied ammoniacal fertilizers are converted by nitrifying bacteria to nitrate is 7-14 days. This rapid conversion of ammoniacal fertilizers to nitrate lessens the toxic effect of ammonium to field crops, but does not eliminate it. Use in the field of fertigation (application of fertilizer through irrigation) and in greenhouse crop production where nitrogen fertilizer is applied frequently, this effect occurs in most all crops grown where ammoniacal fertilizers are utilized. Understanding the impact nitrogen form has on plant growth and crop yield is one of the least understood aspects of plant nutrition and is rarely considered when choosing a nitrogen form to apply to a crop. Emphasizing the least understood statement is the fact that ammonium is toxic to plants when absorbed into the plant until it is detoxified by forming amino acids. Some ammonium is beneficial to most plants and results in an effect of being visually expressed as greening the plant foliage. When does ammonium nitrogen exceeds its beneficial effects, when carbon needed for growth and yield is diverted to the detoxification of the absorbed ammonium at the expense of plant growth process.This effect of ammonium on plant growth when carbon surplus is depleted and growth is affected is depicted in Figure 1-2.

Figure 1-2. Effect of increasing ammonium-N on pansy plant size and root size.



The sufficiency of any nutrient depends on the relative supply of all other nutrients, water, sunlight, temperature, and many other environmental factors. In addition, particular nutrients interact chemically and physiologically with respect to uptake, transport, and function within plant tissue. Since virtually everything in a plant's environment affects plant growth, and plant growth (i.e., dry matter production) affects tissue nutrient concentrations (i.e., the mass of a nutrient compared to the mass of dry matter), and each nutrient affects every other nutrient, and everything in the plant's environment affects everything else, it is easy to see why it is difficult to get a firm handle on how much of a nutrient is enough without use of plant analysis of the tissue in combination with sufficiency ranges for a particular crop. The use of plant analysis allows the grower to determine if the fertility program he has employed is climbing to sufficiency or skidding to deficiency in the plant.

Figure 1-3. Plant analysis is the key to knowing plants fertility level and if hidden hunger is affecting yield.



Plant analysis, tissue analysis, leaf analysis – all basically meaning the same thing – determines the elemental content of a particular plant part for one or more of the essential plant nutrients. Normally, plant analysis refers to a laboratory analysis of collected plant tissue. Using established sufficiency ranges, a comparison is made between the laboratory analysis results with the known values or ranges in order to access the plant's nutritional status. Another system of plant analysis interpretation is called DRIS, Diagnosis and Recommendation Integrated System, a method using ratios of elemental contents to identify those nutrients from the most to the least deficient.

In contrast, sap analysis, is an analysis of extracted cellular sap or juices normally carried out in the field and makes use of special papers, specific reagents and testing kits, and hand-held instruments. These are typically used when a specific nutrient or compound is of concern, such as sugar in grapes.

How to Use and Interpret Plant Analysis Data

Plant analysis, as a diagnostic technique, has a considerable history of application. Historically, it has been used to diagnose nutritional problems in the field once nutritional symptoms have been observed. Unfortunately, when used this way, plant growth reduction and yield loss have frequently already occurred. More recently, plant analysis has been used in combination with soil testing to determine the combined soil and crop nutrient element status. This information then forms the basis for prescribing lime and fertilizer needs. Using a series of plant analyses during the growing season to track the nutrient element status of the crop, growers can determine when supplemental fertilizer applications are needed, whether they be applied to the soil, through fertigation or foliar applications. Because plant analysis routinely includes micronutrients and secondary nutrients, fine adjustments in all nutrients, including micronutrients, are possible, especially using foliar fertilization.

Whether used as a diagnostic tool to verify nutrient deficiencies observed in visual deficiency symptoms in the field, or to monitor nutrient levels during growth cycle of a plant, a primary goal of plant analysis is to allow the plant to tell what is working and what is not. The plant tissue results can determine whether soil fertility levels are adequate to meet crop requirements, and also whether the addition of fertilizers, including macronutrients and micronutrients, are sufficient to provide the plant's needs in both quantity and balance of nutrients. For annual crops, multiple tissue samplings during the growing season for plant analysis are recommended to ensure that all of the essential nutrients are present at sufficient levels during the entire growth cycle. Because of the many dynamics of soil nutrient availability, and uptake and utilization by plants, a single tissue test early in the season may not be enough to predict the nutritional status of a crop later in the season. To gain the greatest benefit from plant analysis, multiple sampling and analyses during the growth cycle is used to understand nutrient interactions and dynamics related is plant growth and yields. From this information, nutritional programs may be developed using fertilization programs to eliminate nutrition as a limiting factor, to give the greatest return on investment from fertilizer inputs, and at the same time, produce high yielding and high quality crops.

Plant analysis is carried out as a series of steps with each step equally important to the success of the analysis and the results obtained. Briefly, these include:

1. Sampling and Handling

Since plant species, age, plant part, time sampled, and fertilizer and pesticides applied are some of the variables that affect the interpretation of the laboratory results for the essential plant nutrients, careful sampling is important. In general, choosing the most recent fully developed leaf for analysis is critical for proper analysis and interpretation of results. As leaves grow older, they export nutrients out of the leaf to support new growth, while a young leaf (not fully developed) is still accumulating nutrients. Selecting leaves that are either too old or too young will result in data that is not a true indication of the overall nutritional status of the plant.

In field situations, representative sampling across the field is needed to understand the overall nutritional needs of the crop. Proper labeling and handling is necessary for the sample to be identified and to arrive at the laboratory in good condition. Tissue samples sent to laboratories should be shipped in paper bags, not plastic to allow the sample to breathe, but not mold or rot. Analytical results are only as good as the sample that arrives at the laboratory.

2. *Sample Preparation*

Whether in the field or in the laboratory, decontamination by washing the leaf may be necessary to remove foreign substances, particularly if the tissue is covered with dust or spray materials that contain nutrients included in the analysis. This is especially true for micronutrients (e.g., copper, manganese, zinc) that may be applied in fungicides or other material utilized in the production system. However decontamination is only partly successful. Oven drying at 80°C and sample size reduction (milling) prepares the sample for laboratory analysis. Then the organic component in the prepared tissue must be removed by either wet acid oxidation or high temperature dry ashing in order for the nutrients to be in a form suitable for analysis.

3. Laboratory Analysis

A number of different analytical procedures are used to analyze all of the essential nutrients. Procedures in use include Dumas or Kjeldahl digestion for nitrogen (N); dry combustion for sulfur (S); colorimetry for boron (B), phosphorus (P), and molybdenum (Mo); flame photometry for potassium (K) and sodium (Na); flame atomic absorption spectrometry for calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), nickel (Ni), and zinc (Zn); and flameless atomic absorption spectrometry for molybdenum (Mo). Specific-ion electrodes or ion chromatography are used to determine chloride (Cl) and nitrate (NO_3) anions.

Plasma emission spectroscopy using an inductively coupled plasma emission spectrometer (ICP) has become the analytical procedure of choice for most of the essential nutrients that had been determined by spectrophotometry (colorimetry), flame emission, or atomic absorption spectrophotometry in the past.

4. Interpretation

Interpretation of the laboratory analysis is generally based on sufficiency ranges for each individual crop. The nutrients are placed into one of the three categories: low, sufficient, or high. The essential nutrients that are low or below the proper sufficiency ranges are identified. The nutrients that are low should be added as additional fertilizer until the leaf level is within the sufficiency range, which is determined by follow up tissue analysis. Because of the potential for nutrient interactions, the next step is to determine what effect the additions of fertilizer for the nutrients that are low will have on other nutrients, especially those that may be low or at the lower end of the sufficiency range. If a nutrient is high, interpretation of the results in combination with an analysis of growing practices should be considered to determine ways to reduce that nutrient accumulation in the plant tissue. In some cases, competing nutrients may need to be applied even when they are in sufficient concentration, to counter the negative effects of excessive levels of other nutrients. For example, applying potassium to a fruit crop that has excessively high nitrogen levels.

"***He gave it for his opinion, that whoever could make two ears of corn or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together".***

Jonathan Swift
Gulliver's Travels

Chapter 2

Plant Nutrition Overview

"An nutrient is not considered essential unless (a) a deficiency of it makes it impossible for the plant to complete its life cycle; (b) such deficiency is specific to the nutrient in question and can be prevented or corrected only by supplying this nutrient; and (c) the nutrient is directly involved in the nutrition of the plant quite apart from possible effects in correcting some unfavorable microbial or chemical condition of the soil or other culture medium." D. I. Arnon and P. R. Stout (1939)

Introduction

The study of plant nutrition has been referenced as the study of mineral nutrients, elements, inorganic plant nutrients, macro & micronutrients, and essential plant nutrients. The 17 plant nutrient elements determined to be essential for plant growth 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), nickel (Ni), and chlorine (Cl).Fourteen of these 17 essential plant nutrients are identified as inorganic nutrients with carbon, hydrogen and oxygen comprising the organic nutrients. The generally accepted requirements for essentiality were established by Arnon and Stout (1939) include:

1. ***Omission of the nutrient must result in abnormal growth or failure to complete plants life cycles.***

2. ***Nutrient must be specific and cannot replaced by another.***

3. ***Requirement is universal among all plants.***

Elements that do not meet these requirements but that might improve plant growth or be required by some plants are called ***beneficial***nutrients. If an essential nutrient is not within an adequate concentration range, normal growth will not occur, and symptoms of deficiency will develop.The current plant nutrient elements, their date of discovery and individual(s) who established their essentiality are presented in Table 2-1.

Table 2-1. Discoveries of Existence and Essentiality of the Plant Nutrients Glass, 1989)

Nutrient	Discoverer	Year	Discoverer of Essentiality	Year
C	**	**	De Saussure	1804
H	Cavendish	1766	De Saussure	1804
O	Priestley	1774	De Saussure	1804
N	Rutherford	1772	De Saussure	1804
P	Brand	1772	Ville	1860
S	**	**	vonSachs, Knop	1865
K	Davy	1807	vonSachs, Knop	1860
Ca	Davy	1807	vonSachs, Knop	1860
Mg	Black	1755	vonSachs, Knop	1860
Fe	**	**	vonSachs, Knop	1860
Mn	Scheele	1774	McHargue	1922
Cu	**	**	Sommer. Lipman & MacKinnon	1931 1931
Zn	**	**	Sommer & Lipman	1926
Mo	Hzelm	1782	Amon & Stout	1939
B	Gay Lussac & Thenard	1808	Sommer & Lipman	1926
Cl	Scheele	1774	Broyer	1954
Ni	Cronstedt	1751	Eskew, et al. Brown, et al.	1983 1987

**Nutrient known since ancient times.

Plant Nutrition as a Science

Growers and scientists utilize the art of plant nutrition to identify nutrients that are present in the plant in deficient or toxic amounts and that ultimately affect plant growth. There are three main methods utilized in diagnosis of nutrient disorders, (1) observation, (2) soil analysis, and (3) plant analysis. The observation of plants from one part of the field, nursery, or greenhouse to another allows the comparison of symptoms. The comparison of plant growth and symptoms from one plant to another not showing the symptoms, in the same growing area to a comparison in different region growing the same plant, is the oldest form of scientific investigation utilized by plant nutritionist. More recent advances in identifying levels of nutrients that are considered deficient or toxic in soils or plant tissues have allow growers and scientists to utilize processes to determine nutrient deficiencies or toxicities in addition to visual diagnosis. Soil tests are used to assess the supply of nutrients in soils or other media and may support the conclusions made by observations. Plant analysis measures the presence of nutrients in plants, and the concentrations within the tissue are compared with standards of sufficiency. The leaf (or other established plant part for the crop) is analyzed in a laboratory, and the deficient or toxic nutrient is identified and corrective measures are recommended. Plant analysis will identify of hidden hunger in the leaves, a deficient condition that exists without the expression of visible symptoms of deficiency. Plant analysis utilizes data that have been established through prior investigations as being sufficient to support optimum growth of the crop. Generally leaves from a specific position on plants, sometimes whole, small plants, are collected and analyzed. If one or more nutrients are found deficient, then the deficient nutrients are applied as fertilizers to correct the deficiency, and the response is monitored. If toxic levels are noted, then the fertilizer programs can be changed for the next crop to restrict this nutrient to levels corresponding to the sufficiency range. If another nutrient can help suppress the negative effects of the toxic levels of a nutrient, then the application of the offsetting or competing nutrient may be applied as well, but not at toxic levels. In correcting a potential nutrient deficiency that may not be visually apparent, the plant nutritionist implements a soil-media-plant analysis program that allows a fertilizer program to be implemented that corrects the most limiting plant nutrient. Many times the application of nitrogen, phosphorus, or potassium may not produce a plant response if one of the other essential plant nutrients is the limiting factor affecting plant growth. One must always remember that of the seventeen known plant nutrients the one that affects plant growth the most is the one that is most limiting at a given point in the growth cycle of the plant. The fact that a nutrient is limiting growth does not necessarily mean that a visual deficiency will be apparent. Much of the fertilizer applied can be lost or not utilized by a plant if the essential nutrient that is most limiting is not applied or available to the plant. Thus, the need for tissue and soil monitoring is a major part of modern crop production.

It is the ability of a plant nutritionist to identify deficiencies or toxicities associated with the essential plant nutrients that the science of plant nutrition is founded upon. Use of the knowledge of plant nutrition must be integrated with a sound background in soil science, plant biochemistry, inorganic chemistry, organic chemistry, and plant physiology, plant pathology, and pesticide science. All of these areas must be integrated with cultural, environmental and genetic factors playing a direct role in interpretation of information forming the knowledge base from which plant nutrition decisions are made.

Fourteen of the seventeen essential nutrients are frequently referred to as soil-supplied nutrients, because they are commonly derived from the soil or growing media. These include the macronutrients (nitrogen, potassium, phosphorus, calcium, magnesium, and sulfur) and the micronutrients (boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc). These 14 nutrients are most commonly taken into the plant through the roots as ions, either anions or cations, from the soil solution. However, these nutrients can be foliar fed to meet many of the nutrient requirements of the plant. The remaining three nutrients are carbon, hydrogen and oxygen and are classified as the structural nutrients and are derived from water and air.

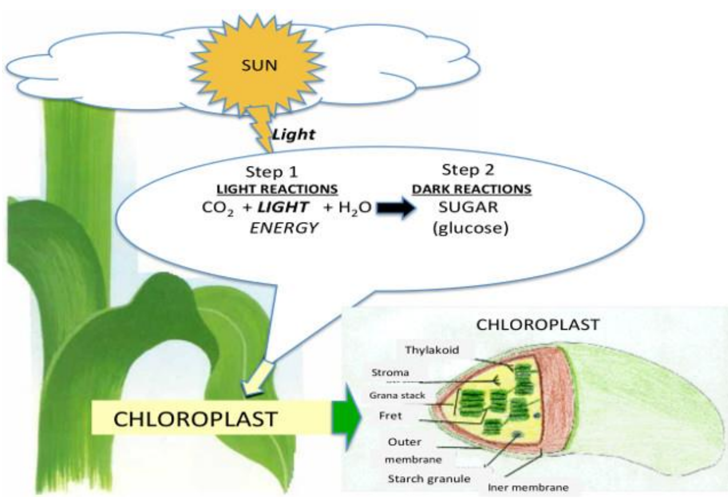
The Structural Nutrients

Seventeen nutrients have been confirmed as essential by plants for growth. Three of these nutrients - carbon, hydrogen and oxygen - constitute 90 to 95% of plant dry weight of most plants, and are classed as the "structural nutrients". They are used to form all carbohydrates, proteins and other organic compounds. These complex organic compounds are derived from simple carbohydrate building blocks formed as a result of photosynthesis. The sources hydrogen and oxygen are water that is taken into the plant by the root, and carbon from carbon dioxide that is absorbed by leaves from the atmosphere that surrounds the plant. Carbon dioxide enters the plant almost entirely through stomata on the leaves. Water also is absorbed through stomata, but the relative amount is small in comparison to the water that enters the plant through the roots. Elemental oxygen (O_2) is also absorbed from air through stomata, roots, or other plant parts. Photosynthesis is the process by which light energy is converted into chemical energy, and a reductant derived from water is formed. The overall process leading to formation of carbohydrates is illustrated by the following equation:

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} + \text{light energy} \rightarrow \underset{\text{carbohydrate}}{(CH_2O)} + \underset{\text{oxygen}}{O_2}$$

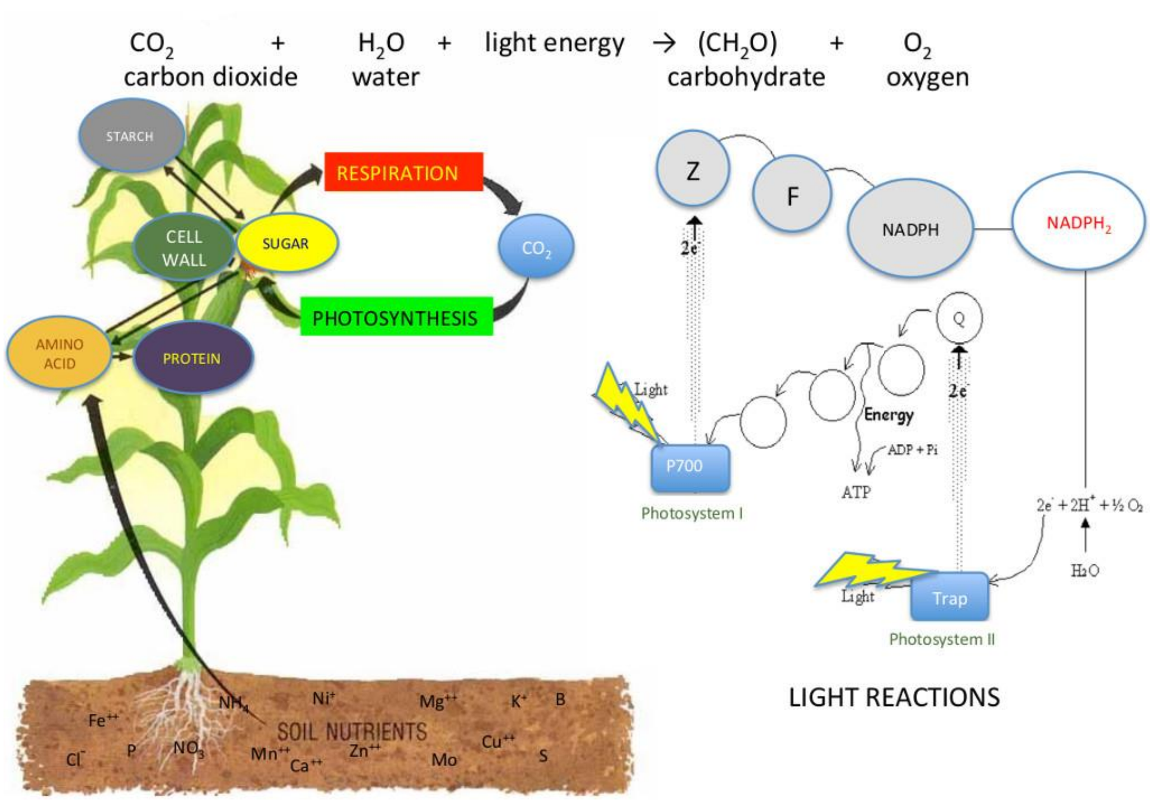
Photosynthesis in this equation occurs in two steps: (1) the Light Reaction and (2) the Dark Reaction. Both reactions are regulated by enzymes, which require plant nutrient elements as either structural components or cofactors (catalysts required for the reactions to take place, but are not consumed).

Figure 2-1. Light and dark reactions.



The Light Reaction involves the conversion of light energy into stored chemical energy in high-energy bonds as adenosine triphosphate (ATP) and the formation of a chemical reducing agent (reductant), n*icotinamide adenine dinucleotide phosphate* (NADPH). A reducing agent is able to give up electrons in a redox chemical reaction and is thereby oxidized, but in the process NADPH gives up energy to fix carbon from carbon dioxide, (simultaneously releasing oxygen gas), and thus drives the formation of glucose (sugar) in the Calvin Cycle. The Light Reaction occurs in the part of the chloroplast known as grana, which are stacks of membranes called thylakoids. Two photosystems participate in The Light Reaction, Photosystem I absorbs light at 700 nm (red light), and transferring the energy as electrons to NADP forming NADPH. Photosystem II absorbs light at 680 nm (red light), and in this system, water is split to release oxygen gas and H^+ or electrons. The electrons flow to Photosystem I replacing electrons that were released by absorption of light. The H^+ is used to bind to NADP to form NADPH. Also, the flow of electrons from Photosystem II back to Photosystem I provides the energy to add an inorganic phosphate (P_i) to adenosine diphosphate (ADP) to form the high-energy phosphate bond in ATP. That is, ADP + P_i + energy from electron flow → ATP.

Figure 2-2. Photosynthesis and plant metabolism.



The Calvin Cycle and the formation of glucose is part of the Dark Reaction, which occurs in the gel-like matrix known as the stroma of chloroplasts. In the Calvin Cycle carbon dioxide is first fix as a part of phosphoglyceric acid, which is then metabolized to form glucose. Thus, the carbon and oxygen of organic molecules in plants are derived from carbon dioxide, and the hydrogen is derived from water.

The Mineral Nutrients

The remaining 14 nutrients are divided into 2 categories, the macronutrients, which include nitrogen, potassium, phosphorus, calcium, magnesium and sulfur; and the micronutrients, boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc. These nutrients are frequently identified as “mineral nutrients.” The macronutrients are expressed as percent concentrations (g/100 g) of the dry matter of the plant, whereas the micronutrients are expressed as parts per million (mg kg^{-1}). The average relative concentration of these 14 essential plant nutrient elements in plants is reported in Table 2-2.

Table 2-2. Average Concentrations of Mineral Nutrients in Plant Dry Matter that are Sufficient for Adequate Growth (Epstein, 1965).

Nutrient	Symbol	mol/g dry wt	mg kg^{-1} (ppm)	%	Relative number of atoms
Molybdenum	Mo	0.001	0.1	-	1
Nickel	Ni	0.001	0.1	-	1
Copper	Cu	0.10	6	-	100
Zinc	Zn	0.30	20	-	300
Manganese	Mn	1.0	50	-	1,000
Iron	Fe	2.0	100	-	2,000
Boron	B	2.0	20	-	2,000
Chlorine	Cl	3.0	100	-	3,000
Sulfur	S	30	-	0.1	30,000
Phosphorus	P	60	-	0.2	60,000
Magnesium	Mg	80	-	0.2	80,000
Calcium	Ca	125	-	0.5	125,000
Potassium	K	250	-	1.0	250,000
Nitrogen	N	1,000	-	1.5	1,000,000

Root Absorption of the Essential Mineral Nutrients

The absorption of all essential plant nutrients by the roots of plants occurs in an area called the ***rhizosphere***. The rhizosphere consists of the area 1-2 mm around the outside surface of the root and all the intercellular space that exist inside the root. The 14 mineral plant nutrient elements are taken into the plant by root absorption in their ionic forms, as either cations or anions. The cationic and anionic forms of these nutrients are listed in Table 2-3.

Table 2-3. Ionic Forms of Plant Nutrients Absorbed by Plants

Macronutrients		Micronutrients	
Nutrient	**Ion Forms**	**Nutrient**	**Ion Forms**
Carbon (C)	CO_2 (mostly through leaves)	Iron (Fe)	Fe^{+2}, Fe^{+3}
Hydrogen (H)	H_2O	Magnesium. (Mg)	Mg^{+2}
Oxygen (O)	O_2, OH^-, CO_3^{-2}, SO_4^{-2}, CO_2 (mostly through leaves)	Boron (B)	BO_3^{-3}
Phosphorus (P)	$H_2PO_4^-$	Manganese (Mn)	Mn^{+2}
Potassium (K)	K^+	Copper (Cu)	Cu^{+2}
Nitrogen (N)	NH_4^+, NO_3^-	Zinc (Zn)	Zn^{+2}
Sulfur (S)	SO_4^{-2}	Molybdenum (Mo)	MoO_4^-
Calcium (Ca)	Ca^{+2}	Chlorine (Cl)	Cl^-
		Nickel (Ni)	Ni^+

Which ionic form exists in the rooting medium solution is determined partly by a combination of the pH of the soil solution and the level of biological activity. The concentrations of these forms are associated with the physiochemical properties of the rooting medium and the fertility levels from past lime and fertilization, and previous cropping practices. These nutrients are brought into contact with the plant roots are by means of mass flow or diffusion. Mass flow occurs when water moves within the rooting medium, carrying the dissolved ions along with the moving water. Diffusion is the process by which ions move within the soil solution from an area of high concentration to an area of lower concentration. Roots can also have contact with nutrients in the soil or growing medium by root growth, but the majority of uptake of these nutrients requires transport by mass flow and diffusion to the root surface.

While all plants require the 17 essential nutrients, the major focus here will be on the 14 mineral nutrients that exist in the root medium and are taken into the plant through the root system. Foliar absorption, another important means for the plants to take in essential plant nutrients, will be dealt with in Chapter 19.

The availability of each essential nutrient is influenced by cultural practices and environmental conditions. In addition, the ability of a plant to absorb nutrients from the rooting medium is influenced by genetic factors. Availability of each essential nutrient varies due to the quantity of the fertilizer nutrient applied, timing of fertilizer application and the reactivity and effectiveness of the form and source of each applied nutrient in a particular medium.

To be successful utilizing a plant nutrition program, all of the essential nutrients must be considered when making decisions regarding fertilizer application, including micronutrients. Which essential nutrients that need to be applied are determined directly by an ongoing plant tissue and soil analysis program. If one nutrient is deficient in the rooting medium, yet all of the other essential nutrients are present at their sufficiency levels, healthy plant growth will not be achieved until that nutrient is taken up.

The most frequent mistake that growers make is their almost exclusive focus on the application of N-P-K (nitrogen, phosphorus, and potassium) fertilizers, with little attention given to the availability of secondary or micronutrients, any one of which may be below the critical level for proper plant growth. This raises the question: ***Which essential plant nutrient is the most important*?** All essential plant nutrients have an absolute requirement by all plants, so each is equally important. However, one nutrient may be the primary limiting factor in plant growth and development at any point in time during plant growth.

Another common misconception is that plant roots will readily absorb any form of an essential nutrient applied to the rooting medium. The form of an applied essential nutrient definitely affects its availability to the plant. The form also can dramatically influence the availability of one or more of the other essential nutrients because of competition, antagonistic, or accelerated (Viet's effect) uptake. Another common mistake in the application of a fertilizer material is to disregard the effect of environmental conditions (such as temperature, light intensity, amount of rainfall or irrigation, and relative humidity) may have on the availability and absorption of each essential plant nutrient. These factors are even more important with foliar fertilization, which will be discussed later in chapter 19.

There is great diversity of plant species, cultivars or varieties grown in the world today. The response to applied fertilizer can differ considerably between plant species, even between cultivars of the same species. Consequently, one single fertility program for all plants, or even one species, will not work for successful crop production.

Also, no single fertilization program will work for the same crop being grown under field conditions, greenhouse conditions, or production in shade houses or other protective structures. The utilization of protective structures for plant culture has resulted in specific cultural methods that are different from open-field production and thus require different nutritional programs for the successful production of plants grown under a protective environment in comparison to those used for field production. With intensive cultural systems come the necessity to rely on soil or media tests and plant analysis to formulate an effective plant nutrition program. Growers using pot culture for production are more likely to create imbalances due to nutrients than are crops grown under field conditions. Depending on production system and growing medium, nutrients can be either accumulate or leached out of the potting medium with the application of irrigation water and/or fertilizers. Those using bed culture will also require constant soil test monitoring to determine the extent of nutrient retention in the root zone, as well as plant analyses to evaluate the extent of foliar absorption that may be occurring from drip or overhead mist or spray systems used to deliver water and essential nutrients.

It should be noted, however, that use of protective structures offers some distinct advantages over field growing. Excessive rainfall that occurs in short periods is a plant stress factor and reduces the retention of certain essential nutrients in the root zone. Reduced chemical application to control pests also is realized and the interaction of these chemicals with nutrient availability is reduced. In addition, greenhouse growing offers the advantage of carbon dioxide enrichment during periods of cloudy weather or of rapid crop growth, an option that is not available in field culture.

Each essential nutrient is affected by the grower-specific cultural practices, site or region environmental conditions, and genetic differences that exist among species and varieties. Although there are 17 essential nutrients required by plants, only 12 of the 17 are typically managed by the grower. The 17 essential nutrients can be grouped into several categories: the major nutrients in water and the atmosphere (carbon, hydrogen, and oxygen); the macronutrients (nitrogen, phosphorus, and potassium); the secondary nutrients (calcium, magnesium, and sulfur); and the micronutrients (manganese, iron, boron, copper, zinc, molybdenum, nickel and chlorine). Chlorine deficiency is rarely observed either in crops or in nature. Chlorine is often part of chemical formulations used in existing fertilizers applied to crops such as potassium chloride (potash) and calcium chloride. Excess chloride and its associated high salt index is more of a concern in cropping systems than is chlorine deficiency. Nickel deficiency is seldom identified in most crops, so nickel fertilization has not been routinely practiced except with crops like pecans where specific nutrient deficiency symptoms have been identified and observed. Even though nickel has been proven to be an essential plant nutrient, little work has been done to determine the range of plant requirements for most crops. Two reasons for this lack of investigation is that nickel is needed in plants in very small quantities and because few crops have been observed to have nickel deficiency symptoms. As more studies are done on nickel, it is anticipated that it will be included in more fertility programs. Consequently, in addition to the three atmospheric nutrients, growers currently seldom manage chlorine and nickel.

I. Carbon, Hydrogen, and Oxygen

Carbon

The carbon requirement of the plant is met from the atmospheric content of carbon dioxide. In general, the grower has little control over the carbon supply of a specific plant since this essential nutrient is acquired as CO_2 from the air that surrounds the plant. During active photosynthesis, however, the air around plants in open fields or protective structures may have less than optimum CO_2 levels available to the plant when air movement (such as on a still, calm day) in densely populated fields or in enclosed structures is not sufficient to resupply CO_2 that has been utilized. Since CO_2 is absorbed through stomata located in the leaf epidermis, any factor that keeps stomata closed will reduce the amount of CO_2 diffusing into the plant. When air temperatures are high, for example, and plants are under high-temperature stress, stomata will close. When plants are under stress of insufficient water, stomata will close. Therefore, both of these environmental factors can prevent the absorption of CO_2 resulting in limited growth, which in turn affects the yield and quality potentials. There are genetic differences among varieties that can affect CO_2 absorption and utilization, which will result in some varieties being better able to cope with low levels of CO_2 absorption than others. If CO_2 is limiting, growth is less than optimum and results in lower yield. Carbon dioxide enrichment in enclosed environments on cloudy days, during cool growth, or during rapid growth periods might result in increased production.

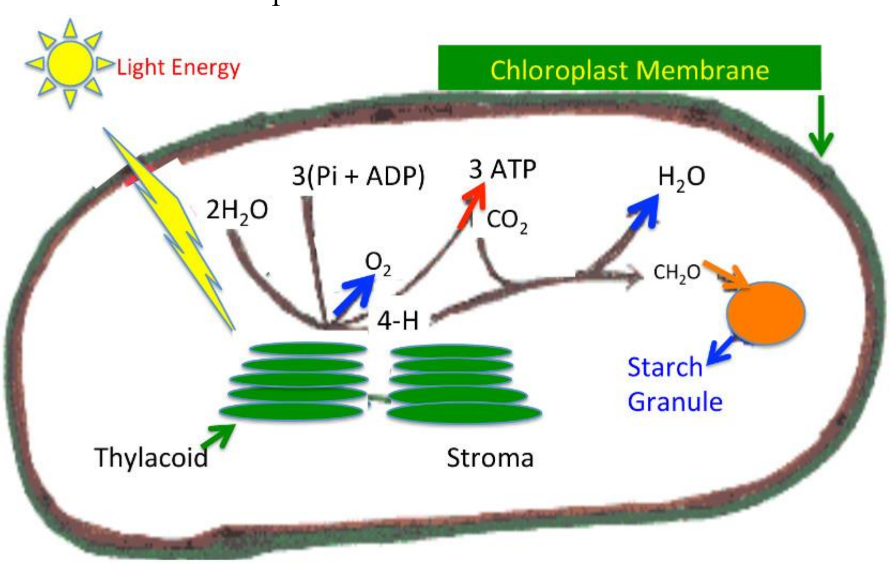
Hydrogen and oxygen

Water is the source of hydrogen, because water is split, and the hydrogen is incorporated during CO_2 metabolism to form a carbohydrate during photosynthesis. The oxygen of organic compounds is derived from the CO_2. Elemental O_2 is evolved from water and is released into the atmosphere during photosynthesis. Plants require O_2 for respiration and acquire this O_2 from air. Growers must realize that a plant utilizes water for many plant processes other than the one in which a water molecule is split and the hydrogen utilized carbon metabolism for plant growth. For example, water is required for the hydration of plant tissues. Hence, C and O are essential nutrients. In addition, if any of the other essential nutrients are limiting, photosynthesis is reduced, and plant growth is less than optimum. Growers need to be aware that any stress that occurs, no matter what the source, can limit plant growth and yield through reduced photosynthesis and carbon utilization, a loss that is never regained during the growth cycle, especially for annual growth crops. With any nutrient deficiency, once the deficiency occurs, irreparable damage to plants has occurred.

Role of Nutrients in Photosynthesis

Photosynthesis is the process by which plants use light energy to transform carbon dioxide and water into carbohydrates and oxygen. In photosynthesis, carbon dioxide diffuses into chloroplasts. The Light Reaction occurs in the parts of the chloroplast knows as grana, which are stacks of membranes called thylakoids. The Dark Reaction occurs in the gel- like matrix known as the stroma of chloroplasts.

Figure 2-3. Plant Chloroplast and reactions sites.



Plant nutrients function in many processes in The Light Reaction and in The Dark Reaction. Enzymes for which the nutrients may be components or cofactors mediate all steps in these processes.

Table 2-4. The following table lists the role of essential plant nutrients in photosynthesis.

Nutrient	Role
Nitrogen	**General.** Nitrogen is a general constituent of the photosynthetic apparatus, being a part of chlorophyll molecules and proteins with which chlorophyll is held in the grana. All enzymes are proteins and, hence, require nitrogen for their formation. **NH_4^+ toxicity.** Ammonium is toxic to photosynthesis. It uncouples ATP formation from electron transport in The Light Reaction. Ammonium also can lead to a degradation of grana structures and chloroplast conformation through interferences in protein synthesis and structure. **Deficiency.** Deficiency results in a loss of proteins and chlorophyll. These losses result in losses of photosynthetic activity.
Phosphorus	**General.** Phosphorus is essential for synthesis of ATP by photophosphorylation(ADP + Pi→ATP) in The Light Reaction. It is also a constituent of NADP. The ATP and the reduced form of NADP are reactants in the Calvin Cycle. **Deficiency.** The disruptions of the energetics of photosynthesis result in suppressed carbon dioxide reduction and suppressed plant growth.
Potassium	**General.** Potassium accumulation in guard cells allows for the opening of stomata, the pores in leaf epidermis through with gases diffuse into an out of leaves. In the dark, potassium leaks from the guard cells, and the stomata close. Opening allows the movement of carbon dioxide into the leaf and oxygen from the leaf. Closing stops gas movement including the loss of water vapor from leaves. **Deficiency.** Potassium has no direct metabolic role in photosynthesis. Effects may occur through the disruption in stomata movement and decline of health in a potassium-deficient leaf.
Calcium	**General.** Calcium is necessary for the maintenance of structures of membranes. Hence, it is required for maintaining membrane integrity in thylakoids. Calcium also is a cofactor in reactions by ATPases, enzymes that conduct photophosphorylation.

	Deficiency. Deficiency results in degradation of thylakoids and suppressed ATP synthesis and suppressed photosynthesis.
Magnesium	**General.** Magnesium is a constituent of chlorophyll. Magnesium is required also for protein synthesis and is essential for maintenance of the chlorophyll-protein complex in thylakoids. Magnesium is needed for all reactions involving phosphate transfers in photosynthesis. **Deficiency.** Protein deficiency results in destruction of lamellar systems of the chloroplast. The protein-chlorophyll complex in chloroplast membranes is disrupted. ATP cannot be made or used without magnesium.
Sulfur	**General.** Sulfur is a constituent of proteins as it is a component of methionine and cysteine, which are amino acids in proteins. Cytochromes are iron-sulfur proteins that function in electron transport between Photosystem II and Photosystem I. Ferredoxin is an iron-sulfur protein that participates in electron transport from Photosystem I to NADP. Sulfur also is a component of lipids that are part of the composition of plant membranes including the membranes of chloroplasts. **Deficiency**. Deficiency results in suppressed protein synthesis, which disrupts thylakoid membranes and could impair synthesis of cytochromes and ferredoxin.
Copper	**General.** Copper is a constituent of plastocyanin, which is known as the blue protein. Plastocyanin is a component of the electron transport system from Photosystem II and Photosystem I. Plastocyanin feeds electrons into chlorophyll in Photosystem I after absorption of light by that system. **Deficiency.** Inadequate plastocyanin leads to disruption of electron transport.
Iron	**General.** Although iron is not a constituent of chlorophyll, synthesis of chlorophyll requires iron. Iron is needed for the synthesis of a precursor of chlorophyll. In The Light Reaction, iron is a constituent of cytochromes and ferredoxin in the electron transport pathways. **Deficiency.** Deficiency of iron leads to leaf chlorosis due to lack of chlorophyll and protein synthesis and failure of the chloroplasts to develop and maintain grana.

Manganese	**General.** Manganese is required for the hydrolysis of water and hence oxygen evolution and release of electrons in Photosystem II. **Deficiency.** Deficiency of manganese impairs oxygen evolution and the generation of electrons (H). With severe deficiency, chlorophyll decreases, and structure of the thylakoids is destroyed.
Zinc	**General.** Zinc is required for activity of carbonic anhydrase, an enzyme that maintains equilibrium between carbon dioxide and bicarbonate in solution. Carbon dioxide is the carbon substrate for photosynthesis. Zinc is also a component of an enzyme called superoxide dismutase. Superoxide (O_2^-) forms during photosynthesis and unless destroyed could lead to auto oxidation of plant cells. **Deficiency.** Zinc deficiency may result in suppressed activity of carbonic anhydrase and thereby limit photosynthesis. This effect may be more important in C4 plants than in C3 plants.
Chlorine	**General.** Chlorine is required for oxygen evolution in Photosystem II. Chlorine has a role in stomatal regulation in some species as an accompanying ion for potassium flux. **Deficiency.** Deficiency of chlorine is unlikely in nature.
Boron	**General.** Boron has no direct role in photosynthesis. The function of boron in plants is unresolved. **Deficiency.** Boron deficiency may suppress photosynthesis by reducing the utilization of light as the result of accumulation of reactive oxygen species, such as superoxide. Boron deficiency causes a wide range of structural symptoms causing tissue death and growth suppression. Carbohydrate transport appears to be impaired by boron deficiency.
Molybdenum	**General.** Molybdenum has no known role in photosynthesis. The functions of molybdenum are related to nitrogen metabolism rather than to carbon metabolism. **Deficiency.** Molybdenum deficiency results in impaired nitrate assimilation, so nitrate accumulates to toxic levels and destroys leaf tissue, thereby suppressing photosynthesis. Molybdenum is needed for nitrogen fixation by legumes.
Nickel	**General.** Nickel has no know role in photosynthesis. **Deficiency.** Effect on nitrogen conversion to protein where urea is the nitrogen source or for nitrogen fixation.

II. Macronutrients

Nitrogen, phosphorus, and potassium are generally referred to as fertilizer nutrients or as primary nutrients since these nutrients are the principal components in most fertilizers. Calcium and magnesium generally are supplied through liming materials in the agronomic field and sometimes as specific fertilizer nutrients in horticultural crops, whereas sulfur is an accompanying anion in some fertilizer ingredients such as ammonium sulfate and potassium sulfate. Because sulfur can be taken up from the air, historically the burning of high sulfur coal provided much of the sulfur needed by crops. However, with the ban on burning high sulfur coal (except with scrubbers to capture sulfur gasses) has resulted in many soils needing the application of sulfur.

Nitrogen

There are three common forms of nitrogen fertilizer, each possibly having a unique and specific effect on plant growth. The three N-forms are urea, ammonium, and nitrate. Urea, NH_2-CO-NH_2, is converted rapidly to ammonium by the urease enzyme that is normally present in bacteria in the growing medium. This enzymatic conversion of urea releases into the rooting medium solution two ammonium (NH_4^+) ions that can be absorbed by the plant roots. If the urea molecule itself is absorbed through the leaves or taken up through the roots, the molecule will be metabolized inside the plant to form ammonium ions. Thus, urea and ammonium-N fertilizers have about the same effect on plants in terms of plant nitrogen metabolism. Nitrate-N is different in that it is an oxidized anionic form of N (NO_3^-) whereas ammonium is a reduced cationic form of nitrogen (NH_4^+). The different charge of these two sources of nitrogen is important for several reasons, one being the shift of the pH that occurs in the root zone when either nitrate or ammonium is absorbed by the plant roots. The positive NH_4^+ ion, when absorbed, results in the release of a H^+ ion into the immediate vicinity of the root zone, which is referred to as the rhizosphere. The bulk pH of 6.0 in a pot or bed medium, as would be measured by a soil test, can be two to three pH units higher than the rhizosphere pH. This difference becomes significant since all the essential nutrients must pass through the rhizosphere prior to absorption by the root. Also, the availability of some of those nutrients is influenced by pH. Simply being present in the medium in sufficient concentration will not ensure absorption into the plant, because the nutrient can be precipitated at the root surface and, therefore, not absorbed; or the acidification may result in an increased availability to excessive levels for certain nutrients. With nitrate-N as the nitrogen source, the negative charge of this anion is balanced by OH^- ions, the result being a two to three unit pH shift toward an alkaline (or higher) pH than is in the bulk soil. This shift would affect the availability and absorption of essential nutrients that are sensitive to a shift in pH toward the alkaline level. Thus, urea- and ammonium-N fertilizers acidify the rhizosphere, whereas nitrate-containing fertilizers move the rhizosphere pH toward alkalinity. A constant monitoring program of media pH is necessary to determine when pH adjustment is necessary through liming or changing the form of nitrogen applied so as to maintain the desired bulk soil pH as well as rhizosphere pH.

The use of herbicides and pesticides can affect the transformation of soil and fertilizer nitrogen from ammonium to nitrate. The presence of some of these chemicals in the soil prevents the conversion by nitrification of ammonium to nitrate, thereby making ammonium essentially the only N-form available to the plant. Nitrite can also be a factor since it is the intermediate product in the soil nitrogen transformation process from ammonium to nitrate. Therefore, if an applied chemical blocks soil nitrogen conversion after the nitrite to nitrate step, an immediate toxicity can occur. Some chemicals can inhibit the oxidation of ammonium to nitrate hence leading to accumulation of ammonium and toxicity in the soil. These toxicities will stress the plant, making it more susceptible to disease or may even kill the plant. The grower should be aware that soil nitrogen transformations, which are mediated by soil bacteria, could be affected in various ways by chemical applications.

Once the ammonium ion is absorbed by the plant or formed in the plant, it enters into organic combination to produce amino acids. This process must occur immediately after absorption by the roots; otherwise, ammonium may accumulate to toxic concentrations in cells, for a healthy plant with an adequate amount of carbohydrate, the response to the added ammonium is positive in terms of plant growth. If the quantity of ammonium taken up exceeds the capacity of the plant to supply carbon for ammonium assimilation, necessary for the formation of nitrogen compounds, growth is suppressed, and the metabolism of the plant is affected adversely. Therefore, there exists a delicate balance between the amount of ammonium the plant can utilize and supply to detoxify the absorbed ammonium ion, and the amount of carbon needed for growth. An example occurs on a cloudy day when the plant is not actively photosynthesizing at a normal rate. In this case the uptake of sizable quantities of ammonium would place an added demand on stored carbon. If the plant were healthy, with adequate stored carbon, there would be no adverse effect on growth. If the carbon reserves in he plant were low, however, the detoxification of absorbed ammonium would compete for the carbon needed for growth processes. The effect of ammonium uptake on the carbon balance in the plant would be particularly detrimental if the cloudy period were extended, which means a reduced photosynthetic rate. Transporters in cell membranes mediate the active uptake of nitrate-N, and nitrate can be stored in the plant as the nitrate ion without adverse effects until needed within limits. So, unlike ammonium, which is toxic if not immediately incorporated into nitrogen-containing compounds, nitrate is stored until needed by the plant for formation of nitrogen compounds. It should be noted, however, that most plants prefer a combination of ammonium and nitrate for optimum growth. Therefore, the nitrogen fertilizer program should be such that ammonium availability and uptake do not exceed that amount of carbon needed to support the normal growth processes of the plant.

Since some of the chemicals applied to control pests may block the conversion of ammonium to nitrate, and since rain or irrigation water leaches nitrate from the rooting zone, the grower must monitor the growing medium and the plants with regularly scheduled soil tests and plant analyses if maximum growth or yields are to be obtained.

Growers who fail to develop a regular monitoring program frequently experience severe crop production problems, with the resulting loss in plant yield or quality

Phosphorus

This nutrient is a very important for successful crop production. There must be a regular system of application and monitoring in place to ensure that phosphorous is available at a continuous sufficiency level. One source of possible phosphorus deficiency unique to acidic soils is the high aluminum content present. As the pH of the soil becomes acidic, iron and aluminum are solubilized and combine with phosphorus to form an iron-aluminum-phosphate precipitate that makes phosphorus unavailable for plant absorption. Also, as the pH of the rooting peat-based or soil-based medium becomes alkaline when limed or with nitrate absorption, the calcium in the liming material combines with phosphorus to precipitate calcium phosphate, thereby removing available phosphorus from the rooting medium solution. By a regular program of soil testing and plant analysis, a shift in either medium pH or level of available phosphorus can be detected, and plant phosphorus sufficiency can be determined so that corrective treatments can be applied before a significant limitation in growth and yield occurs.

Potassium

Potassium is important for the transport of carbon from one portion of the plant to another and is known to be involved directly in the opening and closing of stomata. This nutrient is very important for obtaining the desired color intensity of the plant foliage and particularly for flower color. The ammonium ion competes directly with the potassium ion for uptake from the rhizosphere, making excess ammonium detrimental to adequate potassium uptake. Potassium is involved directly in the postharvest keeping quality of flowers, with critically low potassium levels resulting in wilting and rapid postharvest decline. Potassium should be applied frequently in a plant nutrition program, and its adequacy should be determined by monitoring the plant throughout the growth cycle.

III. Secondary Nutrients

Calcium

Once calcium is incorporated into plant tissue, it cannot be moved to a new location within the plant and is considered immobile in the plant. Because calcium is not mobile in the plant, a constant supply of calcium to the plant must be maintained. This requirement is especially critical for crops that are constantly producing new tissue or plant material such as flowers, fruits, or new vegetative growth. Since calcium is not mobile within the plant after it reaches leaves, sufficient calcium will not be carried into the newly developing tissue, the result being less growth or abnormal growth. Calcium moves to the plant root and into the various plant parts with the transpiration stream. Any factor that creates a water-limited stress, or disrupts the transpiration flow of water, will affect calcium movement within the plant. For example, during periods of high humidity, the plant will transpire less water, and thus calcium transport will be restricted into the new tissue during such a period. In dry air, calcium will flow to the large leaves of plants, and small, young leaves will be deprived of calcium.

By monitoring the most recently formed leaves for their calcium content by means of plant analysis, one can identify problems associated with root diseases or chemical burn through reduced calcium uptake identified in newly formed leaves.

When ammonium-N fertilizers are applied in amounts that exceed the capacity of the plant to detoxify ammonium and support growth, roots will not grow properly, which affects calcium uptake. Also, ammonium in solution in soils or media will compete with calcium for absorption and restrict accumulation of calcium in plants. Therefore, to ensure that calcium is sufficient at all times for optimum growth, plants should be monitored by a regularly scheduled sequence of plant analyses.

Magnesium

Magnesium is important for maintaining the overall quality of plant color and appearance, giving the vivid bright green color that growers desire in foliage crops. A 4:1 or 3:1 percentage ratio of Ca to Mg in the plant tissue is required. Magnesium is required for chlorophyll formation and must be supplied on a continuous basis for normal growth and development. Generally, once magnesium deficiency develops, irreparable damage has been done to crops, and fertilization may not restore growth. Since many growers rely on liming to supply Ca and Mg, periods may occur in depleted media when there is an inadequate supply of Mg needed to maintain normal plant growth and development. Therefore, Mg is a key nutrient that needs continuous monitoring in a plant analysis program.

Sulfur

This nutrient is one of the major essential nutrients and generally is supplied as the sulfate ($SO_4^{=}$) anion in fertilizers, such as those containing ammonium sulfate or potassium sulfate. Many modern concentrated fertilizers are void of sulfur, and growers should select fertilizers that contain at least some sulfate or other available forms of sulfur.

IV. Micronutrients

Manganese and Iron

These two micronutrients are influenced similarly by cultural factors influencing availability. Both nutrients increase in availability as the pH of the medium becomes acidic and are less available as the pH of the medium becomes alkaline. These two nutrients are not usually deficient unless the grower causes a significant shift in the root medium pH through fertilizer or lime applications. Since certain fungicides, such as Maneb, which contains manganese, adds manganese to the surface of the leaf when applied. The additional Mn may eventually be absorbed from the foliar application of the manganese-containing fungicide but definitely is added to the plant manganese level in the analysis of the leaf even though it may exist only on the surface of the leaf and not in the plant cellular metabolism scheme. The plant content of Fe and Mn nutrients should be monitored continually by regularly scheduled plant analyses to ensure that neither nutrient approaches toxic or deficient levels in the plant. Many growers of greenhouse crops have encountered insufficiencies or toxicities of both of these nutrients with failures to use a plant analysis regime as an evaluation technique prior to scheduling an application of either fertilizer or lime.

Boron

This nutrient is not mobile in the plant and, like Ca, is subject to periods of deficiency when water availability is limited and water movement within the plant is restricted. Boron deficiency symptoms appear in the new growth of the plant, although symptoms may occur in other parts of the plant due to the lack of boron mobility. This nutrient is best monitored by means of plant analyses as a part of a regularly scheduled evaluation of the fertility program. Young leaves should be selected for testing.

Copper

This nutrient is not commonly deficient under most growing conditions. If fungicides containing Cu, such as Kocide, are used in the production of a crop, the copper applied can interact with the other micronutrients in the plant to create a deficiency as a result of the high tissue content of Cu. A regularly scheduled program of plant analysis best monitors this nutrient.

Zinc

Zinc is a micronutrient that is involved in some of the several enzymatic plant functions. Availability of Zn in soil or growing media is related inversely to the pH of the root zone, decreasing with increasing pH. Zinc availability also is reduced when P accumulates to high levels in the root zone. Zinc levels in the tissue need to be monitored when high rates of phosphorus fertilizer are applied to the soil or growing media. When high rates of phosphorus are anticipated, then zinc may be applied in-furrow at planting, or foliar applied to maintain adequate zinc levels in the tissue. The heavy use of certain zinc containing fungicides, such as Mancozeb, may cause high levels of Zn in the tissue causing a that contain Zn can pose a problem because high Zn levels can induce an iron and manganese deficiency in the tissue that is difficult to correct. Zinc sufficiency is best determined by regularly scheduled plant analyses.

Molybdenum

This essential nutrient is necessary for the plant to utilize nitrate. Molybdenum is required by the enzyme system nitrate reductase, and without adequate molybdenum, nitrate in the plant cannot be converted to ammonium for the formation of proteins. Molybdenum is often a limiting factor in the formation and activity of nitrate reductase in plants, and without adequate molybdenum, nitrate accumulates in the tissue. Molybdenum deficiency appears in plants as symptoms of nitrogen deficiency or as marginal burn on leaves due to accumulation of nitrate.

Molybdenum is also required in the enzyme system responsible for nitrogen fixation by nitrogen fixing bacteria, e.g., rhizobium. In crops like soybeans, the nodules are sinks for molybdenum and when molybdenum is low in growing media, molybdenum will be translocated from the leaves to the nodules, and can deplete molybdenum in the plant tissue. In crops like soybeans grown on soils low in molybdenum, two or more applications of molybdenum may be required for high yields. An early application is needed to supply nodules with adequate molybdenum for nitrogen fixation, and a second application may be needed to have adequate levels of molybdenum in the plant tissues. Nitrogen fixation is usually not sufficient to provide all the nitrogen needs of high yielding soybeans, and when nitrogen is taken up during midseason

Media pH has an effect on solubility of molybdenum. In acid soils below about pH 5.3, molybdenum may become unavailable even when adequate levels are present in the soil, thus causing a deficiency. Raising the pH, e.g., by liming, may correct this deficiency when adequate molybdenum is in the soil. However, it cannot be assumed that soils with a pH 5.3 or above have adequate molybdenum. Molybdenum is one of the most common nutrients found deficient in soils regardless of pH levels.

Chlorine

This essential nutrient is supplied amply from rainfall and as a salt in many fertilizers. As growers move into protected environments such as greenhouses, greater attention should be paid to this nutrient in the fertility program. Under agronomic fertility the use of fertilizer materials containing chlorine, such as potassium chloride, is sufficient to ensure an adequate supply of this nutrient. Cases of chlorine deficiency are rare. One occurrence was in wheat fertilized with potassium sulfate in soils where chlorine was deficient but unknown.

Nickel

This element has only recently been added to the list of essential plant nutrients. It is required in very small amounts, parts per billion, and accumulates in the plant leaves. This element is mobile in the plant and moves into the plant primarily through xylem vessels. Nickel moves through the phloem to new growth areas and into the seed where it can accumulate. Critical times for this elements requirement in the growth cycle are during rapid growth and organ/seed development.

Sufficient Levels of Essential Plant Nutrients

Hydroponic studies were instrumental in determining essentiality of plant nutrients. By the 1860’s, Ca, Fe, Mg, N, P, and S had been determined as essential to plant development. Improved techniques of purifying nutrient solutions, media, and air led to discoveries of additional essential nutrients. In 1922, the essentiality of Mn was determined; B and Zn were added to the list of essential nutrients in 1926, Cu in 1931, Mo in 1939, Cl in 1954, and Ni in 1987. Once essentiality was established, sufficiency ranges for most of the nutrients were determined through field, greenhouse, and laboratory studies. Plant nutrition includes the study and determination of nutrient levels that can be related to deficient, sufficient, or toxic at the concentration measured through plant analysis. Table 2-5 gives a generic range of each of the nutrients applied through fertilizer in crop production that represent sufficient levels in general for all plants. Specific sufficiency ranges determined for over 1,300 plants is presented in a following section in this book.

Table 2-5. General plant leaf sufficiencyrange of essential nutrients.

Nutrient	Symbol	Typical Concentration
Nitrogen	N	3 - 5%
Phosphorus	P	0.3 – 0.8%
Potassium	K	2.3 – 5%
Calcium	Ca	0.7 – 1.2%
Magnesium	Mg	0.3 – 0.7%
Sulfur	S	0.3 – 1.0%
Manganese	Mn	50 – 300 ppm
Boron	B	20 – 75 ppm
Copper	Cu	8 – 40 ppm
Zinc	Zn	40 -150 ppm
Molybdenum	Mo	0.5 – 5 ppm
Chlorine	Cl	<2000 ppm
Iron	Fe	70 – 400 ppm
Nickel	Ni	1 – 8 ppm

V. Beneficial Nutrients

It has been suggested that other nutrients, commonly referred to, as “beneficial nutrients”, might be essential at a concentration below our current detection limits. Cobalt (Co), sodium (Na), strontium (Sr), vanadium (V), and silicon (Si) are beneficial nutrients. They are required by some plants and improve the growth of some plants when added to the fertility program. However, none of these nutrients meet the current established criteria for essentiality (Arnon and Stout, 1939). Cobalt is required by the symbiotic nitrogen-fixing bacteria existing in nodules on the roots of leguminous plants, for without Co, the symbiotic fixation of atmospheric nitrogen (N_2) will not occur.

Figure 2-4. Symbiotic nitrogen-fixing bacteria in nodules on leguminous plants require cobalt.

But since nitrogen fixation is not a vital process in plants and since nitrogen-fixing plants will grow on inorganic nitrogen (e.g., nitrate or ammonium), Co is not essential. Some reports have suggested essentiality for the nutrients silicon for grain crops, such as rice. Sodium promotes the growth of table beets or sugar beets and may have roles in C4 metabolism in photosynthesis, but no mandatory or universal requirement of sodium has been demonstrated.

Strontium and vanadium are not considered essential for any plant although both nutrients act as partial substitutes for the nutrients calcium and molybdenum, respectively in microorganisms and perhaps in some plants. Silicon is recommended for inclusion in a fertilizer for rice, and sometimes in nutrient solutions formulations for plants grown hydroponically, as silicon may to provide some degree of fungal disease resistance when present in plant leaves at elevated levels. Lanthanum is added in fertilizers in China.

With further research and refinement of procedures, some of the beneficial nutrients may be accepted as essential. Nickel once was considered a beneficial nutrient. But, nickel is needed for the viability of nickel-depleted barley seeds. These seeds did not germinate if V was added, but germinated if Ni was added. This evidence is considered sufficient to allow acceptance of Ni as a plant nutrient.

Chapter 3

Factors Affecting Plant Nutrient Composition

I. Genetic Considerations

Differences in nutrient content and response to applied nutrients are found between many taxonomic categories of plants including class, family, species, and even between varieties and cultivars. Scientific studies suggest that plants genetically control nutrient uptake and content. Different taxa of plants grown in identical media can and do differ greatly in quantitative and qualitative elemental content.

Plants exert genetic control biochemically, by changing internal processes involved in nutrition, and physiologically, by changing their micro- or macro-structure. Because plants are immobile and must adapt to their environment to survive, soils have the greatest impact on nutrient uptake and availability. Consequently, roots are found to be the key site of genetic differences, seen as changes in root metabolic processes or root structure.

Aspects of plant nutrition that may be genetically controlled include absorption, translocation, and utilization or storage of nutrients. Some species or groups of plants do not translocate nutrients, but rather absorb and store certain nutrients at high enough levels that these levels would be toxic to many other plant groups. Some plants may selectively exclude certain nutrients. Halophytes are a group of plants capable of growing in high salt environments because of their ability to either store (i.e., sequester the Na internally) or exclude Na from being absorbed. Many grasses in the Gramineae family (Poaceae) have easily adapted to soils high in metals such as Zn, Cu, Pb, Cr, and Ni. In certain instances, plants may actually adapt going beyond tolerance to actually develop a dependency or requirement for an otherwise toxic level of a nutrient or a harmful nutrient. Plants with an enhanced ability to adapt to changing nutrient soil status may become more important as contamination (such as by heavy metals) and over-fertilization increase elemental levels and nutrient imbalances in soils.

Many of the genetic differences in elemental content between groups of plants have been discovered through research and routine laboratory analyses. Examples of these differences by taxonomic group are given in the following sections. Genetic differences in plant response, both metabolic and physiological, are also discussed in more detail for those nutrients where research has identified as being required in different amounts.

Differences in Elemental Content between Taxonomic Categories

Differences at the Class Level

Subclass Dicotyledonae plants tend to contain more Ca, Mg, and B than do the Monocotyledonae. The relationship, however, is not absolute. Some dicots, such as cabbage, cotton, cucumber and gypsophila contain 3%-4% Ca (dry weight) in healthy mature leaves. Others, such as false aralia, gardenia, geranium, *Ficus* species, jasmine, poinsettia may have less than 0.75% Ca. A similar situation exists with Mg. Many dicots, such as cabbage, collard, cotton, pecan, sugar beet, tobacco, tomato and turnip contain 0.5%-1.0% Mg in mature healthy leaves. However, the concentration in the leaves of some healthy dicots, such as apple, asparagus and some clovers is closer to 0.2%, a value obtained by some monocots, such as corn, bahiagrass, fescue and St. Augustine grass.

Differences at the Family Level

As might be expected, even closer nutrient relationships are found among members of the same family. Relatively high N (> 3.0% of dry weight) is present in mature healthy leaves of Acanthaceae *(Fittonia, Calathea* and *Zebrina),* Araceae *(Aglaonema, Dieffenbachia, Philodendron, Monstera, Spathiphyllum* and *Syngonium),* Begoniaceae (Rieger and waxleaf types), Compositae *(Aster, Chrysanthemum, Cosmos, Gerbera* and *Lactuca),* Cruciferae (broccoli, brussel sprouts, cabbage, cauliflower, kale and watercress), Cucurbitaceae (cucumbers, melons and squash), Gramineae (Bermudagrass, corn and rice), Leguminosae (alfalfa, clover, English pea, peanut, snap bean and soybean), Malvaceae (cotton and *Hibiscus),* Solanaceae (eggplant, pepper, tobacco and tomato), and *Umbelliferae* (carrot and celery). Much lower levels of N (< 1.5%) are present in leaves of Araucariaceae (Bunya-bunya pine and Norfolk Island pine), Anacardiaceae (mango), Bromeliaceae *(Aechmea* and pineapple), Lauraceae (avocado), and Moraceae *(Ficus benjamina, F. elastica, F. nitida* and the common fig). Whereas the elevated N content of Leguminosae leaves is partially dependent upon N-fixing bacteria, N in the leaves of the other families is related entirely to available substrate N. The families Amaranthaceae, Chenopodiaceae, Cruciferae, Compositae, Gramineae and Solanaceae tend to accumulate NO_3-N in the leaf tissue.

The percentage of K in mature healthy leaves of many plant families is about equal to or is greater than that for total N. Notable exceptions occur when the percentage of K is appreciably less than the percentage of N, as was found in mature healthy leaves of Begoniaceae, Euphorbiaceae (poinsettia and tung-oil tree), Gramineae, Leguminosae, and Scrophulariaceae (snapdragon). Plants that have relatively high N and K in their leaves will usually have elevated P (> 0.25%) contents, which may reflect fertilizer practices to some extent. Families that normally have low P percentages (0.15% or less) in their leaves include Anacardiaceae, Aquifoliaceae (holly), Betulaceae (filberts), Ericaceae (blueberry and cranberry), Euphorbiaceae, Lauraceae, Moraceae, Oleaceae (olive), Rosaceae (almond, apple, cherry, pear and plum), Rubiaceae (coffee) and Rutaceae (orange, lemon, lime and grapefruit).

Several members of Cruciferae are noted for their elevated S contents (>0.5% S in mature leaves), but members of Begoniaceae, Cucurbitaceae, Solanaceae and Umbelliferae may have as much or more. On the other hand, many of the Gramineae family will have S contents of about 0.15% or less in the mature leaves of healthy plants.

Calcium percentages vary considerably in mature healthy leaves of different families. They are relatively high (> 2.5% Ca) in Cucurbitaceae, Rutaceae, Polypodiaceae (Boston, leatherleaf and maidenhair ferns) and Solanaceae. Percentages of Ca are intermediate (1.0%-2.5%) in Leguminosae and Rosaceae and less than 1.0% in Aquifoliaceae, Bromeliaceae, Byttneriaceae (cacao), Ericaceae, Graminae, and Pinaceae (jack, loblolly, lodgepole and red pines; Douglas fir; western hemlock and black, red and white spruce).

Magnesium tends to be low (< 0.2% dry matter) in mature healthy leaves of Araucariaceae, Gramineae, Iridaceae (gladioli), and Oleaceae (olives). The nutrient usually exceeds 0.3% of the dry matter in leaves of Compositae, Cruciferae, Cucurbitaceae, Malvaceae, Rosaceae, Solanaceae and Umbelliferae.

Boron is found in concentrations of about 25-50 ppm in mature healthy leaves of Aceraceae (maple), Chepodiaceae (beet), Compositae, Cruciferae, Fagaceae (beech) and Geraniaceae, but is appreciably lower (15 ppm or less) in Agavaceae (sisal) and Gramineae.

Molybdenum is usually present in large amounts (> 2.0 ppm) in leaves of Leguminosae (not *Lespedeza,* though) and Malvaceae, but is less than 0.5 ppm in Ericaceae.

Although there are similarities in the elemental composition of the different plant subclasses and families, differences in nutrient composition are more common. Differences exist between members of related species and have been noted even in closely related cultivars or genotypes.

Differences at the Species Level

Variations in the composition of Mn and Mo have been noted for different species of tropical grasses and legumes; of Zn in different vegetable species; of N, P, K, Ca, Mg and S in grain and grass species; and of most nutrient elements in different species of wild plants. The rather wide differences in composition between different species would make the value of certain pasture mixture analyses questionable. Analyses of different alfalfa/orchardgrass mixtures have been found to show no significant differences in their S or Cu contents. However, the analyses indicated that the percentages of N, P, Ca, Mg, Na, Al, B, Ba and Zn were highest in pure alfalfa herbage and decreased as the percentage of orchardgrass in the sample increased.

Differences at the Variety or Cultivar Level

Variation in the content of a single nutrient has been noted for different cultivars. For example, the content of Al varies in corn; B in apple, beet, grape, pear, sunflower and tomato; Ca in barley, brussels sprouts, cabbage, cauliflower, citrus, clover, corn, fescue, lettuce, lupine, peanut, ryegrass, strawberry and tomato; Cu in wheat; Fe in corn and soybean; Mg in celery, corn, hops, sunflower and several grasses and legumes; Mn in cotton and soybean; Mo in cauliflower, citrus, lettuce, and pasture grasses and legumes; N in rice; and NO_3-N in radish and spinach. A number of nutrients (both macro- and micronutrients) simultaneously can be present in different concentrations in related cultivars that are grown on the same substrate.

Rootstocks can affect the nutrient composition of the scion. Leaves of 'Valencia' orange grown on different rootstocks were found to contain variable amounts of N, K, B, Cl, Cu and Fe, but similar amounts of P, Mg, Na and Zn. However, under different growing conditions, the rootstock affected the concentration of B, Ca, and K, but had little effect on other nutrients.

The composition of inbred lines also can vary considerably, as has been found in corn. The full significance of variable composition among cultivars, or other closely related genotypes, is not understood at the present. Variations in the composition of very closely related plants (cultivars, inbred lines and same scions on different rootstocks) are rather small, and therefore a single set of standards is valid. However, in some cases it may be necessary to have different standards for some certain closely related plants. The variations noted have generally been limited to one or two nutrients, such as P in selected corn hybrids, Cu and Zn in different varieties of navy beans and Zn in different varieties of apples. In some cases, more extensive variations have involved several nutrients, as has been noted for varieties of apple, cotton, snap bean, and sugar cane. At present, the use of a single set of standards for similar genotypes is justified in most cases. As more data accumulates on differences of one or more nutrients within a genotype, it may be desirable to use different critical and toxicity for an increasing number of closely related plants.

II. Plant Tissue, Age and Position

The concentration of nutrients differs not only in different plants, but also in different parts of the same plant. The type of plant, physiological age of tissue, position of the tissue on the plant, available nutrients in the substrate, concentration of other nutrients, several climatic factors, and soil conditions affect the variability of nutrients observed. Of particular concern to the plant diagnostician is the fact that different organs respond differently to varying nutrient concentrations in the substrate. Analysis of the entire plant often does not show an increase in the added nutrients. In early investigations, poor sample selection—selecting the entire plant, or selected parts of plants—skewed the relationship found between plant analysis and available soil nutrients.

Leaves versus Other Tissues

The most recently matured leaf is the most suitable plant organ for routine analysis. Conducting tissue, such as stems or leaf petioles, is suitable for the determination of the soluble nutrients—NO_3, PO_4, and K—and the soluble portions of Ca, Mg, and Fe. Tissues are chosen for analysis because they respond well to nutrient levels in the substrate and they offer ease of collection and a concentration of nutrients high enough to make accurate diagnosis possible. In situations where small leaf size makes collection tedious, stems or portions of stems have been combined with leaves for the determination of total elemental content. When leaves are very large, e.g., banana, a portion of the leaf is generally selected for analysis.

The most recently developed mature leaf has been the organ of choice for most routine total analysis, but some situations require other choices. These situations are usually related to the manner in which different nutrients accumulate in or move to different tissue as their concentration varies in the substrate. At times, the choice is made for convenience in selecting specific tissue for sampling.

The metals Al, Cd, Cu, Fe, Hg, Mn, Pb, and Zn, when present at high levels in the substrate, tend to accumulate in the roots, making root analysis an accurate method of detecting toxic concentrations of these nutrients. Excess Na also tends to accumulate in root tissue. Unfortunately, collecting and cleaning soil contamination from roots is a difficult task, and therefore roots are seldom used for routine analysis.

As fruits increase in size, movement of Ca from leaves to the fruit is very restricted. As a result, leaf analysis of Ca is of limited value in diagnosing the Ca status of the fruit. Calcium analysis of the fruit flesh minus the core (e.g., apple) is a better indicator of the fruit storage potential, which is rather poor if fruit Ca is low.

An analysis of B concentration in the fruit is an excellent indicator of B levels in the tissue, but an analysis of leaves is acceptable for diagnosing B deficiency. Leaves, other than the first fully mature ones, may be better suited for diagnosing the adequacy of certain nutrients. Since B, Ca, Fe, Mn, and Zn are not readily translocated, younger leaves are more suitable for diagnosing deficiencies of these nutrients. The nutrients N, P, and K move readily from older to young tissue, making older leaves better suited for diagnosing these deficiencies. Older leaves are more suitable for diagnosing the accumulation of NO_3^- N. Boron, Cl, F, K, and Na move rapidly in the transpiration stream and are left behind at the edges and tips of the leaves as water evaporates. As the leaf ages, large quantities of these nutrients can accumulate to a level of toxicity, particularly if available amounts are high. The relatively early accumulation of large amounts of B, Cl, Fe, K, and N in older leaves makes them useful in diagnosing toxicities or imbalances of these nutrients.

The use of different leaves has been suggested for diagnosing adequate and critical levels in chrysanthemums. Upper leaves are used for evaluating N, Ca, S, Fe, and B; lower leaves for K, Mg, and Zn; upper or lower leaves for P and Mn; and middle leaves for Cu. While the use of leaves from different positions can improve diagnosis, the use of the most recent fully mature leaf has been used satisfactorily for evaluating all of the above nutrients in chrysanthemum for routine analysis. For anthuriums, the leaf subtending a developing flower and only 90% mature is the better indicator of the nutritional status of the plant. The mature leaf readily transports mobile nutrients to the developing flower and will give variable results depending on flower maturity. The outer wrapper leaves from heading plants, such as cabbage, Chinese cabbage, and lettuce are convenient indices of their nutrient status.

Leaf Parts

Nutrients are not uniformly distributed throughout the leaf blade and petiole. The leaf lamina, or blade, tends to be higher in total N, P, Ca, Mg, S, Al, B, Cu, Fe, Mn, Na, and Zn. The midrib tends to have K values higher than the blade while most of the other nutrients have values higher in the midrib than the blade. These relationships are not absolutes and may vary with the plant species, age of tissue, available nutrients in the substrate, and relative weight relationship between the midrib and lamina.

The blade and the petiole respond differently to available nutrients in the substrate, the response varying with different nutrients. Blades are preferred to petioles for evaluating the nutrient status of K, Ca, Mg, S, Na, B, Cu, Mn, Mo, and Zn, whereas petioles are better suited for evaluating NO_3-N, PO_4-P, and Cl contents.

Several nutrients tend to concentrate in the tip or outer edge of the leaf. The concentrations of N and P are higher in the tip portion of sugar-cane leaves, but the concentration of K is lower. Higher levels of B, Mn, and Si were found in corn leaf margins than in the blades. Blades and margins had higher contents of N, P, Ca, Mg, Al, Cu, Mn, Mo, Si, Sr, and Zn than did midribs. The highest B content of lemon leaves was found in the tips (upper 0.5 inch), followed by the 1.25-inch portion behind the tip, and least in the 1.25-inch base. In several plants, the B and F contents are higher in the upper one-third of the leaves and lower in the middle or lower third of the leaves. Plants grown with high concentrations of nutrients will have higher levels of B, Cl, F, K, and Na in the tips or margins of their leaves. The accumulation of these nutrients in the tip or edge of the leaf makes the selection of these leaf portions more suitable for diagnosing toxicities at times. However, separating this tissue from the rest of the leaf is time consuming and variable by sampler, and the entire leaf is generally satisfactory for revealing toxicities.

Because of the variations in elemental content between different parts of the leaf, selection of specified leaf tissue is required for accurate diagnosis. If the entire leaf is required, collection of only a section of the leaf, or leaves with only part of the petiole attached, can lead to serious errors in diagnosis. The results of such analysis will reflect the shift in composition with variable amounts of lamina and/or petiole.

Leaf Age

Concentrations of nutrients in leaves and other tissue will vary with physiological age. Other changes related to leaf age are affected by the available elemental content in the substrate and by the relative mobility of the nutrients, as well as by the accumulation of dry matter.

Generally, the concentrations of total N, P, K, S, Cu, and Zn in perennial leaves or tops of annuals decrease with the age of the tissue, whereas the concentrations of Ca, Mg, Al, B, Fe, and Mn tend to increase. Changes in composition may not be uniform throughout the growing season. Nitrate-N, relatively low in citrus leaves during the winter and early spring months, rises in the late spring to reach a maximum during the summer months and drops again in the fall. Total N, P, and K concentrations may increase at first before starting to decline. Tracking leaf N, P, K, Ca, Mg, S, B, Cu, and Zn in four legumes with an analysis performed every three days revealed that N, P, K, S, and Zn tended to decrease while Ca, Mg, and Mn increased with time. The B content increased in the early part of the season, but declined later, while Cu showed no consistent trend. The concentrations of all nutrients underwent considerable cyclic changes.

Soluble nutrients, such as NO_3-N, PO_4-P, and K, tend to change with age as the corresponding total nutrients. Soluble Mg is more apt to decline as the season advances. Changes in composition with age are not uniform in all leaf parts. For example, although N and K decreased and Ca increased in both blades and petioles of muscadine grapes as the season advanced, the concentrations of P, Mg, and Cu increased in the petioles, but decreased in the blades.

The change in concentration of total and soluble nutrients with age can be affected by the available supply of the nutrients in the substrate. In some cases, overall trends are changed or modified with different nutrient levels. For example, N levels, which normally decline with age, can be increased by the addition of N side dressings, especially the ammonium forms of N. The rise in concentration, however, is only temporary, as N content will soon begin to fall with age. Similar results have been observed for P and K, but trends in the concentrations of Mg, B, Cu, Fe, Mn, and Zn can be altered completely when nutrient levels differ in the substrate. As the plant ages, its concentrations of B, Fe, Mn, and Zn increase, but Mo decreases.

Leaf Position

The concentrations of nutrients in leaves selected from different positions of the plant usually follow the trends shown for age. Leaves from the tip of the plant of shoot, the youngest leaves, usually have higher concentrations of N, P, K, S, B, Cu, and Zn and lower levels of Ca, Mg, Al, Fe, Mn, and Na than do the basal or older leaves. These relationships do not necessarily hold for all situations; because differences in concentration, as noted for position, are a result of nutrient movement, light conditions and age. The composition of leaves from fruiting and non-fruiting guava branches were found to be quite similar to the above described trends, with leaves closer to the tips of branches being higher in N and P, but lower in Ca, Mg, Al, Fe, and Mn than were lower positioned leaves further back from the tip of the branches. The concentration of B, Cu and Zn did not change uniformly with position. Higher levels of B and Cu occurred in the tip or number one leaf and lower levels in some lower leaves. However, the concentration of these nutrients rose again for leaves closer to the base of the branch. Zinc content did not change appreciably with position, although content of this nutrient tended to rise in the lowest leaves of non-fruiting branches. Five-month-old leaves behind the fruit had less N, P, K, Zn, Cu, Fe, and B, but more Ca and Mg than had either basal or terminal leaves of the same age.

The movement of B, Ca, Mn Fe and Zn from older to younger tissues is rather limited. Nitrogen, P, K and Mg move readily to young tissue, especially if the available levels of these nutrients are low, resulting in lower concentrations of N, P, K and Mg in older or basal leaves.

Nitrogen, P, K, Mg, B, Cu, Fe, and Zn move readily from leaves to fruit, resulting in lower concentrations of these nutrients in leaves of fruiting versus non-fruiting terminals. The movement of Zn from leaves to fruit is limited, however, unless the concentration in the leaves is sufficient or higher.

Shading, which alters the amount of carbohydrates produced by the plant, will change the percentage of nutrients on a dry weight basis. Increases of N, NO_3-N, P, K, Mg, S, Fe, Mn, and Zn have been noted under low light conditions although the percentage of P may decrease with low light levels unless the substrate P is relatively high. The effects of shading on elemental leaf content may not be apparent even though leaves are collected form the basal portion of shoots or from young plants because of the limited amount of canopy present under these conditions. However, shading must be considered when older plants are analyzed, and leaf samples must be collected carefully so that the effects of shade are minimized.

III. Climate

Light

Light affects the concentration of nutrients in plants by its effect on the amount of photosynthate produced and enzyme activity, thereby altering the ratio of nutrient to dry matter concentration. The dilution effect, due to the production of carbohydrates in full light, is characterized by reduced concentration for most nutrients. Calcium concentration may increase as a response to the lower K or increased leaf temperatures resulting from the effects of higher light intensity. In most cases, the degree of reduction is dependent upon the available concentration of that nutrient in the substrate. For example, increasing light exposure reduced the N, P and K concentrations and increased the Ca concentration found in cacao leaves. In another experiment, total N in spinach leaves was reduced from about 4.8% to less than 2.0% as light increased from 600 to 2400 ft. candles with no N applied, and only from about 5.3% to 4.7% with 300 $mgkg^{-1}$ N.

The variations in nutrient concentration caused by different levels of light are also affected by the source of N and genetics. While shade increased the P, K, Al, Ca, Fe and Mn concentrations and decreased the Cu, Mg and Zn concentrations in leaves of Hawkeye soybean receiving NO_3-N, shade increased only K, Mg and Fe and decreased Cu and Zn concentrations in leaves of the same plant variety under NH_4-N nutrition. With another soybean variety, shade combined with NO_3-N nutrition increased the P, K, Al, Cu, Fe and Mn concentrations in leaves. Under NH_4-N nutrition, shade increased P in the leaf and decreased K, Al and Fe.

Variations in light particularly affect the level of NO_3-N in plants. In full light, NO_3-N is lowered by both the dilution effect from high carbohydrate production and the reduction of NO_3-N by nitrate reductase enzyme. Light does not necessarily have a negative effect on elemental concentration. Energy compounds produced through the photosynthetic process provides the energy for active elemental uptake, thus enhancing concentration. Yet this positive effect may be overridden by the growth dilution effect. High light intensity increased nitrate reductase activity and decreases NO_3-N accumulation. Nitrate reductase activity is affected by diurnal variations in light as well as by light quality. Therefore, the results of a NO_3-N test are highly influenced by the time of sample collection.

High light intensity can overcome some of the negative effects of high NaC1 salinity by helping to maintain plant cation concentrations, which may be lower under low light. The adverse effects of excess Na and low K associated with high salinity and low light have been partially corrected by high light conditions.

Disorders associated with a localized shortage of Ca, such as bitter pit in apple, tipburn in lettuce and lowering light intensity can reduce blossom-end rot in tomato. As is often the case, the effects of light are not always consistent, since light intensity interacts with temperature and other factors. The amount of carbohydrate is negatively correlated with night temperatures. Carbohydrates accumulate at low temperatures, but are rapidly dissipated at high temperatures due to accelerated respiration. The degree of change in carbohydrate content with temperature will vary with different plant species as the rate of change is genetically controlled. Since light intensity can affect the temperature, then the interaction between light and temperature can cause variable concentration effects compared to light intensity alone. The degree of this variability depends upon the concurrent temperature and the species of plant. In several perennial grasses grown under controlled conditions, the effects of temperature have been separated from the effects of light. Temperature, rather than light, has the greater effect on elemental concentration levels. Elemental concentration decreases with light at low temperatures, but increases at higher temperatures. On the other hand, Mg tends to increase with light at low temperatures but decrease at the higher temperatures, presumably because temperature influences the speed of metabolic processes in the plant thus causing the growth dilution effect. The concentrations of P, Ca and S were found to be positively related to light, although the effects of light on Ca and S were small. The K concentration, although generally increasing with light intensity, was found to decline for Dallisgrass grown at high moisture

Temperature

Increased temperature can alter elemental composition through stimulating movement, translocation, and utilization within the plant. While responses within the plant are genetically controlled, it is difficult, except under strictly controlled conditions, to separate the effects of air and substrate temperature. In the few experiments that have been conducted, researchers do not specifically differentiate between temperature and genetic effects. Although moderately high soil temperatures tend to increase available soil nutrients and their movement to the plant, the concentration within the plant itself may not be increased. Elemental concentration in the plant may actually be less at higher temperatures due to increased dry matter production and dilution of elemental uptake in the tissue. High temperatures can also accelerate respiration, thus depleting carbohydrates. In a comparison of potato plants grown at 5°C and 29°C, the P, K, Ca, Mg, Mn and Fe contents were higher in the tops of the plants when they were grown at the higher temperature. Potassium, Mg and Fe decreased in concentration in the roots at the higher temperature, while the Ca and Mg contents were at about the same concentration when grown at either 5°C or 29°C. Higher temperatures favor the accumulation of Mn in alfalfa and wheat. High temperatures reduce nitrate reductase activity, which in turn increases the NO_3-N content in plants. High temperature increases transpiration, and if temperatures are not excessively high and soil NO_3-N is not limiting, the uptake of NO_3-N will increase. The net effect is that plant NO_3-N will increase and be stored in the cell vacuoles while nitrogen incorporated into proteins and other nitrogen compounds can decline. Concomitant effects of light and moisture may mask the effects of temperature. Under controlled light conditions, N and P concentrations of several warm-season grasses were found to decrease as the temperature increased at both low and high moisture. The concentrations of Ca, Mg, and S in two *Cynodon* species were also lower as the temperature was increased. In two *Paspalum* species these nutrients, as well as K, were higher with increased temperature.

Rainfall

The effect of rainfall on plant elemental composition is dependent upon amount and duration. Rainfall that increases soil moisture by bringing the level within the beneficial range (between wilting and field capacity) tends to lower the nutrient concentration in the plant since plant growth is normally stimulated when soil moisture is readily available. The resulting increase in dry matter dilutes the elemental content in the plant even though ideal soil moisture conditions also increase nutrient availability as well as increasing the availability of nutrients,which are translocated by the additional water movement in the plant. On the other hand, excess rainfall beyond the soils capacity can cause significant leaching of NO_3. In coarse soils, the nutrients K, Mg and B are also leached. Excess rainfall in short periods of time can cause erosion on sloped soils, the lost soil carrying many nutrients but especially N, P and S. Prolonged rainfall periods produce are associated with concurrent cloudy, reduced light levels which slow plant dry matter production with an accompanying increase in the elemental content of the plant. High light levels from few or no clouds have the opposite effect on the dry matter-elemental content, as was noted above. In addition, periods of intense and/or prolonged rainfall periods, K can leach out of leaves, thereby reducing its concentration.

Periodic (every three days) analyses of peanut, green bean, lima bean and southern pea plants for their N, P, K, S, Ca, Mg, B, Cu, Mn, and Zn contents showed that only the nutrients, B and K, were affected by light rainfall or overhead irrigation. Boron concentration increased and K decreased during dry periods.

Air Humidity

Air humidity affects the rate of transpiration and thus indirectly the elemental content of plants. Boron, Cl, F, K, and Na, which move readily in the xylem, can be expected to increase in the upper portions of the plant and at the outer edges of leaves as the transpiration stream evaporates, leaving these nutrients behind. In fact, the B content of tobacco leaves has been found to be two times as high when plants were grown at 45% relative humidity as it when the plants were grown at 95%. So dependent is the movement of B and Ca on transpiration that deficiencies of these nutrients have been noted during periods of high relative humidity, when sufficient quantities of B or Ca do not reach the leaf tips. Asparagus tip deterioration due to Ca deficiency has been identified with high relative humidity periods (and resulting reduced transpiration). High humidity, however, is considered to be the cause of lowered NO_3-N concentration in 'Hamlin' orange leaves in midsummer, a time when leaves from drier climates contain maximum NO_3-N.

Low relative humidity (vapor deficits above 14-15 mm Hg) induces blossom-end rot of tomato, a disorder frequently considered to be a Ca deficiency. Excess transpiration brought about by low humidity and/or high temperature has also been noted to increase the occurrence of blossom-end rot in tomato. This Ca related physiological disorder can occur as upward water flow, arising from positive root pressure, transports Ca into unemerged leaves and developing fruit when humidity is high at night experiences a break in the water column supporting transpiration in the plant. Positive root pressure is required to reconnects the water column in the plant. If growth of the plant and fruit continues during this disconnect of the water column then a calcium related fruit disorder would occur as well as tip and marginal necrosis of the leaf tissue.

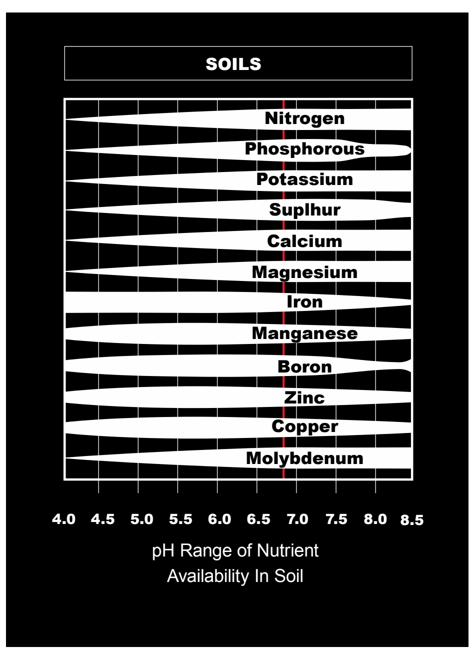
IV. Soil Properties

Soil pH

The pH of the soil/rhizosphere influences plant nutrient concentration by affecting the availability of nutrients. Low soil pH, for example, will increase the availability of Al, B, Cu, Fe, Mn and Zn, but decrease Mo. The concentrations of Cu, Fe, Mn and Zn in soybean tops were found to be negatively correlated (r = -0.78, -0.63, -0.87, respectively) with soil pH as the pH increases from 5.1 to 6.47.

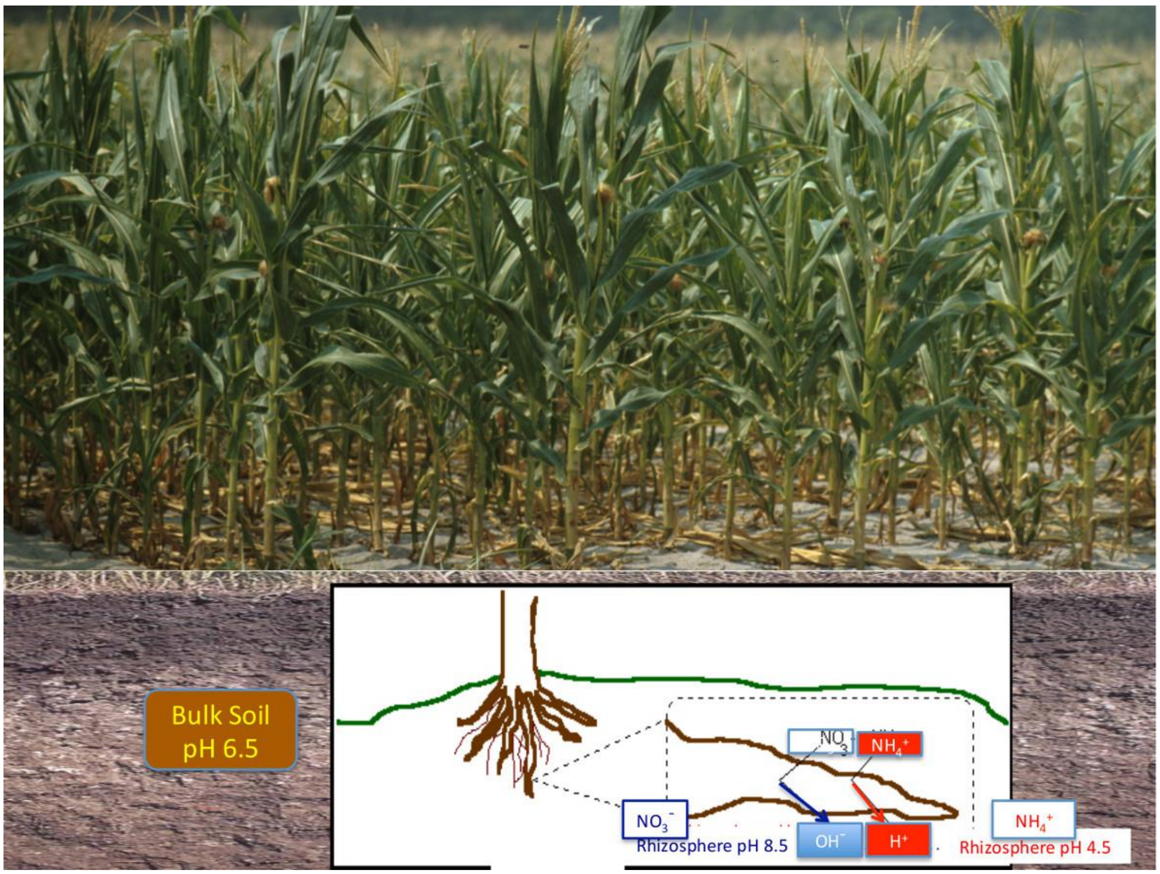
Acidic soils have higher levels of soluble Al and Fe, and these soils are usually associated with a reduced availability of P. The availability of P is also decreased as the pH rises above 7.0, but this decrease is associated with the interaction of P with increased levels of available Ca and Mg at higher pH's and the formation of Ca and Mg phosphates.

Figure 3.1. Influence of rhizosphere pH on nutrient availability for absorption by plant roots.



Though N is absorbed at all pH levels, ammoniacal-N is absorbed best at a pH that approximates 7.0, and its absorption is reduced as the pH becomes acidic. On the other hand, NO_3-N is absorbed better at an acidic pH. In addition, the use of ammoniacal-N fertilizers will normally reduce the soil/rhizosphere pH, while nitrate-N as the primary N source will increase the soil/rhizosphere pH (Figure 3-2 and 3-4).

Figure 3.2. Influence of N-form absorbed by plant root on rhizosphere pH.



Ammonium absorption can result in a drop in the rhizosphere pH two full units less than the surrounding bulk soil in the rhizosphere while nitrate can increase the rhizosphere pH two-pH units higher than the surrounding bulk soil pH. This effect of N-form on rhizosphere pH is most evident at the rhizoplane (root surface) where nutrients come into contact with the plant roots for absorption into the plant. In addition, some plant species can markedly lower the rhizosphere pH by producing organic acids, thereby increasing the availability of some nutrients, including Fe. Plants that are considered Fe-efficient are very effective in reducing the pH of the rhizosphere even in soils that are strongly alkaline.

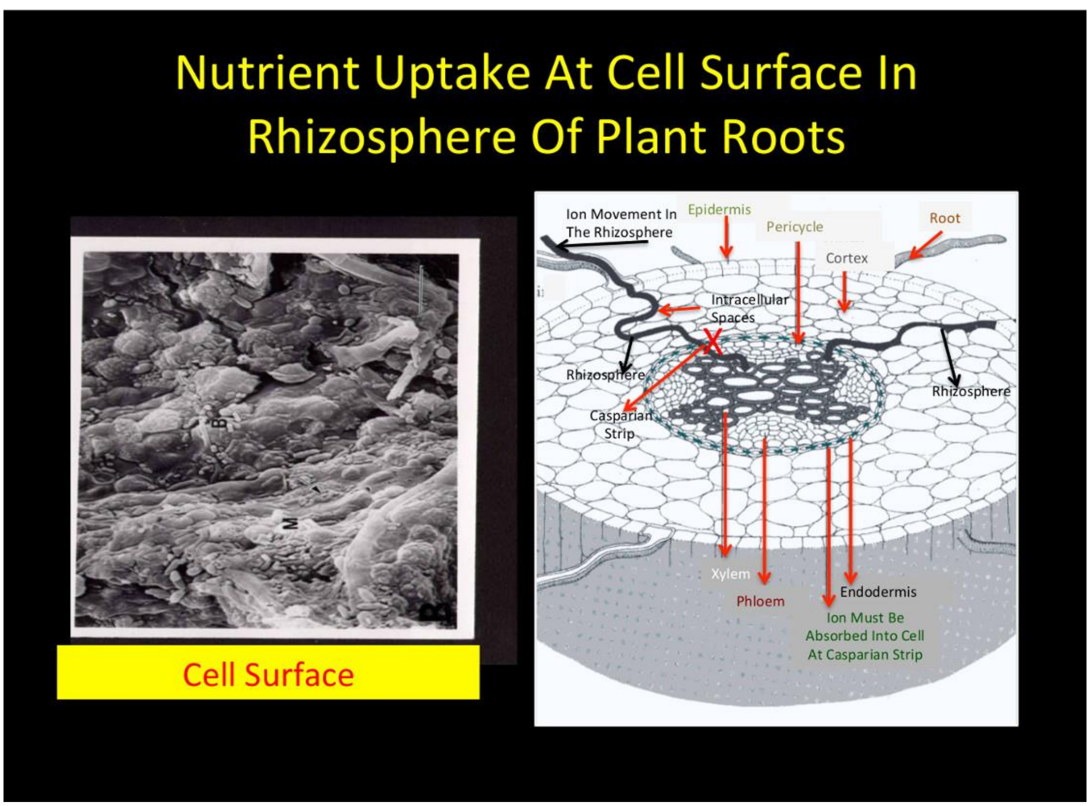
Fixation of gaseous N_2 by the free-living bacteria, primarily *Azotobacter,* occurs at a pH above 6.0, but the fixation capability is limited if the pH rises above 8.0. Fixation of gaseous N_2 by symbiotic organisms, primarily *Rhizobia,* occurs most readily when the pH ranges from 6.0 and 7.0, although a few species can function well at a pH near 4.5.

Soil pH affects the loss of N as ammonia gas (NH_3) from the soil. Free ammonia, which can volatilize from the soil, may be formed from ammonium salts and urea at pH levels of 7.2 or above. Nitrogen loss is partly related to the cation exchange capacity (CEC) of the soil, as a high CEC can absorb and hold the NH_4^+ cation. Losses of N as gaseous dinitrogen (N_2), or as one of the oxides of N (N_2O or NO), can take place in normal soils as well as water-logged soils at pH levels that range between 4.0 to 10.0. Losses are highest when the pH level ranges between 7.0 to 7.5 due to the greater microbial activity within this pH range.

Rhizosphere pH

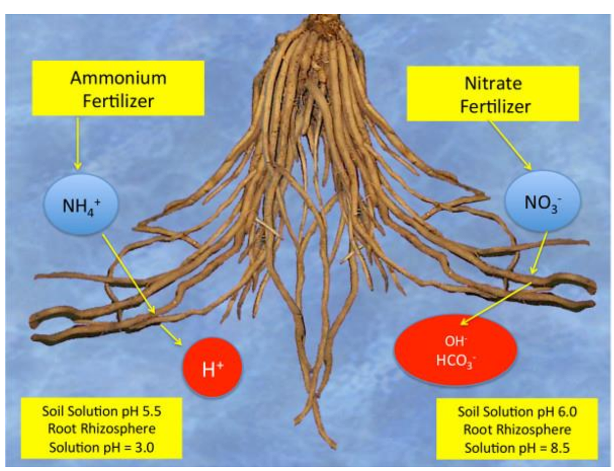
Determination of soil nutrient levels is important to know the level of nutrients that can contribute to the nutrition of the plant. No nutrient from the soil is absorbed into a plant without passing through the rhizosphere area of the root. The area of the root that comprises the rhizosphere is the area outside the root in a 1-2 mm distance from the surface and the intracellular spaces inside the root prior to an ion being absorbed into the root cell. Intracellular spaces in the root can exist up to the Casparian Strip which blocks the movement of an ion from entering the plant until absorbed into a root cell. The rhizosphere is the area in the root that is most influenced by pH and nutrient availability for absorption into the plant cells.

Figure 3-3. Rhizosphere area in roots is where nutrients are absorbed into root cells and then transported to sites of use in the plant.



The influence of plant roots on soil pH is an integral component that contributes to a frequent poor correlation between nutrient availability in soils and actual nutrient uptake by plants. Although the chemical properties of the bulk soil, such as pH, are very important for root growth and mineral nutrient availability, the conditions in the rhizosphere and the extent to which roots can modify them are decisive in mineral nutrient uptake The rhizosphere conditions, are correlated to the root surface area or "spatial availability". The thickness of the rhizosphere around plant roots varies from 0.1 to 2.0 mm depending on the length and abundance of root hairs. The pH of the rhizosphere soil may differ from that in the bulk soil by more than two units. The direction (increasing or decreasing) of pH changes in the rhizosphere is determined by plant factors, whereas the degree of pH changes and their extension from the root surface toward the bulk soil are determined by both plant and soil factors. The important soil factors are the initial bulk soil pH and the pH buffering capacity. Because in most soils the pH buffer capacity is lowest at about pH 5, the root induced pH changes in the rhizosphere are maximal at bulk soil pH between 5 and 6 and decrease in magnitude at either lower or higher bulk soil pH. The plant factors that are responsible for changing rhizosphere pH are excretion or reabsorption of H^+ or HCO_3^-, evolution of CO_2 by root respiration (reacting with water to form HCO_3^- in the soil), and release of low molecular weight root exudates (e.g., organic acids and amino acids). Microbial production of organic acids and CO_2 released from root organic carbon release also contribute to the changes in rhizosphere pH. In aerated soils, CO_2 is presumably of minor importance for changes in rhizosphere pH, since it rapidly diffuses away from the roots through pore space. Major changes in the rhizosphere induced by root exudates are more the exception then the rule. Changes in rhizosphere pH are brought about primarily by differences in net excretion of H^+ (or of HCO_3^- and OH^-) due to an imbalance between cation and anion uptake, thus the differing effect of the uptake of NH_4-N and NO_3-N on rhizosphere pH.

Figure 3.4. Effect of N-Form applied as a fertilizer on rhizosphere pH of the soil solution around the root.



Nitrogen Form

The form of nitrogen taken up by plants has the most prominent influence on rhizosphere pH (Marschner and Romheld, 1983) Nitrate supply, particularly in combination with available calcium (Ca^{+2}), is correlated with lower rates of H^+ net excretion (and with relatively higher rates of HCO_3^- or OH^- release) resulting in higher pH. Conversely, ammonium supply, or N_2 fixation by legumes or nonlegumes (e.g., Alnus and Casuarina), is correlated with higher rates of H^+ secretion, and for the average root systems, with rhizosphere acidification. Romheld. (1984) showed that compared with bulk soil pH, the rhizosphere of uninoculated soybean (*Glycine max L.*) was much lower when fertilized with an ammonium nitrogen fertilizer ($[NH_4]_2SO_4$). Conversely, with uninoculated soybean fertilized with nitrate nitrogen ($Ca[NO_3]_2$), rhizosphere pH was lowered only slightly in apical root zones but was significantly increased in basal root zones. The rhizosphere of soybean plants inoculated with Rhizobium without applied N is between that of the two forms of mineral nitrogen. A common thread between all three treatments was a higher pH in the basal region of the plant roots in comparison to apical regions. Changes in rhizosphere pH are readily demonstrated by either infiltration or covering the root-soil interface with agar containing a pH indicator like bromocresol purple (Marschner and Romheld, 1983; Romheld, 1986) or by use of antimony microelectrodes.

Solubility, concentration in the soil solution, ionic form, mobility, and thus availability of micronutrients for uptake by plant roots are strongly affected by the soil pH. As pH decreases, the availability of zinc, manganese, and to a lesser degree, iron, increases, whereas molybdenum availability decreases. For copper, which is predominately bound to organic matter both in the solid phase and in solution (complexed), no clear relationship exists between soil pH and solubility (Sanders, 1982; Jefferey and Uren, 1983).

Considering the important role of soil pH in micronutrient solubility and availability, the nitrogen form applied can markedly affect the uptake of micronutrients in soil-grown plants. Thomson et al. (1993) found fertilization of bean plants (*Phaseolus vulgaris L.*) with calcium nitrate resulted in less plant uptake of Fe, Mn, Zn, and Cu, when compared to fertilization with ammonium sulfate used with a nitrification inhibitor. Availability of boron is also affected by rhizosphere pH. Adsorption of borate on various aluminum and iron oxide minerals is strongly pH dependent with a maximum adsorption, and thus unavailable to the plant, in the soil pH range 7-8 (Goldberg and Glaubig, 1985). Accordingly, in a soil with pH around 7, the form of nitrogen fertilizer can considerably affect the concentration of boron in plants. Reynolds et al. (1987), found the boron concentrations in dry weights of leaves (young and old) and stems was significantly higher in cauliflower (*Brassica oleracea* var. *botrytis*) fertilized with ammonium sulfate (used with the nitrification inhibitor nitrapyrin) than those fertilized with calcium nitrate. These increases in boron concentrations of plants supplied with ammonium may also be the result of a shift in the boron ion species in the rhizosphere solution in favor of boric acid, which is taken up more readily than the borate ion (Oertli and Grgurevic, 1975).

According to the soil chemistry of molybdenum, its availability to plants should decrease with rhizosphere acidification, especially below pH 6, owing to its adsorption of molybdate on sesquioxide surfaces. In agreement with this, ammonium supply decreased and nitrate supply increased the molybdenum concentrations in cauliflower plants grown in sandy loam soil with bulk soil pH of 6 (Trobisch, 1966).

Nutritional Status of Plants

Root-induced changes in the rhizosphere are important factors for adaptation of plants to adverse chemical soil conditions (Marshner, 1995). Quite often suboptimal or deficient levels of a given mineral nutrient induce these changes. A decrease in rhizosphere pH can be observed, even with nitrate supply, in response to phosphorus deficiency in rape (*Brassica napus L.*; Hoffland et al., 1989) and in tomato (*Lycopersicon esculentum* Mill. Heuwinkel et al., 1992), for cotton (*Gossypium hirsutum L.*) to zinc deficiency (Marschner et al., 1987a), and for nongraminaceous species to iron deficiency (Brown, 1978; Romheld, 1987a; 1987b). With the exception of rape, enhanced net excretion of H^+ due to a rise in the cation/anion uptake ratio was responsible for the rhizosphere acidification. Under zinc deficiency, rhizosphere acidification only occurs when the deficiency becomes severe (Cakmak and Marschner, 1990), and thus the ecological relevance of this acidification for zinc mobilization is questionable. Conversely, the iron deficiency-induced acidification is part of a coordinated system of root responses in dicots and nongraminaceous monocots, and is confined to apical root zones (Marschner et al., 1986a; 1987b). Often this acidification is combined with the formation of rhizodermal transfer cells in iron-deficient roots (Romheld and Kramer, 1983). However, transfer cell formation is presumably not a prerequisite for the iron deficiency-induced acidification (Schmidt and Bartels, 1995). Compared with the ammonium nitrogen form related H^+ excretion, the rate of iron deficiency-induced H^+ excretion in apical root zones is much higher. The rate of H^+ excretion will facilitate the iron deficiency-induced plasma membrane-bound reductase activity and the release of reductants and chelators. Even in well-buffered calcareous soils, such a localized decrease in rhizosphere pH may be an effective mechanism for mobilization of sparingly soluble iron compounds. Deficiencies of certain mineral nutrients not only induce H^+ excretion but also increase amounts of certain constituents of root exudates in particular.

Root Exudates

Roots release considerable amounts of organic carbon into the rhizosphere. The amount, expressed as a fraction of the total dry matter production, varies over a wide range from only a few percent to 40% (Lynch and Whipps, 1990). Various forms of stress increase the amount released. These stresses include potassium and phosphate deficiency (Trolldenier and Rheinbaben, 1981; Lipton et al., 1987), drought stress, anaerobiosis (Lynch and Whipps, 1990) and mechanical impedance (D'Arcy, 1982). Both the amounts and the proportion of the various constituents of root exudates vary considerably. Schonwitz and Ziegler (1982), found mechanical impedance increases root exudation of sugars and vitamins by a factor of 3, while D'Arcy (1982) found mechanical impedance increased the exudation of phenolics by a factor of 10. Deficiencies of potassium have been shown to increase the content of organic acids in root exudates (Kraffczyk, et al., 1984), and phosphorous deficiencies lead to an increase in both amino and organic acids of exudates (Graham et al., 1981; Lipton et al., 1987). Phosphorous deficiency-induced increase in citric acid exudation in white lupin (*Lupinus albus L.*), which may reach up to 23% of the total dry weight of plants growing on a phosphorous deficient calcareous soil (Dinkelaker et al., 1989), has considerable effects on the mobilization of micronutrients in the rhizosphere. Thus in white lupin and other cluster-rooted plants, the application of phosphorous fertilizer may suppress the formation of cluster-roots and the excretion of organic acids and simultaneously induce iron deficiency chlorosis (Handrek, 1991; 1992). Root exudates, namely malic acid and phenolics, also dissolve MnO_2 by reduction (Dinkelaker et al., 1995). The rate of MnO_2 reduction by root exudates steeply decreases with increasing substrate pH from 5 to 6. Godo and Reisenauer (1980), found the dissolution of MnO_2 by root exudates increased as pH decreased, and that extractable Mn (via 0.01 M $CaCl_2$) in the rhizosphere was nearly twice that found in the bulk soil.

Carbon Dioxide Production

CO_2 is liberated at the root surface by respiration, and this has often been assumed to have a local acidifying effect. With the exception of water-saturated soils, CO_2 will readily diffuse from the root, and its acidifying effect will not be limited to the immediate rhizosphere but over the whole bulk soil. Nye (1981) calculated that the difference in pressure of CO_2 between the soil at the root surface and the neighboring bulk soil under typical aeration conditions is only 2 x 10^{-6} atm, and its corresponding effect on equilibrium pH is negligible.

Influence of Plant Species

Considerable differences exist between the effect of various plant species on rhizosphere pH in a given soil and even with the same form of nitrogen supply. Smiley (1974), found that eight species of cultivated plants grown for five weeks in a lime-amended fertilized loam soil all induced similar reductions of the rhizosphere pH (0.8 to 1.2 units) with ammonium treatment.

Moisture above field capacity can have negative effects upon concentration by markedly affecting the leaching of nutrients and the availability of nutrients that are dependent on microorganisms. Nitrogen is the nutrient most commonly impacted adversely by short-term moisture excess, primarily from nitrate leaching. In coarse soils, leaching can also seriously deplete K and Mg. Phosphorus and S derived from organic matter decomposition can also be reduced by excess moisture. The reduced oxygen tension resulting from excess moisture tends to have a negative effect upon the absorption of most nutrients, but a few nutrients are increased. In soils rich in native P, available P is increased; Fe and Mn are increased in wet soils. Although Fe availability is increased, the increase is usually not enough to prevent Fe deficiency, which occurs frequently in moist soils. Interacting with the excess P evidently induces the deficiency.

The Fe deficiency is aggravated by the presence of large amounts of bicarbonates. Total Fe in the leaves of deficient plants may be in the normally adequate range, but soluble Fe (2% acetic acid or ortho-phenanthroline soluble) is low. The excess Mn in wet soils is associated with higher levels of Mn in plant leaves. Often these levels are high enough to cause toxicity symptoms of Mn which tends to induce Fe deficiency by altering the Fe:Mn ratio. Extend periods of excessive moisture may cause some similar effects as flooding where the soil is effectively under water. While many of the same processes of short-term excessive moisture occur, the continued exclusion of oxygen from the soil results in losses of nutrients by additional processes. For example, short-term excess moisture will cause NO_3-N leaching, while continued excess moisture promotes denitrification and thus losses of nitrogen in various gaseous nitrogen oxide forms. Also, being deprived of oxygen, much of the Fe in the soil becomes reduced and becomes available for uptake by the plant and for reaction with other nutrients. Since S can combine with reduced Fe, available S becomes less available, and with continued excessive moisture in the soil, S levels will drop in the tissue. Extremely high Fe concentrations in tissue, especially if accompanied by lower than normal S concentrations are indicators of extended periods for the crop. When examining tissue test results from fields in the Midwest with extended excessive moisture, but not actual flooding, it was found that the wettest fields could be identified solely by looking at Fe and S concentrations, where in soybeans and corn, Fe would even exceed 4,000 $mgkg^{-1}$ (ppm) and S drop to <10 $mgkg^{-1}$ (ppm). As the fields began to dry, the Fe and S levels would slowly return to more normal levels (author personal observation).

Flooding, which is where water actually covers the soil for a length of time, was found to increase the concentrations of P, Mn and Al, but it decreased the levels of K, Mg and Ca in annual ryegrass leaves. The change in the concentration of these nutrients varied with different cultivars. Flooding of Florida Everglade muck soil (pH 6.5) increases the available Mn and quickly corrects a Mn deficiency in rice. A similar response can be obtained by spraying the leaves with Mn, or drilling about 44.6 $kgha^{-1}$ (50 lbs/ac) $MnSO_4$ with the seed.

Continuous flooding resulted in higher levels of Fe and Mn in rice tops as compared to plants grown with alternate flooding (four days of flooding followed by a dry period allowing the soil to reach a moisture tension of 0-750 kPa), or plants grown with irrigation to maintain a tension of 30 kPa. The higher levels of Fe and Mn were associated with lower levels of Zn. The overall effects were attributed to redox potentials (causing a reduction of Fe and Mn) and pH levels. The pH of continuously flooded soil dropped from 8.2 to about 7.0, but the pH of the soil alternately flooded ranged between 7.5 to 8.0.

Oxygen Tension

The effects of reduced oxygen tension due to excess soil water were discussed previously. In modern farming practices, the effects of reduced oxygen resulting from soil compaction from heavy farm machinery, low soil organic matter content or working soils when wet may equal that of excess moisture. Some of the effects on composition resulting from compaction and poor soil structure are quite similar to the effects of excess moisture. But the effects may differ due to the severity and length of time of the various conditions. While excess moisture may shut off gaseous exchange almost entirely, poor soil structure may still allow variable amounts of exchange. However, poor soil structure may also cause poor root development and slow movement of moisture in soils. Some of these handicaps can be partially overcome by adding small doses of moisture and limiting nutrients (e.g., Fe and Mn) through drip irrigation or by foliar feeding of the limiting nutrients. The effects of these physical factors on plant nutrient concentrations will vary not only with soil and plant, but also with cultural practices.

Leaf concentrations of P, K, Ca, Mg, B, Fe, and Mn in sweet orange seedlings were reduced at oxygen diffusion rates below 33×10^{-8} g/cm^2/min, as compared with plants grown with diffusion rates above 62×10^{-8} g/cm^2/min. Leaf Cl was maximum at oxygen diffusion rates less than 22×10^{-8} g/cm^2/min and minimum at diffusion rates about 30×10^{-8} g/cm^2/min. The P concentrations of corn shoots decrease from 0.59% to 0.33% as the bulk density of a loamy sand increased from 1.3 g/cm^3 to 1.9 g/cm^3. The P decrease was 0.55% to 0.34% as the bulk density of a silt clay soil increased from 1.10 to 1.50 g/cm^3.

Temperature

It is well established that temperature is a key factor controlling the rate of decomposition of plant residue. The cyclic release of essential plant nutrients from organic matter (mainly crop residues) as it decomposes, and the subsequence fixation or transformations of these nutrients are affected by microbial activity. Microbes involved in organic matter decomposition are temperature dependent. The solution of nutrients and their subsequent movement by mass action and diffusion are also regulated by temperature. All of these processes are enhanced as temperature increases up to the limits of each reaction or biological process.

Increasing root temperature increased anion concentration in strawberry leaves, but decreased it in the roots of ammonium-N fed plants. However, the increased root temperature decreased total cation concentration (especially that of K^+, Na^+, and Mg^{+2}), and increased Ca^{+2} in the roots of nitrate-N fed plants. The ammonium ion is more readily absorbed than is the nitrate ion at low temperatures. Increasing root temperatures from 10°C to 25°C increased nitrate-N, Cl and K absorption, but decreased P and had no appreciable effect on S, Ca, Mg, or Na. Increasing root temperature from 10°C to 20°C tended to increase concentrations of K, Mg, and Cu in leaf lettuce. With the exception of Ca, the mineral content of barley tops was higher at root temperatures of 20°C than at 10°C. Increasing the Zn supply greatly reduced P uptake at 20°C, but root temperature had no effect at 10°C.

Low soil temperatures have often been associated with lower concentrations of P, Fe and Zn in a number of plants. The effects on P or Zn concentrations appear to be related to the amounts of available P or Zn (in addition to high levels of either nutrient suppressing uptake of the other), with low soil temperature reducing plant concentrations.

V. Soil Amendments

Liming Materials

pH

The addition of limiting materials increases pH and tends to increase plant concentrations of Ca, Mg (if lime is dolomitic) and Mo, while concentrations of Al, B, Fe, Mn, Na and Zn are decreased. Aluminum and Mn are decreased much more in the roots than in the tops. In some cases, Mn will increase in the roots as it is decreased in the tops. Decreases in Cu tend to be small. The effects on N, P and K vary, depending upon original soil pH as well as on soil and plant characteristics. Generally, liming reduces the concentrations of these nutrients since the extra growth usually obtained dilutes the plant concentration. The large increase in N fixation by legumes sensitive to low pH usually overcomes the dilution effect due to liming, and plant N concentration increases. Some increases in P concentration occur as liming materials are added to soils high in available Al, with P increases more likely to occur as the pH is increased from approximately 4.0 to 5.5. Liming tends to decrease K concentration due to plant growth dilution effects and antagonism from higher available Ca. Potassium concentration may increase if the soil contains considerable K that can be displaced on exchange sites by the large amounts of added Ca.

The effect of liming on plant composition appears to be dependent on the degree of base saturation. Liming to a saturation level of only 40% actually was found to increase the Al, Mn and Zn content in alfalfa grown on seven soils. Increasing the liming saturation levels to 70% or 100% resulted in lower levels of these nutrients in alfalfa grown on six of the seven soils in the experiment. However, plant Al concentration failed to change on one soil despite base saturation.

Calcium and Magnesium

A high Ca-content liming material, such as calcitic limestone, affects plant concentration differently than does dolomitic limestone. Calcittc limestone, or “white lime”, results in higher levels of Ca but lower levels of Mg. Dolomitic limestone, commonly called “red lime”, which contains Mg results in appreciably higher values for Mg. Calcium concentration still tends to increase with the addition of the dolomite, but at a much lower rate. The dolomite containing both Ca and Mg appears to have a greater depressing effect on K than do the high Ca-containing liming materials.

Some differences in plant composition noted with the use of high Ca versus dolomite limestone are related to differences in pH obtained with the different materials. Finely ground dolomite will increase soil pH as well as the calcitic limestone, but coarse dolomite dissolves much more slowly than does high Ca containing liming materials.

Artificial Potting Mixes

A number of components can be used to formulate artificial potting mixes. Sphagnum peat, hypnum peat, reed and sedge peat, peat humus, pine bark, hardwood bark, redwood bark, ashed bark, cypress mulch, aged sawdust, wood fiber, perlite, vermiculite, zeolite, hydatite, calcined clay, polystyrene beads, rockwool, peanut hulls, coir (coconut pith), composted yard waste and sand have been used to produce artificial potting soils in the United States. Various peats, perlite, vermiculite, soft and hard wood bark, ashed bark and polystyrene are the primary components used to produce growing mixes for commercial greenhouse production. Bark and sand mixes predominate the nursery industry.

Nutrition in Artificial Mixes

The primary role of an artificial mix is to provide a growth matrix that holds water, air and a means of mechanical support. Most of the components used to produce commercial artificial mixes provide insignificant levels of plant nutrients when pH values are greater than 5.5. Therefore, growers must provide all of the essential plant nutrients in their fertility program. Many commercial growing mixes have been supplemented with dolomitic limestone, gypsum and a dilute starter nutrient mix. In most cases the starter nutrients last only a few weeks at best. Limestone and gypsum may supply sufficient Ca, Mg and S for short-term crops, but supplemental Ca, Mg and S will be required with container crops in production cycles greater than 4-6 weeks.

N-Form:Most greenhouse plants cannot efficiently use high rates of NH_4-N under low light conditions. Ammonium nutrition consumes carbohydrates during assimilation. Under low light conditions, high NH_4-N nutrition may result in carbohydrate depletion reducing available energy for nutrient uptake and growth. Many commercial greenhouse fertilizers contain a minimum of 50% of the N as NO_3-N. The use of 70-80% of the N as NO_3-N may be more appropriate during extended periods of low-light growth. Unfortunately, water quality and pH management issues may preclude use of NO_3-N levels that would otherwise be considered optimum. In many situations, growers can rotate high analysis NO_3-N fertilizers with a complete N-P-K fertilizer to obtain excellent results.

Bark and Nutrition in Artificial Mixes:'Bark' is a generic term and in artificial mixes `bark' may include inner and outer bark, corky tissue, cambium and a small percentage of wood. The actual composition of 'bark' depends upon the tree debarking methods and processing technology. Softwood and hardwood bark are extensively used in artificial mixes and each have distinct characteristics. The two major nutritional problems for crops grown with bark are:

- Nitrogen deficiency, induced either by biological immobilization or the chemical and physical fixation of N by the bark particles. Bark is an excellent mix component if it has been aged or composted sufficiently. Bark does have a tendency to tie up NH_4-N and fertility programs with mixes containing a high percentage of bark should include periodic applications of NO_3-N.

- The presence of inorganic and organic toxins, Mn being the principal inorganic toxin found in bark. Manganese levels of bark depend upon the bark source and state of decomposition, and can be highly variable. The risk of Mn toxicity in bark containing mixes is greatly reduced when the mix pH is maintained above 5.5. Bark may contain a variety of organic toxins such as phenol, monoterpenes, catechin, tannic acid and likely some toxic compounds not yet identified. Sufficiently aging or composting bark normally removes any toxic effects that bark may have on plant growth. Growers should avoid using bark with very low pH or high EC values.

Water Quality and Plant Nutrition

Irrigation water can have a significant influence on the nutrient requirements of artificial mixes. Unlike mineral soils, artificial mixes are poorly buffered and water pH and alkalinity play a major role in determining the ultimate pH of the mix. The pH of artificial mixes will influence nutrients available for plant absorption and thus the elemental content of the plant. Approximately 30% of the growers in the United States inject acid to reduce water alkalinity. Growers that experience persistent media pH problems should evaluate their irrigation water. High water alkalinity promotes high pH of the mix. Conversely, pH problems with mixes resulting from using low alkalinity irrigation water, the problem generally occurs as the mix having too low of a pH. Nutrient analysis of irrigation water is advisable since in some cases, irrigation water may supply significant levels of Ca, Mg, S, or B, which is absorbed by the plant.

Fertilizers, Their Composition, Use and Management Factors

Today, it is estimated that up to 60% of crop yields can be attributable to commercial fertilizer use. In addition, fertilizers, their proper selection and use, are needed in order to obtain high crop yields. Therefore, a working knowledge of what constitutes a fertilizer and how it is to be used is essential in order to achieve essential nutrient element sufficiency for stress-free crop production. A fertilizer can be simply defined as “a substance that is used to make a soil more fertile,” while a more descriptive definition would be “a substance containing one or more of the essential plant nutrients that when added to a soil/plant system, aids plant growth and/or increases productivity by providing additional essential nutrients for plant use.” The *www.wikipedia.com* fertilizer definition is “any organic or inorganic material of natural or synthetic origin (other than liming materials) that is added to a soil to supply one or more plant nutrients essential to the growth of plants.” Fertilizers are sometimes referred to as "plant food” which has become a commonly accepted term. What is known as a “commercial” fertilizer would be one that has been through a processing procedure in order to obtain a product that is uniform in composition and particle size. Another term that can be used to define a fertilizer is the word, "complete," which would designate that most, if not all, of the essential plant nutrient elements are present at some level of concentration in the fertilizer.

A term that relates to the defining of an essential plant nutrient is "nutrient," meaning an essential plant nutrient element, or nutrient element, or simply "nutrient." Today, most define an essential element as being an essential plant nutrient element as the use of the words, "nutrient element" or "nutrient" alone can be confusing as to what it designates. Another term that may be added is "mineral," since all but three essential nutrients, carbon (C), hydrogen (H) and oxygen (O), are minerals.

Among the 13 essential plant nutrient mineral nutrients, three elements have been designated as being "fertilizer elements," the nutrients nitrogen (N), phosphorus (P) and potassium (K). Based on this designation, most substances identified as a "fertilizer" would contain one (single elements), or two or all three-fertilizer elements that would then be designated as a "mixed" fertilizer. However, substances designated asfertilizers may also contain one or more of the other 10 essential mineral elements, such as the other three major elements, calcium (Ca), magnesium (Mg) and sulfur (S) as well as one, several, or all of the micronutrients [boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn)].

What constitutes a fertilizer is regulated by state statutes, statutes which may differ among the states as to what constitutes a fertilizer and what are the requirements for identifying its composition. Under most State statutes, what constitutes a fertilizer is based in its guarantiedpercentage content of each essential plant nutrient element it contains. For the three fertilizer nutrients, the percentage of N is given as its nutrient, while the percentage of P and K are as their oxides, P_2O_5 and K_2O, respectively. These percentage contents as N-P_2O_5-K_2O are given on the fertilizer label in numerical order, such as 10-10-10, 5-10-10, 0-45-0, 0-0-60, 35-0-0, etc. If other elements are in the fertilizer, they may be identified, being either guaranteed in content, or not.

In some instances, the source chemical of the essential nutrients in a fertilizer may be given, or its form, such as a chelated micronutrient. The form of N in a fertilizer, for example, can be important as to its suitable use, forms being urea (45-0-0), ammonium sulfate (21-0-0), nitrate (34-0-0) or phosphate (11-46-0 or 18-48-0), or even as a combination of sources, such as urea-ammonium sulfate (34-0-0). The other forms of N used as fertilizer are calcium nitrate (16-0-0-19[Ca]) and potassium nitrate (13-0-34). Other essential plant nutrient elements may be given on the fertilizer label by adding a 4^{th} numeral (see calcium nitrate above), such as that for ammonium sulfate (21-0-0-24), the 4^{th} numeral being the percentage of sulfur (S) as its nutrient. The percentage of a nutrient in a fertilizer is total for most nutrients, except for K that is water extractable and for P, citrate-soluble.

There are two objectives for the use a fertilizer, one based on providing that or those essential plant nutrient elements required by the crop being grown, and that based on the establishment and maintenance of a designated soil fertility level, whether it be a soil or soilless organic medium. The first concept is designed to satisfy the plant essential nutrient element requirement that primarily relates to the nutrient N and the micronutrients, while the second concept focuses on what is needed to establish and then maintain the rooting medium sufficient is terms of the availability of the essential plant nutrient elements existing in the soil or other types of rooting media. The first concept is determined primarily by plant species, stage of growth and crop use, while the second involves the input of soil type and the physio-chemical properties, such as pH, cation exchange capacity, organic matter content, structure, etc. of the rooting media. In this second concept, the proper use of a fertilizer begins with a soil test, or a water-equilibrium test for an organic rooting media, and/or a plant analysis, all essential for obtaining an essential nutrient element-requirement recommendation (Jones, 2012).

The common errors in fertilizer use are associated with improper selection, inadequate or excessive rates of application, and the accumulation of nutrients resulting in excesses and/or elemental imbalances. The use of soil tests and plant analyses as monitoring tools can be used as a mean for avoiding the occurrence of such insufficiencies, identifying what essential plant nutrient elements are needed as well as specifying rates and frequency of application.

The appropriate form, amount, timing, and placement are important in the proper management of fertilizer use in order to achieve good plant growth and health without occurring over application and incurring the potential of environmental contamination. These considerations require knowledge of the chemical and biological processes that determine availability of an essential plant nutrient element for plant root absorption. Temperature, moisture and water movement as well as fertilizer placement, time and method of application will affect availability. Nutrient and ion movement within soil is determined by the processes of mass flow and diffusion, while root extension within the soil mass will enhance soil/root contact, and therefore enhance availability.

Although most of the essential plant nutrient elements are applied as a fertilizer form to the soil or rooting medium to be then root absorbed, under certain circumstances, some of the essential plant nutrient elements, primarily the micronutrients, can be applied in solution form on plant leaves, primarily for correcting an insufficiency occurring during the growth cycle.

In field production, N is generally needed in much greater quantities than either P or K. When only small amounts of either P or K are required, it is nutritionally sound as well as cost effective to apply only a complete NPK fertilize sufficient to meet the P and K needs of the plant, and then provide the remaining portion of the N requirement by applying a N only- containing fertilizer.

In general, greenhouse and nursery crops also require more N than either P or K. Some soluble fertilizers used as "liquid feeds" typically contain as much K_2O as N, and from one-half to equal the amount of P_2O_5. This means that the fertilizers may supply 20% to 40% as much P as N, and 80% as much K. Whereas nursery crops and turf grass are typically fertilized with slow release nutrient element sources, such as sulfur-coated urea. Greenhouse cropsare usually fertilized through the watering system, with fertilizer being injectedinto the irrigation water at each irrigation or on a grower selected timing of fertilizer application. A typical set up for fertilizer injection is given in the following Figure 3-5.

Figure 3-5. Blue/green fertilizer solution tank with fertilizer made to a specific concentration and then injected into irrigation water for greenhouse crop production.

With this method, fertilizer solutions are injected into the watering system at concentrations calculated to deliver a particular N concentration [typically 100 to 200 mg kg^{-1} (ppm) N], with the P and K as well as other essential plant nutrient elements being supplied in proportion to their concentrations in the selected fertilizer. This approach provides optimal, or above optimal N for plant growth, and almost certainly applies unnecessarily high quantities of P and K, if the fertilizer contains one-half to equal amounts of P_2O_5 and K_2O as N. Therefore, an adjust in greenhouse fertilizer management programs may be required in order to reduce the amount of plant nutrient elements applied unnecessarily, which ultimately can become potentialpollutants in the discarded runoff irrigation water.

When applying a fertilizer, there is the potential for antagonistic or synergistic interactions to occur among the essential plant nutrient elements, interactions that can lead to plant nutrient element insufficiencies. A list of the known synergistic and antagonistic interactions among the essential plant nutrient elements is given in the following table:

Nutrient Interactions

Table 3-1. Relationship of elemental excess to potential nutrient deficiencies in plant tissue.

Nutrient in excess in media	Nutrient possibly deficient in plant tissue
Nitrogen	Potassium, Calcium
Potassium	Nitrogen, Calcium, Magnesium
Phosphorus	Copper, Zinc, Iron
Calcium	Magnesium, Boron
Magnesium	Calcium, Potassium
Sodium	Potassium, Calcium, Magnesium
Manganese	Iron, Molybdenum
Iron	Manganese
Zinc	Manganese, Iron
Copper	Manganese, Iron, Molybdenum
Molybdenum	Copper
Aluminum*	Calcium, Potassium, Copper
*Aluminum is not an essential nutrient and high levels are rare in artificial soils. High aluminum will precipitate phosphorus as aluminum phosphate and can highly reduce short-term phosphorus availability.	

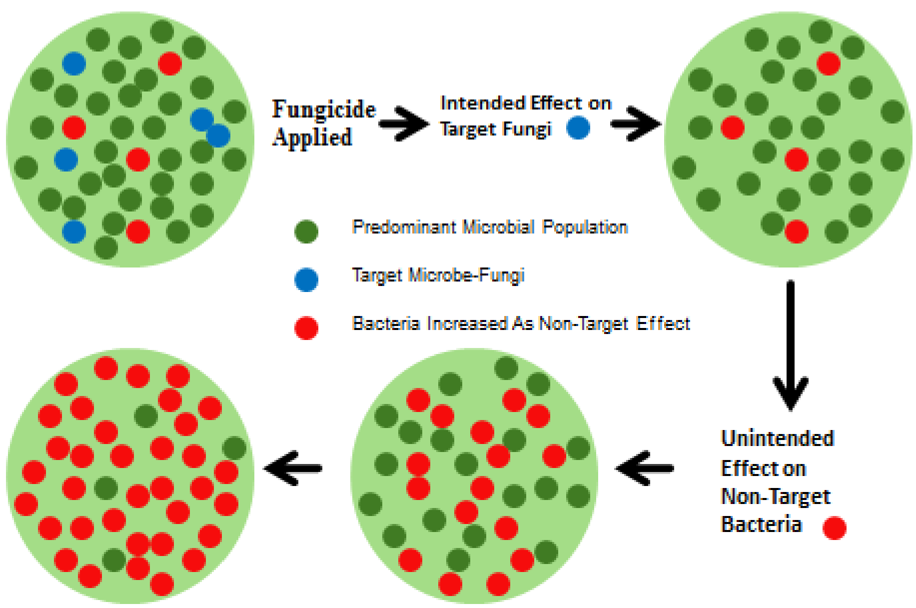
Rhizosphere. Uptake of Essential Plant Nutrient As Influenced By The Interaction of Chemicals and Pesticides on soil Microbes.

The rhizosphere, the soil environment around the root and the internal root cellular spaces, has been studied for over 100 years as the hotspot for microbial, nutrients, air and water interacting to influence the plants nutritional health and ultimately yield. Microbes inhabiting the rhizosphere spaces in a plant root can compete with plants for essential plant nutrients, whichin turn can cause plant nutrient deficiencies. Pesticides commonly used in agriculture's agronomic and horticultural industries can have a direct impact on plant nutrition through pesticides non-target effects on the microbial community. A pesticide is any substance or mixture of substances intended to prevent, kill, or otherwise reduce the damage caused by a pest. Pesticide is a broad classification, which in agriculture typically includes formulations prepared as herbicides, insecticides, fungicides, bactericides, nematacides and rodenicides. Rhizosphere bacteria responsible for N transformations are particularly susceptible to fungicides, which can have an effect on crop growth and yield.

The fungicide benomyl which was used to kill certain fungus diseases also stimulated the pseudomonad bacterial component in rhizospheres of treated crops, which, stimulated high proportions of the certain rhizosphere bacterial population. These higher populations of bacteria reduced plant growth through overproduction of plant growth regulating compounds, overwhelming the endophytic microbial component within the plant. Fungicides including benomyl also inhibit the development of mycorrhizal-root associations.

This non-target effect of a fungicide is depicted in Figure 3-6.

Figure 3-6. How pesticides can affect rhizosphere microbial makeup.



In conventional agricultural and horticultural production for the past 60 years or more, a majority of pesticides sold and used have been synthetic chemicals. These chemicals have been screened for their ability to control targeted pest or pests, that is, to determine its efficacy for the target pest or closely related pests, such as with general purpose insecticides or broadleaf herbicides. Because synthetic chemicals are xenobiotic, that is, the chemicals are not naturally or normally found in the plants or in other living organisms, then the application of these pesticides may have effects on the non-intended or non-target organisms. Non-target organisms are any living organisms other than the pest the chemical is designed to control. Simultaneous with application of these chemicals to control targeted pests, non-target organisms may be influenced including the crops to which the chemicals are applied, beneficial insects, earthworms and other arthropods in the soil, and plant and soil microorganisms (both beneficial and detrimental). Pesticides labeled to be applied directly to soil are designed to control soil borne disease pathogens, root-attacking insects and nematodes, or germinating weeds. These pesticides can directly affect the soil microbial community (including those microbes that influence nutrient availability) and plant growth. Pesticides applied to plant foliage also reach soil through runoff from leaves, overspray and spray drift. Some pesticides have systemic properties whereby they are absorbed by the plant tissues (e.g., leaves, stems, roots, flowers, fruits) and are translocated to other parts of the plant. Systemic fungicides, bactericides and insecticides are often used to enhance or extend the efficacy of the pesticide, but there are relatively few of these systemic pesticides on the market. The systemic fungicide Benlate 50 DF was removed from the market as it had produced non-target selection and promotion of IAA producing *Pseudomonas* bacteria that resulted in elevated IAA levels being release as a waste by-product that was absorbed by the plant and caused growth regulator type effects in many horticultural crops. Many of these affected plants showed nutritional type symptoms that could not be corrected by normal cultural practices of applying nutrients to correct the leaf chlorosis.

Figure 3-7. Benlate treated plant showing leaf chlorosis distorted leaf growth and insert picture of untreated (no Benlate fungicide) Leatherleaf Fern leaf with no chlorosis and proper plant leaf growth.

Figure 3-8. Orchids Treated with fungicide Benlate shows distortion and chlorosis that could not be corrected with fertilizer applications.

Figure 3-9. Chlorosis in Blue Pacific Juniper due to the fungicide Benlate DF stimulation and promotion of IAA producing *pseudomonas* bacteria that resulted in a leaf chlorosis that could not be corrected by the addition of any of the essential plant nutrients.

A high percent of herbicides must be absorbed into plants to be able to control targeted weeds, and thus have systemic properties. Certain herbicides, most notably glyphosate and related herbicides, translocate and accumulate in the shoot tips and in the root tips and with a significant amount released into rhizosphere soil. The greatest use of glyphosate-based herbicides is with genetically modified (GMO) crops, such as corn and soybeans, which have been modified to tolerate glyphosate-based herbicides. The current widespread use of these transgenic crop cultivars allows glyphosate to be used in a non-selective weed control program with these crops. Glyphosate has become of particular interest because it is the most widely used herbicide in the world today, and because of the multiple effects of this systemic herbicide on availability of plant nutrients and on soil microbial activity and diversity. Glyphosate is ionized at physiological pH (≥ 7.0) and at soil pH ≥ 5.6 and is potentially a strong chelator of divalent and trivalent nutrient cations. Uptake and translocation of the micronutrients, Fe, Mn, Zn, Cu, and Ni, are drastically reduced in glyphosate-susceptible (non-GMO) crops by glyphosate drift ($\approx 0.025\%$ of herbicidal rate) as well as in transgenic glyphosate resistant crops with recommended application rates.

Immobilization of these micronutrients is readily observed in transgenic crops by the "yellow flash" observed in leaves soon after glyphosate application.

Figure 3-10. Soybean leaves on left showing symptoms of yellow flash and right, yellowing of the younger leaf giving the appearance of iron deficiency though iron in the tissue is adequate. Photos courtesy of R. Kremer and L.H.S. Zobiole, ARS-USDA.

This yellowing of the younger leaves persists until plants replenish the immobilized micronutrients. These micronutrients are still in the plant tissues but are not bioavailable for use by the plant. Nutrients bound in glyphosate complexes may remain unavailable to the crop during growth and development of the transgenic crop affecting many metabolic processes and ultimately grain yield. Tissue analyses may indicate adequate sufficiency levels for the affected nutrients because they are present within the plant tissue as glyphosate-nutrient complexes, although these complexed nutrients are not available to the plant. In order to detect such complexes, sensitive analytical techniques such as electron paramagnetic resonance spectroscopy are required.

The consequences of the reduction of these available micronutrients within the tissue are that glyphosate affects synthesis of aromatic compounds, which are building blocks for siderophores and Fe reductase necessary for Fe mobilization and uptake by roots from soils. Insufficient aromatic compounds also decrease formation of plant defense compounds, leading to potential root infection by soilborne pathogens and subsequent interference with nutrient uptake and other physiological processes.

Glyphosate not only complexes nutrients within plants, but also when it is released intact into the rhizosphere by roots. By binding these nutrients next to the root surface, this slows the uptake and replenishing of the glyphosate-bound nutrients within the plant.

Glyphosate also causes numerous indirect effects on nutrient availability to crops by its effects on the soil microbial community. Glyphosate alters the diversity and distribution of microbial groups, which can impact nutrient cycling and also potential pathogenic microbial groups. Microbial groups capable of reducing nutrients including Mn and Fe are suppressed by glyphosate thereby reducing plant availability, K immobilization also increases, and potential pathogens involved in bacterial and fungal root rot and vascular blockage are stimulated. Glyphosate also depresses activities of specific microbial groups including rhizobia, resulting in reduced nodulation, nitrogenase activity in soybean, and mycorrhizal fungi, potentially reducing uptake of several nutrients including N, P, K, S, and Fe.

Other herbicides including 2,4-D and atrazine are also implicated in altering the plant rhizosphere community and may have detrimental effects on microbial mediated nutrient uptake and metabolism in plants. Many fungicides used for controlling fungal phytopathogens in agricultural and horticultural crops cause shifts in microbial communities (microbes), in the plant and/or in the plant root rhizosphere.

Continuous use of many currently available pesticides through annual or more frequent applications on perennial, annual or short-season crops without incorporating pesticide rotation and other cultural and management practices to maintain or improve nutrient availability may lead to consequences of plants and soils with lower uptake and nutrient availability (i.e., lower soil fertility), sub-optimum crop production, and feed and food of lower nutrient quality.

Chapter 4

Nitrogen (N)

Atomic Number: 7
Atomic Weight: 14.01

Discovered by Rutherford in 1772
Proven to be essential to plants by de Saussure in 1804

Nitrogen in the Soil

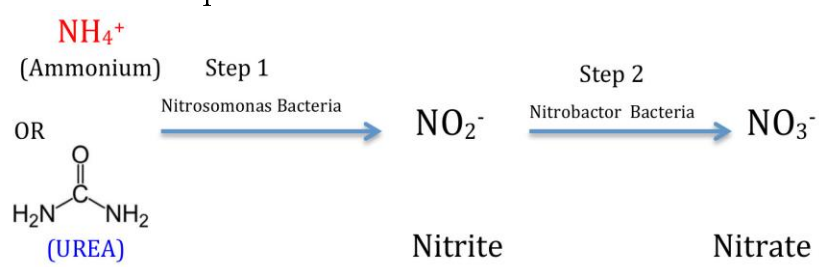
Forms

Most N in soils (98%) is associated with organic material. Total N levels in soils range between 0.02% in subsoil's to 2.5% in peat. The soil plow layer (approximately the top 8 inches or 20 cm) of the majority of cultivated soils contains 0.02-0.04% N by weight. However, due to the continuous changes in N forms and availability, determinations of soil N levels are of limited value in predicting short-term availability to plants. This is partly due to oxidation state transformations that occur naturally in the soil due to chemical, biochemical and microbial processes. The sum of these reactions form what is known as the nitrogen cycle. The nitrogen cycle is dynamic with N forms having oxidation levels of +5 in N_2O_5 and HNO_3; +4 in NO_2; +3 in N_2O_3 and HNO_2; +2 in NO; +1 in N_2O, HNO and H_2N_2O; 0 in N_2; -1 in NH_2OH; -2 in NH_2-NH_2; and -3 in NH_3. Because of these constant transformations, nitrogen is the most dynamic plant nutrient in the soil.

Soil N can be found in three main fractions: (1) organic matter; (2) ammonium (NH_4^+) ions fixed on exchange sites of clay minerals; and (3) ammonium and nitrate (NO_3^-) ions in the soil solution. The forms of N that are of primary importance in plant nutrition are ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). Both nitrate and ammonium are the N forms taken up by plants and also the majority of N applied to soils is either in the nitrate and ammonium forms, or in forms that quickly convert to nitrate and ammonium once in the soil. On the other hand, nitrite is important to plant nutrition because it is toxic to plants at very low levels [less than 5 $mgkg^{-1}$(ppm)]. Nitrite generally becomes a concern only when environmental or cultural practices (including applied chemicals) interferes with the nitrification process in the soil (the microbial conversion of NH_4^+ to NO_3^- with NO_2^- being an transition form of N).

In the soil, N may be (1) transformed by mineralization (conversion of organic N into inorganic N – most commonly to ammonium), followed by nitrification (conversion of ammonium into nitrate); (2) incorporated by symbiotic N-fixation (conversion of the nitrogen gas (N_2) into ammonia, ammonium or organic nitrogen forms); or (3) lost by denitrification (transformation of nitrate into nitrogen gas), ammonia volatilization (conversion of ammonium into gaseous nitrogen compounds), dissimilatory nitrite reduction (transformation of nitrite into nitrous oxide gas), or plant uptake (mainly ammonium and nitrate). Aerobic/anaerobic conditions, soil pH, temperature, and the presence of chemical inhibitors or the use of certain fungicides/pesticides may alter the rates of these naturally occurring transformations.

Traditionally in most cropping systems, nitrate has been the primary N form absorbed by plants primarily due to the rapid conversion of ammonium in the soil by nitrification to nitrate. The nitrification process includes two steps.



First, bacteria *(Nitrosomonas* spp.) oxidize ammonium into nitrite (Step 1), and then *Nitrobacter* bacteria transform nitrite to nitrate (Step 2). Under most soil conditions the rate of Step 2 is higher than that of Step 1 and nitrite does not accumulate in soils. However, nitrite can accumulate if Step 2 is blocked by an environmental condition or cultural practice. Also, nitrification requires oxygen and releases hydrogen (H^+) ions, thereby acidifying the soil over time resulting in the need for lime application to raise the pH of the soil.

Higher plants and microorganisms compete for available N in the soil. Because microorganisms use the carbon compounds in organic matter for energy and because their distribution in the soil makes them more efficient in intercepting N than plants, the availability of N for plant growth is dependent on the soil carbon:nitrogen (C:N) ratio. When C:N > 30:1, N is immobilized in the decomposition processes of organic residue by soil microbes. When 20:1 < C:N < 30:1, limited immobilization and release of mineral N occurs into the soil environment. Nitrogen is available for plant uptake when C:N < 20:1. In order to increase N available for plant uptake, fertilizers containing N are routinely applied to cropped soils thereby reducing the C:N ratio.

Fertilizers

The form of N contained in fertilizer usually groups nitrogen fertilizers into three types of N sources, urea, ammonium, and nitrate.

Urea-based ($CO(NH_2)_2$) fertilizers include granular urea and liquid solutions of urea ammonium-nitrate (UAN), urea-ammonium phosphate, urea-ammonium sulfate, urea-nitric phosphate, urea phosphate, water-soluble urea-formaldehyde, methylenediurea, dimethylenetriurea, and stabilized urea-formaldehyde. Urea is generally converted rapidly to ammonium by hydrolysis or reacting with water in the soil solution. Plants can take up the N as ammonium, or as nitrate, if nitrification converts the ammonium to the nitrate form prior to absorption by the plant (conversion of ammonium to nitrate, nitrification, normally takes 7-14 days under normal field growing conditions).

Ammonium-based fertilizers include gaseous anhydrous ammonia, granular ammoniated superphosphate, ammonium chloride, ammonium nitrate, ammonium nitrate-limestone, diammonium phosphate, monoammonium phosphate, ammonium phosphate nitrate, ammonium phosphate sulfate, ammonium polyphosphate, and ammonium sulfate. Ammonium can be absorbed by the plant or be converted to nitrate by nitrification before absorption by the plant. If negatively charged clay/humus particles are present in the soil, ammonium is less likely to leach due to its positive charge causing a bond to the clay/humus particles.

Nitrate-based fertilizers include calcium-ammonium nitrate solutions, and granular calcium nitrate, potassium nitrate, magnesium nitrate, and sodium nitrate. Nitrate is not strongly bound to soil colloids, and is therefore prone to leach during rainfall or irrigation.

Organic N-containing fertilizers include dried blood, castor bean pomace, cottonseed meal, dried fish scrap, bird guano, manure, and sewage sludge. These sources of N primarily release ammonium upon decomposition, which again can be converted to nitrate by nitrification.

Since N fertilizers are applied in fairly large quantities to cropland soils, N fertilizers can have a marked effect on the soil pH. Urea- and ammonium-based fertilizers have a strong acidification effect on the bulk soil. Acidification results both from protons being released during the nitrification process and during the absorption of ammonium by the roots. Consequently, organic-N sources have an acidifying effect through mineralization. Thus, continued long-term use of ammoniacal or urea-based N fertilizers can result in soil acidity, which may require regular liming to stabilize pH. The main concerns over low soil pH are increased availability of Al and Mn and potential plant toxicities of these metals. Conversely, the use of nitrate-based fertilizer results in a temporary increase in soil pH.

Nitrogen Uptake and Assimilation by Higher Plants

Uptake

Growers often talk of applications of units of nitrogen, ignoring the differences in the forms of nitrogen applied. In contrast, in plant nutrition, nitrate and ammonium should be regarded as two different nutrients due to their different reactions within plants. It is generally recognized that ammonium *greens* a plant while nitrate *grows* a plant. Inside plant tissues, ammonium is a free radical and is toxic to a plant. Because of this toxicity, when it is absorbed, ammonium is quickly combined with carbon to form organic N compounds in the plant. This is to prevent ammonium from damaging the plant. If high levels of ammonium are available to the plant, whether from fertilizer application or from rapid decomposition of organic matter, ammonium will tie up available carbon in the plant. If the carbon used to detoxify the ammonium would normally be used to support growth of the plant, a smaller plant will result. Since ammonium is incorporated into organic N compounds in the roots first, the first impact of high levels of ammonium will be observed in reduced root growth. When ammonium ions are absorbed beyond the ability of the root system to detoxify them, then the excess ammonium ions will be translocated to the top portion of the plant. There carbon used for leaf and stem growth will be diverted into detoxification of the absorbed ammonium. In severe cases, this carbon depletion results in symptoms of ammonium toxicity and can actually kill plants, such as high ammonium nutrition applied to young tomato seedlings can kill them.

Ammonium uptake is optimal at neutral pH. At increasingly lower pH's, lower ammonium uptake has been observed due to the competition between hydrogen and ammonium ions for binding sites on plant roots. As the hydrogen ion concentration increases (as pH decreases), its competition with ammonium becomes more intense. The uptake mechanism for ammonium ions is currently unknown. By comparison, nitrate is taken up in plants in large quantities by both passive and active absorption. Plants will continue to absorb nitrate as long as it is present in the soil. However, nitrate uptake can be depressed by ammonium. Nitrate uptake decreases at pH levels above 6 or under 4.5. Reductions in nitrate uptake at high pH may be due to the competitive effects of hydroxyl (OH^-) ions.

Nitrate and ammonium uptake are both temperature dependent, with uptake increasing as temperature increases. Nitrate is transported upwardly in plants through the xylem. Simultaneously, organic anion synthesis increases with a corresponding increase in accumulated inorganic cations, such as Ca, Mg, K, and Na in roots.

After absorption, nitrate either can be stored in the vacuoles or incorporated into organic molecules. Nitrate is reduced and incorporated into organic molecules by the light-activated enzyme nitrate reductase (NR), the activity of which is genetically controlled.

Ammonium must be rapidly incorporated into organic molecules because free ammonium disorganizes the photosynthetic mechanism by uncoupling redox reactions and affecting the photosynthetic membrane stacks (grana) in chloroplasts.

As stated above, the ammonium ion is toxic to plants and must be incorporated into N compounds immediately upon absorption. In contrast, nitrate is not toxic and can be stored in the plant until utilized. Regardless of the inorganic form of N absorbed, it is the ammonium form of N that is used to make all amino acids, proteins and most enzymes in plants, with the first step being the incorporation of ammonium into alpha-ketoglutarate to yield glutamate in the chloroplasts. This reaction is controlled by the enzyme glutamate dehydrogenase. Other amino groups may be added to glutamate residues to produce glutamine under the control of the enzyme glutamine synthetase. These reactions are reductive assimilations (where NADPH + H^+ is transformed into NADP) and require energy transfer from ATP. Two glutamate residues may also be formed by transamination of alpha-ketoglutarate by glutamine, under the control of the enzyme glutamate synthetase. A series of transaminations using glutamate and glutamine as amino-group donors initiates the synthetic pathways of other essential amino acids using the corresponding alpha-keto acids as receptors.

Nitrogen Nutrition in Higher Plants

Essential roles

Nitrogen is involved in the structure of all amino acids, proteins, and enzymes. Nitrogen is also part of the puric and pyrimidic bases, and therefore is a constituent of nucleic acids (DNA and RNA). Nitrogen is also present in the tetra-pyrrole ring of chlorophyll, NADH, NADPH, choline, and indoleacetic acid (IAA). Nitrogen is also found as free nitrate in the vacuole sap. Nitrate will accumulate at substantial concentrations (>1,000 ppm) in the conductive tissue (petioles and stem) during the vegetative period of growth. Therefore, petioles of certain crops have been used as indicators of the N status during vegetative growth stages. However, deficient molybdenum levels in the plant can increase nitrate concentration in petioles, as molybdenum is required for nitrate reduction either in the roots or shoot. Without being assured, through leaf analysis, that molybdenum is sufficient, use of petiole nitrates as a nitrogen sufficiency indicator is flawed.

Adequate Range and Nutritional Disorders

Sufficiency Range

Nitrogen concentrations in plants typically range between 1.0 and 6.0% of the dry weight in leaf tissues depending on plant species, stage of maturity, and several other factors. High N contents, however, can cause rapid stimulation of plant growth, which can produce nutrient deficiencies of other nutrients (if they are not supplied as well) due to dilution effects. Petiole measurements of nitrate range from 8,000 to 12,000 ppm N during early growth to 3,000 to 8,000 ppm N during mid-season. Nitrate is concentrated primarily at the base of the main stem and in the petioles of recently matured leaves.

Deficiency

All N forms are mobile in plants. Therefore, N deficiency symptoms first appear on older leaves. Under N shortage, plants grow slowly, and are weak and stunted. Leaves are small, the foliage color is light green to yellow, and older leaves often fall prematurely.

Figure 4-1. Nitrogen deficiency.
Left-mum older leaves showing yellowing due to nitrogen deficiency.
Right-pepper plants showing older leaves turning a uniform yellow color.

Figure 4-2. Nitrogen deficiency.
Left-geranium
Right- corn.

Necrosis of leaves or parts of the leaf occurs at a rather late and severe stage in the deficiency. Root growth is reduced and branching is restricted; yet, there is usually an increase in the root/shoot ratio. Yield and quality are significantly reduced. Fruits of many crops become brightly colored.

Toxicity

Plants can tolerate excess nitrate to a much greater degree than excess ammonium. Ammonium levels can be toxic to plants if not incorporated into carbon containing N compounds after absorption (as discussed above). Excessive ammonium can have a herbicide effect on when absorbed in quantities that exceed the plants ability to detoxify.

Figure 4-3. Ammonium toxicity in a tomato leaf.

Figure 4-4. Ammonium toxicity in sugarcane resulting from high ammonium from chicken litter being applied as a N-source.

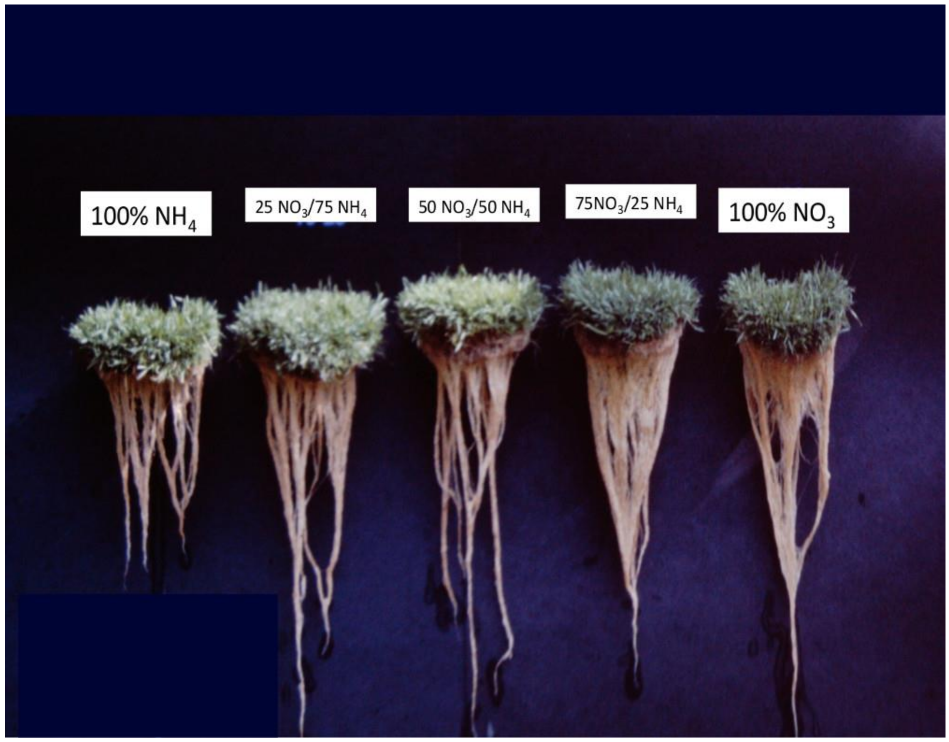
Figure 4-5. Ammonium toxicity in corn leaves which is really a calcium deficiency caused by high ammonium and its suppression of calcium uptake.

Ammonium can also restrict K uptake by competing for root uptake binding sites. When ammonium is the dominant form of N available for plant uptake, a toxicity condition may develop. The toxicity of ammonium ions is characterized by restricted root growth, which is often discolored, and results in a breakdown of vascular tissue, thereby restricting water uptake. Foliar symptoms can include chlorosis (yellowing) and necrosis (dying) of leaves, epinasty (downward growth of leaves and stems), and stem lesions. Plants leaves wilting are common with ammonium toxicity. This effect can be caused by suppression of potassium uptake due to the excessive ammonium competing with potassium for movement into the plant cells in the root and leaves.

Figure 4-6. Wilting tomato plant due to ammonium toxicity.The ammonium ion can compete with and restricting potassium uptake, causing a plant to lose ability to regulate water transpiration.

However, a small application of an ammonium-based fertilizer at the end of the growing season on leafy vegetables or ornamentals results in a desirable darker green leaf color without reducing growth. With ammonium fertilization, secondary problems, such as K, Ca, or Mg deficiencies often occur. Fruits may develop blossom-end rot symptoms as well as poor fruit set. Even C-4 plants such as grasses are not immune to excessive ammonium fertilizers affecting plant growth. Turf grass for golf course greens generally express excessive ammonium uptake as a reduction in root growth.

Figure 4-7. Bentgrass root growth showing effect with different percentages of ammonium supplying the N-form.



Interactions with other Nutrients

Competition for Uptake

Ammonium depresses the uptake of the essential cations such as K, Ca, and Mg, while nitrate depresses the uptake of essential anions such as P and S. Chlorine (Cl) can also compete with nitrate for uptake.

Effect on pH

Ammonium-fed plants often have higher P contents than nitrate-fed plants due to acidification of the rhizosphere (root zone) with ammonium absorption by the roots and subsequent H^+ ion release into the surrounding soil. Ammonium applications can reduce the incidence of Fe deficiency in calcareous soils.

Molybdenum

Because the enzyme nitrate reductase requires Mo, a Mo deficiency reduces the rate of nitrate reduction and thereby decreases N use efficiency. Mo induces (stimulates) the production of nitrate reductase and often limits the quantity of this enzyme in plant tissue, which in turn may lead to the accumulation of nitrate in the tissues.

Nitrogen Fertilizer Additions and Management

Nitrogen (N) generally undergoes complex transformations in the soil. Most commonly, N is applied in the forms of urea, ammonium, or nitrate to cropped soils. Urea is rapidly broken down in the soil to the ammonium form. In the presence of a carbon source such as plant material or residue, urea applied to the soil surface can break down to ammonia gas and be lost to the atmosphere. The same can happen when ammoniacal N is applied to high-pH soils or is irrigated with alkaline water (pH 7.2 or higher). Ammoniacal N is positively charged, so it is attracted to soil particles as part of cation exchange. In addition, plant roots can take up ammonium, or it can leach out of the root zone, especially in soils with low cation exchange capacity (CEC), such as sandy soils. When urea or ammonium N is incorporated into the soil, soil bacteria can convert it to nitrate N. This process, known as nitrification, is an acidic transformation, so it lowers the pH of the soil. Nitrate-N is highly soluble and is negatively charged so it is not retained in the soil by cation exchange. Plants can readily take up nitrate-N, but leaching easily removes excess nitrate in the soil solution. In poorly aerated soils, especially due to excessive irrigation or rainfall, other soil bacteria that live on decomposing organic matter can convert nitrate N to gaseous nitrous oxides. Anaerobic sites in the rhizosphere of normal crop conditions results in N loss through the denitrification process in amounts that can reduce yields significantly. Part of the positive plant response to frequent N applications to crops is in the replacement of N loss from the rhizosphere of plants.

Since there are many ways that N can be lost from the root zone, and since excessive N in surface and ground waters can lead to excessive aquatic weed growth or possible health problems if consumed as drinking water, it is important to manage N appropriately. Nitrogen should be applied conservatively, with split applications throughout the growing period preferable to large preplant applications. Much of the loss of N results from excessive water in or moving through the soil, so avoid excessive irrigation, and avoid applications of soluble N fertilizers to the soil just before or during periods of high rainfall when water movement cannot be prevented.

The selection of the form of N to apply is most often an economic decision, although soil factors can be important. Plants can absorb and utilize either ammonium or nitrate N forms. Where frequent applications of N are made to cropped soils and greenhouse cultures, the plant absorbs more of the applied ammonium-N in the ammoniacal form. Microbial transformation of urea or ammonium lowers soil pH, which can be an advantage or a disadvantage, depending on the current soil pH and the preferences of the crop. If soil pH is low, the acidifying effect must be offset by lime application. In contrast to field soils, microbial transformation of ammoniacal N may not occur in greenhouse or nursery situations (especially in soilless growing media), so plants may absorb much of their N in the applied ammoniacal form. Many plants are sensitive to the ammonium form of N, when this form is the predominant N form absorbed. In general, plants absorbing ammonium produce a smaller, darker green plant with a higher percentage N on analysis. This is in contrast to nitrate, which grows a larger plant, lighter green in color and with a lower percentage N on analysis.

In order to prevent loss of N to rivers, streams, lakes and other bodies of water, plant uptake should be maximized. Unfortunately, many university and crop consultants recommend high N fertilizer rates up to 89 to 357 $kgha^{-1}$ (100 to 400 lbs/ac), depending on the crop and location, frequently in one or two applications. The practice of applying high rates of N fertilizer (regardless of form), especially long before the crop needs it is incorrect and ultimately leads to the pollution of the environment. In turf production, N is often applied at rates of about 2 lbs N per 1000 square feet. Nitrogen is commonly applied in the irrigation water in greenhouse production in concentrations of 100 to 200 mgL^{-1} (ppm) from once to twice per week up to "continuous feeding," in which the fertilizer solution is applied at each watering. In most cases, N application rates are above actual crop requirements in order to avoid risk of yield or quality loss due to deficiency, and to counteract leaching caused by excessive irrigation and rainfall. In these cases, using smaller, more frequent doses and using tissue analysis to determine total fertilizer application needed for optimum growth can improve N fertilizer efficiency.

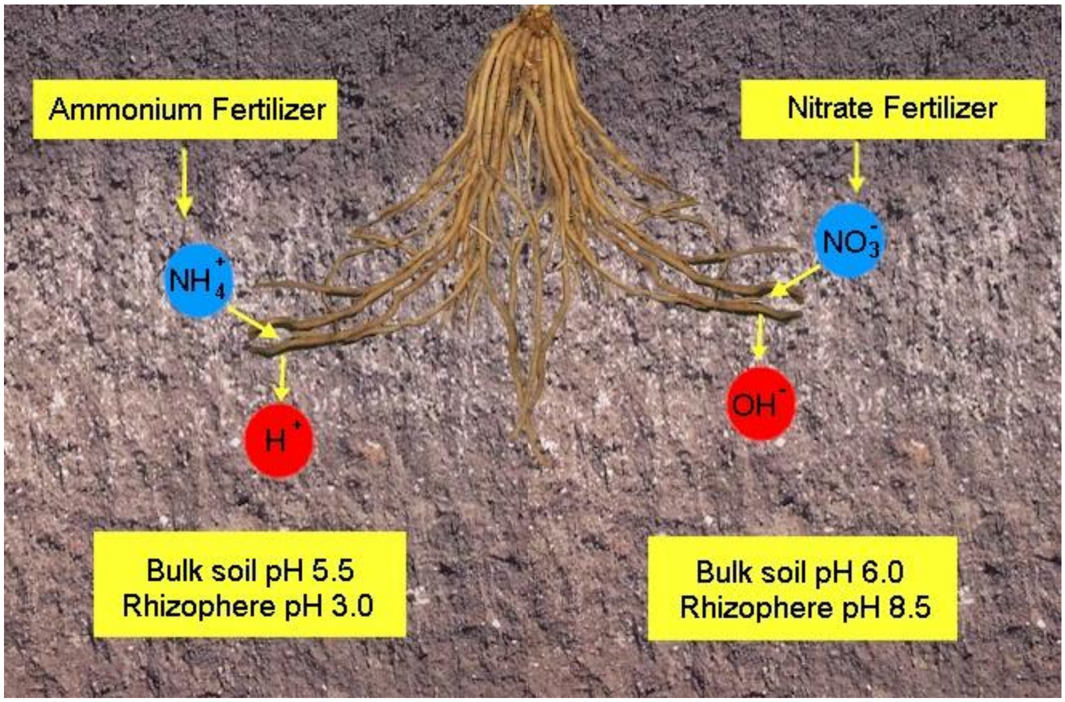
Forms of Nitrogen

The addition of N usually increases total plant N, but the increase obtained is higher with ammonium-N than with nitrate-N fed plants. Plant species differ in the accumulation of cations (e.g., Ca, Mg, K) as N nutrition varies. For example, cation accumulation was less for pea than for cucumber shoots. The use of ammonium-N reduced the Ca and Mg composition of tomato, but not that of pea. The form of N regulates the Ca and Mg composition of the roots, but the plant itself regulates the transport and relative Ca and Mg concentrations in the tops.

Iron content is affected by the source of N. Plant receiving all N as ammonium-N have higher Fe contents than do plants receiving all nitrate-N. Potato plants receiving both nitrate-N and ammonium-N had higher levels of Fe than did plants receiving a single source of N. Increasing the level of applied N as nitrate did not affect the concentration of total Fe. But the higher levels of applied N did increase the incidence of chlorosis and the P:Fe ratio in an Fe-inefficient (unable to take up adequate Fe easily) soybean cultivar, as compared to an Fe-efficient one (able to take up adequate Fe easily).

Part of the variation in plant elemental concentration noted with ammonium-N versus nitrate-N nutrition is induced by a lower pH in the substrate with ammonium-N nutrition and a higher pH with nitrate-N, such as the case of higher Fe content with ammonium-N mentioned above. The form of nitrogen being absorbed by the plant is very important to the interpretation of soil pH value measured by the laboratory and how to interpret the pH of the rhizosphere and the effect of nitrogen induced pH effects on nutrients available for uptake by the plant.

Figure 4-8. pH of the rhizosphere can differ by 2.5 pH units from measured bulk soil pH based on N form absorbed.



Although ammonium-N tends to reduce the uptake of Mn, the lower pH associated with its use increases Mn availability in the soil and is probably responsible for the higher concentration of Mn often noted in plants supplied with mostly ammonium-N. Continuous use (19 years) of $(NH_4)_2SO_4$ for an experiment with 'Washington' orange trees results in a soil pH of 4.5 as compared to pH levels of 7.9 and 8.7 when $Ca(NO_3)_2$ and $NaNO_3$, respectively, were used over the same time period. The lower pH induced by the $(NH_4)_2SO_4$evidently was responsible for the higher levels of Mn, Fe, and Zn found in the orange tree leaves.

The effect of different nitrogenous fertilizers on plant composition is influenced by the accompanying ions as well as by their nitrate-N or ammonium-N content. For example, leaves of apple trees fertilized with $NH_4H_2PO_4$ had less N, Ca, Mg, Cu, Mn and Zn, but more P and K than did leaves of trees fertilized with $(NH_4)_2SO_4$. The influence of the accompanying ion on plant composition is attributed, in part, to the effect of the ion on substrate (soil or growing media) pH.

Soluble versus Slow Release Forms of Nitrogen

The effects of different N compounds upon plant composition are also related to the release of N, whether in a soluble or available form, and the time elapsed prior to its analysis in the plant. Water soluble N fertilizers, such as NH_4NO_3, $(NH_4)_2SO_4$, $Ca(NO_3)_2$, will tend to give higher plant N contents than do the slow-release forms such as urea formaldehyde, sulfur-coated urea, resin-coated N, or tankage such as sewage sludge, swine manure, etc. The effect is altered if the analysis of the plant is deferred for long periods after the N application, especially if the materials are subjected to leaching conditions or high temperatures which tend to promote rapid release of N from many slow release N fertilizers.

Timing of Nitrogen Application

The higher levels of plant N induced by the soluble forms of N are due in large part to the time when N is available to the plant. Early application of N is especially effective for increasing plant N in short-season crops. Split applications of N will yield lower concentrations of N after the initial application, but plant N will tend to be higher after subsequent application(s).

Rate of Nitrogen Applied and Nutrient Interactions

As would be expected, plant composition is influenced by the rate that N is applied. Very low levels of N, which result in deficiency symptoms, will have a marked effect not only on N, but on other elemental components as well. The effect on the other nutrients will vary with plant species, soil pH, and the level of other ions present in the rooting media. Using a nutrient-culture solution technique where it was possible to regulate ion content, it was found that reducing N in solution resulted in much lower N content, but raised the concentrations of P, K, Mg, S and Na in lettuce leaves. No change was noted in the Ca leaf content. Inducing N deficiency symptoms by eliminating N in a sand-culture experiment resulted in a lower N content, but higher contents for P, K, Ca, Mg, S, Fe, Mn, and B in *Dracena godseffiana* leaves. An induced deficiency of N in *Dracena sanderiana,* however, gave lower levels of all the nutrients tested. In a similar experiment with *Dracena deremensis* `Warneckii', the elimination of N produced lower N, K, S, and Mn levels but higher plant contents for P and Fe. However, there was no appreciable effect on the concentrations of Ca, Mg, S, and B in these plants. Lowering the N to 20% of the control induced deficiency symptoms in an experiment on pear trees. A pear tree grown in sand culture had lower levels of N, Ca, Mg, and Fe in its leaves, but higher contents of P, K, B, Cu, Mn, Mo, and Al. These variations may have been partly attributed to the form of N provided to the plant whether it is an anion (NO_3^-), cation (NH_4^+), organic (urea) or a combination of these. However, elimination of N from a sand-culture system resulted in lower N, Ca, and Mg but higher P content in mature spinach leaves. The effect on the immature leaves was somewhat different. In the no-N treatment group, the K content was higher and the Mg was lower, while the level of Ca in the leaves was the same with or without N in the nutrient solution. In another experiment, N was eliminated from sand cultures used for growing 12 flowering annuals, resulting in various nutrient changes. Leaf N was lowered in all cases, P was raised in eight but lower in four, K was lower in 11, and Mn was raised in 10, with variable effects on the other nutrients. Omitting N from a nutrient solution used to grow sweet potatoes lowered N and P plant contents but increased S, K, and Ca with little effect on the Mg or Fe content in the tops.

Increasing the amount of N supplied to a plant above the deficiency level has resulted in variable effects. Increasing N application from 0 to 112, 224, and 336 kg/ha, increased the N content of mature turnip leaves at three different sampling periods (roots beginning to enlarge, roots 6-8 cm in diameter, and just before harvest). Leaf P was increased at the first two sampling dates and decreased at the last date, while leaf K generally decreased at all sampling dates with N application. Annual rates of 446, 893, 1339, and 1786 kg ha^{-1} N (500, 1000, 1500, and 2000 lb/ac) applied as NH_4NO_3 resulted in higher levels of N, and lower levels of K and Ca, but did not affect the P or Mg content in Japanese boxwood leaves a the N rate increased. Higher levels of N have increase N, decreased K, but had no affect on P, Ca, or Mg levels in *Ilex opaca* 'East Palatka' leaves. A similar treatment raised N and P, and lowered K, Ca, and Mg contents in highbush blueberry leaves. In another study with highbush blueberry, increasing the N fertilizer rate also raised N and K leaf content and lowered the Ca, Mg, and P contents. An increase of Fe and a decrease of Mn in leaf content also occurred, but no effect was seen on either Cu or Zn with higher N rates. Raising NO_3-N rates from 0 to 20, and then to 40 or 80 mgL^{-1} (ppm) in a daily solution applied to a soil-sponge rock mixture increased N, decreased P, K, Ca, Mg, S, and Mn contents, but did not affect Zn in macadamia leaves. An increase in rates from 89 to 178, 223, 268, and 357 $kgha^{-1}$ N (100 to 200, 250, 300, and 400 lbs/ac) from three different N sources increased the N, but decreased K and P concentrations of 'Valencia' orange leaves.

Increasing the total N from 2.7 to 5.4 or 10.8 kg/92.9m^2/year by additions of NH_4NO_3 depressed Cu and Zn, but had no appreciable effect on S, Fe, or Mn in the tops of `Tifgreen' Bermudagrass. The same rates of N derived from urea depressed the Cu, S, and Zn content of tops, while increasing the concentrations of Mg and Mn. Milorganite, supplying 5.4, 10.8, and 16.2 kg/92.9 m^2/yr, increased the Mn, Cu, and Zn contents of tops, but had no apparent effect on the content of other nutrients.

The N concentration was varied in a modified Hoagland's solution with additions of NH_4NO_3 to provide 30, 60, 90, 120, 180, 240, 300, 420, 840, and 1260 mgL^{-1} N (ppm) for pecan seedlings grown in sand culture. Higher N in all plant parts was noted with each increase in N. The effect of applied N on the elemental content depended upon the degree of N deficiency or the toxicity produced. From 0 to 60 mgL^{-1} N (ppm), the content of P and K tended to increase, with Ca, Mg, Cu, Fe, Mn, Mo, and Zn decreasing. From 60 to about 300 mgL^{-1} N (ppm), which produced toxicity, the K content decreased and then remained ata relatively constant level. At first, Ca rose with increasing N up to about the 180 ppm level before falling constantly until the 420 ppm N rate, at which point the Ca plant content remained fairly constant. Phosphorus in the plant tissue fell slightly with increasing N concentration in the solution up to about 180 mgL^{-1} N (ppm), after which it remained constant, the initial rise occurring with the increase of N up to 60 mgL^{-1} N (ppm). Magnesium first increased as N rose from 60 to 180 N (ppm) in the solution, but fell again as N was increased to 300 mgL^{-1} N (ppm), remaining fairly constant as the N concentration further increased. Copper, Fe, Mn, Mo, and Zn reacted somewhat similarly. Their concentrations remained fairly constant as N in the solution was increased from about 60 to 240 mgL^{-1} N (ppm).

Chapter 5

Phosphorus (P)

Atomic Number: 15
Atomic Weight: 30.97

Discovered by Brand in 1772
Proven to be essential to plants by Ville in 1860

Phosphorus in the Soil

Forms

Phosphorus exists in the soil as: (a) Ca-phosphate resulting from the weathering of primary P-containing minerals; (b) non-labile, or strongly bound P; (c) organic P in humus and organic residue; and (d) soluble and adsorbed phosphates which constitute P in solution (0.1 μg P/mL). Of the adsorbed P, only the mononuclear fraction is considered to be in equilibrium with P in solution, and therefore accessible to plants.

Dynamics

The pKa's of phosphoric acid are 1, 6, and 12. In the pH range of 5.5 to 7.0, the dominant form of P is H_2PO_4, and P availability is highest. Insoluble Fe- and Al-phosphates are formed at low pH, while insoluble Ca- and Mg-phosphates are formed at pH levels above 7.0. Phosphorus released from decomposition of plant residues can be a relatively significant source of plant-available P.

Because P is relatively immobile in the soil, banding P 5 to 8 cm to the side and 3 to 5 cm below the seed is preferable to broadcast applications. Flooding due to rain or excessive irrigation leaches only the P in the soil solution, while soil erosion is the major means of P removal from the soil.

Fertilizers

Phosphorus in fertilizer is expressed as phosphate, which refers to P_2O_5. The main sources of P are normal superphosphate (0-20-0), triple superphosphate (0-46-0), mono- (MAP, $NH_4H_2PO_4$, 11-48-0) and di- [DAP, $(NH_4)_2HPO_4$, 18-46-0] ammonium phosphates, ammoniated superphosphates, and potassium phosphate (KH_2PO_4).

Phosphorus Uptake and Assimilation by Higher Plants

Movement to the Roots

Phosphorus reaches the root surface mainly by diffusion along a concentration gradient. However, P only moves a short distance in the soil and must be placed close to the root for absorption. Soil factors such as moisture, buffering capacity, or temperature, and plant factors such as root length, root mass, or intensity of mycorrhizal infection all influence the rate of P uptake by roots.

Uptake

Phosphorus is taken up actively as H_2PO4 and does not undergo redox changes in the plant. Phosphorus in root cells and xylem sap has been measured at levels 100-1000 times greater than P in soil.

The absorption of P utilizes either a co-transport or an antiport system. The co-transport system comprises ATPases that pump H^+ into the apoplast to protonate a phosphate carrier, which then crosses the plasmalemma. pH in the apoplast controls P uptake. In the antiport system, HCO_3^- is pumped out while H_2PO_4 is pumped in. For each H_2PO_4 absorbed, the equivalent of one OH^- is released into the soil, which tends to increase the rhizosphere pH.

Phosphorus uptake by plants is genetically determined and differs between species and cultivars. This genetic factor influencing P absorption is especially important in choosing rootstock material. The uptake of P is greater in younger plants and decreases with maturity.

Translocation and Assimilation

Within minutes of uptake, most P is converted to organic P (mostlyhexose-phosphates and uridine diphosphate) and is quickly metabolized. P is mobile in plants, and downward movement occurs mainly in the phloem as either inorganic or organic phosphorus (phosphatidylcholine). Most of inorganic P (85 to 90%) may be stored in vacuoles, primarily as orthophosphate.

Phosphorus Nutrition in Higher Plants

Cell Buffer Systems

Since phosphoric acid is a tri-acid, its successive dissociations forming different charges (e.g., $H_3PO_3^{+3}$, H_3PO_{+2}, P^0, $H_2PO_4^-$, HPO_4^{-2}, PO_4^{-3}) allowing P to buffer the cell pH and maintain homeostasis (internal equilibrium).

Metabolism Regulation

Levels of inorganic P regulate the activity of several enzymes such as phosphofructokinase (regulates climacteric respiration in ripening fruit and the conversion of starch to glucose) and ADP-glucose pyrophosphorylase (involved in control of starch synthesis)

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Energy Carrier

Inorganic P is involved in the transfer of energy within the plant cell and the plant. This energy transfer uses P-P bonds with energy stored when a P-P is formed and released with the breakage of the P-P bonds. The most common P-P bonds are found in diphosphate nucleotides (mainly adenosine diphosphate, ADP) and triphosphate nucleotides (mainly adenosine triphosphate, ATP). ATP is the primary energy currency and carrier used in plants. When ATP gives off an inorganic P, it releases energy and forms ADP. ATP is regenerated when an inorganic P is reattached to ADP from phosphocreatine, when another energy rich inorganic P bond is broken. Energy released from the conversion of ATP to ADP may be used for biosynthesis or ion uptake. Another source of energy in plants is the reduction of nicotinamide adenine dinucleotide phosphate ($NADP^+$) into NADPH. Energy from this reaction is used in respiration, glycolysis and CO_2 fixation.

Nucleotides

Phosphorus is part of genetic material of the plant. Mono-, di- and tri- phosphates are constituents of nucleic acids (DNA, tRNA, mRNA and rRNA). Additionally, uridine triphosphate (UTP) is required for sucrose and callose synthesis; cytosine triphosphate (CTP) in phospholipid synthesis; and guanidine triphosphate (GTP) in cellulose formation.

Energy Reserves as Phytin in Seeds and Fruits

Phytin is the Ca or Mg salt of phytic acid (also known as inositol hexaphophoric acid). Phytin is believed to be the primary compound to store organic P in seed and fruit. Phytin in the fruit is often used to supply P to the maturing seed. During seed germination, phytin stored in the seed is hydrolyzed to free inorganic P, which is used to form organic compounds for energy transport, cell wall formation and other metabolic processes.

Constituent of Organic Molecules

Phosphorus is an integral part of membrane phospholipids (phosphatidyl inositol, phosphatidyl serine and choline). It serves as an anchor for lipids constituent of some lipo-proteins and lipo-polysaccharides. Phosphorus plays are role in membrane permeability and structural integrity of phospholipids.

Adequate Range and Nutritional Disorders

Sufficiency Range

Phosphorus concentrations in mature leaves of most plants range from 0.2 to 0.5%. Phosphorus content in actively growing plant parts is higher because of the need for extensive formation of complex molecules (anabolism) that require multiple energy-transfer reactions involving ATP.

Deficiency

Phosphorus deficiency generally occurs when the P content of a plant is below 0.2%resulting in a purple coloration initially on the older leaves. Phosphorus deficiency can be caused by low soil temperature. This is particularly prevalent in temperate climates with early-spring planting, where cool, wet soil conditions can reduce root growth and the ability of the root to mine the available P outside the current root volume through normal root growth into new soil containing available P.

Figure 5-1. Phosphorus deficiency commonly occurs in cool/wet soils and soilless media.
Left corn seedlings in soil with leaves showing purple coloring on edge of leaf.
Right pansy plants grown outdoors in cool weather in soilless media showing purple coloration on older leaves.

This is why high phosphorus fertilizers, e.g., 6-24-6, 9-18-9, 3-18-18, are used as 'pop up' or starter fertilizers with some field grown crops. These fertilizers are applied in furrow or close (*two inches to the side of the plant stem*) to the young seedling or transplant.

Phosphorus deficiency results in retarded growth and a lowered shoot/root ratio. Deficiency symptoms include a darker green color in the older leaves, followed by purplish color.

5-2. Phosphorus deficiency in Tomato leaves.

Figure 5-3. Phoshorous deficiency.
Left gerber daisyleaf showing purple coloration.
Right arugula seedling with puple stem.

Necrotic (dying) tissue along the leaf margins may also appear. Deficiency results in low production of fruits, seeds, and flowers, and also poor plant and fruit quality.

Toxicity

Very high P levels in the growing medium can depress growth, primarily by decreasing the uptake and translocation of Zn, Fe and Cu.

Interactions with other Nutrients

Nitrogen

For many crops, a N:P of 10:1 is considered optimum. In alkaline soils ammonium-based fertilizers increase the availability of P because of their acidifying effect, while nitrate-based fertilizers can suppress P uptake.

Calcium

Increased Ca in solution increases P uptake. It has been proposed that this is because Ca stimulates the transport of P at the mitochondrial membranes. However, all calcium phosphate salts have low solubility in water at high pH.

Magnesium

Magnesium is an activator of kinase enzymes. Kinase enzymes are responsible for the transfer of phosphate groups from donor compounds, such as ATP, to acceptor compounds, typically proteins, and thereby releasing energy for metabolic use.

Aluminum

Aluminum can form aluminum phosphates in the intercellular regions of root tips that can restrict P translocation to the rest of the plant, thus inducing a P deficiency. However, Al uptake is often accompanied by increased P uptake, and high root P levels often occur with high Al levels. It is unclear, though, if this P is available for use by the plant.

Iron

Iron is believed to interfere with the absorption, translocation andassimilation of P by forming iron phosphates.

Zinc

High levels of P will induce Zn deficiency symptoms in plants even when adequate levels of Zn are found in the tissue. Conversely, high levels of Zn have been found to interfere with normal P metabolism.

Fertilizer Additions and Management

Phosphorus (P) is generally applied in the form of phosphate. Phosphate solubility in the soil is reduced at low pH by the formation of aluminum compounds, and at high pH by the formation of calcium compounds. Since soluble P in agriculture soils is generally low, leaching of P is generally limited. The greatest loss of P from the soil is by soil erosion. Plant P uptake depends on roots growing to where P is located, so P deficiency is common in cool, wet soil early in the spring when root growth is slow. This also occurs in dry soils where soluble P in the soil is low, and also root growth is slowed.

Application of soluble P in a starter solution for early crops often increases early seedling vigor. Care must be taken in applying P fertilizers in irrigation water especially in water high in Ca (i.e., hard water conditions), since formation of insoluble compounds can clog the system and reduce the availability of P to the crop. In some cases high pH water can cause problems related to nutrient availability and/or efficacy of chemicals mixed with irrigation water. In such cases, phosphoric acid can be injected into the irrigation system to lower soil pH and at the same time supply P to the cropped soil, however, care should be taken when injecting fertilizers or other products containing Ca. since Ca and P can react forming insoluble compounds which clog filters and reduce the availability of both nutrients to the crop. Actual amount of P applied should be based on soil test and/or tissue analysis results. Application rates for high value vegetable crops commonly range from 89 to 178 kg ha^{-1} (100 to 200 lbs/ac) of P_2O_5, or about 36 to 71 kg ha^{-1} (40 to 80 lbs) of actual P.

Phosphorus Forms

Phosphorus is typically provided in fertilizers as orthophosphate and polyphosphate. The orthophosphate form is the predominant from of P taken up by many plants. Polyphosphate is not normally taken up until it is converted to orthophosphate. Under warm, moist conditions, comparisons of ammonium polyphosphate and ammonium orthophosphate have resulted in no consistently significant differences in P concentrations in the tissue of several crops. However, at low soil temperatures, P as orthophosphate has produced slightly higher plant P concentrations, indicating poor hydrolysis of the polyphosphate at low temperatures. This would indicate an advantage of high orthophosphate fertilizers as starter fertilizer in early spring. Also, P as orthophosphate seems to offer a slight advantage for rice grown under flooded soil conditions.

Phosphorus Compounds

The source of P affects plant P concentrations and the concentrations of several other nutrients. An experiment using potato compared the P concentration in leaf petioles produced by applying each of the following P fertilizers: concentrated superphosphate (CSP), monoammonium phosphate (MAP), ammonium polyphosphate (APP), rock phosphate (RP), and 10% and 20% acidulated rock phosphate ($ARP_{10\%}$ and $ARP_{20\%}$). Diammonium phosphate (DAP) was not used in this study. The resulting petiole P concentrations were: 0.21% for MAP, 0.20% for $ARP_{20\%}$, 0.18% for APP, 0.17% for $ARP_{10\%}$, 0.17% for CSP, 0.14% for RP, and 0.13% for no P applied (0P). In another study, P content of soybean tops was found to be related to the source of P applied: 0.35% for DAP, 0.31% for MAP, 0.29% for APP, 0.28% for no P applied, and 0.26% for monocalcium phosphate (MCP). Manganese content of soybean tops were in the following order: DAP > MAP > APP > 0P with no applied Mn. The order changed to MAP > APP > MCP > DAP > 0P when 25 ppm Mn was added to the P fertilizer treatment. Comparisons of superphosphate (SP) and concentrated superphosphate (CSP) resulted in almost equal P concentrations in leaves of several citrus varieties grown on slightly alkaline soils. But CSP was found more effective than SP in raising the leaf P content of trees grown on acid soils. Soft rock phosphate (SRP) gave slightly higher leaf P values than did rock phosphate (RP) for both acid and alkaline soils. The use of CSP tended to produce higher leaf Mg, but lower K contents than the use of SP. Generally, differences among the P sources SP, CSP, MAP, DAP, trisodium phosphate (TSP) and liquid phosphoric acid in supplying P to typical crop production soils with more neutral pH are not readily discernible. The P supplied by this group is usually greater than that supplied by RP, ARP, SRP, basic or Thomas slag, fused Mg phosphate, or nitro-phosphates. However, differences in supplying P to crops may vary based on both the crop and soil type.

The relative effectiveness of the different phosphate materials for increasing yield and plant P content has been attributed to the water-soluble P content of the material. This approximates 20% for SP, 46% for TSP or SCP, 50% for MAP, and 54% for DAP. Other phosphate materials with little or no water-soluble P content will have influence on affect plant P concentration to a much lesser degree. The difference in P concentration with these products is due to the variable amounts of citric acid soluble P they contain. The amounts of citric acid soluble typically vary from about 10% to 20% for basic or Thomas slag, about 20% for fused Mg phosphate, and about 30% for rock phosphate.

Those P fertilizer sources that contain little water-soluble P can be used effectively for such crops as buckwheat, cabbage, clover, lupine, mustard, rape, and Swiss chard. Their relative efficiency increases as particle size is reduced (greater surface area for exposure to roots and soil solution) and when the soil pH is < 5.5. Water-soluble P may be increasingly leached from the rooting profile as the percentage of sand and gravel content of the soil increases, and as the climate becomes more tropical. Many of the above crops that can effectively use P fertilizers with little water-soluble P are cool season crops grown in more temperate zone. High water solubility may be of little advantage in providing P to the plant if the soil has a high P-fixing capacity, and/or the P fertilizer is broadcast and/or is acidic with a high soluble Al level. This is part of the reason for applying water-soluble liquid starter fertilizers high in phosphorus in the furrow or close to the roots. By doing so, makes phosphorus readily available to the young plant's roots, thus reducing the percentage of loss due to leaching, fixing to soil particles, or forming insoluble aluminum phosphates.

Phosphorus Availability

Besides reducing plant P concentrations, low or deficient substrate levels of P have been found to be associated with lower concentrations of N, K, Ca, Mg, and Fe in sweet potato tops; and lower K and Zn and higher Cu, Fe, and B contents in rose leaves; lower N, but higher S, K, Ca, Mg, and Na contents in lettuce; lower N and Mg, but higher K, Mg, Fe, Mn, and B contents in *Dracena godseffiana* plants; lower N, K, Ca, Mg, S, B, and Mn, but higher Fe in *Dracena sanderiana* plants; lower N and K but higher Ca, S, and Mn contents in mature leaves of *Dracena deremensis* `Warneckii'; lower Ca and Mg, but higher K, Al, Cu, Mn, and Zn contents in pear leaves; and lower Ca and higher K, but little effect on N or Mg contents in mature spinach leaves. In a study of 11 flowering plants, the lack of P was associated with lower N, K, and Ca, but higher Fe and Mn contents in leaves, with B associated with lower N, K, and Ca but higher Fe and Mn contents in leaves, with B and Mg leaf contents being about equally lowered or raised.

The use of heavy (5x) application rates of P are associated with higher concentration of P, N, Ca, Mg, B, and Mo, but lower K, Fe, and Al contents in pear leaves with B, Cu, and Zn contents in pear leaves not affected. Doubling the P concentration in solution culture from 31 to 62 ppm increased P, K, and Cu but lowered B and Zn concentrations in rose leaves. Large applications of P have resulted in deficiencies of Cu, Fe, and Zn. Nitrogen applied with P often increases the concentration of P in plants, but the increase varies with the type of N as well as with soil conditions. No increase may occur, however, if plant growth dilution effects are greater than the enhanced P uptake.

Generally, the increase of P is more marked with ammonium-N than with nitrate-N nutrition. Various reasons for this effect have been proposed: increased availability of P in the soil due to soil pH changes induced by the form of N; increased root growth resulting from N application, and therefore greater P uptake; more N compounds in the leaves as a result of the N application, requiring greater amounts of P; and increased transfer of P across the initial cellular barrier; and the movement of P into the xylem. Phosphorus supply has an effect on total N and nitrate-N composition of some plants. As seen in Table 5-1, the effect varies with the location on the plant.

Table 5-1. Effects of phosphorus supply on the percentages of Total N and NO_3-N in soybean (Hewitt, 1963)

Stem Position	Total N		NO_3-N	
	Minus P	Plus P	Minus P	Plus P
	%			
Upper	2.28	2.34	0.176	0.363
Middle	3.12	1.73	0.182	0.434
Lower	3.20	1.16	0.262	0.172

Phosphorus-Aluminum

The P concentration of a number of plants is decreased as Al is increased, and the decrease is less for cultivars tolerant to Al. The decrease in P concentration is also less in the roots than in the tops or leaves. Conversely, plant Al concentration is decreased as soil P increased. The close association of Al and P concentrations in the plant has prompted the suggestions that Al toxicity is due in large part to its negative effect on the P supply in the plant. This can occur as a result of P being precipitated on the root surface, or within the root tissue (that is, within the “apparent free space” of the root) as some form of aluminum phosphate. Alternatively or additionally, the P content in the plant may include the effect of absorbed Al upon P metabolism in the plant. Evidently, one of the beneficial effects of applied P to acid soils is the reduction of toxic levels of Al. Occasionally increased P concentration will result from Al additions. This may be a result of impaired membrane integrity resulting from lack of Ca in solution culture experiments that are conducted with little or no Ca in the nutrient solution.

Phosphorus-Calcium

High concentrations of Ca in the soil may have variable effects on P levels found in plant tissue, depending upon the type of soil and soil pH. In heavier textured soils with greater content of clay and oxides of Fe and Al, large amounts of Ca promote desorption of adsorbed P, thereby enhancing its uptake by plants. However, high soil Ca can precipitate appreciable quantities of P, especially if at high soil pH. The adverse effect of Ca upon P availability is greater with lighter textured soils.

Calcium does appear to stimulate the uptake of P, but may be only important at low concentrations of P and lower pH ranges. Since high pH promotes the formation of relatively insoluble forms of Ca phosphates, such enhancement of available P by Ca is probably limited to Ca sources or amounts that do not increase the soil pH into the range from 6.5 to 8.3. In other words, soluble P declines as the pH rises from 6.5 to 8.3.

Phosphorus-Magnesium

Phosphorus fertilization reduced the Mg content of tomato and spinach leaves and increased the Mg concentration in apple leaves. The effect of applied P on plant Mg may well be determined by the amount of P or P plus lime added. Applications of 10, 40, and 120 ppm P to gravel culture nutrient solutions resulted in 0.42, 0.51, and 0.39% Mg contents, respectively, found in chrysanthemum leaves. When Mg was added to the nutrient solution, the P content increased in chrysanthemum leaves, stems, and roots. An increase of P in a sandy soil lowered the Mg concentration in tomato leaves, but the reduction in Mg was greater as less lime was added. Applications of Mg as either dolomite or $MgSO_4$ increased the P content found in watermelon leaves.

Phosphorus-Micronutrients

In a great number of plants, deficiencies of Cu, Fe, and Zn have been associated with high concentrations of P in the substrate. Studies have shown that these micronutrients are reduced in concentration in plant tops as P availability is increased. The adverse effect of P on plant concentrations of Fe and Zn is more pronounced at a high pH because the availability of these micronutrients is reduced in the rhizosphere by high pH. N modifies the reduction of Zn concentration by high P to some extent and K. Nitrogen promotes both the uptake and utilization of Zn, while K favors Zn by suppressing P. Not all deficiency symptoms of Fe and Zn brought about by high levels of P are caused by reduced concentrations of these micronutrients. Often the plant concentration, particularly of Fe, is just as high in a Fe deficient plant. Deficiency symptoms are associated more with high P:Fe and P:Zn ratios than with the actual concentration of either Fe or Zn. Attempts have been made with little success to quantify the ratios associated with these deficiencies. The failure to firmly establish either a critical P:Fe or P:Zn ratio appears to be due to either caused by genetic variations within a crop, the interactions of P and Fe/Zn with other ions, the complexities of extracellular P, or just the simple lack of understanding of sufficiency levels for Fe and Zn. In the case of Zn deficiency induced by excess P, Fe plays an apparent role with high Fe concentrations being present in the Zn-deficient plant. In some cases, Fe deficiency is associated with lower soluble plant Fe (i.e., the Fe soluble in dilute acid), but is not correlated with total Fe concentration. It would be useful to know whether high levels of P reduce the level of soluble Fe in the plant.

There have been conflicting reports as to what effect P has on the plant content of Mn. It has been postulated that enhanced Mn concentration of soil-grown plants resulting from P applications result from both a lowered soil pH plus an interaction effect of increased levels of Mn in the soil solution, coupled with an antagonistic effect of the accompanying cation. Adding superphosphate to soils with a pH below 5.0 raises the pH, which, in turn, decreases the available Mn. But adding superphosphate to soils with pH levels above 5.5 decreases the soil pH, thereby increasing Mn availability. It has been shown that increasing P may have a positive, neutral, or negative effect on the Mn concentration of cotton, depending upon the Ca:P ratio in solution. At low concentrations of Ca (Ca:P = 1:2), Mn concentrations increase with increasing P. At Ca:P ratios of 1:2 or 1:1, the highest plant Mn was obtained with the lower [0.2 mgL^{-1} (ppm)] solution P content. Plant Mn progressively decreased as the ratio of Ca to P increased from 2:1 to 4:1.

Phosphorus-Beneficial Nutrients

The application of silicates have increased yields, but this result has been attributed to an increase in available P. Silicates increase P availability from (1) the binding of excessive Al by silicates; (2) the competition of silicates with P on clay adsorption sites, thereby releasing P into the soil solution; and/or (3) more efficient use of P within the plant due to silicates. Rice, a plant that responds favorably to additions of silicon (Si) fertilization, showed increased leaf and stem P concentrations with Si additions, but only when grown in solutions containing low levels of P. At more adequate levels of P, the addition of Si reduced P concentration in the leaf and stem tissues. However, there was an increase in the P concentration of the grain.

Another beneficial, but not essential nutrient is selenium (Se). When applied at 2.5-10 mgL^{-1} (ppm) to a sandy soil, the P concentration of wheat tops drop. This mutually competitive relationship between P and Se permits the use of large applications of P to overcome the toxic effects of Se.

Chapter 6

Potassium (K)

Atomic Number: 19
Atomic Weight: 39.10

Discovered by Davy in 1807
Proven to be essential to plants by von Sachs and Knop in 1860

Potassium in the Soil

Forms

In soils, K exists as: (a) a structural component of primary minerals; (b) fixed K between the lattices of clay minerals; (c) as adsorbed and exchangeable ion on the surface of soil colloids; and (d) a solute in the soil solution. Total K content ranges between 0.5 to 2.5% in most soils, which represents approximately 0.5 to 25 tons of K per acre (1.1 to 5.6 metric tons of K per hectare). However, only 0.1 to 2% of total soil K is readily available to plants.

Dynamics

The weathering of K-containing feldspars and micas results in the release of K into the soil solution, thereby allowing K to become available for plant uptake. This K also becomes attached to the surface of soil particles as exchangeable K. Potassium also may migrate between the lattices of clay particles and become trapped. This process, called K-fixation, is of importance in agriculture with clay soils since 1 to 2g K may be fixed by 100g of clay minerals.

Fertilizers

The main fertilizer sources of K are potassium chloride (KCl), potassium sulfate (K_2SO_4), potassium nitrate (KNO_3), and the natural double salt potassium magnesium found in langbeinite and commercially known as Sul-Po-Mag or K-Mag (0-0-22-11Mg-22S). Because potassium magnesium sulfate is a very abrasive crystalline product and somewhat poorly soluble in water, use of this fertilizer has traditionally been limited to soil applications. More recently liquid fertilizer with the same nutrient ratios as Sul-Po-Mag called Nutra-Boost® (6K–3Mg–6S) was developed by AgriGuardian™. This product can be applied directly to the soil or foliar applied to plants (see Fig. 19-2, p. 217).

Potassium Uptake and Assimilation by Higher Plants

Movement to the Root

Principal movement of K in the soil is by diffusion, moving in solution from exchange sites on soil particles or from fixed K (nonexchangeable) in the clay lattice through the soil solution to plant roots. Since diffusion is a relatively slow process, K fertilization is needed to maintain high levels of exchangeable, nonexchangeable, and soluble K in the soil to enhance rates of diffusion. Increased uptake by rapid plant growth will deplete K in the soil solution and from the soil particles adjacent to roots. When nonexchangeable, exchangeable, or soluble K is readily available in the soil, good soil moisture and warm temperatures increase the movement of K from the soil to the root and ensure adequate levels to plants to sustain growth.

Uptake

Potassium is absorbed (taken up) by plant roots as a free cation (K^+) in greater quantities than most other nutrients except N. During peak demand periods, actively growing crops may require up to 3 to 4 pounds of K per acre per day (3.4 to 4.5 kg of K per hectare). Plants usually absorb most of their K during the first half of their growth cycle. However, critical peak demand periods for K absorption exist for most crops, with especially high peak demand during flower and fruit development. For example, low potassium availability and uptake at grain-fill in corn and pod-fill in soybeans may limit yield potential of these crops. Depletion of available K (and N) at these final stages of crop development can suppress yields markedly.

Enhanced K uptake by roots has been attributed to the presence of ionophores, lipid-soluble molecules that bind to K^+ and then facilitate the transport of K across cell membranes into the root cells. Potassium is also absorbed by an active ATPase system, and consequently the oxygen level in the soil affects potassium uptake, since this active transport system requires energy from respiration. Potassium accumulation is generally very sensitive to oxygen depletion in the soil.

Translocation and Assimilation

In the plant, the main direction of K transport is upward in the xylem. Redistribution from older to younger leave occurs in the phloem. For K to move downward from shoot tissues to roots, it is thought that K binds with malic acid (malate) prior to translocation in the phloem into the roots. When K is foliar applied, such as with AgriGuardian™ Nutra-Boost®, the rapidly absorbed K is used at the point of absorption (leaves, stems, reproductive structures), or it is quickly moved to locations of greatest demand for K, i.e., K sinks

Potassium Nutrition in Higher Plants

Essential Roles

Potassium is involved in maintaining plant water movement within the plant, maintaining cell turgor pressure and controlling the opening and closing of stomata. Potassium also plays an important role in the upward (xylem) transport of nutrients, including nitrate, phosphate, magnesium, and calcium. Since the opening of stomata affects the availability of carbon dioxide and oxygen, K has an indirect control over photosynthetic activity and respiration.

Potassium also affects membrane functioning and participates in. the formation of adenosine triphosphate (ATP), the high-energy product in photosynthesis. When K is deficient, processes dependent on ATP production are slowed down, including the accumulation and translocation of newly synthesized carbohydrates. This role is particularly important during grain-filling period of crops like corn, wheat, and soybeans. When K deficiency slows transport, sugars and starch tend to accumulate in the leaves and stems where they are formed, thereby reducing the amount accumulated in roots, fruit, and seed (grain) where they are normally stored.

Potassium also is involved in the utilization of carbohydrates in the synthesis of cellulose, which provide strength and rigidity to plant structures, including leaves, stems, and fruits. With K deficiency, cell walls and stems are weakened and plants will lodge (fall over) either by breaking, bending, or collapsing, and fruits are soft. In crop production lodging occurs most often as a result of heavy winds or blowing rain on the weakened plants.

Potassium also is involved in the formation of proteins and is involved in the activation or stimulation of numerous enzymes involved in plant metabolism. When K is deficient, soluble carbohydrates and N compounds accumulate, but with adequate K, starch and proteins accumulate in storage organs, e.g., grain.

Because of the many roles of K in the plant, it affects the yield and the quality of crops, including nutritional value and shelf-life of fruits and vegetables and the protein and carbohydrate content of grains. Potassium can counter the negative effect of high nitrogen on fruit and vegetable quality.

Adequate Range and Nutritional Disorders

Sufficiency Range

In healthy, recent fully developed leaves, the typical sufficiency range for K is 1.5 to 4% on a dry weight basis, with a N:K (w:w) ratio of 1:1. With stem tissue of some vegetable crops, sufficient range for K can be as high as 6 to 8%. Highest concentrations of K are in new leaves, petioles, and stems. High-yielding crops absorb between 50 and 500 lb K/acre (56 and 560 kg ha^{-1}). However, many plant species absorb more K than they need. Excess accumulation is frequently referred to as 'luxury consumption'. This accumulation does not affect yields but adds to the expense of crop production as K is removed without any increase in yield.

Deficiency

Since K is mobile in the plant, deficiency symptoms first appear in old tissues.

Figure 6-1. Potassium deficiency in soybeans.

For most crops, K deficiency symptoms usually begin as a light green to yellow color around the edges and tips of the old leaves.

Figure 6-2. Various stages of potassium deficiency in soybean.

Old leaves that are severely K-deficient look as if they had been burned along the edges, a symptom commonly known as 'scorch'.

Figure 6-3. Soybeans Left picture and Basil Right showing leaf edge scorch from potassium deficiency.

Deficient plants easily lodge and are more sensitive to diseases because of thin cell walls. Similarly, K deficiency negatively impacts the yields of grain, fruit, and flowers as well as their overall quality and shelf life. Potassium deficiency typically affects yields and quality factors of crops prior to the onset of visual symptoms. This ‘hidden hunger’ is particularly of concern at critical stages of crop growth, such as at grain fill, fruit swelling, and root enlargement. Red ginger is susceptible to potassium deficiency where the flower used in the cut flower market shelf life is diminished when potassium is deficient.

Figure 6-4. Red ginger older leaves showing the beginning of potassium deficiency expression on the leaf margin.

Figure 6-5. Tomato older leaves showing potassium deficiency expression on the leaf.

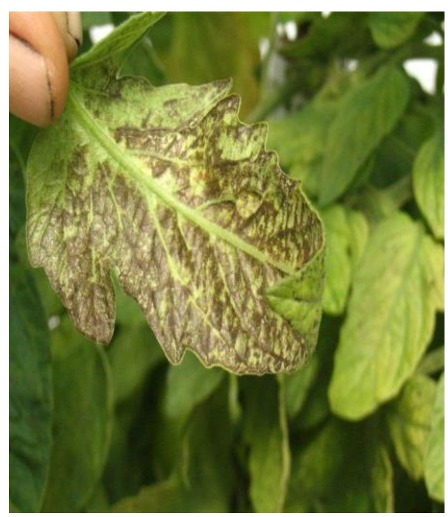


Figure 6-6. Corn leaves showing severe potassium deficiency on leaf margin.

Figure 6-7. Potassium deficiency in sugar cane on the lower leaves.

Figure 6-8. Gerbera Daisy older leaves showing initial stages of potassium deficiency expression on the leaf as chlorosis on the leaf margin, which then continues to cause a chlorotic leaf prior to characteristic death of the cellular tissue and necrotic leaf edge scorch.

Figure 6-9. Left-Arugula with potassium deficiency and Right-geranium leaves with potassium deficiency in older leaves.

Figure 6-10. Heirloom roses with potassium deficiency showing a red necrotic tissue on the edge of the leaf.

Toxicity Symptoms

Accumulation of K above luxury consumption in plant tissues can induce Mg deficiency and, in some cases, Ca deficiency, because excessive K causes an imbalance in the K in relation to Mg and Ca, especially if Mg and Ca are at the low end of their sufficiency range in the plants.

Interactions with other Nutrients

Potassium is taken up as K+. Having a positive charge, K interacts with other major cationic nutrients in relationship to their uptake and accumulation within plant tissues. There is an interaction among ammonium nitrogen (NH4+), calcium (Ca+2), magnesium (Mg+2), and sodium (Na+) with K+ since these are the predominant cation nutrients in the soil. Sodium (Na+) is not a plant nutrient. and is less of a concern related to K+ except in high-sodium growing environments. Because of these interactions, it is necessary to consider the relationships of (1) tissue concentrations of these cations and (2) the quantity of each nutrient that is available either in the growing medium (e.g., soil) or is applied as fertilizer to the growing medium or applied directly to plant (e.g., foliar fertilization).

The sum of cations, K+, Ca+2, and Mg+2 as chemical equivalents (commonly expressed asmeq or milliequivalents/100g), is fairly constant in most plants tissues. The use of meq takes into consideration the chemical charge of the individual nutrients, instead of simple percentages of nutrients by weight. With potassium, Ca+2 and Mg+2 influence the uptake and concentrations of K+ in plant tissues, but Ca+2 and Mg+2 do not individually have the same influence on K+ because they have different equivalent concentrations for the same quantity (weight) of nutrient. Expression as percentages by weight tends to minimize the influence of Mg+2, while magnifying the influence of K+ in the total accumulation of cations in plants. The equivalent concentrations of K+, Ca+2, and Mg+2 in plant tissue can be calculated in meq/100g by multiplying their percentages by 25.57, 49.90, and 82.24, respectively.

Calcium and Magnesium

The levels of competing or antagonistic ions affect the concentration of K, Ca, and Mg in plant tissue. Thus, the relative level of any one or two of these cations also has an influence on the plant concentration of the second or third cation. Potassium seems to be the most reactive of the three cations, having a greater depressing effect on Ca and Mg than does either Ca or Mg have on K plant content. Magnesium has a greater depressing effect on K plant content than on Ca content in some plants. Calcium appears to be less antagonistic to Mg than to K. Evidently there is a strong mutual antagonism between K and Ca, since high concentrations of both of these nutrients seldom exist in plants together.

Although the K:(Ca+Mg) ratio and sum of K, Ca and Mg as equivalents in plant tissue tends to be constant, variations are caused by the source of N, stage of growth, lime additions, and deficiencies of either Mg or K. The use of nitrate favors cation uptake, although sodium nitrate can depress Ca uptake. Total cations in plants tend to increase with age when levels of K in the tissue are low. Total cation amounts also tend to increase when lime is added, possibly due to the replacement of the H^+ cation on the exchange complex with Ca when lime is applied, or by Ca and Mg when dolomitic limestone is used as the liming material. Total equivalents of cations tend to decrease if either K or Mg is deficient.

When Ca and Mg remain at the same level, the ratio K/(Ca+Mg) increases as growing media K increases and decreases with increasing Mg or Ca in the growing media. The percent of K in oat straw is lower, even with higher K in the growing medium, with increasing N, Mg, and Ca content in growing medium. With low levels of N and K, increased Mg levels in the growing media decrease Ca content in the straw. The effect of Mg on the Ca content of the straw is reduced as the level of either K or N increases in the growing medium. Increasing the K level in the growing medium lowers the Mg content in oat straw. With lower N and higher Ca, Mg concentration is even lower.

Plotting the concentrations of K, Ca, and Mg from the analysis of a large number of corn ear leaf samples has disclosed five different combinations of antagonism for each of these nutrients upon the others. These combinations can be summarized as follows:

1. K deficiency where K-Mg antagonism is most striking and the meq of K is 25% or less of the total cations.
2. Intermediate K level where K-Ca and K-Mg antagonisms are present and the meq of K makes up about 25% to 40% of the total cations.
3. Higher intermediate K level, in which the meq of K is 40% to 60% of the total cations, Ca is 30% to 42%, and Mg is 10% to 18%. K-Mg antagonism is less marked and K increases largely at the expense of Ca.
4. High K level, which favors K-Ca antagonism. The concentration of meq of K is 60% to 70%, Ca is 22% to 30%, and Mg is 8% to 12% of the total cations.
5. Very high K level consisting of the meq of nutrients over 70% K, 22% Ca, and 8% Mg with marked K-antagonism and a potential for Mg deficiency. Deficiency of Mg occurs when its concentration falls below 6% of the total cations.

Figure 6-11. Example of magnesium deficiency symptoms in basil caused by high potassium accumulation in the foliage and the antagonist effect on magnesium.

Despite the interrelationships among K, Ca and Mg in plant tissue, critical values based on percent of these nutrients are usually not seriously affected unless the ratio of one of these nutrients to another is very wide. In corn, for instance, a ratio of K:Mg of 10:1 or less in the ear leaf is satisfactory, but a ratio of 14:1 can seriously restrict growth, even though Mg is above the critical concentration of 0.3% Mg in each ratio. Symptoms of Mg deficiency appear as it did in Figure 6-9 even though Mg is boarder line deficient.

Percent Base Saturation in Soil

The concentration of K, Ca, and Mg in plant tissue is dependent to some extent upon the relative saturation of these cations on the soil exchange complex. Some soil scientists have proposed an *ideal* percentage saturation of 65% to 75% for Ca, 10% to 15% for Mg, and 2.5% to 7.0% for K. Attempts to bring the cation exchange complex of the soil to these ideal percentages has not led to higher yields. It appears, however, that extreme ratios should be avoided. For example, Ca deficiency is not likely unless the ratio of Ca:Mg as meq is <2:1, and Mg deficiency is not likely until the ratio > 20:1. Using percent by weight instead of meq, these ratios are <3.3:1 and >33:1, respectively.

Nitrogen

Levels of K and N are related closely in most plants. In general, abundant N increases sensitivity to disease infection, whereas K increases resistance to infection. Nitrogen stimulates rapid, soft growth, and adequate K balances this effect by promoting the growth of firmer tissues.

Not only are K and N present in similar concentrations in leaves of most crops, but their response to applications of either nutrient often is dependent on the actual level of the other. Applications of K without sufficient N may lead to decreased N content in young plants. Without sufficient K, N was found to increase in outer cabbage leaves as well as in tomato upper stems and leaves.

The source of N has a bearing on the accumulation of K. An increase in nitrate levels tends to result in K accumulation, whereas ammonium accumulation tends to depress K concentration. Increasing Ca levels tends to nullify the negative effects of increased N on K uptake. Ammonium has a greater depressing effect on K in soil-grown plants than those grown in solution culture because it interferes with the diffusion of K from the clay lattice in addition to competing with K for uptake.

Potassium also influences the uptake and utilization of the two forms of N. The uptake of nitrate is enhanced by K, a factor that is thought to be one of the essential functions of K. For most crops, larger amounts of ammonium can be used without causing toxicity when the amount of K in the tissue is increased. This phenomenon suggests the existence of an optimum NH_4:K ratio for growth. In tomato, the occurrence of stem lesions increases as the NH_4:K ratio in the growing medium exceeds 1:4.

Sodium

Because K and Na ions are univalent cations, Na may replace K in several of its essential roles in some plant species. However, K is an essential nutrient, and Na is not. Sodium applications may reduce the effect of K shortage but will not result in healthy plants when K is deficient. The extent of this substitution is dependent on plant species (occurring primarily with C-4 plants) and the amount of K present.

Sodium substitution for K can be substantial in plants such as sugar and table beets, spinach, turnip, and Swiss chard, but only if the level of available K is low. Substitution is small or non-existent in plants such as barley, buckwheat, corn, flax, millet, rape, rye, soybean, and wheat. This substitution of K by Na may make the interpretation of K status difficult for some plants. In the case of sugar beets, for example, this problem can be avoided by using the leaves rather than the petioles for K diagnosis. Under saline conditions, Na concentrations in several tropical and temperate crops may be reduced by applications of potassium chloride (potash).

Potassium Fertilizer Additions and Management

The concentrations of potassium in fertilizers ranges from about 2% to 60% expressed as oxide (K_2O) (Table 6-1). Plant residues, vegetative portions and rinds, hulls, and husks, are good sources of potassium, and all of the potassium in these materials is water-soluble and available. Farm manures have less potassium, about 2% K_2O, than the feed which the livestock received. Much of the potassium is eliminated with the urine of large animals and frequently is lost. Composts are also much lower in potassium than the original plant material, about 1% K_2O, because much of the potassium is lost by leaching during composting. Since manures and composts are of plant origin, their potassium is water soluble and is fully available to plants. However, because of the low concentrations of potassium in manures and composts, large applications of these materials are needed to provide the amounts of potassium required for crop production.

Once it was believed that soils did not require potassium fertilization because of the high total contents of potassium in soils. People who held this belief were unaware of the chemistry of potassium in soil. They did not realize that most of the potassium in soils is held in the primary minerals and as such is unavailable to plants. The fertility of a soil with respect to potassium depends on the amounts of potassium that are held in the exchangeable and nonexchangeable forms and to a much lesser extent on the amount in the primary minerals. The soluble fraction is important only in fertilized soils. In some soils, the exchangeable and soluble potassium are soon exhausted and not replenished from the reserves in the primary minerals. These soils are said to have a low potassium-supplying power. Several years may be required before the weathering of the primary minerals is sufficient to restore available potassium to a level to support production of a good crop. The length of time for restoration to occur is related somewhat to the total potassium in the soil. Generally, the more total potassium in the soil, the more that is available for weathering, and the faster the restoration. Restoration will be much slower in a sandy soil than in a clay soil. On the other hand, the more intensive the crop production, the faster available potassium will be depleted from the available sources.

Fertilization of crops with nitrogen and phosphorus enhance crop yields and accelerate the rate of depletion of potassium from soils. Squanto, the American Indian whom some people call our first extension agronomist, taught The Pilgrims to fertilize corn by placing fish in the hills. Yields of corn were raised, and in a few years, the available potassium was depleted from the soils of Massachusetts. These soils had a poor potassium-supplying power, and the productivity of soils was lost because of depletion of available potassium. In Squanto's time (about 1630), potassium had not been discovered as an nutrient (discovered about 1790), and nothing was known about its requirements by plants (essentiality demonstrated about 1860). However, if the Pilgrims had used wood ashes or seaweed in their fertilization program, productivity of fields could have been maintained better than with the fish alone.

The concentration of potassium often increases with depth into the soil. More unweathered primary minerals are found deeper in the soil than in the topsoil. Deep plowing turns up these minerals and enriches the topsoil with potassium. This action does not increase the fertility of the soil, for these unweathered minerals have very low capacities to supply potassium to the available pool. In fact, erosion, which removes the top layers of soil, may lead one to believe that the potassium fertility of soil has not been reduced by erosion. Removal of the top layers exposes layers with higher total potassium concentrations than the original pre-eroded soil, but in this case, the higher potassium is due to higher relative amounts of unweathered primary minerals, which have very low capacity to supply potassium to a crop. In fact, the potassium-supplying power of a soil is diminished by erosion because of the loss of the fine particles, which are more subject to weathering and more likely to contain soluble or exchangeable potassium than soil particles from deep zones.

Potassium is generally applied as a compound with chloride, sulfate, or nitrate. Potassium nitrate is the most effective source of increasing potassium in the plant followed by potassium sulfate and lastly potassium chloride. Potassium chloride (muriate of potash, or simply, potash) should be avoided in certain specialty crops such as leafy crops, as the chloride can cause foliar burn. Potassium is positively charged, so it can be retained on cation exchange sites. Potassium remains soluble in the soil and undergoes little chemical or biological transformation. Soil testing is used to determine actual K levels in the soil, but application rates typically range from 80 to 160 lbs K/ac (71 to 143 $kgha^{-1}$) to 100 to 200 lbs K_2O /ac (89 to 178 $kgha^{-1}$) for many vegetable crops.

Because of fixation, leaching, and luxury consumption of potassium, frequent light applications of potassium during the growing season are better than one large application at planting. Making several applications is labor intensive and requires more use of equipment than one application. Growers should balance these costs with those of the fertilizer and consider only one application if costs of labor and equipment exceed the cost of potassium fertilizer for some crops such as plantation crops. Also to be considered is the increase in product yield versus not applying this fertilizer multiple times during the plant growth cycle. In addition to sidedressing, potassium may be foliar applied in liquid products such as 3-18-18, 0-0-30 and 0-0-6-3Mg-6S (AgriGuardian Nutra-Boost®, see Fig. 19-5, p. 221). For more information on foliar application of K, see p. 190.

Luxury Consumption

If potassium is in an abundant supply in soil, plants will absorb potassium beyond the amounts that they need (luxury consumption). Plants may absorb 2 to 4 times the amount of potassium that they need for their metabolic requirements. In soils with high capacities to supply potassium, luxury consumption is unavoidable. Most often, luxury consumption results from over-fertilization. The principal problem with luxury consumption is that it is wasteful of potassium. If the vegetation of a crop is harvested for sale off the farm, the grower is wasting money by removal of the large amount of potassium in the over-fertilized vegetation.

Leaching

All of the potassium in soil solution is subject to leaching. The amount of leaching varies with soil texture. In coarse-textured soils (sands, loamy sands, sandy loams), water moves rapidly through the large pore spaces, and potassium in solution is transported rapidly downward. Coarse-textured soils have weak capacities to hold potassium in exchange and fixed sites; hence, the soil has little capacity to hold potassium against the forces of leaching. Yearly, losses of potassium may reach 100 lb per acre in uncropped sandy soils, leading to rapid depletion of native soil potassium or of potassium added with fertilizers. Fine-textured soils have small pores through which water can move only slowly. This slow movement restricts losses from leaching. Slow percolation of water downward also keeps it in contact with clays and organic matter, which can hold potassium by exchange and by fixation. Losses of potassium from uncropped silty or clay soils may be only 1 lb per acre per year.

Fixation

Potassium becomes fixed in clay soils. The term fixed potassium is synonymous with nonexchangeable potassium. Fixed potassium is that which is trapped in the lattices (plates) of clay. In general, the higher is the clay content, the greater is the fixation. Clays differ in their capacities to fix potassium. Kaolinite, which does not have a lattice or plate structure, does not fix potassium, although it will hold potassium ions in its relatively limited exchange sites. The plate-like clays also differ in their capacities to hold potassium in fixed sites. These differences are related to the structure of the clays in relation to the size of potassium ions.

Potassium that is applied from fertilizers may be trapped in the lattice of clays. This potassium is temporarily unavailable to plants and may be a problem in creating shortages of potassium for plant nutrition in soils in which the potassium is fixed strongly. On the other hand, fixation by clays holds potassium against leaching so that in clay soils, leaching is virtually nil. In sands, which have limited capacity to hold K^+, as much as 30% of fertilizer potassium may be lost by leaching. Fixed potassium has an important role in nutrition of crops, because a portion of the fixed potassium is available to crops. As much as 75% of the potassium nutrition of a crop may be obtained from fixed potassium as potassium is released from the fixed sites during the entire growing season.

Table 6-1. Potassium concentrations in dry fertilizer sources.

Sources of Potassium	Concentration of Potassium(% dry wt)^{z}		Available K(% of total)
	K_2O	Actual K	
Organic			
Plant residues			
Vegetative (leaves, stems)	4	3.3	100
Hulls & rinds	2	1.7	100
Seeds	1.5	1.2	100
Seaweed (kelp)	5	4.2	100
Manures			
Dehydrated	2	1.7	100
Fresh (wet wt basis)	0.6	0.5	100
Composted	1	0.8	100
Wood ashes	10	8.3	100
Greensand	7	5.8	0
Granite dust	5	4.2	0
Chemical			
Potassium chloride (muriate of potash)	60	50	100
Potassium sulfate (sulfate of potash)	48	40	100
Potassium nitrate (nitrate of potash)	44	37	100
Potassium magnesium sulfate (sulfate of potash magnesia)	22	18	100

Chapter 7

Calcium (Ca)

Atomic Number: 20
Atomic Weight: 40.08

Discovered by Davy in 1807
Proven to be essential to plants by von Sachs and Knop in 1860

Calcium in the Soil

Normal ranges for calcium in the top six inches of an acre of unlimed soil are 1,000 to 8,000 lb in humid regions. Fine-textured soils have more calcium than coarse-textured soils. Although calcium is held tightly and is the dominant cation on soil particles, it leaches from soils in humid areas so that it is the most abundant cation in tile drainage waters and streams. Surface layers of soil will have less calcium than lower horizons. In arid regions, calcium in the topsoil may be up to 20,000 lb per acre mainly as calcium sulfate or calcium carbonate or bicarbonate.

Forms and Dynamics

Calcium is present in various soil minerals including phosphates (apatite), silicates, sulfates (gypsum), and carbonates (calcite and dolomite). The weathering of these minerals releases Ca^{+2} ions. These divalent ions may then be adsorbed onto organic and inorganic soil colloids, thus contributing to clay flocculation, particle aggregation, and soil structure. Calcium adsorbed on the surface of soil colloids and in the soil solution is available for plants. In soilless media, lime is added as a pH buffer because most fertilization additions to soilless media are ammonium based nitrogen sources (20-20-20), which tend to reduce media and rhizosphere pH's.

Fertilizers

The primary sources of Ca^{+2} are liming materials such as calcite, dolomite, hydrated lime, precipitated lime, and blast furnace slag. Although Ca^{+2} is often called a `base' or 'basic cation', the increase in soil pH after liming comes from reactions involving carbonates and carbonic acid, and not Ca^{+2} itself. Other Ca^{+2} sources have a limited effect on soil pH; they include gypsum, calcium nitrate, and calcium chloride.

Calcium Uptake and Assimilation by Higher Plants

Movement and Uptake

Calcium moves in the soil mainly by mass-flow. Calcium uptake is passive and restricted to the tip of the young roots where the walls of the endodermis cells are still unsuberized. Calcium uptake is reduced when root tips are damaged by nematodes or chemically altered by ions such as ammonium, Na, or Al. Calcium uptake is also depressed by competitive uptake with ammonium and K. Water stress can also depress Ca^{+2} uptake by damaging root tips.

Translocation and Assimilation

Calciumis translocated in the xylem mainly through the transpiration stream. Upward movement in the xylem is also facilitated by exchange sites where Ca^{+2} is momentarily adsorbed, and by chelation with organic acids of the xylem sap. The higher the concentration of Ca^{+2} in the xylem sap, the faster it moves through the plant, preferentially towards the shoot apex of growing plants.

Calcium is also transported in the phloem but in very small amounts. Thus, Ca^{+2} levels in plant organs largely provided through the phloem are rather low, with downward Ca^{+2} movement limited. High relative humidity can reduce Ca^{+2} movement to meristematic tissue, creating a Ca^{+2} deficiency in the growing tips of plant tissue.

Calcium Nutrition in Higher Plants

Effects of Calcium on Plant Growth and Quality

Plants remove from 30 to 50 lbs of calcium per acre per year. The higher the yield of crop vegetation or fruits, the more calcium is removed. Calcium deficiency occurs most commonly in acid, sandy, highly leached soils in which calcium has been depleted to low levels. Calcium deficiency also occurs in dry soils. In this case, water is insufficient for dissolution of calcium and its absorption and transport by plants. Calcium deficiency can occur also in soils that are highly fertilized with potassium or ammonium fertilizers. Potassium and ammonium competitively suppress calcium absorption by plants, and if calcium concentrations in the soil are marginal, deficiencies may occur. Deficiencies of calcium frequently cause disorders of several horticultural and agronomic crops and render the products unmarketable or undesirable for consumption.

Essential Roles

Most of the Ca^{+2} present in the cell is located in the apoplast and vacuoles, while cytoplasmic concentrations are low. The main structural role of Ca^{+2} occurs in the middle lamella between adjacent cell walls, where it binds with free carboxyl groups of pectin's.

Therefore, Ca^{+2} acts as cement between adjacent cell walls. Calcium is also involved in cell elongation in the shoot and growing tips of roots.

The removal of Ca^{+2} from the cell wall is part of leaf abscission and fruit ripening processes. Applications of Ca^{+2} to senescing leaves reduced the catabolic effects of cytokinins. Therefore post-harvest quality and rate of decay in flowers, foliage, fruits, and vegetables is dependent on Ca^{+2} levels. Calcium is also involved in the expression of chilling-injury symptoms during cold storage.

In vacuoles, Ca^{+2} may form insoluble crystals of oxalate, carbonate, sulfate or phosphate, thus regulating the levels of these anions under toxic levels. In the cytoplasm, the Ca-calmodulin complex can allosterically activate enzymes such as cyclic nucleotide phosphodiesterase, adenylate cyclase, membrane bound Ca^{+2}-ATPase, and NAD-kinase. Calcium alone is believed to directly activate mitochondrial enzymes such as glutamate dehydrogenase, as well as several a-amylases involved in starch degradation in the chloroplast.

Calcium also stabilizes the mitotic spindle apparatus during cell division, and enhances pollen tube growth and germination. Accumulation of callose in the germination tube helps the movement of the pollen content into the female cell.

Monocotyledons have lower calcium content than dicotyledons. Plants adapted to acid soil (calcifuges) usually have lower calcium requirements for optimum growth. The calcifuges are usually more resistant to Al-toxicity and often more susceptible to lime-induced Fe deficiency than are calcicole plants. Once calcium is deposited in older leaves it can only be mobilized in minute quantities to the growing tips and fruit in development.

Adequate Range and Nutrition Disorders

Growing Point Disorders

Internal tipburn of cabbage, lettuce, and brussels sprouts is caused by calcium deficiency. The outer leaves of these vegetables appear normal because they are the oldest leaves of the heads. When the head is cut longitudinally through the core, browning of the tips of the young leaves is manifested. Internal tipburn greatly lowers the value of these crops.

Blackheart of celery is a similar disorder to internal tipburn. In this case, the prized hearts of celery are blackened by death of the growing points and young leaves that constitute the hearts.

Fruiting Problems

Blossom-end rot is an expression of calcium deficiency of tomato, eggplant, pepper, and watermelon. The blossom-end is the portion of the fruit opposite point of attachment of the fruit to the stem. Blossom-end rot is tough, leathery, dead tissue. Secondary infections with decay organisms usually do not occur with blossom-end rot, but these fruits have no market value and may ripen at very small sizes. Maintaining well-irrigated conditions during the fruiting of these crops will help reduce blossom-end rot when calcium is available in the soil. Calcium enters plants with the flow of water, and in dry soils insufficient calcium enters plants to prevent development of blossom-end rot. Also in dry soils, potassium and other cations from salts more soluble than calcium compounds will be taken up preferentially to calcium, suppressing calcium absorption by plants.

Calcium nitrate (not organic) is sometimes applied to soils in which plants are showing blossom-end rot. Fertilization will prevent further development of blossom-end rot on young unblemished fruits, but fruits that show the disorder will not recover. Adding available calcium to soils at planting of crops can help prevent this disorder.

Bitter-pit of apple is a nonpathogenic disease from calcium deficiency. In this case, small, skin-deep pits with a bitter taste develop in the peels of apples. Other disorders that occur during storage and which greatly shorten the storage life of apples are caused by inadequate calcium in the fruit. Internal breakdown and watercore after harvest are reportedly caused by insufficient calcium in fruits. These disorders often are prevented by dipping fruits in slurries of calcium chloride to increase the concentration of calcium in the fruits.

Peanuts require calcium for fruiting. The peanut flowers above ground. After pollination, the flowers develop an organ called a peg or gynophore. The peg burrows into the ground so that peanuts form in the soil. The peg will not grow properly into soil in which calcium is deficient.

Root problems

Calcium-deficient roots are stunted and stubby. Cavity spot of carrot is a disorder that may appear on otherwise normally developed roots. The disorder appears as blackened sunken lesions on carrot roots. It is caused by imbalances from fertilization with potassium or with ammonium relative to calcium supply in the soil. Heavy applications of fresh farm manure are suspected to promote formation of cavity spot in soils with marginally low levels of calcium. The potassium or ammonium in the manures may suppress calcium absorption by the carrot to the point of deficiency.

Sufficiency Range

Adequate levels of Ca^{+2} in mature leaves range between 0.5 to 1.5%. Approximately 800 ppm (0.08%) Ca^{+2} is considered chemically active. Higher levels of Ca^{+2} are required to counter the effects of other ions and their negative effects on plant metabolism.

Deficiency

Calcium deficiency symptoms are not general expressed visually in plants but appear as physiological disorders. Calcium deficiency is characterized by a reduction in the growth of meristematic tissues. The deficiency occurs first in the growing tips and youngest leaves because Ca^{+2} is immobile in the plant. Calcium-deficient leaves become deformed and chlorotic; in later stages, they become necrotic on the leaf margins.

Figure 7-1. Serrated leaf margins on corn due to calcium deficiency.

In the picture above the edge of the corn leaf looks ragged due to a calcium deficiency and this visual symptom can be caused by high ammonium as the N-form absorbed by the plant and the suppression of calcium uptake into the plant. This calcium deficiency on the leaf edge causing abnormal leaf patterns to occur when ammonium is the nitrogen form absorbed is generally related to reduced root growth and death of the root tips. This effect on root growth restricts the ability of the roots to supply the water requirements of the plant during periods of high transpiration. Reduced transpiration translates into reduced calcium uptake. Most calcium related disorders are generally induced by either environmental or cultural practices or their interaction. High light intensity and duration, adverse temperatures, high humidity is typical environmental factors influencing the incidence of calcium deficiency.

Figure 7-2. Necrotic leaf margins on lettuce due to calcium deficiency. Left mild symptoms. Right severe symptoms.

Temporary Ca^{+2} deficiencies may occur when Ca^{+2} levels in the xylem are low due to reduced transpiration rate on humid, cloudy days or when water shortage occurs. Even temporary water stress on a hot day can result in death of the growing point cells due to Ca^{++} deficiency.

Figure 7-3. Ca^{++} deficiency in marigold seedlings.

A shortage of Ca^{+2} to growing and transpiring fruits results in bitter pit of apples, tip burn and brown-heart of leafy and heading vegetables,blossom-end rot of tomato, squash, watermelon, and bell pepper, and asparagus tip deterioration. Blossom-end rot is an irreversible disorder. In reproductive tissues in the vegetable and fruit industry, calcium deficiency takes the greatest toll on size and quality and marketable fruit. Calcium deficiency appears in tomatoes, peppers, and melons as blossom end rot and in fruit as bitter pit, fruit softening, internal breakdown and cracking. In cotton boll retention is affected and in peanuts the kernel in the peg does not fill out. In beans and peas the pods will split.

Figure 7-4. Top blossom end rot in watermelon and bottom tomato fruit with blossom end necrotic tissue, Both fruit symptoms due to Ca^{++} deficiency during early fruit development.

Foliar applications of Ca^{+2} may be used as a preventive measure but will not correct existing symptoms. Water stress is one of the biggest issues with calcium deficiency. Calcium deficiencies are likely to occur any time a plant is subjected to wilting/water stress during initial fruit development before the waxy suberization prevents water loss from the fruit surface of tomato and watermelon. Water stress during flowering can result in cell death in the flower tissue or abortion of the flower. Death of tissue cells often occurs in fruit subjected to water stress before the waxy suberization forms to protect the fruit from excessive water loss through evaporation.

Figure 7-5. Calcium deficiency in cauliflower due to water stress affecting calcium movement to the developing flower.

Figure 7-6. Calcium deficiency in pepper fruit.

Toxicity

Plant symptoms of excess Ca^{+2} in crops such as vegetables are uncommon, but appear mainly as Mg- or K-induced deficiencies.

Interactions with other Nutrients

Nitrogen

Calcium uptake is affected in decreasing order by the presence of ammonium, $NH_4^+ > Mg^{+2} > K^+ > Na^+$. Foliar Ca:Mg ratios of 2:1 and K:Ca of 4:1 are considered optimum for plant growth. Generally, additions of N will increase the Ca content of leaf tissue, but any large increase of dry matter resulting from the N addition will result in an apparent decrease in Ca content. Such negative effects occur when the growth response to N is large (particularly when substrate N is initially low) and/or when substrate Ca is low (due to either low pH and/or low Ca saturation in soil). In 75 randomly selected citrus leaf samples collected in the West Indies, Ca decreased linearly as N increased. An increase in Ca content, if it occurs, tends to be greater when nitrate-N is the N source than when the source is ammonium-N. However, the Ca content is somewhat dependent on the Ca level in the soil, its pH, and other nutrient substrate contents. Genotypes differ in their responses to soil characteristics as influenced by the use of either ammonium-N or nitrate-N, and also to the transfer and utilization of ammonium-N and nitrate-N in the plant. Such differences result in variable concentrations of tissue Ca as well as variable contents for several other nutrients.

Ammonium

The use of ammonium-N has a greater depressing effect on the Ca content in fruit than in leaf tissue, and this effect is aggravated as the tissue ages. The greater depressing effect of ammonium-N on Ca concentration in the fruit is affected in part by the dependence of fruit tissue on phloem transport, which decreases as the fruit ages.

Nitrate

Nitrate usually increases Ca uptake, possibly by the formation of Ca-organic acid chelates released during nitrate uptake.

Phosphorus

In acid conditions, P favors Ca uptake. The formation of low-solubility calcium phosphates in soils with pH > 7.0 reduce the availability of Ca.

Phosphorus and Copper

Calcium availability has been reported to be affected by P and Cu. When Cu is deficient, adding P may decrease Ca uptake. When Cu is available, Ca uptake is increased as P concentration is decreased.

Micro-nutrients Increases in pH after liming with calcium can results in induced Fe, Mn, B, or Zn deficiencies and subsequent chlorosis when soil pH increases above toward and above pH 7.

Boron Calcium and B have a synergistic effect in reducing the incidence of disorders near actively growing points.

Aluminum In soils at pH < 5.0, Ca may bind with Al and Fe hydroxides. In the cell, Al toxicity is due to the competition between Al and Ca for binding sites on calmodulin. Calcium uptake by roots is restricted due to competition with Al for root uptake at the cellular binding sites.

Calcium Salts When decreasing the proportion of Ca to the other salts in a nutrient solution, the Ca concentration in both tomato and celery leaves was found to decrease. The extent of the Ca reduction varied with the source of the other salts and followed the order: NH_4> Mg > K > Na.

Heavy Metals Much less Ca is needed if certain nutrients, such as Al, Cd, Cu, Fe, Mn, and Zn, are absent or present in very low concentrations in the rooting substrate.

Calcium Concentrations in Fertilizers

The organic grower generally does not make a deliberate effort to apply calcium fertilizers. Generally, the calcium requirements of plants are met through applications of materials to supply nitrogen and phosphorus and to regulate soil acidity. On the other hand, conventional growers who use concentrated soluble fertilizers for nitrogen, phosphorus, and potassium, particularly if the fertilizers are applied as liquids, may have to take specific action to ensure that soils provide adequate calcium. Some materials that provide calcium are listed in Table 7.1. The calcium contents will vary with the origin, purity, and hydration of these materials.

Finely ground limestone and other liming products added to correct soil acidity will provide adequate calcium to crops, providing no other factors such as water supply are limiting. Gypsum is added to fine-textured soils to improve their structures. Gypsum is called a soil amendment rather than a fertilizer, since its use is in improving soil structure rather than to supply calcium. Clays on which calcium is the dominant cation in the cation-exchange sites are flocculated to form aggregated structures, which improve the structure of fine-textured soils. Gypsum adds calcium to the soil so that structural improvements can be made without raising pH. Gypsum can be a source of calcium for plants growing in soils in which liming is unneeded or undesirable.

Crops that are fertilized with bonemeal or superphosphates will receive enough calcium. Availability of calcium from rock phosphate is limited by its low solubility, and unless practices are taken to improve the availability of phosphorus from rock phosphate, calcium may be inadequately supplied. Plant residues, composts, and manures applied in quantities that will meet the nitrogen requirements of crops also will supply adequate calcium to the crops. Fruits and seeds are low in calcium, having only 0.1% calcium, and are not suitable to consider as calcium-containing fertilizers because of the large amounts of these materials that would have to be applied to supply sufficient calcium for plant nutrition.

The availability of Ca in the fertilizer product helps determine the quantity of the fertilizer used to provide adequate Ca for a crop. Traditional limestone is used typically used to raise the pH on acid soil, and is used in relatively large quantities. However, because of its slow availability, the benefit in terms of available Ca may be inadequate for the needs of the existing or upcoming crop. Even when pH is not a problem, the percent base saturation of calcium may be too low, especially is soils high in magnesium or sodium. In such cases, additional or alternative applications of more readily available calcium may be needed. As indicated in Table 7-1, quicklime and hydrated lime are dry products that are readily available. Care must be taken in the rates used of these products because of their reactivity within the soil or growing medium.

Liquid forms of calcium are available on the market. Some liquid calcium products are finely ground limestone suspended in an aqueous medium. While the Ca in these products is more available than traditional limestone, the benefits come from the increased surface area of particles by being very finely ground. Calcium can be applied as true solutions, and made using water-soluble calcium compounds such as calcium nitrate and calcium chloride. Calcium nitrate is often used in through irrigation systems at low concentrations to provide both nitrogen and calcium to a growing crop. Liquid calcium is also available as a sugar-based chelated calcium product, e.g., Agri-Cal®. This product is recommended at a rate up to 5 gallons per acre depending on need. For this product, the manufacturer prefers to use percent base saturation of calcium in the soil to determine rates to apply as opposed to just the concentration of Ca in the soil test. Under drought conditions, 3 gallons per acre of Agri-Cal® applied over the covered seed furrow increased corn yields from 51.5 bu/ac to 83.1 bu/ac, presumably by improving soil tilth, root penetration and nutrient availability. Again using 3 gallons per acre of Agri-Cal®, when calcium levels were moderately low in the soil, 3 gallons per acre increased cotton yields from 1086 pounds per acre of lint to 1170 pounds per acre. The use of liquid calcium products is primarily to provide available calcium to the current crop, but improvements in soil pH and available Ca in the soil has been observed using such products. When using liquid calcium products, especially those in true solutions or chelated forms, they should not be mixed with phosphate fertilizers or chemicals such as glyphosate. When calcium comes together in solution with these phosphate compounds, they form insoluble calcium phosphate, which precipitates out resulting in the loss of the nutrients and clogging lines and filters of application equipment. With glyphosate, the herbicidal activity of the glyphosate is lost as well.

Foliar application of calcium fertilizers is another method of getting calcium into growing crops. However, fewer options are available that are effective as foliar fertilization. Calcium chloride has been used as a foliar application, but care must be taken because of potential burn to foliage. Newer liquid calcium chelates, e.g., Agri-Cal®, have been effective in getting calcium into plant tissues with less risk of foliar damage. For more information on foliar application of calcium see pp. 191-192.

Table 7.1. Calcium concentrations in lime, soilamendments and fertilizers.

Material	Concentrationof Ca (%)	Availability of Ca
LIME		
Agricultural limestone	40	Slow
Dolomite	22	Slow
Quicklime	70	Rapid
Hydrated lime	50	Rapid
AMENDMENTS		
Gypsum	30	Moderate
FERTILIZERS		
Ordinary superphosphate	20	Moderate
Triple superphosphate	16	Moderate
Rock phosphate	33	Very slow
Bonemeal	38	Slow – moderate
Calcium nitrate	24	Soluble
Sugar-chelated liquid calcium*	10	Rapid
PLANT RESIDUES & MANURES	1 (highly variable)	Moderate

*Sold under the trade name Agri-Cal®

Sources of Calcium

Calcium sources that increase soil pH [CaO, $Ca(OH)_Z$, $CaCO_3$, CaCO3•$MgCO_3$] differ markedly from those such as $CaSO_4$ that do not, in terms of their effect on plant nutrient composition. The former group of Ca sources generally lowers the Al, B, Cu, Fe, Mn, Ni, and Zn contents in the plant and raises the Mo concentration. The Ca content of *Viburnum suspensum* leaves, for example, was highest when $CaCO_3$ was applied, less with $CaCO_3$•$MgCO_3$, and least with $CaSO_4$ additions. Unlike $CaSO_4$, the application of $CaCO_3$ or $CaCO_3$•$MgCO_3$ had a depressing effect on both the total N and P content. The P content of tomato leaves was found to increase slightly as Mg was increased, and the Ca content decreased with the application of most liming materials.

Sources of calcium in commonly applied fertilizers to crops are:

1. Superphosphate (18 - 21% Ca)
2. Triple superphosphate (12 - 14% Ca)
3. Calcium nitrate [$Ca(NO_3)_2$] (19% Ca)
4. CaEDTA (3 - 5% Ca)
5. Sugar-chelated liquid calcium (10% Ca) (Agri-Cal®)
5. Various micronutrient carriers (4 - 12% Ca)
6. Calcium cyanamide ($CaCN_2$)
8. Calcium phosphate and di-calcium phosphate

Chapter 8

Magnesium (Mg)

Atomic Number: 12
Atomic Weight: 24.31

Discovered by Davy in 1808
Proven to be essential to plants by von Sachs and Knop in 1860

Magnesium in the Soil

Forms

Magnesium exists in the soil: (a) in primary ferro-magnesium minerals such as biotite, hornblende, olivine, or serpentine; (b) in secondary clay minerals such as chlorite, illite, vermiculite, or montmorillonite; and (c) in inorganic salts such as carbonates, sulfates, or dolomite. Magnesium is seldom associated with the organic matter complex.

Magnesium in primary and secondary minerals is nonexchangeable. Exchangeable Mg adsorbed onto the surface of soil colloids, and soluble Mg in the soil solution are available to plants over the 5.4-7.0 pH range. In organic soils, magnesium is most available at pH's between 4.5 and 7.0. In inorganic soils, it is most available between 6.5 and 8.5.

Dynamics

Isomorphous substitution between Fe^{+3} or AP^{+}, and Mg^{+2} results in the creation of positive charges at the surface of clay minerals. Low soil pH favors the weathering of ferro-magnesium minerals resulting in the release of Mg. Exchangeable Mg represents approximately 5% of the total Mg in soil. Magnesium levels in highly leached or sandy soils are usually low. Tropical soils are generally low in Mg and require Mg fertilizer applications for proper plant growth.

Fertilizers

Magnesium is found in liming materials primarily as dolomitic limestone. The rise in soil pH induced by these liming materials comes from reactions involving carbonates and carbonic acid, not Mg itself. Particle size of Mg-containing liming materials affects Mg availability as these materials have relatively low solubility. Finely ground dolomitic limestone changes soil pH faster than coarse material. Under intensive cropping systems, Mg availability may be limited to the second or third crop. Reduced Mg availability is due to slow rate of release and not to low Mg levels. Dependency on Mg release from dolomitic lime is not adequate to support intense cropping systems and necessitates supplemental Mg fertilizer applications during the growth cycle. Applications of Mg as its nitrate, chloride, or sulfate forms are common and have little effect on soil pH.

Magnesium Uptake and Assimilation by Higher Plants

Movement and Uptake

Magnesium moves to the roots by mass flow. Magnesium uptake is passive, possibly mediated by ionophores in which Mg^{+2} moves down an electrochemical gradient. The involvement of ionophores may explain the effect of cation competition (ammonium, K, Ca, and Na) on Mg uptake. Upon absorption, the rhizosphere pH would be lowered but not to the same degree as with ammonium.

Translocation and Assimilation

Magnesium is mobile in the phloem and can be transported from older to younger leaves or to the shoot apex. Since fruit and storage tissues are dependent on the phloem for their mineral supply, they are higher in K and Mg than in Ca. In some cases, bitter pit may be due to a localized Mg toxicity rather than a Ca deficiency.

Magnesium Nutrition in Higher Plants

The essentiality of magnesium was demonstrated with solution culture of plants in the 1860s (Sachs, Knop). Magnesium is a constituent of the green pigment, chlorophyll, of plants. The requirement of magnesium for chlorophyll synthesis is absolute. No other nutrient will substitute for magnesium in this role. About 1% to 3% of the magnesium of plants is in chlorophyll. Although only a small fraction of the magnesium of plants is in the chlorophyll, its function in this role is a major one. Chlorophyll is required for photosynthesis, a process by which plants convert light energy into chemical energy. The chemical form of energy generated by photosynthesis is a compound known as adenosine triphosphate or ATP. ATP is also a product of chemical transformations of energy during respiration. Magnesium is required for biosynthesis and metabolism of ATP during photosynthesis or respiration. Magnesium is essential for activation of many enzymes, which are organic catalysts in metabolism. Magnesium activates more enzymes in plants than any other nutrient. Many of these enzymes are involves in phosphorus metabolism. Also, magnesium through its action in activation of enzymes and biosynthesis of ATP is essential for protein synthesis in plants.

Magnesium found in the center of the tetrapyrrole ring of the chlorophyll molecule makes up 15-20% of the total Mg in plants. Another 70% of the total Mg is associated with anions and organic anions, malate and citrate.

Magnesium is a cofactor of kinase enzymes such as hexokinase and phosphofructokinase, which require a divalent cation such as Mg^{+2} or Mn^{+2} for activity. These enzymes catalyze the transfer of phosphoryl groups between ATP and ADP.

Magnesium is essential for the activity of the two-principal CO_2 fixing enzymes, ribulose phosphate carboxylase and phosphoenolpyruvate carboxylase. Magnesium activates ribulose phosphate carboxylase in the light reactions of photosynthesis in chloroplasts. Light triggers the import of Mg^{+2} into the stroma of the chloroplast in exchange for H^+, which provides optimum conditions for the carboxylase reaction.

With its two positive charges, Mg^{+2} also stabilizes the tail of phosphoryl groups in ATP and ADP by weakly binding with negative charges. Magnesium is the most important cation neutralizing the non-diffusible anions of the thylakoid membrane. Magnesium also stabilizes the ribosomes in adequate configuration for protein synthesis.

Adequate Range and Nutritional Disorders

Crops remove between 15 and 30 lb of magnesium per acre per year. Magnesium concentrations in leaves are about 0.4% on a dry weight basis. Concentrations below 0.15% to 0.25% are too low for adequate nutrition of most plants. Concentrations over 1% may be toxic and indicate excessive magnesium in soils. Excesses of magnesium are rare but may arise in soils derived from rocks high in magnesium or from excessive magnesium fertilization. Organic growers should rarely encounter excesses arising from over fertilization, unless they have applied higher than agronomic rates of magnesium fertilizers or have used dolomitic (high magnesium) limestone repeatedly.

Sufficiency Range

The normal concentration of Mg in plants ranges from 0.15% to 0.40%.Magnesium deficiency may occur in highly leached, acid, sandy soils from which it has been depleted. Organic soils with marl deposits may be magnesium deficient because of the antagonism of calcium with magnesium in absorption by plants. Soils with low magnesium contents and limed with calcitic limestone may become deficient because of the antagonism between calcium and magnesium. Potassium and ammonium fertilization also can producemagnesium deficiency by cation antagonism. Pastures that are growing in soil in which magnesium is just sufficient for crop growth may have depressed concentrations of magnesium in the forage following liberal applications of potassium fertilizers. In some cases, the forage may not have sufficient magnesium for livestock nutrition.

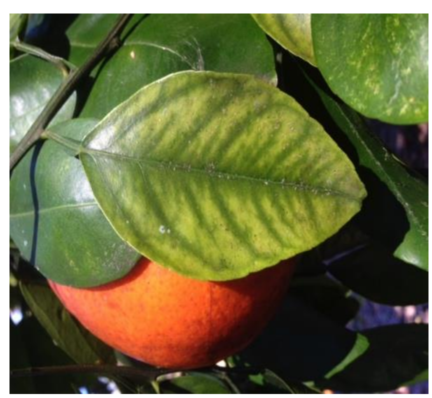
Deficiency

Magnesium is a mobile nutrient in plants. Symptoms of deficiencies will appear first on the old leaves, as magnesium may be translocated from old leaves to young leaves or to reproductive or storage organs. Deficiencies appear as yellowing of the old leaves. Yellowing occurs initially between the veins with green color remaining along the veins.

Figure 8-1. Magnesium deficiency in poinsettia.

This pattern of expression of deficiency is called blotching or mottling.

Figure 8-2. Magnesium deficiency as interveinal chlorosis.
Left-greenhouse bell pepper leaf.
Right-citrus leaves.



The lower leaves of grasses will have alternating yellow and green stripes, being green along the veins and yellow in between. Some plants (cotton, grapes) may show purpling over the blades. In advanced stages of magnesium deficiency, dying of tissues occurs so that the symptoms are indistinguishable from those of potassium deficiency. If symptoms appear on plants, it is usually to late to take corrective action.

Since magnesium is relatively mobile in the plant, deficiency symptoms develop first in the older leaves and then the younger leaves. Magnesium deficiency is characterized by an interveinal yellowing of the leaf that moves to the edge of the leaf. The most typical pattern of Mg deficiency is, therefore, green conductive tissue surrounded by a yellow background.

Figure 8-3. Magnesium deficiency in **Left** picture-Redbud. **Right**-October Glory.

Figure 8-4. Magnesium deficiency in **Left** picture-Tomato leaf. **Right**-Corn Seedling leaf.

Ultimately, leaves become stiff and brittle and the veins become twisted. Magnesium uptake is strongly influenced by pH, its availability markedly declining when the soil pH is less than 5.5.

Figure 8-5. Magnesium deficiency in Rabbit eye blueberry.

Figure 8-6. Magnesium deficiency in Oil Palm.

Figure 8-7. Magnesium deficiency in blackberry.

Figure 8-8. Left magnesium deficiency in most recently matured anthurium leaf, right in Spathiphyllum.

Figure 8-9. Magnesium deficiency in Lorpetalum.

Toxicity In field conditions, Mg toxicity rarely occurs.

Interactions with other Nutrients

Nitrogen

Highest Mg concentration in snap bean leaves was obtained with $NaNO_3$ as the source of N, followed by NH_4NO_3 and (NH_4),SO_4. Lower levels of N in pasture herbage were obtained when the herbage was treated with $(NH_4)_2SO_4$ as compared to applications of NH_4NO_3. The lower concentrations of N were traced to the antagonism of the NH_4 cation on Mg uptakeas well as to the lowered soil pH induced by the SO_4 anion. In the case of mixed herbage, another factor may contribute to a lower Mg content of the sward, since a lower soil pH with the addition of N favors grass growth, and grass normally has a lower Mg content than does a legume. An excess ofammonium can decrease magnesium uptake and possibly bring about deficiencies of Mg in the plant, especially in soils that are deficient in Mg or when high amounts of ammonium fertilizers are added.

Potassium

K:Mg of 8:1 are considered optimum for plant growth. Any time potassium fertilizer is applied; magnesium uptake and/or the level in the plant that was sufficient can now become deficient due to higher ratio of potassium to magnesium in the tissue. Magnesium deficiencies are created more often than not due to the application of fertilizer high in potassium.

Calcium

Foliar Ca:Mg ratios of 2:1 to 3:1 are critical for most plant to prevent a magnesium deficiency. The addition of lime or high calcium liming materials is one of the most often means by which magnesium deficiencies are created by cultural practices. Soilless mixes which incorporate lime into the mix to buffer against the use of ammoniacal fertilizers in the horticultural industry set the plants being grown in these mixes to an improper Ca:Mg ratio from the start of the plant growing cycle.

Manganese

Magnesium depresses Manganese uptake. The plant symptoms for magnesium and manganese are similarly with the blotchy yellow interveinal chlorosis in the initial stages of development on the leaf. Many times the magnesium or manganese deficiency is made worse when the wrong corrective action or nutrient, Mg vs. Mn, is applied.

Aluminum In acidic soils, Al competes with Mg for uptake at root uptake binding sites. Aluminum-induced Mg deficiency has been implicated in acid rain-induced forest declines in Europe and in tropical soils fertilized with ammonium-based fertilizers.

Table 8-1. Magnesium content of limestoneand fertilizers.

Material	(%)Magnesium concentration
LIMESTONES	
Dolomite	8-12
Dolomitic limestone	1.3 to 6.5
Average agricultural limestone	4.9
FERTILIZERS	
Magnesium sulfate (Epsom salts)	10
Potassium magnesium sulfate	11
Talc and soapstone	19

Chapter 9

Sulfur (S)

Atomic Number: 16
Atomic Weight: 32.06

Element known since prehistoric times
Proven to be essential to plants by von Sachs and Knop in 1865

Sulfur in the Soil

Forms

In the soil, over 90% of available S is in association with organic matter, which has a 10:1 N:S ratio. Soil organic sulfur is in protein and amino acids and may be associated with Fe and Al oxides, clay minerals, or soil humus fractions. In well-drained soils, inorganic S exists as(a) soluble sulfates (SO_4^{-2}) of Ca [calcium sulfate is sparingly soluble], Mg, K, Na, or ammonium in the soil solution; (b) sulfate adsorbed on clay surfaces; (c) sulfate adsorbed to Al or Fe hydrous oxides at pH <4.0; and (d) sulfates coprecipitated with natural calcium carbonates at pH > 7. In general, most of the available sulfate is found at lower depths, where pH and base saturation are low and exchangeable Al is high. The availability of subsoil sulfate to plant growth depends on the crop rooting habits and on movement of soil water during periods of high evapotranspiration for the soil surface.

Dynamics

In the soil, S is made available to plants from sulfur containing rainfall, fertilizer application, or microbial activity on soil organic matter. Volcanic eruptions and the burning of fossil fuels (from automobiles, power plants, and factories) liberate sulfurous gases into the air, which are deposited on soils by rainfall. This phenomenon, called acid rain, may annually return to the soil up to 45 lb S/ac (50 kg ha^{-1}) in some locations but varies widely and is commonly about 5 or 6 lb/ac in modern times.

Environmental conditions can influence sulfur availability, such as soil oxygen levels related to prolonged rainfall (see example p. 235). Also, under aerobic conditions, soil microorganisms mineralize S-containing amino acids such as cysteine into sulfate, annually releasing 4 to 12 lb S/ac (4 to 13 $kgha^{-1}$).

Under anaerobic conditions, mineralization and sulfate reduction byDesulfovibrio bacteria may produce hydrogen sulfide (H_2S), which can be released into the atmosphere. In waterlogged soils, the anaerobic degradation of organic matter releases organic sulfides or hydrogen sulfide. Hydrogen sulfide may be oxidized to elemental S by chemotrophic sulfur bacteria. When aerobic conditions are restored, H_2S readily undergoes oxidation to sulfate.

Photosynthetic green and purple bacteria can oxidize hydrogen sulfide to S by utilizing the hydrogen in photosynthetic electron transport. When this process is restricted, hydrogen sulfide may accumulate to toxic levels and thus impair plant growth in poorly drained soils.

Sulfur can be removed from the soil by leaching or crop uptake or can be lost as various gases. Sulfates adsorbed to Al-OH or Fe-OH groups may be displaced by phosphates, which are more strongly adsorbed to Al and Fe oxides than are sulfates. Sulfate adsorption decreases with increasing pH in acid soils and is negligible above 6.5. The desorbed sulfate is relatively mobile in soils and may then be taken up by plants or leached or remain in the soil solution. Although plants remove almost as much S as P, larger amounts of S are lost from the growing zone through leaching.

Fertilizers

Sulfur frequently is applied as a fertilizer element since sulfate is the accompanying anion in ammonium sulfate (24% S), magnesium sulfate (13% S), potassium sulfate (17.5% S), and calcium sulfate (18.6% S). Sulfur is also present in ordinary superphosphate since sulfuric acid is used to acidulate phosphate rock and convert P into a soluble form in the manufacture of superphosphate fertilizer. This practice is becoming limited as triple superphosphate, made with phosphoric acid, and ammonium phosphates are dominant in the fertilizer trade and superphosphate is becoming rare. The world production of sulfur in 2011 amounted to 69 million tons (Mt), with more than 15 countries contributing more than 1 Mt each. Countries producing more than 5 Mt are China (9.6), US (8.8), Canada (7.1) and Russia (7.1). Sulfur production is as a side product of other industrial processes such as oil refining. Today, sulfur is produced from petroleum, natural gas, and related fossil resources, from which it is obtained mainly as hydrogen sulfide.

Sulfur Uptake and Assimilation by Higher Plants

Elemental S is also available as a yellow powder (Flowers of Sulfur), which upon addition to the soil is oxidized microbially to sulfuric acid, which lowers soil pH. An application of 1 $kgha^{-1}$ of sulfur (0.89 lb/ac lowers the pH approximately 0.5 pH unit.

Sulfur generally is supplied in adequate amounts for crop production as a companion nutrient in other fertilizer materials. In the past, there was significant amounts of sulfur supplied by atmospheric deposition due to use of high-S fossil fuels, but stringent air quality regulations have reduced this source to levels that have increased the incidence of sulfur deficiency in many crops. In addition, the trend to apply fertilizers higher in primary nutrient concentration to lower transportation and handling costs has resulted in less fertilizer sulfur being applied with conventional NPK additions. Also the trend to not apply fertilizer to build the soil nutrient content and to rely upon tissue analysis to only apply the nutrients that are many become deficient is being practiced more widely in agriculture crop production.

Uptake

Sulfates move to the root mainly by mass flow, which uptake of sulfate dependent upon soil moisture content and its availability in the root zone highly influenced by irrigation and rainfall. Concentrations of 3 to 5 mg S L^{-1} (ppm) in the soil solution are adequate for most plant species. Once sulfate in in the rhizosphere, sulfate ions are absorbed actively against an electrochemical gradient. Generally, soil pH and the presence of other nutrients have little influence on sulfate absorption. Sulfur may enter into leaves through the stomata as sulfur dioxide (SO_2). Atmospheric concentrations of sulfur dioxide normally are between 0.5 to 0.7 mg $m\text{-}^{3}$.

The N:S ratio in the growing medium may be as important as total sulfur alone or the ratio of sulfate-S to total sulfur. An adequate N:S ratio for most plants species is 15:1; for crucifers is 3:1; for legumes is 13:1; and for cereals is 17:1. For most crops, sulfur accumulation is similar to that of phosphorus, and ranges from 11 kg ha^{-1} in grasses. to 50 kg ha^{-1} in crucifers. Plant hormones are involved in the regulation of sulphate uptake and assimilation. Cytokinins auxins are involved in the regulation of sulfur metabolism.

Translocation and Assimilation

Following uptake, sulfate is translocated to the shoot in the xylem. Sulfur moves in the phloem mainly in the reduced -SH form (thio group). Older leaves will not contribute significantly to the S supply of younger tissues as sulfur has limited mobility in plants once it enters into leaf cells. Sulfate must be reduced before it is incorporated into the amino acids cysteine or methionine. Sulfate reduction occurs in the chloroplast membranes, during daylight hours since the energy and reductant of photosynthesis is used in the assimilation of sulfate. Sulfate reduction is competitive with photosynthesis and nitrate reduction. Sulfate is largely stored in the cell vacuoles.

Sulfur Nutrition in Higher Plants

Essential Roles

Several essential functions are attributed to sulfur as part of amino acids and proteins and an important role in redox control of cellular process and in plant defense mechanisms. It is a constituent of proteins, lipids, and some vitamins and metabolic cofactors. Disulfide bonds (-S-S-) are formed by two -SH groups of cysteine and methionine. These bonds are involved in the tertiary structure of proteins and in the linking and folding of protein chains. Folding of proteins is involved in the conformation and activity of enzymes.

Sulfur is also essential for the formation of glucosides and volatile compounds in plants characteristic of the smell associated with the onion and brassica families and other species rich in secondary metabolites. Sulfur promotes legume nodule formation and is important in seed production. One of the major S-containing proteins is ferredoxin, which is involved in photosynthesis, glutamate synthesis, N_2 fixation, and nitrite reduction.

Sulfur is also a constituent of Coenzyme A (CoA) and the vitamins biotin and thiamine. CoA is a cofactor in the Krebs (citric acid) cycle and plays an important role in fatty acid metabolism. Biotin is associated with nonphotosynthetic CO_2 transfers and decarboxylation reactions. Thiamine is a coenzyme in the decarboxylation of pyruvate. Sulfur is also a component of glutathione. Plant hormones such as cytokinins and auxins, as well as stress-related hormones such as abscisic acid (ABA) are involved in the regulation of sulfur metabolism.

Adequate Range and Nutritional Disorders

Sufficiency Range

Sulfur content in leaf tissues ranges from 0.15 to 0.50% on a dry weight basis. Symptoms of sulfur deficiency may occur in newly emerging plants but tend to disappear as root development allows sulfur to be taken up from the soil.

Deficiency

Sulfur deficiency is expressed as an overall chlorosis in the leaf with some green color remaining (sulfur chlorosis is more uniform over the leaf than observed with nitrogen deficiency).

Figure 9-1. Sulfur deficiency in citrus leaves measured at 0.06% S.

Veins and petiole can show a distinct reddish color on the underside of the leaf. Brown lesions and necrotic spots along the petioles express severe sulfur deficiency with the leaves becoming twisted and brittle. Sulfur is not highly mobile in the plant with sulfur-deficiency symptoms appearing first on young leaves. Fruit set is restricted and fruit color can appear light green and lack succulence. Roots are longer than normal, and stems become woody. The most typical symptoms of sulfur-deficient plants are smaller leaves that appear chlorotic and stunted in growth, with short, thin, and woody stems. With legumes, root nodulation is inhibited; with grain crops, maturity is delayed. With tobacco, mild sulfur- deficiency is desired to obtain proper leaf color and burning quality.

Toxicity

Plants do not express a distinct response to high sulfate concentration in the growing media. However, acute sulfur dioxide damage from air pollution is quite common, and its occurrence is usually localized near the source of pollution and is related to weather conditions favoring slow dispersion of the gas. Toxicities are common when atmospheric sulfur dioxide concentration exceeds 0.5 to 0.7 mgm^{-3} and generally are described as water-soaked areas, which develop into well-defined dry, white necrotic spots, mainly on the underside of leaves.

Interactions with other Elements

Nitrogen

A close relationship exists between sulfur and nitrogen in plants. Field crops require about 1 part S to 15 parts N by weight for protein synthesis, although this ratio ranges from about 1:14 for grasses, and to about 1:17 for legumes. Generally, additions of S will increase the N content of plants. Sulfur deficiency symptoms are more pronounced at high nitrogen levels.

Boron Sulfur fertilization reduces the uptake of boron.

Molybdenum Sulfur fertilization reduces the uptake molybdenum. Sulfate-molybdate antagonism at the soil-root interface and within the plant increases with sulfate supplied in fertilizer. Increasing sulfur results in lower molybdenum concentrations in the plant tissue.

Sulfur Fertilizers Additions and Management

Ammonium Sulfate Ammonium sulfate (21-0-0-24S) is used as an N fertilizer but also to correct or prevent a sulfur deficiency. Use of this fertilizer reduces soil pH toward acidity two ways.

1. In the soil, ammonium ions (NH_4^+) in this material are converted to nitrate by soil bacteria N*itrosomonas* spp. and N*itrobacter* spp. This microbial process releases hydrogen ions (H^+) into the soil solution and acidifies the soil.

2. Ammonium ions absorbed by the plant in excess of anion absorption results in hydrogen ions being released from the plant into the soil solution and acidify the soil.

Thiosulfate Ammonium thiosulfate is another sulfur-containing material that is applied in irrigation water. It is compatible with fertilizers solutions such as aqua ammonia, nitrogen solutions containing ammonium nitrate, urea solutions, and most nitrogen only, nitrogen-phosphorus, or complete fertilizer solutions, It is not applied with anhydrous ammonia or acid solutions such as phosphoric acid as these materials will decompose the thiosulfates.

Elemental sulfur (0-0-0-90S) Elemental sulfur is a convenient form of sulfur that can be broadcast or band applied. Elemental sulfur is insoluble and to be available to plants must break down into small particles through a physical process and then be oxidized. Microbial activity converts sulfur to the sulfate ion in well-aerated soils. Transformation of sulfur to sulfate is a slow process often taking months. For most annual crops, a sulfate fertilizer like ammonium sulfate is recommended and elemental sulfur is not because of the slow availability of elemental S.

Calcium Sulfate Gypsum (0-0-24) has been used widely for many years as a sulfur- and calcium-bearing material for fertilization and soil

(Gypsum)

reclamation. It is a neutral salt and has no effect on soil acidity. Gypsum is only slightly soluble but has sufficient solubility to supply S requirement of most crops.

Other

Potassium sulfate, potassium magnesium sulfate, and magnesium sulfate are used to supply potassium and magnesium to crops. At the same time, they supply sulfur in the readily available sulfate form.

Potassium sulfate is used on specialty crops such as tobacco and potatoes. Potassium magnesium sulfate (trade name K-Mag or Sul-Po-Mag,) is used to supply the three nutrients to crops as a granular product. AgriGuardian Nutra-Boost® is a liquid formulation with similar K-Mg-S ratios to Sul-P-Mag, but in a liquid form for soil or foliar application (see Fig 19-1, p. 187). For more information on foliar application of sulfur, see p. 192.

Ordinary superphosphate used to supply phosphorus, but it also supplies sulfur as this fertilizer is half monobasic phosphate and half calcium sulfate on a molecular basis.

Table 9-1. Fertilizer sources of sulfur.

Name of Fertilizer	Chemical Formula	Analysis $N-P_2O_5-K_2O$	Percent Sulfur
VERY SOLUBLE			
Ammonium sulfate	$(NH_4)_2SO_4$	21-0-0	24
Ammonium. . thiosulfate (60% aqueous solution)	$(NH_4)_2S_2O_3 \bullet H_2O$	12-0-0	26
Magnesium sulfate	$MgSO_4 \bullet 7H_2O$ (Epsom salts)	0-0-0	14
Ordinary superphosphate	$Ca(H_2PO_4)_2 \bullet CaSO_4$	0-20-0	14
Potassium magnesium sulfate (Sul-Po-Mag)	$K_2SO_4 \bullet 2MgSO_4$	0-0-22	23
Potassium sulfate	K_2SO_4	0-0-50	18
SLIGHTLY SOLUBLE			
Calcium sulfate (gypsum)	$CaSO_4 \bullet 2H_2O$	0-0-0	17
INSOLUBLE			
Elemental sulfur	S	0-0-0	88-98

Chapter 10

Boron (B)

Atomic Number: 5
Atomic Weight: 10.82

Discovered by Gay Lussac and Thenard in 1808
Proven to be essential to plants by Sommer and Lipman in 1926

Boron in the Soil

Forms

Forms of boron in soils depend on the type soil, the level of organic matter in the soil. Total boron content in soils ranges between 20 to 2,000 $mgkg^{-1}$ (ppm), but available boron ranges from 0.4 to 5.0 ppm (Under areas with high rainfall boron levels available for plant absorption is less than soils in low rainfall areas). Boron is found in primary minerals such as borax ($Na_2B_4O_7 \bullet 10H_2O$), kermite ($Na_2B_4O_7 \bullet 4H_2O$), colemanite ($Ca_2B_6O_{11} \bullet 5H_2O$), ulexite ($NaCaB_5O_9 \bullet 8H_2O$), kotonite [$Mg_3(BO_3)_2$], and ludwigite ($Mg_2FeBO_3$) Boron may also bind with organic matter or with the carbohydrates released during the humification process. In most agricultural soils, boron associated with humic colloids is the principal pool of boron for plant growth. The total boron content of a soil is not a good indication of the amount that is available to plants. The soluble boron in the soil is mainly boric acid, $B(OH)_3$. Undissociated boric acid is the main form available for absorption. Since the major soil form is undissociated and neutral in charge, the major loss of boron from soils is by leaching. Organic matter can hold boron because the carboxylic acids of humic colloids condense with the boric acid. The bond in organic matter is probably stronger in acid and neutral soils than the bond between borate anions and clay minerals. Therefore, in most agricultural soils, humic colloids may be the principal pool of boron. Boron can be leached in sandy soils or soils that are poor in organic matter. It is readily leached from these soils and a deficiency can occur with heavy rainfall and/or irrigation.

Dynamics

Most of the soil boron utilized by plants comes from decomposition of soil organic matter. Most organic matter is located in the plow lawyer (root zone). This makes soils low in organic matter more often subject to plant boron deficiencies than soils high in organic matter. As boron-containing rocks weather, boron is released into the soil solution in the non-ionized boric acid (H_3BO_3) form. In this form, boron is an easily leached from the soil. Liming may decrease boron availability through the action of lime causing a subsequent rise in soil pH.

Soil pH

The availability of boron is dependent upon pH, soil texture, and soil moisture content. Boron uptake has been found to decrease with increasing pH, since boric acid dissociates at high pH levels. The availability decreases at a pH above 6.5. At a pH of 9.0, boron becomes adsorbed by sesquioxide and clay minerals. Unlike most other essential elements, soluble boron is prominent in most soils in the non-ionized form, H_3BO_3 (boric acid). Only above pH 9.2 is the formation of the anion form ($B(OH)_4^-$) significant.

Soil Fertilizers

The most commonly used source of boron is borax ($Na_2B_4O_7•10H_2O$, 11% B). Other sources include sodium pentaborate ($Na_2B_{10}O_{16}•10H_2O$, 18% B), Solubor ($Na_2B_4O_7•5H_2O$ and $Na._2B_{10}O_{16}•10H_2O$, 20% B), boric acid (H_3BO_3, 17% B), colemanite ($Ca_2B_6O_{11}•5H_2O$, 10% B), and B frits (2 to 6% B). Boron is also found as a trace in borated superphosphates.

Banding is usually more effective than broadcasting boron fertilizers. Application rates between 0.6 to 1.2 $kgha^1$ of boron are used with most crops to correct a deficiency. Rates may be increased to 1.2 to 3.2 kg $ha^{-1}$of boron for legumes or sugar beets. However, optimum rates of boron application to soils depends on soil type, cultural practices, rainfall, liming and soil organic-matter content. The plant boron content should be used as the final judge as to whether boron should be applied to a crop.

Foliar Fertilizers

Boron is applied in foliar sprays, especially when soils may fix boron or when high pH reduce availability. Borax and Solubor are the most commonly used source of boron in foliar sprays at rates determined by plant analysis between 0.5 and 1.5 $kgha^{-1}$ boron. New forms of liquid chelated boron are now available to stable and readily absorbed by foliage, e.g., AgriGuardian Boron.

Boron Uptake and Assimilation by Higher Plants

Uptake

The bulk of boron enters the root passively with the transpiration stream as undissociated boric acid. However, small amounts of boron are taken up actively. Factors reducing transpiration such high relative humidity or drought reduce boron uptake and translocation. In general three different mechanisms have been describe related to boron movement into the plant: (1) passive transport across the plasmalemma by diffusion when high amounts of boron is available in the soil solution; (2) energy dependent high-affinity transport at low boron levels in the soil; (3) facilitated transport carried out by NIP channel proteins.

Translocation and Assimilation

Once within the root free space, boron may associate with polysaccharides, remain free as surface film boron, or become bound onto cell walls. Boron moves primarily in the xylem as a sugar-borate complex. For most plants boron is relatively immobile within the plant. Transport of boron in the phloem of most plants is poor with the exception of plants that utilize complex sugars as transport metabolites. Boron, generally when in excess in the plant, may be lost through guttation from hydathodes at the edge of the leaf. Boron is thought to enter roots passively in water flow as undissociated boric acid; although some studies have shown small amounts of B are taken up actively. Boron is relatively immobile in plants and usually the boron content increases from the lower to the upper parts of the plant. The transpirational rate influences the upward transport of boron in the plant supporting that boron is translocated in the xylem. It may possibly move in the xylem as sugar-borate complex and some researchers believe it moves (though limited) in the phloem this way also. In general, dicots require more boron than do monocots. The ranges are: monocots, 1-10 ppm; dicots, 20-70 ppm; and dicots with latex systems (Euphorbiaceae), 70-100 ppm. Thus, there is a wide variation in the boron content of plants depending upon the species. In most plants, average boron in dry plant tissue is 20-100 ppm. Boron deficiency generally occurs when the level is below 15 ppm in the dry matter while toxicity can be expected when the level exceeds 100 ppm though the effect of this toxicity is variable among plant species.

Levels of boron in plants vary with plant part. Boron has been found to accumulate in leaf tips and margins and to be lost through guttation from hydathodes. High levels of boron are found in reproductive plant parts such as anthers, stigma and ovaries, and fruit, sometimes at levels twice those in stems. Most boron accumulates in leaf margins and tips, at levels 5-10 times that of leaf blades. Requirements and, therefore, levels of boron vary with type of plant.

Boron Nutrition in Higher Plants

Essential Roles

Boron functions in the plant are related to meristematic growth and are directly involved in cell differentiation, maturation, division, and elongation. The molecular basis of this function stems from boron being necessary for the synthesis of uracil. Uracil is a component of RNA and a precursor of uridine diphosphate glucose. When boron levels are limiting, cell division rates are reduced and the number of undifferentiated cells increases.

In addition, boron affects the growth of pollen tube, possibly by increasing sugar absorption and metabolism, and increasing respiration. Therefore, boron also exerts an indirect control on germination.

Several other roles attributed to boron include complexing with polyhydroxy substrates, enzymes, and co-enzymes to stimulate or inhibit certain metabolic pathways. Boron may protect indoleacetic-acid oxidase by complexing with its inhibitors. Boron may combine with phosphogluconate to block the pentose-phosphate pathway so that glycolysis is favored and phenols do not accumulate. Boron is involved in the biosynthesis of lignin and differentiation of xylem vessels.

Adequate Range and Nutrition Disorders

Sufficiency Range

The tolerance of plants to boron varies greatly. In most plants, the average boron content is 20 $mgkg^{-1}$ (ppm) on a dry weight basis. Boron is unevenly distributed within the plant with the highest levels of boron found in reproductive plant parts such as anthers, stigma and ovaries (sometimes at levels twice those in stems) and fruits. In the leaves, most boron accumulates in margins and tips, at levels 5 to 10 times higher than those found in blades.

Boron requirements vary with plant type; in monocotyledon species, leaf content ranges between 1 and 6 ppm; in most dicotyledons, between 20 to 70 ppm; and in dicotyledons with latex system, between 80 to 100 ppm. Crops such as sugar beet, celery, apple, pear, or grape have higher B requirements. Brassica crops such as turnips, cauliflowers, cabbage and Brussels sprouts as well as some legumes, also have high B requirements.

Deficiency

Boron deficiency is the most common and widespread of all micronutrient deficiencies. Anything reducing the transpiration stream, i.e. high humidity, dry weather, etc. may induce boron deficiency. Boron deficiency occurs most frequently with over limed or alkaline soils rather than on acidic soils suggesting that this is an antagonistic interaction between calcium and boron. The existence of free calcium in heavily limed soils will restrict the availability of boron, both through action of Ca^{++} and through rise in soil pH. OH^- ions may interact with and suppress the plants uptake of boron. It may be described as an abnormal or retarded elongation of growing points and/or apical meristems. Young leaves are misshapen, wrinkled, thicker and darker in color. Eventually, terminal growing points die. Leaves and stems may become brittle due to either affect on cell wall formation or accumulation of phenols. The accumulation of auxins and phenols induce necrosis of leaves and other plant parts. Roots are slimy, thick and bumpy, and have necrotic tips.

Boron deficiency is specifically responsible for crown and heart rot in sugar beet. Young leaves are stunted and brown or black; the growing points dies and the crown rots. In turnip, boron deficiency causes hollow, cracked roots with a glassy appearance. In celery, boron deficiency causes cracked roots. In cauliflower brown discoloration shows in the developing flower.

Figure 10-1. Boron deficiency in cauliflower

Fruits of boron-deficient plants may be small, misshapen and of poor quality and shortened postharvest shelf life. In apples and tomatoes, corky material forms in boron-deficient plants.

Figure 10-2. Boron deficiency in watermelon during pollination can cause misshapen fruit during development.

Boron deficiency in corn can cause kernels not to develop causing barren ears.

Figure 10-3. Boron deficiency effect on kernel development in corn.

Figure 10-4. Boron deficiency in Pinus taeda (Loblolly or Old-field Pine) seedlings.

Boron deficiency symptoms for specific crops are presented in Table 10-1.

Toxicity

Symptoms of reported toxicity to plants suffering from boron toxicity are leaf tip and leaf marginal chlorosis and necrosis, and eventually scorch and burn (dead tissue) of the whole leaf. Boron is relatively immobile in plants, older leaves showing toxicity to boron before younger leaves, and the boron content increases from the lower leaves to the upper parts of the plant.Symptoms of boron toxicity show lower leaves affected first and then upper leaves as a general rule.

Figure 10-5. Boron toxicity in squash fruit showing cell death on fruit surface as brown necrotic spots.

Figure 10-6. Boron toxicity in strawberries.

In arid regions where boron is not leached to a large extent, boron may accumulate in toxic levels in the upper soil layer. Boron availability is also related to seasonal changes. Boron mobility is impaired during dry seasons, while extremely wet seasons may leach boron. The range between adequate and toxic levels of boron is narrow. Species sensitive to boron toxicity include peach, grapes, figs, and kidney beans. In arid areas, boron may accumulate in top-soil layers due to high levels of boron in irrigation water. Levels above 5 ppm in water are toxic for most plants. Above 10 ppm, toxicity may become visible on tolerant plants. Symptoms of toxicity are leaf tip and leaf marginal chlorosis and necrosis, and eventually scorch and burn of the whole leaf. Under severe boron toxicity plants can prematurely drop their leaves. Death of entire plant can occur with sever boron toxicity.

Figure 10-7. Death of strawberry plants due to boron toxicity.

Some plants such as watermelon and squash can have toxic levels of boron in the leaves but may not express visual boron toxicity symptoms on the leaves. However, the effect of these toxic levels in the leaves may indicate high levels in the fruit, which can affect the fruit shelf life during the postharvest period with rapid decline in fruit quality due to cell deterioration occurring after harvest.

Figure 10-8. Boron toxicity in tree fern.

Table 10-1. Crop specific boron deficiency symptoms.

Crop	Deficiency Symptoms
Alfalfa	Death of terminal bud, rosetting, yellow top, little flowering and poor pod set.
Almond	Flowers fall and nuts abort or are gummy.
Apple	Pitting, skin discolored, cracking and corking.
Apricot	Twigs die back and fruit fails to set.
Beet (Table)	External spotting, cracking and canker.
Broccoli	Hollow stems, internal discoloration, and brown curds.
Cabbage	Hollow stem, watery areas, heads hollow, plants stunted.
Canola	Leaves distorted. Blank or partially filled seed heads.
Carrot	Reddening of leaves and root splitting.
Cauliflower	Leaves curled, hollow stem, curds dwarfed, brown.
Celery	Stem cracked and striped brown, heart blackened.
Citrus	Thickened ring, gum pockets near axis, discolored patches.
Clover	Poor stands, growth and color. Reduced flowering and seed set. Leaves cupped and shriveled, and become brittle.
Corn (all)	Short, bent cobs, barren ears, blank stalks, poor kernel development, elongated, watery or transparent stripes later becoming white on newly formed leaves, dead growing points.
Cotton	Shedding of squares and young bolls, ruptures at base of squares, dark fluid exuding from ruptures, internal discoloration at base of boll, half-opened bolls, green leaves until frost.
Dry Bean	Interveinal chlorosis of leaves. Bushy appearance.
Grape	"Hen & Chick" symptom, dead main shoots.
Lettuce	Stunted growth, discoloration of leaves, brittle.
Crop	**Deficiency Symptoms**
Peanut	Dark, hollow area in center of nut, called "hollow heart."
Pear	Blossom blast, pitting, internal corking and bark cankers.
Pistachio	Fruit set decreases, and blanks and non-split nuts increase.
Potatoes	Plants have a bushy appearance. Leaves thicken and margins curl upward.
Radish	Pale roots, brittle stems, watery flesh and flecked coloration.
Rutabaga	Roots are tough, fibrous and bitter. Upon cutting, they have soft, watery areas, often called "brown-heart."
Sorghum	Leaves are narrow and have a gray appearance with watery, transparent stripes. Seed heads are not filled.
Soybean	Yellow leaves, chlorotic between veins, downward curling of leaf tips, crinkling of leaves, dieback of tips, no flowering, roots stunted.

Strawberry	Pale chlorotic skin of fruit, cracking and dieback.
Sugar Beet	Yellowing or drying of leaves, cracking of leaf midrib, brown discoloration of internal tissue, rotting of crown.
Sunflower	Leaves appear wilted. Abnormal head fall due to weak peduncles.
Tobacco	Leaf puckering and deformed buds.
Tomato	Thickened leaves, brittle leaves, fruit fails to set.
Turnip	Hollow center or brown heart, watery areas.
Walnut	Dieback from shoot tips, leaf falls.
Wheat	Distorted heads and chlorosis of leaves.

Factors Affecting Availability

pH

High pH reduces, and low pH enhances availability.

Leaching

B is mobile, so coarse soils and high rainfall may cause temporary soil shortages.

Low Organic Matter

Organic matter is a reservoir for B, and many other nutrients

Low Moisture

Boron uptake is in part determined by water uptake rate, therefore drought reduces B uptake. Also, B deficiency reduces root growth, thus aggravating the B stress.

Soil Ca:B Balance

Some work has indicated that high soil Ca levels, independent of soil pH can reduce B uptake. In most situations however, high soil Ca will be accompanied by higher soil pH, and the pH effect will dominate. In some cases of B toxicity, applications of a soluble form of Ca have reduced the toxic effects.

K:B Ratio

Work has show that high K rates can sometimes depress corn yields if B is limiting.

Zn:B and P:B Ratio

Work with barley showed that Zn applications could reduce B accumulation. This same work showed that high P applications increased B accumulation.

Interactions with other Essential Elements

Nitrogen

Applications of N have induced B deficiency in plants when soil B levels are low, evidently the result of a dilution of B and its failure to move from older to developing meristematic tissues. An N deficiency was found to result in an accumulation of B in grape leaves. Low N availability decreases the vigor of plants to an extent that it may fail to take up adequate amounts of many other nutrients. Boron uptake can be affected in this way.

Phosphorus

Foliar applied KH_2PO_4 has been found to lower B in pecan leaves. An induced P deficiency increased the B content in grape leaves. The B content of two out of three strawberry cultivars was found to be higher in plants not receiving B when P was deficient. However, in the presence of excess B, the B content was lower in two out of three cultivars receiving adequate or high levels of P.

Low levels of B in plant affect phosphate incorporation into nucleic acids and reduce levels of other P-containing compounds such as ATP. The adsorption of P at the roots of B-deficient plants may be reduced by half.

Potassium

High levels of K have been found to decrease B content in plant. Increasing K decreases the Ca:B ratio in plant. Increasing K in the substrate increased the B content in tomato tissue, especially if the substrate B was high. Increased plant K accentuated B deficiencies, but unlike Ca, increased K failed to diminish B toxicity symptoms. The Ca:B ratio in the plant decreases markedly with increased K, but Ca has little or no significant effect upon the K:B ratio. Increased K in the substrate also decreased the B content of cotton, peanut, and soybean. Adequate B may eliminate the depressive effect of large amounts of K in the soil upon Ca and Mg concentration in soybean.

Calcium

Boron and Ca must be in balance for proper plant growth. For soybeans, the correct Ca:B ratio has been found to be 500:1, while for sugar beets the ratio should be 100:1. Spraying apples with B has shown to be effective in reducing bitter pit, a disorder related to Ca deficiency. Calcium added to the soil helps decrease the incidence of B toxicity. Calcium inhibition of B uptake is especially marked in high pH soils.

A close relationship exists between Ca and B in a great number of crop plants. Generally, larger quantities of B are needed to avoid B deficiency with high rather than with low levels of Ca. Also, much larger quantities of B can be tolerated in the presence of high Ca levels without causing toxicity symptoms.

In field studies, liming has been associated with B deficiency and lowered B concentration in a number of crop plants. On soils with high pH induced by added lime or on naturally occurring high pH soils, plants can tolerate appreciably more added B without showing B toxicity symptoms. This association of liming with plant B concentration appears to be affected by pH but not by Ca, since pH affects the amount of B fixed by a soil, whereas addition of Ca as gypsum does not. Increasing the amount of applied lime reduces B diffusibility, especially when the water content in the soil is reduced.

Although the existence of a relationship between Ca and B has been proven for a great number of plants, the Ca:B ratio has not been used to a great extent in interpreting B status. This limited use may be attributed to the effectiveness of leaf B concentration as a satisfactory indicator of B sufficiency, and the fact that a low Ca:B ratio may indicate a deficiency of Ca or a toxicity of B. Deciding whether a specific ratio represents a deficiency or a toxicity is possible only if the substrate Ca and/or B is also known.

Arsenic

Applied As decreases the acidity of grapefruit juice, thereby hastening the maturity of the fruit, but B applications increase the acidity, nullifying some of the As effects. However, As appears to have no significant effect upon leaf B.

Fertilizer

The most familiar B fertilizer is borax. Boric acid is commonly applied as a leaf spray. The very narrow range of concentrations of B in the soil at which either deficiency or toxicity may occur can create a problem with boron application. The use of boro-silicate glass frits provides a slow release of boron into the soil while band or foliar application is generally more efficient than broadcast applications. Boron frits release boron slowly and are used in order to avoid excess application of boron, because the range between sufficiency and toxicity is so small.

Table 10-2. Commonly used boron fertilizers.

Name	Formula	Approx. % B
Borax (most widely known)	$Na_2B_4O_7 \cdot 10H_2O$	11
Sodium pentaborate	$Na_2B_{10}O_{16} \cdot 10H_2O$	18
Sodium tetraborate		
Fertilizer borate – 46	$Na_2B_4O_7 \cdot 5H_2O$	14
Fertilizer borate – 65	$Na_2B_4O_7$	20
Solubor	$Na_2B_4O_7 \cdot 5H_2O$ $Na_2B_{10}O_{16} \cdot 10H_2O$	20
Boric Acid	H_3BO_3	17
Colemanite	$Ca_2B_6O_{11} \cdot 5H_2O$	10
Boron frits		2-6
Liquid chelated boron*		10

* Marketed as AgriGuardian Boron.

Chapter 11

Chlorine (Cl)

Atomic Number: 17
Atomic Weight: 35.453

Discovered by Scheel in 1774
Proven to be essential to plants by Broyer in 1954

Chlorine in Soil Environment

Because chlorine is usually supplied to plants as the anion chloride (Cl^-) from soil reserves, irrigation water, rain, fertilizers, and air pollution the discussion of this plant nutrient will focus on the chloride ion.

Forms in Soil

Chloride is distributed widely in the environment and exists in the soil as a constituent of primary minerals, such as chlorapatite [$Ca_5(PO_4)Cl$], carnallite ($K,MgCl_3.6H_2O$) and sodalite ($Na_4A1_3Si_3O_{12}Cl$). Upon weathering of these minerals, the chloride is released into the soil solution. Chloride is also in the soil as a consequence of the common applications of chloride-based fertilizers.

Dynamics in Soil

In the soil solution, chlorine exists as monovalent chloride anion (Cl^-), and, due to its high mobility is leached easily from the topsoil by rainfall or irrigation water. In humid climatic areas, chloride is at very low concentrations in surface soils, as it is moved downward with the flow of water in the soil. In arid or semi-arid climatic areas, chloride concentrates in the surface horizon, rise with the movement of capillary water, thereby leading to soil salinity.

Applied road salt can be a source of chloride accumulation as it is carried from roads and roadsides into nearby soils by runoff, aerosols, or dust.

Fertilizers

Chloride is a component in many commonly used fertilizers, such as potassium chloride (KCl, 47% Cl^-), sodium chloride (NaCl, 60% Cl^-), ammonium chloride (NH_4Cl, 66% Cl^-), calcium chloride (CaC_2, 64% Cl^-), and magnesium chloride ($MgCl_2$, 74 % Cl^-).

Chloride Uptake and Assimilation by Higher Plants

Movement and Uptake

In the soil, chloride follows water movement and is taken up as the chloride (Cl^-) anion. The greater the chloride concentration in the soil solution, the greater the uptake of chloride. The chloride ion is taken up against an electrochemical gradient mediated by a protein carrier. Chloride also may be absorbed into the plant leaf as the chloride ion or as chlorine (Cl_2).

Translocation and Assimilation

Chloride is very mobile in the plant and remains in the chloride form.

Chloride Nutrition in Plants

Plants take up chloride readily. Chloride is the major form in plants and is highly mobile as a free anion within and between cells and in the vascular system. Most of the chloride in plants is not incorporated into organic molecules or dry matter, but remains in solution as chloride and is loosely bound to organic molecules.Chloride might have several physiological and biochemical functions in plants. Chloride stimulates activity of some enzymes including asparagine synthethase, amylase, and ATPase. Chloride is perceived as an essential cofactor for the activation of the oxygen-evolving mechanism in Photosystem II. Chloride plays an osmoregulatory function, increases tissue hydration and turgor pressure, thereby expanding tissues such as elongating cells of roots and shoots, plays a role in opening and closing of stomata in plants, and functions to maintain the cation/anion balance within the plant.

The plant requirement for Cl^- is very low, and concentrations in plants range considerably, from 10 to 5,500 $mgkg^{-1}$ dry wt., the actual concentration varying with plant species, plant part, and supply of chloride in the soil solution. The concentration of Cl^- in plant tissues is usually highest in leaf blades, with lower concentrations in the petioles, stems, and fruits.

Most plant species will accumulate more chloride than is needed without a toxic effect. This action is related to the osmoregulatory role of Cl^- in some plants. Because of many readily available chloride sources in nature for plants and relatively rare incidences of chloride deficiency, relative few studies have been conducted to evaluate critical concentrations of chloride in field-grown crops.

Sources of Chloride

Plants are exposed to $Cl^-$from a wide variety of sources such as rainwater, air, irrigation water, animal manures, plant residues, fertilizers, and some crop-protection chemicals. Chloride additions from the atmosphere range from 18 to 36 kg/ha/year for most cropland in the USA and >100 kg/ha/year for coastal areas. Chloride deficiency in plants is not a commonly occurring problem in soils. To induce Cl^- deficiency in a plant, the seed, applied chemicals, water, the rooting medium, and the air surrounding the plant must be essentially void of Cl^-.

Salt Effect

Soil salinity is associated with the accumulation of soluble salts in the soil with a major portion being Cl^- With increasing soil salinity; plant growth will be affected adversely as plant-water relations are affected. Plants will wilt due to their inability to absorb water from the soil/media to replace, that which is lost through transpiration.

Salinity imparted by Cl^- occurs mainly in locations with little rainfall, which results in the accumulation of chloride in the root zone soil solution. Compared to chloride deficiency, chloride effects from soil salinity are much more common and can be a factor in limiting plant growth in arid and semi-arid areas. Under saline soil conditions, the adverse affect of Cl^-on root function is due to the osmotic effect of the salts in solution, not due to a toxic effect of a high concentration of chloride. A high Cl^- concentration in the tissues of plants can affect the ability of some plants to withstand transpiration loss of water in arid climates, as stomata remain open. High levels of Cl^- will affect adversely the postharvest quality of some vegetables by reducing shelf life.

Irrigation Water

Irrigation water with a Cl^- concentration exceeding 71 mgL^{-1} may result in plant damage when applied to nursery, greenhouse crops, and field crops. Generally, Cl^- levels in irrigation water with the range between 70 and 345 mgL^{-1} is questionable as to suitability, and >345 mgL^{-1} is unacceptable for use for most crop plants.

Adequate Range and Nutritional Disorders

Sufficiency Range

Chloride concentration in plants range between 50-200 $mgkg^{-1}$ (ppm) [above you say from 10-5000].Chloride deficiency can vary greatly between plant species. Most plant chloride concentrations are between 2 to 30 $mgkg^{-1}$ and are not harmful or deficient at these levels. Most fruit trees, garden bean, and cotton are considered sensitive to chloride and are harmed at concentrations more than 3.5 mgg^{-1} leaf dry weight.

Deficiency

The most common symptoms of Cl^- deficiency are chlorosis and wilting of the young leaves and appear as a flat depression in the interveinal area of the leaf blade. A bronzing on the upper side of the mature leaf can be observed with higher concentrations of Cl^- in the tissue. Chloride deficiency may occur if the soil chloride content is less than 2 $mgkg^{-1}$. Visual plant symptoms of severe Cl^- deficiency are chlorotic leaves with brown necrotic leaf margins. Marginal leaf necrosis may be preceded by wilting at the leaf margins, curling of the younger leaves followed by shriveling and necrosis, and a reduction in leaf area.

Toxicity

Toxic symptoms consist of one or more of the following expressions, leaf spotting, interveinal chlorosis, necrosis of the leaf margins of older leaves.

Figure 11-1.Left-Bosque Lacebark Elm showing leaf spotting and Right-Myrima Zelkova showing interveinal chlorosis and necrosis of the leaf margin.

Additional symptoms are growth inhibition, or leaf death resulting in premature defoliation. In trees, the blooming of flower buds that have not entered dormancy usually follows premature defoliation. Ornamental nursery growers in areas where salt-waterinfusion into the irrigation water source are experiencing chloride toxicity to their plants. Both old and young tissue is affected when chloride levels in the irrigation water are toxic and delivered through the overhead irrigation system.

Figure 11-2. Chloride toxicity to magnolia.

Specific chloride levels that are toxic to a plant will vary with species. Sugar beet, barley, corn, spinach, and tomato are tolerant to chloride, whereas tobacco, bean, citrus, potato, lettuce and some legumes are prone to toxicity and are known as *chlorophobic* plant species. Susceptible plant species willshow toxic symptoms if their roots are exposed to Cl^- concentrations of 460 to 673 mgL^{-1}, whereas resistant plant species will show toxic symptoms if the Cl^- concentration ranges from 887 to 3,546 mgL^{-1}. These high concentrations seldom are reached under field conditions. However, because of fears of Cl^- toxicity, some growers avoid use of KCl as a potassium fertilizer and use K_2SO_4 instead. This substitution has led to Cl^- deficiency in some of the few reported cases of Cl^- deficiency in nature.

Interactions with other Elements

Nitrate

The most commonly occurring anionic antagonism is between Cl^- and NO_3^-. High Cl^- supply in the nutrient medium lowers nitrate uptake and *vice versa*. Increasing fertilizer NO_3^- applications may help to reduce Cl^- toxicity in crops

Chapter 12

Copper (Cu)

Atomic Number: 29
Atomic Weight: 63.54

Element known since prehistoric times
Proven to be essential to plants by Sommer in 1931 and by Lipman and Mackinney in 1931

Copper in the Soil

Most copper in soils is sparingly soluble and essentially immobile due to its binding strength with organic matter. Liming and raising the pH generally decreases copper availability, possibly by strengthening the adsorption of Cu^{+2} or $Cu(OH)^{+}$ or by precipitation. Available copper in soils is most likely present as adsorbed Cu^{+2}, which can bind to carboxylic, carbonyl, or phenolic groups of organic matter in the soil. Complexed and soluble Cu^{+2} are in the soil solution. High concentrations of organic matter or humus in a soil results in the complexing of copper removing it from the soil solution needed for uptake. Such complexes have high stability constants, thereby making copper less available for plant uptake. Reclamation disease, a copper deficiency disorder that occurs in peat soils that have been brought into cultivation, has been treated successfully for years by the addition of copper salts.

The total soil content of copper ranges from about 5-50 mg kg^{-1}. Ideally, for crops, total copper should be higher than 4-6 mg/kg for mineral soils and 20-30 mg kg^{-1} for organic soils. Concentration of copper in soil solution is low, ranging from 1 x 10^{-8} to 60 x 10^{-8} M, and most of copper in soil solution (98%) is bound to organic matter.

Copper Uptake and Assimilation by Higher Plants

Uptake

The uptake of copper is active and metabolically controlled. Roots absorb Cu^{+2} or chelated Cu^{+2}.

Translocation and Assimilation

Copper moves in the xylem complexed with soluble compounds such as amino acids. Copper is slowly mobile in plants. Approximately half of the plant active copper is in the chloroplast. Copper concentration in shoots is highest when plants are young and decreases steadily as plants grow and mature. In flowers, most of copper is in anthers and ovaries.

Copper Nutrition in Higher Plants

Essential Roles

Copper is a component of several enzyme complexes that influence carbohydrate and nitrogen metabolism of plants. Plastocyanin is a Cu-containing enzyme involved in the electron transport chain of photosynthesis. More than half of the foliar copper is associated with plastocyanin. In the mitochondria, copper containing cytochrome oxidases are part of the respiratory pathway of oxidative phosphorylation. In thylakoids and mitochondria, phenolases catalyze the oxidation of phenols to quinones. Phenolase and laccase are copper-containing enzymes and are involved in lignin synthesis.

In the chloroplast, three isoenzymes of superoxide dismutase protect plants from superoxide (O_2^-) damage by its reduction to H_2O_2. This enzyme also contains Zn atoms or Mn or Fe. In the cytoplasm and cell walls, ascorbic acid oxidase catalyzes the oxidation of ascorbic acid to dehydroascorbic acid. Amine oxidases catalyzes the oxidative deamination of NH_2-containing compounds, including polyamines.

Adequate Range and Nutrition Disorders

Sufficiency Range

Copper content in most plants ranges between 2 and 20 $mgkg^{-1}$ ppm). The sufficiency range in leaves is 3 to 7 ppm. The use of copper fungicides will elevate the tissue level of copper analyzed in the laboratory, sometimes as high as 200+ ppm, unless the surface copper is removed by washing the leaf prior to analysis.

Deficiency

Since copper is slowly mobile in the plant, young organs are the first plant parts to show deficiency symptoms. Effects consist of reduced or stunted growth with distortion of young leaves and growing points, as well as necrosis of the apical meristem.

Figure 12-1. Copper deficiency in Nepenthes or Pitcher plant showing stunted young leaves.

Figure 12-2. Copper deficiency in Neanthe Bella palm.

In chrysanthemums, lateral buds may be distorted or fail to form. Young leaves may have white or bleached tips. This malady occurs typically in cereals along with limited growth and inflorescence formation. Copper deficiency increases the incidence of lodging, especially when stimulated growth occurs in response to nitrogen fertilization. Flowering and fruiting may be affected or absent, since pollen and ovaries are very sensitive to copper deficiency. Also rough bark, gum oozing, witch's broom, dieback, wilting, cracked peelings (orange), grey speck, and various discoloration of foliage are symptoms of copper deficiency.

Toxicity

Excess copper can induce iron deficiency. Root growth may be stunted, with little lateral root formation, possibly due to membrane damage by excess copper. Legumes are generally more sensitive to high copper levels than other plants.

Interactions with other Elements

Nitrogen

Increased need for copper may be related to the dilution effect caused by plant growth following nitrogen fertilization. Nitrogen additions, especially to soils with low copper contents, have increased copper deficiency in several crops. Applications of nitrate are less likely to induce copper deficiency than the addition of ammonium. A reduction of copper availability for plant growth may be traced to competition with other metals, to dilution, or to fixation. When copper and iron levels in the substrate are adequate, the addition of nitrogen increases plant copper. The highest increase in plant copper content is related to the use of HNO_3, followed by NH_4NO_3 and $Ca(NO_3)_2$.

Foliar applications of copper increase plant nitrogen as well as P, K, Ca, and Mg. These increases may be due to the catalyzing effect of the copper on plant metabolism, thereby increasing element uptake.

Phosphorus

In citrus, heavy or prolonged use of phosphorus fertilizers induces copper deficiencies. Additions of phosphorus lowered plant copper contents in crops such as flax, snap bean, tomato, table beet, and papaya.

Potassium

The use of K-containing foliar sprays on pecans reduced the level of foliar copper.

Calcium

Calcium added as a liming material can reduce the copper concentration in plants.

Iron

In citrus and lettuce, high copper levels induced iron chlorosis. The harmful effects of high copper levels on the availability of Fe are well documented.

Manganese Copper stimulates the uptake of manganese.

Zinc Increasing copper concentrations in media significantly inhibits the uptake of zinc. Zinc is believed to interfere with copper at the absorption site.

Molybdenum Copper interferes with the role of molybdenum in the enzymatic reduction of nitrate. A mutual antagonism has been found between copper and molybdenum in some plants.

Aluminum Aluminum has been shown to affect the uptake of Cuadversely.

Table 12-1. Commonly Used Copper Fertilizers

Name	**Formula**	**Approx. % Cu**
Copper(II) sulfate pentahydrate	$CuSO_4$-$5H_2O$	25
Copper(II) sulfate monohydrate	$CuSO_4$ H_2O	35
Basic copper(II) sulfates	$CuSO_4 \cdot 3Cu(OH)_2$ (general formula)	13-53
Malachite	$CuCO_3 \cdot Cu(OH)_2$.	57
Cuprous oxide	Cu_2O	89
Cupric oxide	CuO	75
Chalcopyrite	$CuFeS_2$	35
Chalcosite	Cu_2S	80
Copper(II) acetate	$Cu(C_2H_3O_2)_2 \cdot H_2O$	32
Copper(II) oxalate	$CuC_2O_4 \cdot 2H2O$	40
Copper(II) ammonium phosphate	$Cu(HN_4)PO_4$	32
Copper chelates	Chelated copper - Ethylenediaminetetraacetic acid (EDTA), Copper-disodium complex, Chelated Copper - Diethylene Triamine Penta Acetic Acid (DTPA) Copper	14 12
Copper polyflavonoids		5-6.7

No effect in the availability of copper supplied by $CuSO_4 \cdot 5H_2O$, CuO, $CuSO_4$, $Cu(OH)_2$, or CuEDTA was observed in tissue levels of copper when these solutions were applied to organic soils. Although a 12-fold difference in solubility occurs with applied Cu-sources such as $CuSO_4 \cdot H_20$, CuEDTA, and a synthetic copper phosphate, Cu accumulation in wheat was quite similar among these fertilizers. This study also revealed the importance of thorough mixing of poorly soluble copper compounds with soil in order to enhance the availability of copper for plant absorption.

Foliar Application

Foliar applications of $CuSO_4$ or Cu-chelates at 0.3 to 1 kg Cu ha^{-1} (0.27 to 0.90 lb/ac) also are used commonly. While copper sulfates can be used for foliar application, they may burn or scorch foliage. Chelated coppers products are more effective than copper sulfate products. Also, Bordeaux mixture, a combination of copper sulfate and lime, is used commonly as a fungicide for grapes and other plants. Plants generally show a growth response to the copper in Bordeau mixture application when copper is low.

Figure 12-3. Greenhouse production of foliage plants routinely utilizes foliar applied micronutrients as a primary means of delivering these essential plant nutrients through the leaves to maintain sufficiency levels for proper growth.

Chapter 13

Iron (Fe)

Atomic Number: 26
Atomic Weight: 55.85

Element known in prehistoric times
Proven to be essential to plants by von Sachs; Knop in 1860

Iron in the Soil

Forms

Iron is present in large amounts (up to 5% of the soil weight) in primary minerals, such as ferromagnesian silicates (olivine, augite, hornblend, and biotite), and oxides (hematite and magnetite). However, because of low solubility of primary minerals and iron oxides, a weak correlation exists between total and available iron in soil

Dynamics

As weathering of primary mineral occurs, iron appears in clay minerals and also accumulates as hydrous oxides. Iron chemistry in the soil is complex and depends largely on pH and oxidation-reduction potential. Soluble inorganic forms include Fe^{+3}, $Fe(OH)^{+2}$, and Fe^{+2}. Fe^{+2} is stable as long as reducing conditions prevail. However, in the soil solution of well-aerated soils, Fe^{+3} is the dominant form. Extended rainfall and anaerobic conditions can change the availability of Fe (see Example #3, p. 235).

Fertilizers

Most iron deficiencies are due to low availability of iron in an unfavorable pH range, not to low total iron levels. The mobility of soluble iron does not exceed 1.5 cm from the site of placement. Hence, foliar fertilization with $FeSO_4$, $FeCl_2$, or Fe-chelates at 3 to 5 $kgha^{-1}$ Fe (2.7 to 4.5 lb/ac) is preferable to soil applications.

Iron Uptake and Assimilation by Higher Plants

Uptake

The Fe^{+3} (ferric) form of iron is the dominant ionic form in the soil, but Fe^{+2} (ferrous) is absorbed by most plants (grasses an exception). Iron uptake and nutrition are genetically controlled and not well understood.

Two mechanisms of Fe uptake have been identified in root cells and called Strategy 1 and Strategy 2. In the plasmalemma of root cells of the epidermis and cortex, Fe^{+3} is reduced to Fe^{+2} by iron reductase and is accompanied by the release of protons that acidify the medium (Strategy 1). In Strategy 2, which is common in grasses, Fe^{+3} is taken up after chelation with plant-synthesized molecules called phytosiderophores. Once in the root, Fe^{+3} is translocated in the xylem as Fe^{+3} associated with citrate.

Translocation and Assimilation

Iron is transported in the xylem mainly to the leaf cells where it enters chloroplast and where its levels are controlled by reversible binding with the ferric phosphoprotein (phytoferritin).

Iron Nutrition in Higher Plants

Roles of iron are related to changes in oxidation-reduction states and electron transfer reactions. Iron is a component in enzyme systems, such as oxidases, catalases, and peroxidases, and is a component of cytochromes and other heme-containing proteins that participate in enzymatic reactions, as in photosynthesis and respiration. Iron is also part of the protein ferredoxin, which is required for nitrite reduction, sulphate reduction, N_2 assimilation, and photosynthetic electron transport in production of reduced NADP. Other. Fe-containing enzymes include superoxide dismutase that detoxifies free radicals, aconitase that is an enzyme in respiration, as well as several enzymes in ethylene biosynthesis, peroxidation of fatty acids, and chlorophyll synthesis.

Adequate Range and Nutrition Disorders

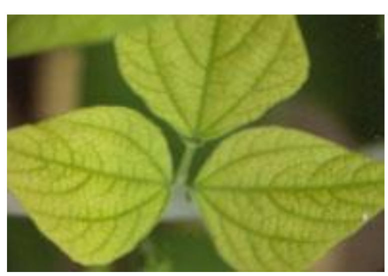
Sufficiency

The sufficiency range for iron in most plants is between 50 to 75 $mgkg^{-1}$ Fe (ppm).

Deficiency

The most common symptom of iron deficiency is interveinal chlorosis of the youngest leaves, which evolves into an overall chlorosis and finally a bleached leaf.

Figure 13-1. Iron deficiency in snap beans.



In blueberry's it is quite common for a magnesium deficiency and an iron deficiency to be expressed together.

Figure 13-2. Iron deficiency in Rabbit eye Blueberry with terminal leaf showing white bleached out appearance characteristic of iron deficiency while older leaves are showing a magnesium deficiency. Leaf analysis confirmed this plant is low in iron and magnesium.

Figure 13-3. Iron deficiency in blueberry.

Figure 13-4. Iron deficiency in azalea.

Figure 13-5. Gardenia "Frostproof" with severe iron deficiency.

Figure 13-6. Iron deficiency in poinsettia.

Figure 13-7. Iron deficiency in greenhouse tomato.

Figure 13-8. Iron deficiency in young tomato leaves under greenhouse culture.

Figure 13-9. Iron deficiency in field grown pepper plant due to high soil pH.

Some necrotic spots can develop with severe iron deficiency. Iron is not very mobile and the symptoms in the youngest leaves will show a greening effect on veins first when iron deficiency is corrected with fertilizer application. Calcareous soils and anaerobic conditions promote iron deficiency. Iron deficiency can be induced by excess of heavy metals. The plant itself can influence iron uptake by plant, with plants among or within species being either ***Fe-efficient***or ***Fe-inefficient***. Iron-efficient plants are able to acidify the rhizosphere or to release siderophores, which enhance the uptake of Fe.

Toxicity

Iron toxicity develops as a bronzing of the leaves, followed by tiny brown spots. Iron often can accumulate to 300 to 400 $mgkg^{-1}$ in some plants without inducing toxicity.

Interactions with other Essential Elements

Minimizing crop losses due to inadequate iron is complicated by the fact that Fe deficiency is seldom caused by a shortage of total iron in the soil. Most iron deficiencies occur when the availability is lowered by high soil pH or high lime, which imparts high pH (frequently referred to as lime-induced chlorosis), or high phosphorus, which can precipitate iron at high pH.

Plant analysis for total iron content often fails to determine whether iron is deficient. Some plants, although showing typical iron deficiency symptoms and responding to foliar applied iron, have as much or more iron in the analyzed plant part as in the corresponding plant part of a normal-appearing plant. A controversy surrounds early iron research as these analysts may have failed to remove dirt particles from samples prior to analysis, and the dirt may have contributed to the iron content reported in sufficiency ranges for various crops. Abnormally high iron concentrations of over 1000 $mgkg^{-1}$in plant leaves likely are due to contamination with soil dust. Later, with investigations using modern techniques to remove dirt or dust, researchers obtained higher correlations between iron deficiency symptoms and total plant iron content. However, in some cases, chlorotic leaves may still contain as much or more total iron than is in normal-appearing plants. Perhaps, iron is immobilized by precipitation in plant tissues and is not available for metabolism. Some technicians have suggested that soluble iron may be a better indicator of plant iron status than total iron.

The plant itself may be a significant factor in determining its sensitivity to iron deficiency. So-called “Fe-efficient plants” have the ability to release H^+ ions at their root surface to dissolve iron and to produce Fe-complexing substances that enhance iron uptake into root cells. “Fe-inefficient” plants lack these abilities. This plant root characteristic varies among plant species and varieties within a species. Therefore, the simple selection of a Fe-efficient species or variety may be a way to avoid iron deficiency under many growing conditions.A good way to determine iron efficient plants for soils in your area is to examine neighborhood plants or botanical gardens.

Soil pH

An increase in pH (>7.0) from liming can result in iron chlorosis. This malady is due primarily to the unavailability of iron as $Fe(OH)_3$ or other sparingly soluble compounds at high pH. A high pH in the soil appears not to affect iron movement within the plant.

Nitrogen

In plants, higher iron contents in the plant tissue result from ammonium-N applications than from nitrate-N applications. The use of nitrate-N sources on high pH soils increased iron deficiency in several crop plants, due to the elevated rhizosphere pH following nitrate absorption. The beneficial effect of ammonium-N in reducing iron deficiency problems is due to the effect of the uptake of ammonium ions and nitrification on lowering substrate and rhizosphere pH.

However, the use of ammonium-N does not always have a beneficial effect on plant iron. In acid soils or low pH-nutrient solutions, the further lowering of the pH level can have a deleterious effect on plant growth and particularly root development, thereby resulting in a decrease in roots and the plants ability to mine available iron for uptake. Nitrogen fertilization will also increase iron deficiency due to increased growth of the organs and dilution of the amount of iron present in the plant tissue.

Phosphorus

High soil phosphorus appears to suppress iron uptake, and high plant phosphorus concentrations have been considered as a cause of iron deficiency in a number of plants, likely from precipitation of sparingly soluble iron phosphates in the soil under alkaline conditions or within the plants. A P:Fe ratio of 29:1 (w:w) is considered optimal for most plants.

Potassium

Potassium increases mobility and solubility of iron in plants and may also indirectly increase the rate of iron uptake.

Bicarbonate

The cause of Fe deficiency in high pH soils may not be caused necessarily by a shortage of iron, but by the physiological effects of the HCO_3^- anion on iron availability. The presence of HCO_3^- reduces iron uptake and mobility, because of the alkalinity generated and the resulting precipitation of iron in the soil or in the plant. Transport of iron in plants may be limited by additions of HCO_3- to nutrient solutions as. an increased the proportion of foliar applied iron remains in the conducting tissues (stems and petioles) and limits the amount that reaches the leaves.

Calcium

Increased pH levels from over-additions of calcium containing liming materials or from native calcium compounds in the soil are a common factor contributing to iron deficiency. The higher soil pH reduces the solubility of iron compounds. It should be remembered, however, that calcium does not affect the pH of soils and that the changes in pH are due to the accompanying anions, carbonate, oxide, or hydroxide. Calcium is needed for the absorption of all solutes. Lowering of the calcium level to 1/50 of its normal concentration in a nutrient solution, gave a lower iron content of corn leaves.

Copper

The harmful effects of high copper on iron deficiency have been noted primarily under high copper to iron ratios in solutions (competes with iron for uptake).

Magnesium

The addition of $MgCO_3$ in agricultural limestone lowers the available iron for uptake through the alkalinity developed and resulting precipitation.

Manganese

Observers have noted than an excess of manganese results in a deficiency or iron.

Zinc

High levels of zinc may induce iron deficiency. Applications of zinc have reduced the iron content of corn leaves as well as the leaves of soybean compared to plants grown at low levels of zinc.

Fertilization

Iron chlorosis is a difficult deficiency to correct in the field.Soil applications of inorganic ironsources are not effective because of the rapid precipitation into sparingly soluble compounds such as $Fe(OH)_3$. Soil applications of inorganic Fe^{+2} sources have very little residual effect because the Fe^{+2} ion is converted rapidly to Fe^{+3} in aerated soils.

Correction of iron deficiencies is mainly with foliar application of iron. A recommended method is the application of a 2% $FeSO_4$ solution at 15 to 30 gal/acre. Several applications may be necessary to remedy severe iron deficiencies. Banding or root zone application provides the best results. Injections of $FeSO_4$ have been utilized in trees.

With inorganic salts, little difference in the effectiveness of soil applied ferrous (Fe^{+2}) or ferric (Fe^{+3}) sources is apparent. The Fe^{+2} is oxidized quickly to Fe^{+3} in well-aerated soils. Thus, the application of Fe in inorganic salts is of little value except in cases where a substantial lack of Fe exists. Mixing ferrous sulfate ($FeSO_4$)or ferric sulfate

[$Fe_2(SO_4)_3$] with fluid polyphosphate fertilizer, however, has corrected Fe deficiency of sorghum grown on a soil with a pH of 7.5, whereas neither material corrected iron deficiency when applied separately to the soil.

Organic Iron Sources

Iron chelates with complex organic acids (EDTA, DTPA, EDDHA) are effective iron sources for hydroponic nutrient solutions and for foliar applications. Chelated iron is protected from precipitation by phosphates and other ions or compounds that react with iron. Soil application recommendations with chelated salts are usually less than 1 kg Feperhectare.

Iron chelates. Chelates are compounds that stabilize metal ions (in this case, iron) and protect them from oxidation and precipitation and an iron and a deficiency of iron. Iron chelates consist of three components:

- Fe^{+3} ions
- A complex, such as EDTA, DTPA, EDDHA, amino acids, humic-fulvic acids, citrate, and sugar-based chelates such glucoheptonate.
- Sodium (Na^+) or ammonium (NH_4^+) ions

Note that different chelates hold iron ions in different strengths at different pH levels. They also differ in their susceptibility to iron replacement in the chelated compound by competitive ions such as calcium and magnesium.

Fe-EDTA - is stable at pH below 6.0. Above pH of 6.5, more than half of the iron is unavailable. Fe-EDTA should not be used in alkaline calcium-rich soils or water as this chelate also has high affinity to calcium (*EDTA is a very stable chelate of micro-elements, other than iron, even in high pH levels).*

Fe-DTPA - is stable in pH levels of up to 7.0, and is not as susceptible to iron replacement by calcium.

Fe-EDDHA - is stable at pH levels as high as 11.0, but is also the most expensive iron chelate available.

Use of chelates overcomes iron deficiencies, but the chelate chosen must be stable for the particular condition of the soil to which it is to be applied. Iron EDTA chelate is stable under slightly acid conditions, whereas DTPA or EDDHA chelate is better suited for slightly alkaline conditions. The Fe EDDHA chelate is best suited for strongly alkaline (near pH 8.0) soil conditions.

Chapter 14

Manganese (Mn)

Atomic Number: 25
Atomic Weight: 54.43

Discovered by Scheele in 1774
Proven to be essential to plants by McHargue in 1922

Manganese in the Soil

Forms

The primary manganese-containing minerals form secondary minerals, such as pyrolusite (MnO_2) and manganite [MnO(OH)] in the soil. Manganese also exists in soils as manganese oxides, in part adsorbed on the surface of clay minerals.

Dynamics

The concentration of Mn^{+2} in the soil solutions is governed by oxidation-reduction reactions. These, in turn, are affected by microbial activity, pH level, and water, and organic matter contents. Sterilization of the soil destroys many of the Mn-oxidizing microorganisms; resulting in an increase of soluble Mn^{+2} that can in turn, result in plant manganese toxicity. The amount of Mn^{+2} rises as the water level increases, sometimes resulting in toxic levels of Mn^{+2}. However, the possibility of Mn^{+2} toxicity in high pH (>7.5) soils, even for flooded soils, is very remote. Manganese toxicity is more likely to occur in acid soils (pH <6.0), whereas Mn^{+2} deficiency is more prevalent on alkaline soils. Each unit increase in pH above pH 5.5, for example, reduces the soluble Mn^{+2} content by a divisor of approximately 100. High levels of organic matter, especially in conjunction with high soil pH, increase the formation of complexes that tend to render Mn^{+2} less available. Organic matter reduces Mn^{+2} toxicity through chelation of the Mn^{+2} cation.

Anaerobic and acidic conditions will favor the release into the soil solution of. Mn^{+2}, which is the most important manganese form for root absorption. In slightly acidic conditions, the concentration of Mn^{+3} in the soil solution increases.

Plant available Mn^{+2} depends also on soil organic matter content and microbial activity. Manganese availability is significantly affected by the soil pH, increasing with decreasing pH and soil temperature, and decreasing with increase soil organic matter content, and the form and method of fertilization. Manganese as the Mn^{+2} cation is easily leached from the soil.

Fertilizer

Common sources are manganese sulfate ($MnSO_4$), manganese chloride ($MnCl_2$), and manganese oxide (MnO). Chelated forms are MnEDTA, MnDTPA and sugar-based chelated Mn. The effectiveness of these manganese sources for correcting Mn deficiency depends on the soil conditions, rate and method of application. Foliar application of chelated manganese is more effective than applications of water-soluble manganese sulfate and manganese chloride.

Manganese Uptake and Assimilation by Higher PlantsUptake

Manganese uptake is active. Manganese moves easily from the roots to shoots and this explains why manganese is less toxic to roots than shoots. Manganese is relatively immobile once deposited in the leaves and why manganese toxicity symptoms appear in above ground parts of plants in older leaves first continuous under high manganese and in younger leaves receiving the excessive manganese.

Translocation and Assimilation

Manganese is translocated in the xylem as mainly Mn^{+2} or weak combinations of Mn^{+2} with organic acids, preferentially to meristematic tissues. Manganese is relatively immobile in the plant once it is deposited in a leaf.

Manganese as Mn^{+3} is involved in oxidation-reduction processes, such as in the photosynthetic hydrolysis of water and oxygen evolution. In addition, manganese serves as a cofactor for. hydroxylamine reductase, indoleacetic oxidase, RNA polymerase, phosphokinases and phosphotransferase.

Manganese is an element in some forms of superoxide dismutase, which destroys the free radical and avoids oxidation of cells. Similarly, Mn and superoxide dismutase may be involved in controlling the amount of superoxides and free radicals generated by ozone and atmospheric pollutants.

Manganese is involved in pollen germination and growth of the pollen tube.

Adequate Range and Nutrition Disorders

Sufficiency

Leaf content ranges between 10 to 200 mgkg^{-1}, with the sufficiency range being between10 to 50 mgkg^{-1}, and critical levels to avoid deficiency are between 10 to 20 mgkg^{-1} in plant leaves. These values are consistent among plant species and cultivars and differing environmental conditions.

Manganese tends to accumulate in the leaf margins at 5 times the concentration of that in other parts of the leaf blade; therefore, plant analysis may be affected by the extent of marginal accumulation and the ratio of sampling of total leaf blade to margin. Some scientists recommend the removal of the leaf margins to obtain an accurate measure the Mn content of the leaf.

Deficiency

In general, manganese deficiency symptoms appear asleaf chlorosis between the veins of young leaves.

Figure 14-1. Manganese deficiency in tomato leaf.

Figure 14-2. Appearance of manganese deficiency in hydroponic basil plant leaves, at 12.9 ppm.

Figure 14-3. Manganese deficiency in soybean plant.

Deficiency symptoms may vary among plant species, and often symptoms look similar to that of iron or zinc deficiency.

Figure 14-4. Manganese deficiency in azalea plant.

Manganese deficiency can resemble magnesium deficiency by similar interveinal leaf chlorosis symptoms, except that manganese deficiency symptoms appear in young leaves, whereas magnesium deficiency symptoms occur in older leaves.

Figure 14-5. Manganese deficiency in Golden Pothos or Devil's Ivy.

The chloroplast is severely affected under severely manganese-deficient conditions.

Figure 14-6. Manganese deficiency in Cyclamen.

Increased peroxidase activity (associated with increased IAA-oxidase activity) is prevalent under manganese- deficient conditions.

Manganese-deficient plants have exhibited greater susceptibility to freezing injury than manganese-sufficient plants.

Manganese deficiency in plants occurs on calcareous peat soils (high organic matter and high pH) or soils that are unusually low in available manganese. Manganese deficiency often is observed in crops following cold or dry periods and may be attributable to impaired root activity under these conditions.

Crop species sensitive to manganese toxicity include apple, cherry, citrus, raspberry, sugar beet, sorghum, and small grains. Commonly mentioned manganese deficiency symptoms are grey speck of oat and marsh spot of peas.

Toxicity

Manganese toxicity symptoms vary with plant species and among plant tissue organs. On older leaves, manganese appears on plant leaves as brown spots with surrounding chlorotic tissue. Leaf marginal chlorosis and necrosis (e.g., alfalfa, rape, kale, lettuce), leaf puckering (e.g., snap bean, soybean, and cotton), chlorosis and necrotic spots of young leaves (e.g., barley, lettuce, soybean), and interveinal chlorosis of upper leaves (e.g., bean, eggplant, pepper, tomato, and spinach) are commonly occurring symptoms for these crop species.

Other physiological disorders attributable to manganese toxicity are crinkle leaf of cotton and bean (associated with manganese-induced calcium deficiency), stem streak necrosis in potato, internal bark necrosis of apple trees, and growth retardation and leaf tip burn of carnation, and blossom-end fruit cracking of muskmelon. A physiological disease known as measles is seen as black specks of manganese oxide in the surface of leaf tissues and fruits.

Manganese toxicity metabolic effects include auxin destruction and deficiency due to increased activity of IAA oxidase. This action reduces cell wall expansion and the development of binding sites for Ca^{+2} transport. Decreased auxin levels, along with death of terminal buds, may account for the loss of apical dominance and the resulting shoot proliferation (sometimes called "witch's broom") in plants exhibiting manganese toxicity symptoms.

Interactions with other Essential Elements

Nitrogen

Manganese uptake can be stimulated by the nitrate anion. Availability of manganese for uptake is increased by the acidifying effect of ammonium on the rhizosphere pH.

Calcium

Manganese deficiency of tobacco was greater when calcium was high in a solution culture experiment than when calcium was low. As has been pointed out before; available Mn in the substrate is associated with soil pH. Calcium compounds that raise the pH level have a suppressive effect on plant manganese content, whereas the addition of calcium compounds that do not affect pH produce variable effects. Adding $CaCl_2$ increased citrus leaf manganese, but adding $CaSO_4$ had no effect on manganese in nectarine leaves and increased the manganese content in clover and bahiagrass tops.

Boron

Manganese accumulation is correlated positively with boron content of tomato leaves and in wheat and soybean tops.

Iron

The iron-manganese antagonism involves competition for absorption.

Molybdenum

The simultaneous occurrence of molybdenum deficiency and manganese toxicity at low pH values is quite probable because of the contrasting effects of pH upon the two elements. The symptoms of the two maladies are quite similar and are difficult to diagnose. Adding manganese to a culture solution increased plant molybdenum concentration of white clover and, adding molybdenum increased the manganese content of white clover shoots. Positive correlations between manganese and molybdenum occurred also for wheat and soybean.

Zinc

The relationship between manganese and zinc nutrition is complex and variable with crop. Increased manganese in the substrate decreased zinc in sorghum and corn leaves, increased it in soybean and wheat plants, and had no effect on zinc in pear leaves

Fertilizer Sources

Manganese sulfate and Mn-oxysulfate, a formulation of manganese sulfate and manganese oxide, have been about effective in increasing the manganese content of soybean leaves when soil applied.The effectiveness of $MnSO_4$ and MnO is about equal if the MnO is finely ground and plowed under.Manganese sulfate, $MnC1_2$, $Mn(NO_3)_2$, MnEDTA, sugar-based chelated Mn, and Mn-lignosulfate are effective in increasing leaf manganese content if applied as foliar sprays. Chelated manganese is best applied as a foliar spray rather than a soil application. For more information on foliar application of Mn, see p. 193.

Chapter 15

Molybdenum (Mo)

Atomic Number: 42
Atomic Weight: 95.95

Discovered by Hzelm in 1782
Proven to be essential to plants by Arnon and Stout in 1939

Molybdenum in the Soil

Molybdenum is one of the most common micronutrient deficiencies found in agriculture. It is routinely misdiagnosed for several factors 1) molybdenum is not routinely tested in the soil or plant tissues, 2) deficiency symptoms appear as nitrogen deficiency, 3) the erroneous assumption that if the soil pH is neutral or above, then plenty of molybdenum is available from the soil. There is also a fear than high molybdenum levels are toxic to plants and animals. However, molybdenum toxicities in plants are virtually non-existent in normal crop production.

Forms and Dynamics

Molybdenum in the soil solution occurs predominantly as MoO_4^{-2}, $HMoO_4$ and H_2MoO_4. The main reservoir of Mo in the soil is molybdenite sulfide (Mo_2S). The sulfide molybdenite (MoS_2) is common in certain granitoids. Most excess Mo is associated with Fe and Mn hydroxides. Molybdenum is found as a relatively insoluble salts in association with Pb, Ca or Fe, and in association with organic matter. The weathering of these materials and the decomposition of organic matter release MoO_4 into the soil solution.

Molybdenum exists largely as impurities in soil minerals, especially in the clays and oxides of secondary minerals, and in freshly added organic materials, particularly in leaves. The secondary minerals usually surround the soluble molybdenum and occlude it, thus reducing its availability. Decomposition of organic material releases the molybdenum in a soluble form.

Soil Factors / pH

Molybdenum can be fixed in the soil at low pH levels, but is readily displaced and released by hydroxyl (OH^-) ions. Therefore, it becomes more available at higher soil pH. Mo reacts differently to soil conditions than do the micronutrients B, Cu, Fe, Mn and Zn, all of which tend to decrease in availability as the pH level rises. Mo behaves more like phosphorus, with availability increasing with rising soil pH. Concentration of MoO_4^{-2} and $HMoO_4^-$ increases dramatically with increasing soil pH. The molybdate anion's (MoO_4^{-2}) availability is increased 10-fold for each unit increase in soil pH. At low pH, Mo is strongly absorbed by iron and aluminum oxides in the soil. Mo can be a limiting factor in growth for plants with relatively high Mo requirements grown on acid/clay soils (e.g., soybeans grown in Georgia). Liming acid soils will make Mo in the soils more available to plants. However, available Mo is commonly deficient in soils regardless of pH, and simply raising the pH of the soil does not guarantee adequate Mo is available.

Soil Content

Mo levels in the soil solution can vary widely typically from <0.01 to 20-30 ppm. Some soils in Hawaii with Mo content as high as 73.8 ppm. The main factor that controls the quantity of available Mo is the quantity of Mo contained in the native soil minerals. Also, much of the Mo in the soil is tied up in organic matter, including plant residues. The mineralization of this organic component in the soil often provides much of the Mo provided to crops. In many intensively cultivated soils, Mo deficiency has become a more common problem. However, because Mo is not routinely included in soil and tissue tests, growers and agronomists do not know that it is a problem. Low available Mo in the soil occurs because of low Mo content in the native minerals, low pH, heavy rainfall and/or excessive irrigation, limited organic matter, low Mo content in organic matter, and poor mineralization of the organic matter in the soil. Some soils naturally have low levels of Mo and others have high levels of Mo. Traditionally, Mo levels in the soil solution are considered to be very low, in the range from 0.2 to 5 ppm. However, with high yield cropping programs, Mo is also removed with the harvested crop. Thus molybdenum demand often exceeds the capability of soils to provide, and the application of Mo fertilizers is becoming more prevalent, especially foliar application of chelated or other readily available Mo.

Uptake and Assimilation by Higher Plants

Molybdenum is taken up as the molybdate anion (MoO_4^-) and translocated preferentially to the leaves. Molybdenum can be absorbed through leaves using foliar application of chelated Mo. However, active nitrogen fixing structures, such as nodules in soybeans, are sinks for molybdenum, and Mo tends to accumulate in the roots and nodules during active nitrogen fixation. Molybdenum is required in the enzyme system for nitrogen fixation.

Molybdenum Nutrition in Higher Plants

Molybdenum has some unique features not shared by other micronutrients. For example, the normal seed of some plant species may store, in an available form, ten times the total Mo needs of the plant to be grown from the seed (Meagher et al. 1952). However, it cannot be assumed that seed will have adequate Mo to meet the needs of the crop, since the seed may have been derived from plants deficient or low in Mo. Also, the plant tolerance to Mo applications are high as compared with other micronutrients, the range between deficiency and excess of this element being 50 times that of other micronutrients (Purvis, 1955). Mo is only moderately mobile in the plant. It is located primarily in the phloem and vascular parenchyma.

Molybdenum is considered an essential micronutrient due to its role in several redox reactions, but most importantly as the metal cofactor of two enzyme systems:

1. Mo is part of nitrate reductase, the enzyme that is involved in the reduction of NO_3^- to NH_4^+ inside by the plant. The need for Mo is greatly reduced by the when NH_4^+ is the predominant form of N absorbed.
2. Mo is a component of nitrogenase, involved in fixation of atmospheric N_2 into the ammonium form in symbiotic relationships in legumes.

Because of the role of Mo in nitrogen utilization, the application of Mo has been shown to increase protein content of corn and soybeans. Other enzymes that Mo is required include indoleacetic acid oxidase, alanine aminotransferase, glycolate dehydrogenase, glycolate oxidase, catalase and cytochrome c oxidase, peroxidase and aldolase. Because of Mo's role in indoleacetic acid (IAA) formation that regulates the ear size of corn, a small of amount of Mo is needed in young corn plants to ensure proper ear sizing. The role of zinc in this process is well understood, but a small amount of Mo is also required.

The roots in the form of molybdate, MoO4-, take up molybdenum. This anion is considered to be the predominant form of Mo in the plant xylem also. The form in which this element is transported in the plant is not known but there is a possibility of organic complexing (Tiffin, 1972). Mo can be taken up through foliar application in organic chelate forms (see Fig. 19-4, p. 217 and Fig. 23-1, p. 264 for examples).

Molybdenum (Mo) is required by plants in very small quantities. Leaf content is usually less than 1 ppm in the dry matter, sufficiency level range from 0.01 to >5 ppm. Plant content is usually related to the levels of MoO_4^{-2} in the soil solution. Molybdenum can be taken up in higher amounts without resulting in toxic effects.

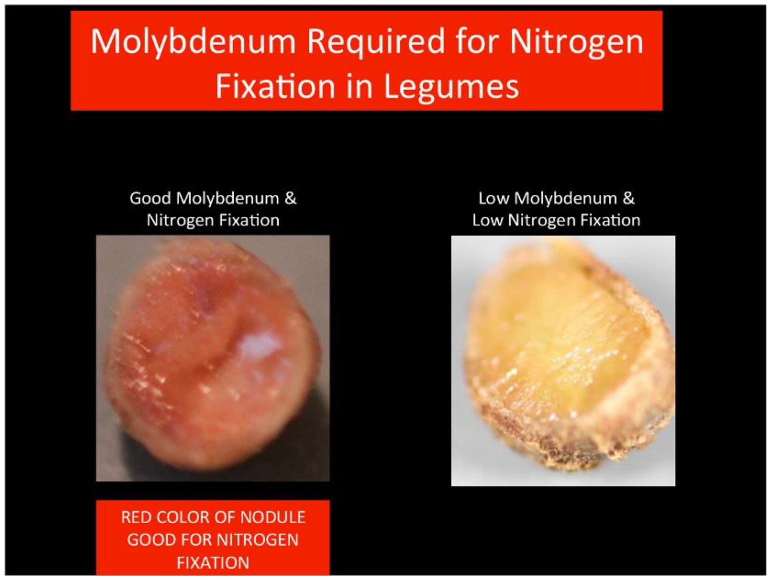
Uptake

Plants absorb Mo as MoO_4^{-2}. At concentrations above 4 ppb in the soil solution, Mo is transported to plant roots by mass flow. At levels < 4 ppb Mo moves by diffusion. This translates to a greater severity of Mo deficiency under dry soil conditions due to reduced mass flow or diffusion under low soil moisture content.

Essential Roles

Molybdenum is an essential component of the two enzymes, nitrate reductase (NR) and Nitrogenase (NI). NR catalyzes the conversion of nitrate into nitrite during the assimilatory nitrate reduction process. NI is required for the fixation of atmospheric N_2.

Figure 15-1. Molybdenum required for nitrogen fixation.



Therefore in theory, plants fed exclusively with ammonium have no requirement for Mo.

Adequate Range and Nutrition Disorders

Deficiency

Many physiological diseases are associated with molybdenum shortages, such as the "yellow spot" of citrus leaves, "whiptail" of cauliflower, and "blue-chaff" of oats. Deficiency symptoms of molybdenum in crops seldom appear until the concentration in the leaves drops to less than 1 ppm. Individual crops differ in their requirements for Mo. Cruciferous and legume crops have a high Mo requirement. Generally, deficiency symptoms occur when the Mo levels fall below 0.2 ppm in the leaf on a dry weight basis, but

Overall Mo deficiency resembles N deficiency with older and middle leaves becoming chlorotic first and in some species rolling of the leaf margin occurs. Molybdenum-deficient plants display chlorosis, particularly mottled chlorosis, and in some crops the chlorosis or yellowing is uniform, more similar to sulfur deficiency than N-deficiency. When nitrate is the primary N-form absorbed by plants, Mo is required for utilization of this N-Form. When Mo is deficient, plants show nitogen deficiency.

Figure 15-2. Molybdenum deficiency in corn leaves has the same visual symptoms as nitrogen deficiency.

Leaves are often small and covered with necrotic spots (especially citrus).In some instances, growth and flower formation are restricted.

Figure 15-3. Molybdenum deficiency in poinsettia.

Crops that are very sensitive to low solution Mo are legumes, crucifers and citrus. Mo-efficient and Mo-inefficient varieties of alfalfa, corn, cauliflower and kale have been identified.

A specific condition is caused by Mo deficiency in cauliflower. The middle lamella of the cell wall is not formed completely and only the leaf rib is formed, hence the symptom name "whiptail"in cauliflower, and in severe cases the loss of the growing point resulting in a condition called 'blindness'.

Molybdenum deficiencies are most likely to occur on:

- Spodosols, strongly acidic and low organic matter soils.
- Soil formed from re-crystallized or secondary minerals, as these minerals occlude the molybdenum.
- Well-drained calcareous soils, since soils have dissolved the available molybdenum and leached it out of the root zone.
- Well-drained serpentine soils as serpentine rocks are low in molybdenum.

Sufficiency

The need for Mo varies by the type of crop and by pathways requiring Mo. Since Mo is needed in the enzyme system for N-fixation, crops that fix N require more Mo than crops that do not fix N. The Mo sufficiency range for most crops is 0.15 to 0.30 mg kg^{-1} dry weight (ppm), while crops that fix N generally need 0.5 to 1.0 mg kg^{-1} dry weight (ppm). Mo is involved with several inducible enzymes, including nitrate reductase, meaning that as Mo concentration increases in the plant tissues, more of these enzymes are formed and Mo is often the limiting factor in the enzyme formation. Consequently, there may be benefits for plants to have higher than these minimum Mo levels in the tissues. Because Mo is required in such small quantities in the plant tissues, and because deficiency symptoms are similar to N-deficiency, the importance of Mo is often ignored, and the true optimum Mo levels in many crops has not been established. Also, high levels of Mo can offset the negative effects of toxic levels of B, Cu, Fe, Mn and Zn. Additionally, while there is concern over too high of Mo levels in forages and feeds in ruminant animals, molybdenum is still required in the diets of animals. A recent study in the Midwest showed swine liver Mo to be consistently 0.02 ppm or less, when the normal swine liver Mo content is 0.6-1.9 ppm.

Toxicity

Unlike most of the other micronutrients, especially B, which can be toxic at relatively low levels in plant tissue, symptoms of Mo toxicity are rare in plants. Concentrations >1000 ppm (0.1% by dry weight) and even >10,000 ppm (1% by dry weight) can produce no negative effects on many plant species. Most plants have such a high tolerance of excesses of Mo that there are few known toxicity symptoms. There are reports of 2,000 ppm of molybdenum in leaves, without any observable changes in appearance. When Mo accumulation is high, it is stored in vacuoles in forms that are not toxic to plants, such as a component of anthocyanin that imparts a bluish or purple color to the plant. When plants are intentionally overdosed with molybdenum, toxic symptoms appear in tomatoes as leaves turning a golden yellow. With alfalfa, excessive Mo can cause a golden yellow chlorosis as well. Cauliflower leaves with excess molybdenum have an intense purple color, and the plants are smaller and have delayed maturity.

Alkaline soils with little water movement through the soil can accumulate Mo. Since Mo exists primarily as an anion, it leaches readily. Areas of excessively high Mo occur in high pH arid soils in western North America and certain areas of western Australia. These areas have high Mo because of low rainfall and higher content of Mo in native soil minerals. Alkaline peats and other poorly drained soils can also accumulate Mo when it is plentiful in the native minerals.

High plant Mo does not normally cause adverse effects in the plant, but can pose a problem for ruminant animals that consume most of their diet composed of plants containing 5 ppm or more Mo, especially when those plants are low in Cu. Examples are cattle or sheep grazing on pastures with high Mo concentrations > 5 ppm. Molybdenum toxicity in livestock causes diseases such as molybdenosis. This disease is caused by feeding of animals on forage corps having more than 10 ppm Mo on dry weight basis (Bear, 1957). Molybdenosis is a disease in cattle resulting from high levels of Mo in their diet causing an imbalance in available Cu. The disease is more prevalent when consumption of Cu in the forage or diet is low, since Mo induces a Cu deficiency in the animals. The toxicity causes stunted growth and bone deformation. Excess Mo in the animal feed seems to interfere with the normal metabolism of Cu in the animal system, resulting in a Cu deficiency. Intake of Cu, either orally or by injection, is necessary to correct this condition. $CuSO_4$ applications to the soil or foliar application of Cu chelates to forages can be used to decrease Mo toxicity for animals.

Excess concentrations of Mo in vegetation may occur on some peat soils, some alkaline soils, and on poorly drained soils. Liming of high Mo containing soils, especially to pastures high in legumes, may produce toxic forages for ruminants. Also, continued applications of large amounts of molybdenum as fertilizers on acidic and poorly drained soil may produce toxic concentrations in animal feed.

In the field, Mo toxicity seldom occurs although some plants may contain over 15 ppm Mo. However, Mo levels above 5 ppm in grasses can be toxic to grazing animals.

Interactions with other Essential Elements

Iron and Aluminum

Mo is strongly adsorbed by iron and aluminum oxides. Soils that are high in Fe, especially amorphous Fe on clay surfaces, tend to be low in available Mo. In tomato plants (Berry and Reisenauer, 1967), the addition of adequate molybdenum enhances absorption and translocation of iron and also decreases the availability of iron compounds in the root media. With barley, the addition of adequate amounts of molybdenum increased the reductive capacity of the roots, thereby increasing the solubility of available iron and hence promoting absorption of this element by plant roots. On the other hand, molybdenum deficiency caused a decrease in the translocation of iron from veinal to interveinal tissue, the result of a decrease in the reduction of iron into more soluble forms. This also accounted for decreased absorption by roots. High levels of molybdenum similarly reduced iron uptake, although by a chemical mechanism external to the plant. The excess molybdenum became coated on iron oxide compounds, resulting in a decreased solubility (and hence availability) of iron of the plant.

Nitrogen

Molybdenum is essential for the operation of plant enzymes and for the functions of the enzymes nitrogenase and nitratereductase.Also, the fixation of atmospheric N by both free living and symbiotic microorganisms and the utilization of nitrate-N by plants depend upon Mo. Lack of Mo can visually appear as N deficiency in plants dependent on such N. Petioles of cauliflower, mustard, and tomato suffering from Mo deficiency had much higher levels of nitrate-N than did N sufficient plants. Plants on ammonium-N nutrition tend to exhibit less Mo deficiency symptoms than do those receiving nitrate-N, but some studies indicate that Mo may be involved in more than nitrate-N reduction reactions.

Phosphorus

Phosphorus has been shown to enhance Mo absorption by plants, probably due to exchange of adsorbed MoO_4^{-2}. A positive correlation between soil-adsorbed P and Mo at a given pH was found in the pH range of 4.0 to around 5.2. Bingham and Garber (1960) and Bingham (1963) conducted greenhouse experiments on the effect of application of P on the micronutrient content of sour orange seedlings. The experiments showed that under the acid soil conditions, P application enhanced the uptake of Mo. On the other hand, in alkaline soils, the uptake of Mo was reduced with excessive P. According to these workers, more Mo is released from the exchange complex under acid soil condition with H_2PO_4 replacement, thus more Mo is available for plant uptake. Phosphates enhance molybdenum uptake. The application of P increases the Mo concentration in alfalfa, lading clover, and Brussels sprouts. Adding 0.25 mg L^{-1} (ppm) Mo to nutrient solution cultures increases the P content in white clover shoots, while concentrations of 1.25 and 5.0 mg L^{-1} (ppm) Mo decreases the P content. A positive correlation between soil-adsorbed P and Mo at a given pH was found in the pH range of 4.0 to about 5.2. Practically no Mo was adsorbed at a pH level of 5.6 and higher. Phosphates replace molybdate from the anion exchange sites at the surface of soil colloids. This increases Mo concentration in the soil solution and Mo availability to plants.

Potassium

Potassium applications reduce the Mo content of corn leaves, with the highest concentration of Mo being present in K-deficient leaves.

Iron

A deficiency of Mo increases Fe in white clover and wheat shoots. The greatest increase of Fe occurred in a wheat genotype susceptible to Mo deficiency.

Sulfur

Molybdenum uptake is inhibited by sulfates. On soils with marginal Mo deficiencies, the application of heavy rates of sulfate-containing fertilizers may induce a Mo deficiency in plants. During initial nutrient absorption, sulfates compete directly with molybdate for absorption sites on the roots.

Manganese

High Mn increased the uptake of Mo in tomato. Adding Mo to a nutrient solution increased the Mn content of shoots of white clover and several tropical legumes.

Fertilizers

Table 15-1.Molybdenum Fertilizer Sources.

Sources	Formula	Percent Mo
Ammonium molybdate	$(NH_4)_6Mo_7O_{24}$-$2H_2O$	54%
Sodium molybdate	Na_2MoO_4-$2H_2O$	39%
Molybdenum trioxide	MoO_3	66%
Molybdenum frits	Fritted glass	1-30%
Chelated molybdenum	Varies	0.001-4%

Using Molybdenum Fertilizers

A few ounces per acre of molybdenum will usually correct a deficiency. This small amount may be mixed into and applied with a fertilizer, or foliar applied (also see pp. 187, 194, 234-235). When mixed with a fertilizer, phosphorus in the blend will promote Mo uptake. The rate and frequency of Mo application is dependent on the concentration in the soil and/or tissue, the specific crop, stage of crop development, soil type, amount of rainfall and/or irrigation, and soil pH. An advantage of foliar application using chelated Mo is that soil pH and other characteristics do not influence availability and Mo uptake.

Rates of Mo application are very low - 0.5 to 5 oz./acre. The solution may be applied to soil, sprayed on foliage, or put on seed prior to planting (latter two methods use lowest application rates). Mo can be combined with N-P-K fertilizers. Foliar applications of Mo may be made with ammonium or sodium molybdate, however, chelated Mo is more easily absorbed by the plant tissues and is more effective in correcting deficiencies. In acids soils when adequate Mo is present, liming can used to increase Mo availability. A soil test for Mo is necessary to know if adequate Mo is in the soil. With high yielding crops, Mo deficiency is becoming more prevalent. Additionally, Mo application is always preferable to liming when an increase in soil pH is not desired.

Sodium molybdate, which ranges from around 40 to 46% molybdenum, is probably the most common Mo fertilizer source. Ammonium molybdate is often used in more soluble clear liquid fertilizer solution. Chelated molybdenum is becoming more popular because of easy of use, including mixing properties with other fertilizers and chemicals, and efficiency of Mo uptake by plant tissues.

Brassicas such as cauliflower need high rates of Mo. This may be applied in the seedbeds before planting, mixed with dry and liquid fertilizers, or foliar applied. With adequate Mo in the seedbed, the plant may be able to accumulate enough Mo to last through the plants' life. Mo and insecticidal root drenches have been developed to prevent cabbage root fly.

Other sources of Mo include molybdic oxide (58 to 62% Mo), and molybdic acid (approximately 58% molybdenum). The oxide and acid forms contain no sodium or ammonium ions, thus reducing salting out. However, these forms must be dissolved in acids before being added to a mixed fertilizer solution.

Chapter 16

Zinc (Zn)

Atomic Number: 30
Atomic Weight: 65.38

One of the oldest known elements
Proven to be essential to plants by Sommer and Lipman in 1926

Zinc in the Soil

For good crop production, zinc levels in the soil solution need to be in readily available forms, or absorbed to soil components that allow for rapid movement into the soil solution for plant uptake. Factors influencing the availability of zinc to the plant are:

1) the total zinc content of the soil,
2) soil pH,
3) organic matter content,
4) clay content,
5) calcium carbonate content,
6) redox conditions,
7) microbial activity in the rhizosphere,
8) moisture level in the soil, and
9) presence of other micro and macro nutrients (especially phosphorus).

Zinc is primarily found in rocks in the earth's crust where the average amount is 78 mg Zn kg^{-1}. In the earth's surface, zinc occurs primarily as the single sulfide mineral sphalerite. Zinc also substitutes for iron and magnesium in silicate minerals and is thus present in the minerals augite, biotite and hornblende.

The level of zinc in soils is highly correlated to the parent mineral material of the soil. Sandy soils and highly leached acid soils generally have low zinc levels. Zinc deficiency is also common among mineral soils low in organic matter, humic gleys (Haplaquepts, Haplaquolls), Alluvials (Fluvents), Regosols (Udipsamments), and Organics (Histosols) soils.

Soils originating from basic igneous rocks are higher in zinc. These soils are inherently more capable of resupplying zinc (due to weathering of this parent rock material) to the soil solution as plants remove this ion.

Though the total zinc content of soils can range between 10-300 ppm, soluble zinc in soils is generally very low, ranging from 4-270 micrograms per liter (ppb). Surface soils contain more zinc than subsoil's as a result of the decomposition of plant residues containing zinc. Loss of topsoil whether by erosion, land grading and leveling, or other reasons are often low in organic matter and thus tend to be deficient in zinc.

Upon weathering, the zinc cation (Zn^{+2}) is released into the soil solution, which is subsequently adsorbed on clay particles, or forms complexes with hydrous oxides and organic matter. While zinc deficiencies are mainly found on sandy soils low in organic matter, they are also found in soils high in organic matter.

Zinc deficiencies often occur during cold, wet spring weather when zinc deficiency is expressed as reduced plant root growth and activity. Under these cool/wet conditions, zinc deficiency is also related to lower microbial activity, which results in reduced zinc release from the mineralization of soil organic matter.

Zinc interacts with soil organic matter, being particularly bound to humus, with both soluble and insoluble zinc organic complexes formed. On average, 60% of the soluble zinc in soil occurs in soluble zinc organic complexes. The soluble zinc organic complexes are mainly associated with amino, organic and fulvic acids, while insoluble organic complexes are associated with humic acids.

Availability of zinc decreases with increasing soil pH. Zinc uptake by plants decreases as soil pH increases from 6.0 to 8.0. At high pH (>7.0), zinc forms insoluble compounds, such as $Zn(OH)_2$ and $ZnCO_3$ resulting in plant deficiency being very common in alkaline soils. Most of the acute zinc disorders in plants occur in calcareous soils that contain large amounts of free calcium carbonate ($CaCO_3$). Zinc deficiently has been accentuated on organic soils where limestone was recently applied, although the soil pH level is less than 6.0. Liming of such soils aggravates zinc deficiency due to soluble zinc being bound to the free $CaCO_3$. The majority of these soils have sufficient total zinc, but it is not available to the plants due to low solubility under such conditions. Below pH 7.7, the Zn^{+2} cation predominates in the soil solution, while above pH 7.7, $ZnOH^{+}$ is the primary form of zinc until it is supplanted by $Zn(OH)_2$ at pH 9.1 and above. Uncontaminated agricultural soils in the USA are reported to have a mean zinc level of 53 mg kg^{-1}. A pH equal to or lower than 5.0 facilitate zinc solubilization, and in humid zones zinc can be easily leached as well as easily extracted by plant roots.

Zinc availability can also be reduced when the available soil phosphorus level is very high. Excessive use of phosphorus fertilizers has been linked with zinc deficiency in plants, particularly for plants grown for their fruit. High levels of available phosphorus and iron in soils also adversely affect plant uptake of zinc. The formation of zinc phosphate is partially responsible for the reduction of available zinc.

Zinc availability to plants at sufficient levels is related to soil movement of zinc by diffusion gradients, and by roots being able to move from areas already depleted of zinc by the roots into areas that have higher zinc soil solution concentrations. Factors that limit the rate of diffusion of zinc into the soil solution, also reduce the availability of zinc for plant uptake. The extensive development and growth of plant roots into new soil areas where zinc can be mined by the plant root is extremely critical to preventing zinc deficiency. Any cultural factor such as compacted soils restricting root growth, excessive fertilizer salts reducing root growth, root diseases and insects that hamper or restrict root growth all can reduce zinc uptake and cause zinc deficiency. Under these conditions, zinc deficiency can occur even when zinc levels in the overall soil is sufficient to support normal plant growth.

Uptake

Zinc is taken up mainly as the Zn^{+2} cation, although $(ZnC1)^{+}$ and zinc chelates may also be absorbed by the plant root. Absorption of Zn^{+2} by the plant root is active and metabolically controlled.

Translocation and Assimilation

Zinc is transported radially across the root to the endodermis through the symplast to the xylem. Zinc may move in the xylem by successive bindings to stable, slowly exchanging ligands similar to what is observed with copper and iron. In rice, zinc delivery to developing tissues is mediated by P-type heavy metal ATPase OsHMA2. Recent reports suggest high mobility of zinc from leaves to roots, from leaves and stems to developing grain through the phloem.

Zinc Nutrition in Higher Plants

Essential Roles

Zinc has a regulatory part in the intake and efficient use of water by plants. Zinc is an essential component of various enzyme systems for energy production, protein synthesis, and growth regulation. Zinc deficiency symptoms occur mainly in new growth. The most visible zinc deficiency symptoms are short internodes and a decrease in leaf size. Delayed maturity also is a symptom of zinc-deficient plants. Zinc is associated most commonly with the production of auxins, such as indoleacetic acid (IAA). Zinc appears to be necessary for the synthesis of tryptophan (a precursor to IAA and other auxins) and by influencing tryptophan production, zinc effects auxin levels in the plant. Zinc is an essential component of several plant enzymes, which are the keys to the formation of many complex organic compounds in plants. Many plant nutritionists associate the functions of zinc in plants closely to those of iron and manganese in that these elements bring about the binding and conformation between enzymes and substrate. Zinc activates a number of enzymes including enolase also by influencing the binding and conformation between enzymes and substrates. Therefore, zinc is classified as a co-factor for several biochemical reactions in which they are required for the reaction to occur, but are not consumed in the reaction. Other enzyme systems activated by zinc are carbonic anhydrase, alcohol dehydrogenase, superoxide dismutase, and RNA polymerase. Some of the enzymes activated by Zn^{+2} can also be activated by other divalent cations also, such as Mg^{+2}, Mn^{+2}, Cu^{+2} or

Ca^{+2}.

Zinc may also have a role in plant metabolism involved in starch formation. The oxidizing capacity, in the form of peroxidase, is enhanced in zinc-deficient systems. Zinc occurs in an enzyme involved n cell oxidation and regulates the use of sugars. Zinc plays an important part in changing carbohydrates from one form to another. Zinc is a component of the enzyme that catalyzes the decomposition of carbon dioxide and water.

Zinc is very closely involved in nitrogen metabolism of the plant. RNA polymerase contains zinc, and when zinc is absent, the enzyme is not functional and RNA synthesis is impaired. Thus zinc deficiency is closely related to the inhibition of RNA synthesis. Zinc deficiency prevents the normal development of chloroplast grana, and thus reduces photosynthesis capability as is noted in zinc deficiency symptom of interveinal chlorosis. In various animals, bacteria, and possibly plants, zinc catalyzes DNA polymerase, which is essential for replication of DNA prior to mitosis and meiosis.

Adequate Range and Nutritional Disorders

Sufficiency Range

Zinc sufficiency in most plant leaves generally ranges from 15 to 50 ppmin the dry matter in recently mature leaves. Plant species vary in their critical level for zinc deficiency to be observed. This range is commonly between 12 and 15 ppm. As little as 1 to 2 ppm variance in zinc content in mature leaves at the critical level may be sufficient to distinguish between deficiency and sufficiency. Therefore, precise measurement of the zinc concentration in plant tissue analysis determination is critical. Some plants can accumulate considerable quantities of zinc (several 100 ppm) without harm to the plant. However, 200 ppm of zinc is considered the critical high level of zinc for most crops. Use of fungicides containing zinc can elevate the zinc level measured in analysis of the leaf. Decontaminating the leaf by washing the surface of fungicide containing zinc may be necessary to give a more accurate zinc level in the leaf sample.

While zinc is normally distributed throughout the plant, it is tends to accumulate and be retained in the root system.

Deficiency

Deficiency symptoms typically include interveinal chlorosis of the leaf with the areas between the veins turning pale green, yellow, or even white.

Figure 16-1. Zinc deficiency in gerba daisy leaf.

In the monocotyledon species, and particularly in corn, chlorotic bands form on either side of the midrib of the leaf.

Figure 16-2. Zinc deficiency in corn.

Figure 16-3. Zinc deficiency in corn seedlings during wet, cold weather giving a general chlorosis of the leaf. Expression of zinc deficiency symptoms across a field is generally not consistent plant to plant.

In fruit and nut trees,leaf development is restricted forming unevenly distributed clusters or rosettes of small stiff leaves; also, fewer buds are formed and many of those buds that formed remain closed.

Figure 16-4. Zinc deficiency symptoms in a pecan leaf.

Symptoms of zinc deficiency in vegetable crops are more species-specific than are deficiency symptoms of other plant nutrient elements. In most cases, symptoms appear as chlorotic areas in leaves with pitting in the interveinal upper surface of mature leaves. Short internodes are observed on some plants.

Figure 16-5. Zinc deficiency in tomato leaf.

Moderate zinc deficiency symptoms may be confused with symptoms caused by deficiencies of calcium, boron, magnesium, iron and/or manganese. When these symptoms occur, plant analysis is often required to determine which of these elements are deficient.

Figure 16-6. Zinc deficiency in poinsettia leaf.

Figure 16-7. Zinc deficiency in citrus leaf.

Figure 16-8. Zinc deficiency in basil leaf, tissue concentration 24 ppm.

Toxicity

Zinc toxicity results in a reduction in root growth and leaf expansion, followed by chlorosis. Many plant species can tolerate fairly high levels of zinc in their tissues without significant observable toxicity symptoms or decline in plant growth. Two hundred (200) ppm of zinc in plant tissues is considered the critical toxicity point for most plants. However, the actual toxicity concentration varying with plant species, variety, stage of growth, etc. A typical zinc excess symptom is iron chlorosis, a lack of chlorophyll, or an absence of green color in the leaves. For plant species that are sensitive to the concentrations of both iron and zinc, the presence of high levels of zinc may induce an iron deficiency. High levels of zinc in the rooting medium can result in iron, manganese, or phosphorus deficiencies.

Interactions with other Essential Elements

Nitrogen

Increasing the amount of nitrogen applied as ammonium tends to increase plant zinc content. The increase in plant zinc concentration is greater with ammonium-N than nitrate-N and effect is related to the rhizosphere acidification induced by ammonium-N, making zinc more available in a soluble form for uptake.

Phosphorus

A high phosphorus application is antagonist to zinc uptake from the rhizosphere resulting in a reduction of zinc absorption and availability of zinc in the leaves of plants. Where zinc is marginally deficient, cellular regulation of phosphorus translocation andmetabolism in the plant is affected with excessive phosphorus being absorbed to potentially toxic levels. It appears that zinc deficiency makes the cellular membranes more permeable to phosphorus uptake.

Iron

Excessive zinc levels in the soil solution depresses iron uptake, which result in the expression of iron deficiency symptoms in plant leaves. The reverse relationship has not been reported in high iron soils.

Fertilizers

Zinc utilization by crops is on the average 0.5 kg/ha/yr. There are three different categories of zinc fertilizers, 1) inorganic compounds, 2) synthetic chelates and, 3) organic complexes:

1) Inorganic sources include: zinc sulfate ($ZnSO_4$), zinc oxide (ZnO), zinc carbonate ($ZnCO_3$), zinc nitrate ($Zn(NO_3)_2$) and zinc chloride ($ZnCl_2$).

2) The disodium salt of ZN-EDTA (Na_2Zn-EDTA) is the most commonly used chelated source of zinc. Synthetic chelates are suitable for mixing with concentrated fertilizer solutions for soil, fertigation and hydroponic applications.

3) Organic complexes consist of zinc salts that are reacted with citrates or with organic by-products from paper pulp manufacture such as lignosulphonates, phenols and polyflavonoids. They are generally much less effective as a fertilizer source of Zn than synthetic chelates.

Zinc sulfate is the most commonly used fertilizer due to its solubility. However, zinc sulfate is highly leachable and thus its use on acid sandy soils is less desirable than foliar applications of zinc. Zinc chelates are preferred with high pH soils over application of zinc sulfate. Zinc deficiencies in crops have increased with intensity of production and higher yielding requirements. Thus, zinc fertilizer applications are receiving much more attention. For example, corn requires needs zinc early in its growth (V4-V5) for the production of IAA, which control the size of the corn ear, that is, the number of kernels the ear will produce. When zinc is low in the soil, typically less than about 5 ppm, a common practice is the application of zinc chelates in the furrow with the seed. Additionally, if tissue tests taken prior to V-5 indicate zinc is low in the tissue, foliar applications of zinc chelates are used to ensure adequate zinc in the tissue for maximum ear size. Once the ear size is set, it cannot be changed. Zinc deficiency can occur later in the crop which may have an effect on photosynthesis (interveinal chlorosis) and zinc contributes to disease resistance with many crops.

Fertilizer Sources

Zinc ammonium nitrate

A liquid mixture of zinc and ammonium nitrates containing 15% zinc and 20% N.

Zinc carbonate ($ZnCO_3$)

52% Zn, insoluble.

Zinc chelates

Zinc chelates are zinc bound to organic chelating molecules. Zinc chelates serve two functions whether applied to soil or in a sprayer tank mix. The chelating molecule helps to prevent the zinc ion from binding with soil particles or forming insoluble compounds whether in the soil or with minerals or chemicals in a liquid tank mix. Binding or forming insoluble compounds would prevent the zinc ions from being available for uptake and utilization by the plant. The second function is to enhance the uptake of zinc through the cutin layer, cell walls and cellular membranes thereby increasing the effectiveness and utilization of chelated zinc. In soils and in liquid tank mixes, chelating agents differ greatly in their ability to chelate Zn^{+2}, that is, to for the chelating agent to bind to the ion and prevent it from reacting with soil particles or other chemicals. In the higher pH range of calcareous soils the effectiveness of Zn^{+2} chelates to bind to the ion are in the order: DPTA (diethylene triamine pentaacetic acid) > CDTA (cyclohexane trans 1,2 diamino tetraacetic acid), HEDTA (hydroxyethyl ethylene diaminetriacetic acid), EDTA (ethylenediamine tetraacetic acid) > NTA (nitrilotriacetic acid), used in solution form as a source of zinc in liquid fertilizers.

Zinc oxide (ZnO)

ZnO contains 78-80% zinc, and is considered insoluble compared to zinc sulfate. ZnO is considered citrate or acid soluble.

Zinc oxysulfate

A soluble form of zinc, also known as basic zinc sulfate. It can be added to fertilizers or used as a spray or dust application for correction of Zinc deficiencies.

Zinc polyflavonoids

10% Zn, organically bound Zn that release zinc over time.

Zinc sulfate ($ZnSO_4 \cdot H_2O$, $ZnSO_4 \cdot 6H_2O$, and $ZnSO_4 \cdot 7H_2O$)

35% Zinc, highly soluble, solubility is 625 lb/100 gal, acidifying effect on the bulk soil, foliar or soil applied. Traditionally has been commonly used as a zinc fertilizer. Generally, soil application of zinc sulfate is preferred. Rates of 50 to 100 kg $ZnSO_4$ ha^{-1} are generally recommended, but proper soil and plant analysis should be the determining factor. The anhydrous salt ($ZnSO_4$) is not used as a fertilizer, but all of the three hydrates, whose formulas are shown above, are used, especially in California, Florida, and along the Gulf Coast. The anhydrous salt is very hygroscopic, readily binding water molecules to it. The monohydrate is the most stable variety in warm climates. Zinc contents of the three hydrates, $ZnSO_4$ H_2O, $ZnSO_4.6H_2O$, and $ZnSO_4.7H_2O$, are 36, 24, and 22%, respectively.

Chicken litter

Typical broiler litter contains 0.19 lb Zn ton^{-1}, but can range between 0.01-0.5 lb Zn ton^{-1}. The litter from hens in egg production (layers) has a mean of 0.15 lb Zn ton^{-1} and a range of 0.08-0.32 lb Zn ton^{-1}. Large applications of chicken litter can add considerable amounts of Zn, Fe and Mn. Rates of application should be determined based on soil and plant analysis. Because of variability of zinc in litters, it is advisable that the litter also be tested for zinc content and other nutrient composition as well.

Manures

Zinc composition (ppm of dry weight) of some manures:

- Beef feedlot manure (100% dry matter) mean = 66; range = 53-102

- Liquid manure: poultry (8.1% dry matter) = 20
- Swine (0.6% dry matter) = 346
- Swine (2.6% dry matter) = 1,234
- Dairy (8.6% dry matter) = 34

However, the concentration of zinc in manures (liquid or solid) is dependent upon the zinc content of the feed provided to animals. Animals fed forages and grain low in zinc will produce manures low in zinc. This principle applies to all micronutrients.

Zinc Application

Zinc may be applied to the soil, tank mixed with liquid fertilizers, and foliar applied. Zinc has even been injected into the trunks of large trees to correct zinc deficiency. The method of application depends on the crop and cropping system. Traditionally, applications of a zinc-containing fertilizer to the soil or growing medium based on soil test results have been viewed as the best method for preventing a zinc deficiency to a crop. A wide distribution of low analysis zinc-containing material can aid by increasing root-fertilizer contact. Also, soil application of zinc sulfate has been the most common and preferred method of application. However, as indicated above, broadcasting zinc sulfate onto soil presents several problems including rapid leaching, binding of zinc with phosphate to form relatively insoluble zinc phosphate, and binding to organic and soil particles. Applications with mixed fertilizers or ammoniacal nitrogen sources may enhance zinc uptake due to the effect on lowering soil pH. Depending on the crop and cropping system, broadcast applications are acceptable but may be relatively ineffective as compared to banding or foliar applications of zinc.

Banding of zinc is typically done with row crops, fruit trees, nurseries and others where the root zone well identified. Since zinc moves in the soil primarily by diffusion, zinc movement in the soil is not sufficient to supply zinc to a crop and emphasizes the importance of where zinc is placed in relationship to the plant root zone. Consequently, traditional side dress applications of zinc after crop emergence represent the least effective method of application.

Corn production is an example where banding of zinc fertilizer in the furrow has become commonplace. With the importance of zinc to ear formation, it is critical to have zinc in the corn plant prior to the formation of the ear at V4-V5. The suppression of zinc uptake by application of high levels of phosphorus is especially important where the use of phosphorus is utilized as a starter fertilizer in soils where zinc is deficient (acid sandy leached soils, high pH soil, etc.). The inclusion of zinc chelates in with starter fertilizers high in phosphorus has become a common practice in many areas low in available zinc in the soil. While dry starter fertilizer can be used, most starter fertilizer is in liquid form. High grade, low salt index, neutral pH liquid fertilizer products permit the application of these fertilizers directly in the furrow with the seed. Common N-P-K products are 3-18-18, 9-18-9 and 6-24-6, all with high phosphorus content. In soils that test deficient to moderately low in zinc, liquid zinc chelates are added to the starter fertilizer to ensure adequate zinc to the young corn plant.

Another method to get zinc into a crop is foliar application. In the case of corn, if zinc is low in the tissue test when the plant is young (V3-V4), regardless of what has been applied to the soil, zinc can still be applied foliar to crop to increase the zinc levels within the tissue. Chelated zinc products are much more effective in supplying zinc in foliar applications than products such as zinc sulfate. By comparison, foliar-applying a solution of zinc sulfate at the rate of 5 to 50 lbs/Ac has proven effective treatment for correcting a zinc deficiency for some tree crops, but the application of liquid chelated 9% zinc typically does not exceed 32 oz/ac. For more information on foliar application of Zn see p. 193.

Another benefit of foliar application of zinc is that it can often be applied with other chemicals and pesticides. However, caution must be taken using zinc products with glyphosate. Glyphosate can tie up zinc in a tank mix. Salt-based zinc products dissociate in solution, and the glyphosate molecule will bind to the zinc ion, rendering both unusable. Even zinc in most chelated zinc products, such as EDTA, will also bind with glyphosate reducing the effectiveness of both. Certain chelated zinc products, such as AgriGuardian™ Zinc was designed to be tank mixed with glyphosate without losing efficacy of either.

Another point with using chelated zinc products with fertilizer mixtures and foliar applications is the pH of the application solution. For example, AgriGuardian™ Zinc is a sugar-based chelated zinc that is very effective in delivering zinc into the plant quickly and also compatible tank mixing with glyphosate, but at higher solution pH's it tends to coalesce forming small soft flakes in the tank. These flakes are still usable by the plant, but they tend to clog filters, and growers do not like clogged filters. This pH issue is rarely a problem with foliar applications, but many starter fertilizers are pH 7.5 and above. Consequently, AgriGuardian™ EDTA Zinc is used with starter fertilizers to eliminate the problem. However, AgriGuardian™ EDTA Zinc is not as effective as the sugar-based chelated AgriGuardian™ Zinc.

While zinc is critical for corn in the development of its ear, zinc deficiency can influence the productivity of all crops. As mentioned earlier, zinc deficiency can have an effect on photosynthesis (interveinal chlorosis) and zinc contributes to disease resistance with many crops. Once a crop is established and zinc deficiency is detected by tissue analysis, then commonly the easiest way to supply available zinc is through foliar application. Foliar applications of zinc to correct zinc deficiency or to supplement zinc to the plant at critical stages of plant growth (e.g., ear set in corn) is now a routine practice in modern agriculture.

Chapter 17

Nickel (Ni)

Atomic Number: 28
Atomic Weight: 58.69

Discovered by Axel Cronstedt, 1751
Proven to be essential to plants by Eskew et al., 1983; Brown et al., 1987

Background

Nickel is the most recent mineral nutrient element to be classified as essential for plants. A difficulty with identifying nickel as an essential plant nutrient is that the requirement by most crops is only in the parts per billion. Tropical legumes typically require higher concentrations of nickel and certain wetland plants require even higher concentrations.

Research on legumes and small grains by Brown et al. (1987) have shown that its deficiency meets the requirements for essentiality. Barley seed produced on Ni-deficient plants did not germinate, and no other nutrient could substitute for Ni. Nickel deficiency has also be shown to be related to an orchard replant problem that leads to tree death has also been shown to be related to nickel deficiency.

Nickel is a component of the enzyme urease, and plants deficient in Ni can accumulate urea in the leaves. Nickel-deficient plants are slow growing, and grain viability is inhibited and limits germinations in barley and other species. The need for Ni is typically low and a nutrient solution containing a Ni concentration of at least 0.057 mg L^{-1} to satisfy plant requirements for this element.

Nickel in the Soil

Occurrence

Nickel is abundant in the crust of the Earth at about 0.008% to 0.010%. Nickel averages 4 to 80 mg kg^{-1} in most soils. Nickel ranges up to 24,000 to 53,000 mg kg^{-1} in soil near metal refineries. Agricultural soils typically contain 3 to 1000 mg Ni kg^{-1}, whereas serpentine soils derived from basic ultramafic igneous or meta-igneous rocks may contain from 2000 to 6000 mg Ni kg^{-1}.

Forms and Dynamics

Ni^{+2} is found in the soil in many compounds and complexes [e.g., $Ni_3(PO_4)_2$, $NiSO_4$, $NiCO_3$, $Ni(OH)_2$, $Ni(NO_3)_2$, NIO, NiS, and various Ni-organic ligands] with a variety of coordination numbers and geometries. Nickel, unlike many other divalent cations, is readily re-mobile within plants. Nickel rapidly re-translocate from leaves to young tissues via the phloem, particularly during reproductive growth. Indeed, up to 70% of nickel in the shoots was transported to the seed of soybeans.

Fertilizers

Nickel normally is applied as $NiSO_4$, by foliar application using 0.08 to 0.16 mg L^{-1} solution, or applied as Ni-chelates. Ni may also be contained in animal manures and sewage sludge. However, Ni is tightly bound to organic ligands and is only slowly available for plant uptake.

Nickel Uptake and Assimilation by Higher Plants

Movement and Uptake

Nickel is taken up by plant roots as either the Ni^{+2} ion or in chelated forms. Nickel readily moves in xylem, but free ions may bind to xylem vessels, slowing translocation.

Translocation and Assimilation

Nickel primarily accumulates in the leaves of plants. Ni is more mobile in plants than other micronutrients. During reproductive growth, Ni moves to the phloem and into reproductive structure, and accumulates in the seed. With soybeans, up to 70% of the Ni in the plant will accumulate in the seed. The translocation of Ni typically occurs with Ni^{+2} ions binding to an organic acid, but it can also move as the free Ni^{+2} ion. Above pH 6.5, the amino acid histidine is probably the most significant chelator, whereas at pH <5, citrate is probably the most significant one. However, depending on specific crop, malate, nicotianamine, and certain oligopeptides may also be involved.

Nickel Nutrition in Higher Plants

Essential Roles

Nickel is a component of urease, and is required for urea metabolism. Nickel is also an essential catalyst of numerous enzymes including hydrogenase and dehydrogenase, as well as those involved in nitrogen fixation and others associated with bacterial processeswithin N-fixing nodules. It also appears to be a required catalyst for certain forms of acetyl coenzyme-A synthase, and may influence a host of primary metabolic processes, including the metabolism of photoassimilated carbon. There are probably several other secondary metabolic processes and physiological functions of Ni not yet identified. The application of Ni has also been shown to reduce the incidence of certain diseases such as brown spot in rice and rice seedling blast, and may be associated with the formation of phytoalexins in the host plant. Also, Ni deficiency can result in an accumulation of urea, making plants more susceptible to disease. Replant disease of fruit trees and pecans may partially due to Ni deficiency caused by root pathogens suppressing Ni uptake.

Adequate Range and Nutritional Disorders

Sufficiency Range

The sufficiency range of Ni varies by the species and type of plant. Pecan, tropical legumes, woody perennials using substantial ureide-N as a nitrogen transport form have a high Ni requirement in the range of 1 to 30 mg Ni kg^{-1} dry weight for normal plant growth. Grasses and plants relying primarily on amide-N for nitrogen transport typically need 0.1-0.2 mg Ni kg^{-1} dry weight for normal plant growth. The availability of sufficient levels of Ni in tissues and organs when they are rapidly growing is typically of greatest metabolic and physiological importance. It is for this reason that it is critical that growing organs and tissues receive sufficient Ni early during their growth phase, i.e., typically at the beginning of the log-phase and again at mid log-phase of organ growth.

Deficiency

Visual symptoms of Ni deficiency rarely are found in actual crop production, but low Ni concentration, or low endogenous bioavailability, can still limit crop performance without expression of symptoms. Crops as diverse as pecan, birch, certain pines, barley, wheat, potato, daylily, coffee, alfalfa, and mint may have yields suppressed by Ni deficiency in field-production. Visual symptoms seem to occur in many woody perennial crops when Ni concentrations drop below 0.5-0.9 $mgkg^{-1}$, whereas growth and yield may be suppressed at 0.9 to 3 $mgkg^{-1}$ with no visible symptoms. However, the leaf concentrations of Zn, Cu, Fe, Mn and P, or combinations thereof, play a role in the actual concentration of Ni needed for proper Ni nutrition through their influence on bioavailability.

In legumes and other dicotyledonous plants, Ni deficiency results in decreased activity of urease and subsequently in urea toxicity, exhibited as blunted leaflet and tip necrosis. There is often a thickening of leaves or leaflets, a necrosis of leaf or leaflet with a dark-green zone adjacent to the necrotic zone and appearance of brittle wood and limbs on shrubs and trees and generally suppressed growth, vigor, and flowering. Other symptoms associated with Ni deficiency include shortened internodes (“bonsai” effect), weak shoot growth, failure to break winter dormancy (apparent cold damage), excessively sharp pointed buds, rosetting, loss of apical dominance, death of shoots and branches, and plant death. Regarding winter damage, Ni deficiency may prevent perennials from being able to access and translocate N stored in organic compounds within the plant. Deficiency also limits lignification of the shoots and shells of pecan.

With nitrogen-fixing plants or with plants grown on urea, nitrate or ammonium, Ni deficiency results in a general suppression in plant growth with development of leaf tip necrosis on typically pale green leaves.

Figure 17-1. Nickel deficiency in pecan. Photo courtesy of B.W. Woods, ARS-USDA.

These symptoms are attributed to the accumulation of toxic levels of urea and organic acids in the leaf tissues. The first demonstration of agricultural Ni deficiency was reported in 2004 (Wood et al., 2004), when it was observed in pecan. Nickel deficiency in pecan is associated with a physiological disorder known as ‘mouse-ear’, or ‘little-leaf’, which occurs sporadically, but with increasing frequency as orchards age.

Figure 17-2. Mouse ear symptoms on pecan due nickel deficiency. Photo courtesy of B.W. Woods, ARS-USDA.

This occurs throughout the southeastern United States (portions of South Atlantic region) where it represents a substantial economic impact. In agreement with the results of Brown et al. (1987), Ni deficiency in pecan results in a disruption of N metabolism and altered amino acid and organic acid profiles.

Toxicity

Nickel toxicity in agricultural soils has not been clearly delineated as specific to Ni. Toxicity to plants normally is associated with serpentine soils, sewage-sludge applications, or industrial pollution sites that contain high levels of Ni. Also, Ni generally is believed to be less toxic to most plant species than other heavy metals such as Cu, Co, Cd, Hg, or Cr.

Leaf concentrations in excess of roughly 80 to 120 $mgkg^{-1}$ in most woody perennials may cause toxicity, but toxicity depends on the species and its relative concentration to competing nutrients (e.g., Zn, Fe, Mn, Cu). Above roughly 60 $mgkg^{-1}$ damage may occur, but visible symptoms might be absent. Certain Ni hyper-accumulating species can possess concentrations in excess of 20,000-30,000 $mg\ kg^{-1}$ without damage. Toxicity can occur in certain Ni-sensitive species at relatively low concentrations as low as approximately 10 $mgkg^{-1}$.

Interactions with other Elements

Competing Nutrients

Zinc, Cu, Fe, Co, Cd or Mg can suppress Ni uptake. The ratio of Ni to the sum of these nutrients is more important in Ni deficiency than is the concentration of the individual elements. Within the plant, Zn, Cu, Fe, Mn, and Co may compete for utilization. The ratio of the sum of these nutrients must be considered when using tissue analysis to determining whether Ni application is needed, and thus a consideration in the rate of Ni application.

Nitrogen

Nickel has a close relationship with N since Ni deficiency can result in urea toxicity and there may be roles of Ni in other aspects of N metabolism yet to be determined. When Ni is limiting, N utilization by the plant is not efficient. With adequate Ni, there is an increase the green color of the plant and protein content of harvested organs. Foliar application of Ni to Ni-deficient crops can increase soybean, alfalfa, and wheat yields, possibly by increasing available nitrogen to the plant.

Nickel Fertilization

Most annual plants grow well where Ni is available in the soil at 0.5 lb per acre (0.6 kg ha^{-1}). Nickel fertilizers are especially important when urea is the primary N source used in crop production; however, use of any N source may also require attention to Ni fertilization. Plants growing on soils exposed to high applications of other metals (e.g., Zn, Cu, Mn, Fe, Ca, or Mg), may require Ni^{+2} to be applied as a foliar fertilizer due to competition with these ions for uptake and for cellular processes. Leguminous crops grown in soils poor in mineral content or with a pH > 6.7 may require available Ni to be applied. Nickel complexes (e.g., Ni-liganosulfonate) and soluble salts, like nickel sulfate ($NiSO_4$), are excellent fertilizers for preventing or correcting plant Ni deficiency. Applying a foliar spray at aconcentration of 0.03–0.06 mg Ni L^{-1} is typically sufficient. Foliar applications at 400 mg L^{-1} to most woody perennials are potentially phytotoxic. Crops sensitive to Ni, such as tomato, may be damaged by 50 mg L^{-1} foliar sprays, which produce necrotic spots on foliage. Soil application of 0.5 lb Ni per acre often is recommended, but because Ni binds tightly to soil mineral and soil organic matter, foliar sprays typically achieve the correction of Ni deficiency best during early stages of growth. While historically municipal biosolid waste (sludge) has been used as a source of Ni, USEPA heavy metal restrictions have limited how much Ni and other heavy metals can be contained in sludge, with a limit for Ni at 420 $mgkg^{-1}$. Table 17-1 summarizes Ni fertilizer sources.

Table 17-1. Nickel fertilizer sources.

Fertilizer	Formula or material	% Ni
Nickel sulfate (also called nickelous sulfate)	$NiSO_4 \cdot 6H_2O$	22%
Anhydrous nickel sulfate	$NiSO_4$	37.5
Nickel nitrate	$Ni(NO_3)_2 \cdot 6H_2O$	20.2
Nickel chloride	$NiCl_2 \cdot 6H_2O$	24%
Nickel(II) EDTA[1]	$NiC_{10}H_{16}N_2O_8$	16.7
Nickel Plus[2]	Nickel lignosulfate + urea	5.4
Sewage sludge[3]	Composite	0.042 - 5.3

[1]EDTA = Ethylenediaminetetraacetatic acid
[2]Nickel Plus also contains N (5%) and S (3%), labeled for foliar use only
[3]Nickel content can vary widely, and shows the importance of testing before applying. Concentration applied to land is often regulated environmental agencies.

Chapter 18

Beneficial and Nonessential Elements and Elemental Toxicities

Although only 17 of the 92 naturally occurring elements have been accepted to be essential for plants, a number of the remaining 75 elements have significant beneficial or detrimental effects on plant growth and development. Much of the interest in these elements has come about largely due to our ability to precisely control the concentration of these elements in the environment to ensure that they are not present in the media, air, or seeds and to determine the responses of plants to these elements. Beneficial elements are those that may compensate for toxic effects of other elements or may replace nutrients in some less specific function such as the maintenance of water status for a plant under draught conditions. The interest of plant nutritionist in beneficial nutrients in commercial production is to ensure that plants are being grown to their optimum genetic potential.

Nonessential Elements Beneficial to Plants

University of California plant scientists, Drs. D. I. Arnon and P. R. Stout, established the term essential mineral element and criteria for elemental essentiality in 1939. Only 17 elements are accepted as meeting the criteria for essentiality. These criteria state that for an element to be essential it must be required for plants to complete their life cycles, all plants must require that nutrient, and it must not be substituted fully by another element. Elements that do not meet all of these criteria are considered nonessential. However, some plants require elements that improve plant growth or quality but not all plants require that element for proper growth.

It has been well established that three elements, silicon (Si), cobalt (Co), and vanadium (V) can be beneficial to plants, although they do not meet all of the requirements for essentiality. For example, Si adds stalk strength to grain crops, such as rice (Takahashi, Ma, and Miyake, 1990) and wheat, as well as providing a considerable degree of fungal resistance to plants (Belanger et al., 1995), whereas sodium (Na) can partially substitute for potassium (K) in some plants and V can partially substitute for the molybdenum (Mo) function in plants.

Legumes that symbiotically fix atmospheric nitrogen, as the nodules on the plant roots require Co to carry out N2 fixation need another element, Co.

Pais (1983) noted that titanium (Ti) has beneficial effects by promoting growth and biomass production.

It was recognized in the 1890s that a number of elements could be beneficial to plants, so when growing plants hydroponically, plant physiologists added what they called an A to Z Solution, a solution that contained small quantities of aluminum (Al), arsenic (As), barium (Ba), bismuth (Bi), bromide (Br), cadmium (Cd), chloride (C1), chromium (Cr), Co, fluoride (F), lead (Pb), lithium (Li), manganese (Mn), mercury (Hg), Mo, nickel (Ni), rubidium (Rb), selenium (Se), strontium (Sr), tin (Sn), Ti, and V, as well as the currently recognized micronutrients boron (B), copper (Cu), and zinc (Zn) to the nutrient solution. At that time, iron (Fe), carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), K, calcium (Ca), magnesium (Mg), and sulfur (S) had been identified as essential elements for normal plant growth.

Basis for Beneficial Actions of Elements

Markert (1994) defined what he called the "Reference Plant" composition that included 26 elements that are not essential but are in plants at easily detectable concentrations (Table 18-1).

TABLE 18-1. Trace Elements of Markert's Reference Plant Composition.

Trace element	**mgkg^{-1}**	**Trace element**	**mgkg^{-1}**
Antimony (Sb)	0.1	Iodine (l)	3.0
Arsenic (As)	0.1	Lead (Pb)	1.0
Barium (Ba)	40	Mercury (Hg)	0.1
Beryllium (Be)	0.001	Selenium (Se)	0.02
Bismuth (Bi)	0.01	Silver (Ag)	0.2
Bromine (Br)	4.0	Strontium (Sr)	50
Cadmium (Cd)	0.05	Thallium (Ti)	0.05
Cerium (Ce)	0.5	Tin (Sn)	0.2
Cesium (Cs)	0.2	Titanium (Ti)	5.0
Chromium (Cr)	1.5	Tungsten (W)	0.2
Fluorine (F)	2.0	Uranium (U)	0.01
Gallium (Ga)	0.1	Vanadium (V)	0.4
Gold (Au)	0.001		

Source: Markert, 1994.

These elements are classified as trace elements since they exist at low concentrations in the plant dry matter. This designation, however, can lead to some confusion since the term "trace elements" is used sometimes to identify what is defined today as the micronutrients or minor elements (Jones, 2012). Those elements, when existing in the soil solution as an ion, can be taken into the plant by root absorption (see Chapter 2). This action means that plants will contain most, if not all those elements present in the soil solution (Jones, 2012). Some of these elements exist at fairly high concentrations in the plant depending on the level of their availability in the soil solution.

Potential Essential Elements

Three elements, Co, Si, and V have been identified as to their potential essentiality for plants, as considerable research has been devoted to each of these elements. Some investigators feel that they are important elements for sustaining vigorous plant growth.

Cobalt

Cobalt benefits leguminous plants because it is essential for nitrogen fixation. The root nodule requires Co so that leghemoglobin can be made and carry oxygen to the nodule, as O_2 is toxic to the nodule. Without Co, the nodules would be inactive, and the legume would then require an inorganic source of N (NO_3^- and NH_4) in the soil solution. In the absence of sufficient inorganic N in the soil, legumes wholly depend on N_2 fixed by the nodules. The plant would then be deficient in N, cease to grow, and eventually die if Co is not present, just as any other plant would die in the absence of adequate nitrogen nutrition. But, the legume will grow as well on inorganic N as with fixed N; hence, Co is not essential.

Silicon

Plants that are soil-grown can contain substantial quantities of Si, equal in concentration (% levels in the dry matter) to that of some of the major essential mineral elements. Silicon is absorbed as monosilicilic acid by diffusion and mass flow. Epstein (1994) identified six physiological and morphological roles of Si in plants. Reviewing 151 nutrient solution formulations, Hewitt (1966) noted that only a few included Si. Epstein (1994) recommends that Si, as sodium silicate (Na_2SiO_3), be included in a Hoagland nutrient solution formulation at 0.25 mM. Morgan (2000) reported that in hydroponic trials, yield improvements for lettuce and bean plants occurred if the Si in the nutrient solution was 0.005 M (140 mg L^{-1}). Studies with greenhouse-grown tomato and cucumber have shown that without Si, plants are less vigorous and more susceptible to fungal disease attack than plants that received Si (Belanger et al., 1995). Best growth was obtained when the nutrient solution contained 100 mg L^{-1} silicic acid (H_4SiO_4). Other common reagent forms of Si that can be added to a nutrient solution are either Na or K silicates since both are water-soluble compounds, whereas silicic acid (H_4SiO_4) is only sparingly water-soluble.

Silicon has been associated with stalk strength in rice and other small grains (Takahashi et al., 1990). In the absence of adequate Si, these grain plants will not grow upright, tending to lodge thereby resulting in significant grain loss.The problem of lodging has been observed primarily in paddy rice, where Si availability and uptake may be limited.

There can be confusion about this element as frequently the element silicon (Si) is improperly referred to as silica, SiO_2, which is an entirely difficulty compound.

Vanadium

Vanadium naturally occurs in the crust of the earth. It is also deposited from numerous anthropogenic activities such as the burning of coal, oil combustion, and emitted into the atmosphere during the production of copper, nickel, iron, and steel, and the incineration of sewage sludge.

Vanadium is considered to be a required micronutrient for the green alga *Scenedesmus obliquus* Kützing. Experiments were conducted in which impure iron salts were utilized to determine the iron requirement of the species. Therefore, part of its requirement as an essential element in algae, at least, is as a replacement for unavailable iron. However, the supply of iron in a readily available form removes this requirement. If vanadium is a beneficial element for higher plants it may be so only when iron or other metals are limiting. A study that evaluated the beneficial effect of Vdetermined that it might be substituting for iron when iron was not available or the form of iron was not in a readily available form, such as a citrate or iron EDTA instead of ferric chloride. Low V concentrations in the growing medium tend to stimulate growth. Vanadium supplied at rates of 10 to 20 mg V L^{-1}, which is considered high, has shown to decrease plant growth and result in reddening of the stem and later in the tips of leaves. High concentrations of V can induce apical iron deficiency chlorosis. Tissue levels of V, where beneficial growth responses occur, would be less than 2 nanograms (<0.002 ppm) V per gram of tissue.

New Beneficial Elements

Morgan (2000) has identified what he calls “New” Beneficial Elements, those being other than Co, Si, and V as:

TABLE 18-2. New Beneficial Elements

sodium (Na)	iodine (I)	lithium (Li)
strontium (Sr)	silver (Ag)	selenium (Se)
aluminum (Al)	rubidium (Rb)	titanium (Ti)

Sodium

- Has a very specific function in the carbon dioxide concentration in some C4 plants.
- Can be a replacement for K in some enzymatic reactions in plants.
- Can be beneficial at low concentrations and detrimental at high concentrations. Sodium levels in plant tissue are recommended to be less than <0.25%.

Strontium

- May partially replace Ca^2 when the calcium requirement is high and not sufficiently available.

Aluminum

- May be beneficial to plants that are adapted to low pH soils.
- Growth stimulation to these plants attributedto alleviation of Htoxicity, and to increased root activity and phosphorus uptake.

Iodine

- The vegetative growth of spinach, white clover, fodder beet, tomatoes, perennial ryegrass, turnips leaves, barley, flax, wheat and mustard was favorably influenced by iodine.

Silver

- Induces production of male flowers on female plants.
- Plays a role in post-harvest physiology by blocking the production of ethylene and therefore cut flower life can be extended by pretreatment with Ag compounds.

Rubidium

- Reported to enhance leaf blade size in sugar beet plants with low K availability
- May play a role in sugar beet plants by enhancing yield and sugar content through having an effect on partitioning of carbohydrates to the shoot over to roots.

Lithium

- Some plants can accumulate Li in high concentrations.
- Lithium may influences the transport of sugars from leaves to roots in sugar beets and increases chlorophyll content of potato and pepper plants.

Selenium

- The incorporation of SeO_4^{-2} into organic compounds in plants occurs in the leaves and is assimilated in the same metabolic pathways as sulfate.
- Selenium can increase the tolerance of plants to UV-induced oxidative stress, delay senescence, and promote the growth of aging seedlings.
- Selenium is reported to aid in the regulation of the water status of plants under drought conditions.

Titanium

- May play a role in photosynthesis and N_2 fixation
- Increases the chlorophyll content of tomato leaves
- Increases yield, fruit ripening, and sugar content of fruits.

Element Substitution

There is considerable evidence that some nonessential elements can partially substitute for an essential element, such as Na for K, Rb for K, Sr for Ca, and V for Mo. These partial substitutions may be beneficial to plants in situations where an essential element is at a marginally sufficient concentration. For some plant species, this partial substitution may be highly beneficial to the plant, for example, the substitution of Na for K in sugar beets. Vanadium seems to be capable of substituting for Mo in the N metabolism of plants, with no independent role clearly established for V. As an example, if Mo is at its sufficiency level in the plant, the presence and availability of V is of no consequence.

Despite considerable speculation, it is not known exactly how such substitutions take place, although similarity in elemental characteristics (atomic size and valance) may be primary factors.

Elements Considered Toxic to Plants

Heavy Metals

A heavy metal is identified as an element whose atomic weight 55 or greater. Five of the seven micronutrients, Cu, Fe, Mn, Mo and Zn, have such atomic weights. Heavy metals, other than the five micronutrients are elements, such as cadmium (Cd), lead (Pb), mercury (Hg), and selenium (Se), which are generally considered dangerous to animal and human life. Plants may exclude or accumulate these elements.

Although these elements are naturally occurring, sometimes at elevated concentrations, it has been the addition of these elements to the environment by way of human activity that is of concern today. Dumping of heavy metals onto land, many times to croplands, was a common practice for the disposal of various types of waste products, i.e., animal manures, sewage sludge, and industrial wastes. Each of these waste products may contain sizable concentrations of heavy metals. In some cases, the accumulation of the metals in soils has been high enough to be hazardous to crop production and has led to concern of accumulation of these metals into human food and animal feed products.

Nutrient Toxicity

Some nutrients can be toxic to plants if present in the root medium at elevated concentrations. For example, five micronutrients, B, Cl, Cu, Mn, and Zn, at high concentrations in the soil solution can be toxic to plants. The toxicity effect may be direct, with the element itself directly impacting the plant, or the effect may be indirect by reducing the availability of another element.

Toxicities may arise from several practices and phenomena, such as over fertilization, soil acidification, or use of heavy metal base pesticides. The range between sufficiency and toxicity of B is narrow. Boron fertilization can limit the growth of a crop, such as corn, if applied at rates that would be required for a high B-requirement crop, such as peanut or cotton. The accumulation of Cu from the early long-term use of Cu-based fungicides on orchards and vineyard poses significant problems for crop production on these sites. Manganese can be elevated to toxic concentrations in the soil solution when the pH in soils is less than pH 5.5.

If present at high concentrations in the soil solution or plant, Zn will interfere with Fe metabolism in the plant, the result being development of Fe-deficiency symptoms. This effect might be due to suppression of Fe absorption and/or an antagonism of Zn with Fe metabolism in plants.

Chloride has low toxicity to plants and can accumulate to concentrations that are hundreds or thousands of times the requirement of plants for Cl. However, some evidence notes that Cl may have a toxic effect on some crops. The use of potassium sulfate rather than potassium chloride may help to avoid this problem. Saline soils generally are high in NaCl, which affects the water relations of crops, thereby restriction water uptake by plants. Salinity is a major problem in many areas of the world. Coastal areas with ocean mists depositing salt water, or the use of high salt-containing irrigation water may increase salinity in soils.

A common nonessential element that can be toxic to plants is Al, an element that can reach toxic levels in the soil solution due at low pH. Aluminum can affect the plant content of several elements. Notably, high Al (1 or 2 mg L^{-1} in solution) will suppress the content of P, K, Ca, Mg, and Zn in the plant. While the general effect of Al is to reduce P concentrations in plant tops, Al may increase the P content in ryegrass, barley, and cranberry. In a nutrient solution, K uptake is stimulated at low Al concentrations and is inhibited at high concentrations (5 to 10 mg L^{-1}). Toxic levels of Al have been associated with high levels of N, Cu, Fe, and Mn in the leaves or shoots of plants. Toxicity symptoms of excessive Al can take various forms, with shoot growth being stunted (particularly in the early stages of growth) and root development being impaired.

Plants have the ability to protect themselves from excess heavy metals in the growing environment. Examples of protective mechanisms include:

- Selective uptake of ions
- Immobilization of ions in roots, foliage, and seeds
- Differences in the structure and function of membranes
- Removal of ions from metabolism by deposition (storage) in fixed and/or insoluble forms in various organs and organelles, such as roots, foliage, and seeds
- Release of ions from plants by leaching from foliage, guttation, leaf shedding, and excretion from roots.

Trace element toxicity or tolerance by the plant may be due to interaction of the element with another element, typically with a major element. Calcium and phosphorus are thought to be antagonistic or synergistic to the toxic effects of heavy metal elements. For example, it has been suggested that a major role of Ca in the plant is to counter the toxicity effect of certain heavy metals, potassium, magnesium, and phosphorus. Therefore, the concentration of Ca in the plant may be equally important in terms of its ameliorative effects as its direct role in plant growth and development.

Summary

The leading beneficial elements aluminum (Al), cobalt (Co), sodium (Na), selenium (Se), and silicon (Si) are not required by all plants but can promote plant growth and may be essential for particular plant species. Enhance resistance to biotic stresses such as pathogens and herbivory, and to abiotic stresses such as drought, salinity, and nutrient toxicity or deficiency has been reported for these beneficial elements at low dose application. The beneficial effects of low doses of Al, Co, Na and Se is important to understand through continued research in order to understand how these elements can improve crop productivity and enhance plant nutritional value for plants showing a positive response to these nutrients.With our expanding knowledge of those elements not considered essential to plants at this time, as well as our ability to analytically determine their presence and concentration in plants showing a positive response to their application in the fertility program is critical to the acceptance of these elements in plant nutrition

Figure 18-1. The beneficial element silicon is being applied routinely to golf greens.

Chapter 19

Plant Nutrition and Foliar Fertilization

Plants are able to absorb essential plant nutrients through leaves, a fact known for decades. Foliar fertilization has been used for years primarily with high-value crops such as vegetables, fruits and ornamentals. Early uses of foliar fertilization were primarily used to offset micronutrient deficiencies such as iron deficiency with blueberries, or to enhance the appearance and shelf life of foliage plants and cut flowers. Also, foliar applications of nutrients can offset nutrient deficiencies caused by diseases, hail damage, insect damage and help plant recover from other stress conditions. Both quantity and quality of yield can be increased by the foliar application of deficient nutrients regardless of cause. Traditional fertilizers, especially micronutrient fertilizers, are often inefficient when applied to the soil. Soil pH and other nutrients, and even pesticides, can tie up micronutrients and make them unavailable to the plant. With micronutrient deficiencies becoming common among all crops including agronomic crops, foliar fertilization is accepted as an effective and efficient means to meet the nutritional needs of most crops. Foliar fertilization is being used more broadly than in the past, and is being used as a primary source of nutrients, including for agronomic crops such as corn and soybeans. This usage applies to macronutrients as well as micronutrients.

Figure 19-1 Use of a highboy in the production of field agronomic and horticultural crops to apply foliar nutrients throughout the growth cycle of the crop. Pictures provide by *BRANDT*, Springfield Il and Holzwarth Flying Services.


Figure 19-2. Use of a airplane to apply foliar nutrietns to crops.Pictures provide by *BRANDT*, Springfield Iland Holzwarth Flying Services.

Foliar application of nutrient is especially important 1) when the plant demand for nutrients exceeds the capacity of the roots to take and deliver nutrients to the plant, 2) when redistribution of nutrients within the plant cannot meet localized plant demands, 3) when soil nutrient levels or other growing media condition are inadequate to deliver sufficient usable nutrients to the plant root system to meet the plant demand.

Fertigation is a method of applying nutrients through an irrigation system. Both the foliage and ground receives the soluble nutrients applied by this method.

Figure 19-3. Left, application of fertilizer through a pivot irrigation system called fertigation, applying nutrients to both foliage and soil. Picture on right shows a system of applying a mist with nutrients more directed toward foliage only application.

The success of foliar applied nutrients is the result of replacing or supplementing soil-applied fertilizers with water-soluble fertilizers containing urea, chelated or complexes (sugar- or acid-bound) nutrients, and certain effective salt-based fertilizers, such as magnesium nitrate. Absorption takes place through 1) the waxy cutin layers of the epidermis of the leaf, 2) the stomata of the leaves, and 3) other natural breaks or openings in the cutin layer. The majority of foliar nutrient uptake is through the epidermis with most plants. Absorption is often more efficient through the underside of the leaf because of greater stomata and the cutin layer is typically thinner on the underside of leaves. With crops like corn and soybeans, stomata occur on both the top and bottom of the leaves. Plants are also able to absorb nutrients through their bark.

Nutrient Mobility and Foliar Fertilization

Foliar fertilization is particularly important for nutrients that are poorly mobile in the plant. A continuous supply of these nutrients is needed to ensure that plant has adequate nutrition for acceptable growth and yield. If the supply of these nutrients from the soil or growing media is unable to keep up with demand, then new growth will suffer from nutrient deficiency. Foliar application for these nutrients is important 1) at critical peak demand points for the nutrient in the plant's development, 2) when the soil is unable to deliver the nutrient to the plant roots, or 3) the plant is unable to translocate the nutrient from the roots to the active growing. The application for moderately mobile or very mobile nutrients is also important when the crop cannot take and deliver adequate nutrients to the growing points of the plant, but mobile nutrients have the benefit of being able to taken for older plant tissue and translocated to the new growing points. Foliar application of mobile nutrients will help prevent the depletion by older tissue by these mobile nutrients.

One difficulty in using foliar sprays to supply nutrients to crops is that absorption and translocation of the applied element may not be rapid enough for increasing crop yields if foliar application is the major source of a nutrient. This problem is greater for macronutrients. However, as a supplemental source of an element, foliar application of plant nutrients continues to gain increasing widespread acceptance. The mobility of nutrients generally is classified into three categories of mobility: very mobile, moderately mobile and poorly or slightly mobile.

Table 19-1. Mobility of plant nutrients within plant tissues.

Mobility of Plant Nutrients

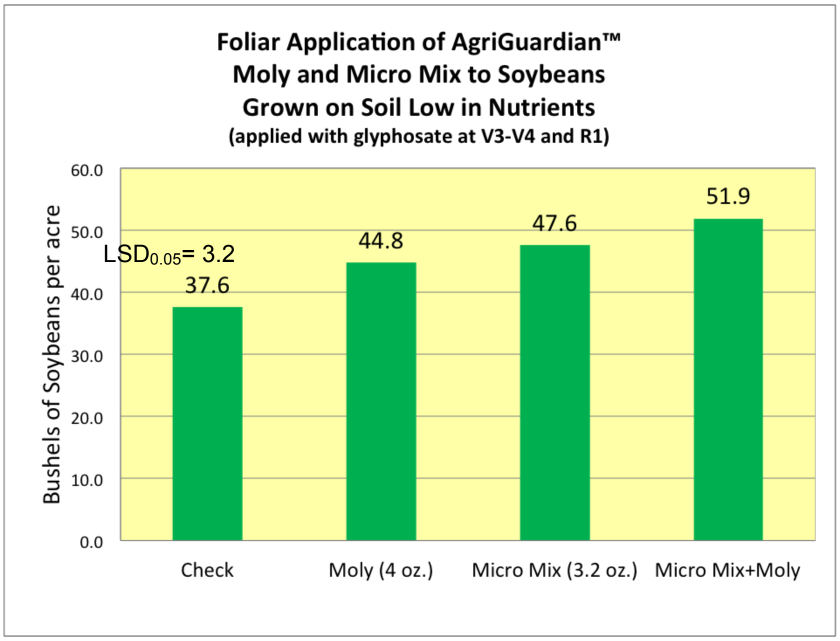
Mobility of elements in the plant often defines the location
of visual symptoms of nutrient deficiencies or toxicities:

Very Mobile	Moderately Mobile	Poorly or Slightly Mobile
Nitrogen	Magnesium	Iron
Phosphorus	Sulfur	Manganese
Potassium	Molybdenum	Copper
Nickel		Zinc
Chlorine		Calcium
		Boron

The importance of foliar fertilization using poorly or moderately mobile nutrients is demonstrated by a study conducted by the University of Missouri on soybeans grown in soils low in both macronutrients and micronutrients. Micronutrients were foliar applied in a tank mix with two applications of glyphosate. These foliar applications totaled up to

14.3 ounces per acre of micronutrient fertilizers, and increased yields up to 14.3 bushels per acre (Figure 19.2). No nitrogen, phosphorus, potassium or other macronutrients were applied. This result clearly demonstrates the importance of foliar applied micronutrients in crop production, especially when glyphosate is used.

Figure 19-4. Yield response to foliar application of AgriGuardian Moly (4% molybdenum) and Micro Mix (six essential chelated micronutrients) tank mixed with glyphosate and foliar applied to soybeans at V3-V4 and at R1. No macronutrients were applied.



Nitrogen

Nitrogen is a very mobile element within the plant, and foliar sprays using urea, ammonium and nitrate salts have been used to supplement the nitrogen levels in plants. Entry of nitrogen is dependent on nitrogen form. The primary forms of foliar applied nitrogen are urea, and ammonium and nitrate salts solutions.

Urea. Urea is the most effective form of foliar nitrogen followed next by ammonium ion and then by nitrate ion. Urea is easiest to traverse the cutin layer to enter the plant, and is considered the most suitable form of N for foliar application because of its non-polarity, rapid absorption, low phytotoxicity and high solubility. Urea absorbed by the leaf is rapidly broken down to ammonium and then assimilated into amino acids. Urea has a low salt index and high solubility and has been used successfully on many crops to supplement plants deficient in nitrogen or to support critical-growth-stage requirements. Approximately half of the urea applied to foliage is absorbed during the first two hours after application. Amounts up to 15 pounds of urea per acre at one spraying have been used with beneficial results on mature apple trees late in the season. The usual concentration for apple trees is 5 pounds of urea per 100 gallons of water. Higher concentrations burn the leaves. Plant sensitivity to foliar urea varies with species and the age of the leaf. Young plants and leaves have high urease activity (required to convert urea into ammonium) and are able to metabolize the urea into organic nitrogen compounds more quickly than older leaves. Fall application of foliar urea to trees after bud set and even during senescence is effective in increasing the stored nitrogen in the plant for next year's growth for ornamental and fruit trees. Urea commonly is mixed with other fertilizers and applied with regular spray materials at weekly intervals early in the growing season followed by late fall application for crops producing grain and fruits. Some growers add urea with surfactants to facilitate rapid uptake by the leaf. Factors such as applying early in the morning or late in the day to avoid drying of the spray on the leaves during the heat of the day, reduce the potential for leaf burn. A wind speed of less than 5 miles per hour is desired. Wind evaporates the water and increases the potential for leaf burn due to the increased concentration of the urea on the leaf. The air temperature between 65 and 85 degrees F is preferred at the time of application for maximum effectiveness of foliar applied urea. Aerial irrigation or rainfall during the first 48 hours after application results in washing of the urea from the leaf surface and reduced benefits of the urea spray.

Ammonium.Ammonium application effectively boosts growth and yield for many crops through foliar application. Like urea, the plant assimilates most of the ammonium within 48 hours after application. Ammonium, once inside the plant cell has a similar effect on plant nitrogen, as does urea. Even though foliar application of ammonium is not an effective means of supplying all of the nitrogen needs for most plants, correcting deficiencies and increasing grain and fruit yield at the end of the growth cycle is an important aspect of using foliar applied ammonium. Foliar ammonium applications also are used in the foliage-crop industry to improve plant color when applied just before harvesting and marketing. Application of ammonium to field corn is an effective means to increase the kernel development at the end of the ear, thereby increasing grain yield. The same effect is observed for sweet corn, when the kernel development at harvest needs a boost to finish filling out at the end of the ear prior to marketing. Increased kernel development in response to foliar ammonium, applied three days before harvest, has been observed in sweet corn production. Understanding how to utilize ammonium effectively in a foliar application to plants starts with knowing that the ammonium ion is toxic to plant cells and requires immediate detoxification. Detoxification of ammonium occurs in the plant cell by enzymatic assimilation into organic acids (2-oxyacids or α-keto acids; also called carbon skeletons) to form amino acids, which are not toxic and can be stored or utilized by the plant. High rates of urea or ammonium can be detrimental to the plants, primarily because of carbohydrate depletion resulting from the need for carbohydrates to supply energy to convert toxic free ammonium into nontoxic amino acids. The success of utilizing foliar applied ammonium, as a supplemental nitrogen source, is highly dependent upon the amount of photosynthetic products available to detoxify the ammonium upon absorption into the leaf cell. Plants under physiological or environmental stress will not respond well to foliar applied ammonium and can restrict leaf and plant size and limit fruit and grain yield. It is especially critical to not apply ammonium during the flowering stage for most plants, as the carbon necessary for flower development will be shifted to detoxifying the ammonium upon absorption into the leaf and flower and fruit abortion may occur. An ideal time to apply ammonium as a foliar application in the greenhouse industry is during cloudy weather if plants are healthy and growing properly.

Nitrate. Nitrate, though absorbed by the plant effectively, is less effective as a foliar source of nitrogen than urea or ammonium because it must first be convert into ammonium through nitrate reduction. Also, the enzyme nitrate reductase, which converts nitrate to ammonium, requires molybdenum in the tissue. Nitrate reductase activity in plants generally declines with plant age. However, nitrate reductase is an inducible enzyme, which means that when nitrate and molybdenum are present (molybdenum typically being the limiting factor), and has adequate carbohydrate supply, the plant will make more nitrate reductase. Foliar application of molybdenum with nitrate fertilizer is often beneficial where molybdenum levels are low in the tissue. Use of nitrate compounds as a foliar spray is considered the least effective of the three sources of nitrogen (urea, ammonium, and nitrate) for supplementing nitrogen requirements of plants. Potassium nitrate, calcium nitrate, magnesium nitrate, and ammonium nitrate are the sources that are used generally. Many times research reporting a positive plant response to these sources of nitrate does not separate the effect of the cation (K^+, Ca^{2+}, NH_4^+, Mg^{2+}) accompanying the nitrate anion (NO_3^-) in discerning whether it was the nitrate ion or the accompanying cation that resulted in the plant response. The biggest disadvantage of utilizing nitrate, relative to ammonium or urea, as a source of foliar applied nitrogen, lies in the energy requirements for assimilation of nitrate. Nitrate is assimilated by two enzyme-catalyzed reactions called nitrate and nitrite reductasethat convert nitrate into ammonium for assimilation into organic products in the leaf cells.

(5) (3) (-3)

$$\mathbf{NO_3^-} \xrightarrow{\text{Nitrate reductase}} \mathbf{NO_2^-} \xrightarrow{\text{Nitrite reductase}} \mathbf{NH_3}$$

These enzyme-catalyzed reactions are influenced by plant age (activity of these enzymes decline with leaf age), light levels (enzymes require the energy of products of photosynthesis), and require molybdenum and iron to mediate this conversion. Molybdenum is an essential cofactor in nitrate reduction, while iron is part of sirohem, which is a cofactor in nitrite reduction. The effectiveness of nitrate is lessened as a foliar nitrogen source as plant age (to grain filling and fruit development), during cloudy weather when sunlight is reduced, and when molybdenum is deficient.

Phosphorus

Phosphorus is a very mobile element within a plant and its application through foliar application is an effective means of supplying phosphorus. Combinations of orthophosphates and polyphosphates, e.g., liquid 3-18-18, are used as foliar applied phosphorus because these compounds have low burn and enhanced foliar absorption characteristics. Phosphorus foliar application can increase the concentration of phosphorus in the foliage and is more effective method of delivering phosphorus to the plant via the soil. One reason is that in most soils, only a small percentage of phosphorus fertilizers is recovered by the plant (averaging about 20 percent for the first year), whereas when phosphorus is sprayed on the leaves, nearly all of it can be absorbed.

Foliar applied phosphorus at the rate of 1.3 lbs. per acresprayed on tomato leaves promoted a 12% higher rate of early growth than did 60 pounds per acre of phosphorus applied to the soil.

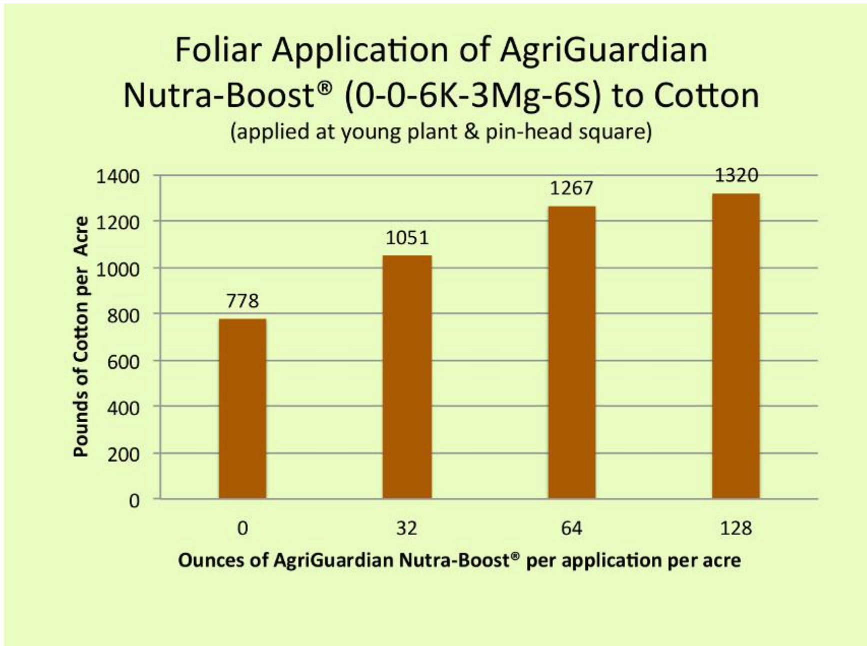
Potassium

Potassium is a very mobile element, and applications as foliar sprays utilize potassium polyphosphate, potassium sulfate, potassium nitrate, potassium thiosulfate, or potassium hydroxide. Many of these sources have low salt index, are highly soluble, and can provide potassium to plants in situations where a deficiency of this element will reduce yield or is needed for foliage plants going to market. Leaf injury is the main deterrent from using high levels of potassium, and leaf burn prohibits the use of high salt-based potassium chloride. While soil potassium is normally viewed as main source of potassium to crops, foliar application can be very effective in increasing yields to crops having high demands for potassium, especially during pod fill (e.g., soybeans) and fruit development (e.g., peaches). Factors such as neutral pH, low salt index, proper dilution and proper application timing are important in reducing leaf damage from foliar application. High quality 3-18-18 (neutral pH, low salt index, no heavy metals and 100% orthophosphate, i.e., clear product) has been applied routinely in the Midwest to soybeans during pod fill at rates as high as 7-8 gallons per acre when diluted in 20 gallons of spray solution. Multiple applications of the same 3-18-18 at 2-5 gallons in 10 gallons of water has been used successfully to offset potassium deficiency with soybeans, corn and watermelons. Potassium foliar applications in combination of other nutrients can greatly increase yields, e.g., K-Mg-S (Figure 19-2).

Magnesium

Magnesium is considered a moderately mobile element and is commonly applied to plant foliage to correct deficiencies. Solutions of magnesium sulfate (Epsom salts) have been used for years to apply this element to the soil to correct magnesium deficiencies in plants. More recently magnesium nitrate, as a foliar source of magnesium, is used on high-value crops. Field observations show that magnesium nitrate penetrates into the leaf quickly. It is thought that this action is due to the smaller negative charged nitrate anion in magnesium nitrate than the larger sulfate anion with magnesium sulfate is able to move with the positive magnesium ion across the cell membrane more readily. Other forms of magnesium in combination with other commonly needed nutrients have demonstrated positive results on nutrient accumulation and yield (Figure 19-3). One reason for the increased use of foliar applied magnesium is that soil applications of magnesium commonly takes three years to correct magnesium-deficiency symptoms of perennial crops such as apple trees, whereas foliar sprays are effective within a few days after application. Foliar application of a two per cent solution of magnesium sulfate, magnesium nitrate or other soluble form of magnesium to crop like tomatoes, oranges, or apples can relieved magnesium deficiency and increase crop yields. The foliage and vegetable industry routinely uses magnesium nitrate to prevent or correct magnesium deficiencies.

Figure 19-5. Influence of AgriGuardian Nutra-Boost® (0-0-6K-3Mg-6S) foliar applied to cotton at pinhead-square stage at rates of 0, 32, 64 and 128 oz per acre on the yield of cotton in pounds of cotton harvested per acre in University of California-Davis study.



Calcium

Calcium has not been typically considered for foliar application because of poor absorption through the cutin layer and limited mobility in moving from one site in the plant to another. Historically, calcium seldom was applied as a foliar spray to agronomic or plantation crops. Instead calcium was supplied through the addition of lime or gypsum to the soil or growing media. Modern agricultural practices use recently developed plant cultivars designed for rapid growth and high yield. Also, the practice of building the soil nutrient levels has become cost prohibitive, especially on rented land. Additionally, most of the nitrogen supplied to crops is in the ammonium form whether from ammonium salts, urea, urea ammonium nitrate (UAN, 28%, 32%) or manures. Ammonium interferes with calcium uptake, and calcium deficiencies have become more common.

Calcium has limited mobility in the plant from old leaves to young leaves. The movement of calcium from the soil to developing fruits is highly influenced by environmental factors affecting transpiration. Most of the calcium moving into fruits or developing organs primarily is transported through xylem transport of water from the roots to the developing leaves and fruits. The inability to move calcium from older plant components to developing leaves and fruits emphasizes the importance of the timing of calcium applications so that the fruit and other critical plant components receive the calcium that they need. This requirement also means that the applications of foliar calcium must be directly to or close to the organ or tissue needing the additional calcium.

Three conditions must be considered in the use of foliar applied calcium that influence the success of foliar applied calcium.

1. Maturity (age and timing) and degree of suberization of the plant tissues and organs influence the ability to utilize foliar applied calcium. Leaves or fruit that are aging are covered with thicker layers of wax (suberization) and the thicker the wax layer, the more difficult it is for calcium to penetrate through the cutin into the tissues. With tomato fruit foliar application of calcium to supplement calcium taken up by the roots must be made before a waxy material is formed on the fruit. Ninety percent of the calcium entering a tomato fruit moves into the fruit when it is the size of a thumbnail (before the waxy coating has developed). Application of calcium to correct blossom-end rot after symptoms appear does not work. Blossom-end rot begins at the cellular level when the fruit is just beginning to form. Without adequate calcium, the cell walls cannot form properly, leading to breakdown of the fruit tissue and the development of blossom-end rot. The calcium must be available with the cell walls are formed. Similarly, calcium sprays to the surface of apple fruit just before harvest do not prevent the development bitter pit. Calcium may penetrate some areas of the fruit but it is not redistributed within the fruit to cells that are deficient. Apples are sometimes dipped in a solution or slurry of calcium chloride to feed the apples with calcium before they are place in storage. Use of sprays to apple fruits and tomato fruits must be made when the fruit are young and do not have a thick protective waxy cover.

2. Understanding the impact that rainfall or high humidity has on ability of plants to supply calcium to newly forming tissue (growth) is essential. Transpiration during high humidity is reduced, and so is calcium movement with the transpiration stream to young leaves. Greenhouse production of plants is particularly subject to calcium deficiency, especially in cold climates, where air exchange in the greenhouse is reduced to maintain temperature levels favorable for plant growth. When air exchange is reduced, humidity rises in greenhouse, especially during the night, and in turn reduces plant transpiration and calcium movement to young leaves. Use of foliar sprays to reduce calcium-related disorders during these periods of high humidity is a critical cultural practice to improve plant growth and prevent calcium deficiency, and the spray must be directed to the affected organs and tissues. In tropical areas where heavy and frequent rainfall occurs which increases the relative humidity, foliar sprays of calcium are used as a means to offset the physiological effects of reduced calcium movement into developing plant leaves and fruit.

3. The ability of the calcium source to penetrate and deliver calcium to the deficient plant organs must be considered. Calcium chloride has traditionally been used as a foliar spray. Chloride toxicity to foliage might limit the amount of this calcium-containing fertilizer that can be applied. Sugar-based calcium chelates, e.g., Agri-Cal®, offer an alternative to increase the efficiency of foliar absorption of calcium.

Sulfur

Sulfur is limited to moderately mobile with deficiency showing in the young leaves and over the entire plant. Deficiencies of sulfur have become an issue as environmental regulations have reduced sulfur emissions into the atmosphere and thus reducing sulfur availability to crops from acid rain and the atmosphere. Incorporating the practice of applying applications of sulfur is becoming an established cultural practice, using both soil and foliar applications. Because sulfur is obtained from the atmosphere, tissue tests must be used to evaluate the sulfur status of plants. Foliar application of sulfur based on tissue tests is more effective than depending on soil-applied sulfur alone.

Iron

Iron has been sprayed on foliage since about 1916 to relieve chlorosis. The first of such research work was carried out with chlorotic pineapples growing on highly alkaline soils in Hawaii. Ferrous sulfate has commonly been applied to Hawaiian pineapples. Even though the iron moves readily into the leaves, it translocate very slowly. As a result, iron chlorosis may appear on leaves that did not receive the iron spray. Iron chelates also have been successfully used as a spray. In high pH soils, iron chlorosis is common. Applications of iron fertilizers to high pH soil have not been very successful because the iron is quickly converted to insoluble forms. Foliar application of chelated iron is the most effective method of applying iron to growing plants, especially sugar-based chelates that quickly traverse the cutin layer of plants.

Manganese

Soil manganese is also poorly available in alkaline soils, and in many states in humid regions of the country, manganese deficiencies are also reported for crops in peat and muck soils. In the peats and mucks, depletion of manganese by leaching and chelation to the soil organic matter has created manganese deficiencies for crop production. In alkaline soils, an acid-forming material, commonly ammonium fertilizer, is applied to lower the pH of the soil in rhizosphere and reduce fixation of soil-applied manganese.

Manganese deficiencies may be corrected by spray applications of manganese sulfate, usually 5 to 10 pounds per acre. Fungicides containing manganese also provide some benefit to manganese deficient crops, but tissue must be washed thoroughly of these pesticide residues before testing to ensure accurate tissue content of manganese. However, foliar application of chelated manganese is the most effective method of applying manganese to growing plants, especially sugar-based chelates that quickly traverse the cutin layer of plants.

Zinc

Zinc is sprayed often on the leaves of apple and pear trees to relieve leaf rosetting. Approximately 25 pounds of zinc sulfate in 100 gallons of water applied per acre or to wet the foliage (roughly a three per cent solution) to apple trees just before the buds open has corrected zinc deficiency. Fungicides containing zinc also aid in correcting zinc deficiencies, but tissue used must be washed thoroughly of these pesticide residues before testing to ensure accurate tissue content of zinc. However, foliar application of chelated zinc is the most effective method of applying zinc to growing plants, especially sugar-based chelates that quickly traverse the cutin layer of plants.

Boron

Foliar applied boron has been successfully used to offset boron deficiencies and reduce internal cork of apples and "cracked stem" of celery. Products such as boric acid, borax (sodium tetraborate) and chelated boron can be foliar applied. Extreme care must be used in applying boron to crops, especially foliar applied with highly effective chelated forms of boron.

Copper

Copper deficiency can controlled by spraying leaves with a mixture of $CuSO_4$ and $Ca(OH)_2$. Without the calcium hydroxide, the copper sulfate can injure the foliage. Fungicides containing copper (e.g., copper hydroxide) also aid in correcting zinc deficiencies, but tissue used must be washed thoroughly of these pesticide residues before testing to ensure accurate tissue content of copper. However, foliar application of chelated zinc is the most effective method of applying zinc to growing plants, especially sugar-based chelates that quickly traverse the cutin layer of plants.

Molybdenum

Molybdenum is an essential nutrient required by all crops but is often assumed to be present in the soil at levels sufficient to meet most crops' needs. Tissue tests in the Midwest have proven that molybdenum is frequently deficient even when soils have high pH levels making the nutrient more available to the crop. Traditional foliar application of molybdenum uses sodium molybdate; however, sodium molybdate does not seem to be readily translocated within the plant. Spraying only the lower half of a citrus tree that showed molybdenum deficiency with sodium molybdate does not cure the deficiency symptoms on the upper half of the tree. Molybdenum sugar-based chelates (technically, a molybdenum organic complex) move more readily within the plants than salt-based products. Foliar molybdenum applications are particular useful with highly acid soils, molybdenum is fixed in an unavailable form, thus causing deficiencies, particularly for legumes and brassicas. When applied to active nitrogen fixing legumes, such as soybeans, the nodules act as sinks for molybdenum, and molybdenum will translocate to the nodules causing depletion of molybdenum in the leaves. Additional applications of molybdenum may be required maintain adequate levels of molybdenum in the leaves to sustain active nitrate reduction. For all crops, molybdenum may be needed when nitrate is the predominant form of nitrogen available to the plants.

Inconsistent Research Results

Interest in foliar fertilization with agronomic crops began in the late 1970's through the 1980's in hopes of reducing the cost of fertilizer inputs. Extensive research findings were published during this time. However, the results of these studies were often variable and even contradictory. Because of these inconsistent results, University Extension Services and agronomists seldom recommend foliar fertilization as part of routine nutritional program. Fortunately, with greater interest being placed on micronutrients, foliar fertilization is again being evaluated as a potential means to ensure adequate nutrients are provided to crops.

Historically, foliar fertilization has been used widely with high value horticulture crops for decades, where both quality and quantity of harvest are both important. Also, high value crops justify the cost of tissue testing and the use of more chelated and other specialty foliar applied nutrients. However, foliar application to agronomic crops has only recently increased in use. Even so, many university extension services and agronomic consultants have been reluctant to recommend using foliar fertilization as a method of applying nutrients. This stems back to the 1970's and 1980's when extensive research was conducted by universities to determine the potential for foliar fertilization to improve agronomic crop yields. These studies showed inconsistent responses and considerable variability to foliar fertilization, thus raising doubts to the effectiveness of foliar fertilization. The exception to this was the occasional use of foliar applications of chelated iron to reduce iron chlorosis on soybeans, or chelated zinc to eliminate yellow stripping on corn, and until past couple of decades even these applications were rarely done.

What was not realized in the 1970's and 1980's was that many of the studies were flawed due to the absence of utilizing plant analysis in their studies. Consequently, some researchers would get the process right, and others would not, causing widely ranging and inconsistent results. Without a clear picture of what was going on, agronomists were not willing to embrace foliar fertilization as a routine part of agronomic crop production. Many of early researchers on foliar fertilization made several errors in conducting research to draw their conclusions. These include:

1. ***Improper fertilizers for foliar application, absorption and utilization***.Nutrients that are applied to the surface of leaves, stems, flowers and fruits must be in a form that can readily be taken up by the plant, while at the same time not cause burn or other toxic effects on the plant. Fertilizers that have high salt indices, high Cl content, high pH, low solubility indices, poor ability to dissolve at high air humidity (poor deliquescence), or strongly polar tend to be poor or slowly absorbed by the leaf tissue. Many traditional salt-based fertilizers can easily cause leaf burn or toxicity especially at high concentrations in solution. Because some of these fertilizers may adhere to the foliage, tissue analysis many show adequate or high levels, but the plant is unable to benefit from the applied nutrients, or may actually be harmed by their application. Researchers would take traditional granular fertilizers, dissolve them in water and apply the solution to the plants. Many, if not most, of these are salt-based fertilizers, many with high salt indices. Salt-based fertilizers may be absorbed through the stomata, but the efficacy of these applied salt-based nutrients will vary by environmental and plant conditions, and the specific chemistry of the compound. Unless nutrients can pass through the

waxy cutin layer on the leaves, or be absorbed through the stomata or other openings, the plant cannot take advantage of nutrients applied to the leaves, stems and fruits. Most salt-based fertilizers are not readily absorbed into the leaves, and are simply washed off the leaves with the next rainfall or irrigation, providing minimal benefit once entering the soil. There are, however, a few granular fertilizers that can be mixed with water for foliar application such as urea, calcium nitrate and magnesium nitrate. In recent years, most nutrients used for foliar fertilization are liquid products (often in chelated forms) for ease of use, and proper chemistry for rapid uptake and utilization by the crop. These include organic (carbon-based nutrients, such as urea) chelated nutrients, sugar- or acid-bound nutrients, and some salt-based fertilizers. For research to be valid, the form of nutrients applied must be in a form that can be taken up by the plant foliage and other plant parts, and can be used by the crop.

2. ***Improper tank mixing***. There several problems with tanking mixing foliar fertilizers are 1) the final pH of the nutrient spray solution, 2) fertilizer reactions and incompatibility, 3) too high or too low of nutrient concentrations, and 4) salt index too high. For plants to take up nutrients readily, the solution delivering these nutrients performs better if it is in the slightly acidic range (pH 5.5-6.7). Crops being foliar applied fertilizer solutions with a pH above 7.3-7.5 have difficulty absorbing these nutrients. Also, if nutrients are tank mixed that are reactive, their end product may not available for absorption by the crops. The classic example is mixing calcium and phosphate fertilizers in the same tank resulting in insoluble calcium phosphate, thus losing the benefit of both nutrients to the crop. Too high of fertilizer concentrations and/or salt index can cause burning of foliar and poor uptake. Too low of nutrient concentration does not provide enough nutrients to be effective, or high volumes of these low concentrations of nutrients just run off onto the ground.

3. ***Improper application***. Foliar applied nutrients are most readily taken up by plants in a film of water on the surface of the plant, thus the reason for applying foliar fertilization most commonly as in a spray application. Foliar applications made in the heat of the day, during low relative humidity, under windy conditions, and/or using very small droplet sizes results in rapid evaporation of the nutrient solution from the leaf surface before it has a chance to be absorbed into the plant. In extreme cases, the water in the spray solution actually evaporates before the spray hits the leaves resulting in the plants being dusted with nutrients. While many nutrients, especially sugar-based chelates can be readily absorbed very quickly into the leaves, the longer the nutrients can remain on the surface in a liquid environment, the more effective the applied nutrients are. Another concern is that heavy rain immediately after application can also wash the nutrients off of the plant surfaces. Plants also respond to environmental conditions such as stomata closing during hot dry periods to reduce water loss, but stomata closing also

reduces nutrient uptake. During cold temperatures, crops are slower to respond to foliar applications as well. Application of foliar nutrients under environmental conditions that are not conducive for uptake and utilization also make the research results invalid.

4. ***Improper stage in plant development for foliar fertilization***. For foliar fertilization to work, it must be applied when the plant can take up the nutrients through the foliar and also be able to use the nutrients. With many crops, the cutin layer and cell walls thicken as the leaves mature, making the uptake of nutrients more difficult. Virtually all plants have critical time periods for needing essential plant nutrients and when applied outside of these critical time periods, the value of the foliar applied nutrients is diminished. For example, corn needs zinc (and also molybdenum) by V4-V5 to ensure the production of indoleacetic acid (IAA), which regulates the number of rounds of kernels on the ear of corn. Once the number of rounds of kernels is set, it cannot change and the size of the future ear is fixed. Applying zinc at V6 or later is too late and will have little effect on the size of the ear. This time period is critical to ensure that the corn plant has adequate zinc. Every crop has some critical time period for one or more nutrients. Random application of foliar applied nutrients without considering the plant's physiology and the critical needs of crops greatly reduces the potential benefits of foliar fertilization. An understanding of the plant's nutrient needs and ability to take up foliar nutrients is essential to have valid foliar fertilization research results.

5. ***No tissue testing to determine crop nutrient needs***. When much of the research on foliar fertilization was beginning with agronomic crops, tissue testing of nutrients was in its infancy. Most university labs did not do it, and there were few tissue nutrient standards to help the research understand what the tissue test results meant. Consequently, virtually none of the researchers of foliar fertilization during this time did tissue testing to determine what a crop actually needed before they applied the foliar nutrients. Consequently, if the crop already had adequate levels of an applied nutrient, then the crop would likely gain very little benefit from the foliar applied nutrient even when nutrients were applied in a form and manner that the crop could readily take up and use. Alternatively, if a crop had a yield-limiting deficiency of a nutrient and that nutrient is foliar applied (again in a form and manner that the crop could readily take up and use), an observable yield response would be anticipated. For example, if a crop is deficient in potassium (as determined by tissue testing) and adequate in nitrogen, and nitrogen is foliar applied, then such foliar fertilization will have limited benefit. However, if potassium is applied then there is a high probability that a yield (and/or quality enhancement) will occur. This assumes that potassium is the primary nutrient limiting crop performance. Even in recent years, the majority of foliar fertilization research has not used tissue analysis to determine the actual

nutrient levels within the plant. One of the benefits of the foliar fertilization is its ability to use tissue tests results. Tissue test results can help determine the nutrients that are limiting crop performance (whether by being deficient or being out of balance with other nutrients) and also serve as a foundation to determine the amount of foliar applied nutrients to overcome these deficiencies or imbalances. With the wide range of fertilizers that can be foliar applied currently on the market, most nutrients that are identified to be limiting crop performance by tissue tests can be easily applied. A proper tissue test for foliar fertilization will include all macronutrients, and all micronutrients including molybdenum. Because of nutrient interactions, measuring only the nutrient of interest is not adequate. For example, if a nitrate fertilizer (e.g., magnesium nitrate, calcium nitrate) is foliar applied, the nitrate taken up by the plant requires adequate molybdenum to be able to convert the nitrate into usable nitrogen. Molybdenum needs to be included in the tissue test. Other nutrients are competitive or antagonistic to other nutrients, thus applying moderate to high levels of one nutrient may induce a deficiency of another nutrient. For example, high levels of applied phosphorus may induce a zinc deficiency within the plant. One of the reasons for the variability of foliar fertilization research results is the failure to know the nutritional status of all the nutrients within the test plants.. Without tissue tests to determine which nutrients are limiting crop yields or quality, and the potential interactions of existing and applied nutrients, researchers cannot draw valid conclusions from their research on the effectiveness of foliar applied nutrients to crops.

With these five constraints, it is understandable that the results of foliar fertilization of agronomic crops have been inconsistent. Unfortunately, researchers of foliar fertilization continue to make these same mistakes and draw erroneous conclusions from their results. The most common misinterpretation of results is when a statement that foliar fertilization does not work, but the details of the study are not provided. For example, claiming that foliar applied zinc to young corn plants does not influence ear size, but fails to mention that the zinc was foliar applied at V8 (after ear size has been set). It is often necessary to read the details of the methodology of foliar fertilization research to verify the validity of the conclusions drawn.

Foliar Fertilization versus Fertigation

Foliar fertilization is differentiated from fertigation in that fertigation is the application of nutrients in irrigation water. With fertigation, nutrients can be applied in large volumes through sprinkler systems, central pivots, traveling guns and even flood irrigation. Also, fertigation may inject nutrients into water applied directly to the ground such as drip irrigation. With fertigation methods, the majority of nutrients end up in the soil, and not on the plant. Fertigation systems may be used for foliar fertilization when they deliver low volumes of water through misters or small spray nozzles directly to the foliage of the plants, and the intent is cover the foliar with a nutrient enriched spray.

Biostimulants and Foliar Fertilization

Biostimulants can aid in the availability and absorption of plant nutrients by leaves, reproductive structures and roots. Biostimulants often have two modes of action. One is directly on the plant through growth regulator effects, including membrane permeability and cell division. Certain types of biostimulants stimulate root growth, causing an increase in root surface area and penetration through the soil promotes nutrient uptake, especially phosphorus. The second mode of action is the stimulation of microbiolial populations on plant surfaces and in the rhizosphere. In the soil, microbial populations produce organic acids that increase the availability of nutrients in the soil. They also help mineralize organic bound essential plant nutrients. Biostimulants often contain chelating agents, which assist with nutrient uptake by the plant, whether through the shoots, or the roots. When used with foliar applied nutrients, biostimulants can promote the rapid uptake these nutrients directly into the leaves and reproductive structures.

Table 19.2. Application of 32 oz/acre of foliar applied AgriGro®FoliarBlend® tank mixed with glyphosate to production field grown young corn plants (V3-V4) and influence on concentration of macronutrients approximately 10 days later.

AgriGro®FoliarBlend®Biostimulant 32% Foliar Application and Influence on Tissue Nutrient Content of Young Corn Plants

	N	P	K	Ca	Mg	S
	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	% - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -
Control	3.00	0.28	4.51	1.17	0.35	0.32
FoliarBlend®	3.16	0.47	4.41	1.82	0.37	0.36
% Change	5.3	67.9	-2.2	55.6	5.7	12.5

Summary

Most nutrients and fertilizers are taken up through the roots, but nutrients coming from the roots frequently cannot keep up with the needs of crops to produce high yields. Foliar fertilization or foliar feeding is a way to ensure that crops get the essential plant nutrients they need to produce optimum yields. Many crops cannot meet their genetic potential because of “hidden hunger”, that is, when plants look good, but nutrition is still limiting the quantity and quality of the crop. With tissue testing and foliar fertilization, most “hidden hunger” can easily be corrected, and thereby increase yields, quality and profitability of crops. Also, foliar fertilization has a potential to meet nutritional needs of crops to enhance yield and quality while reducing fertilizer inputs.

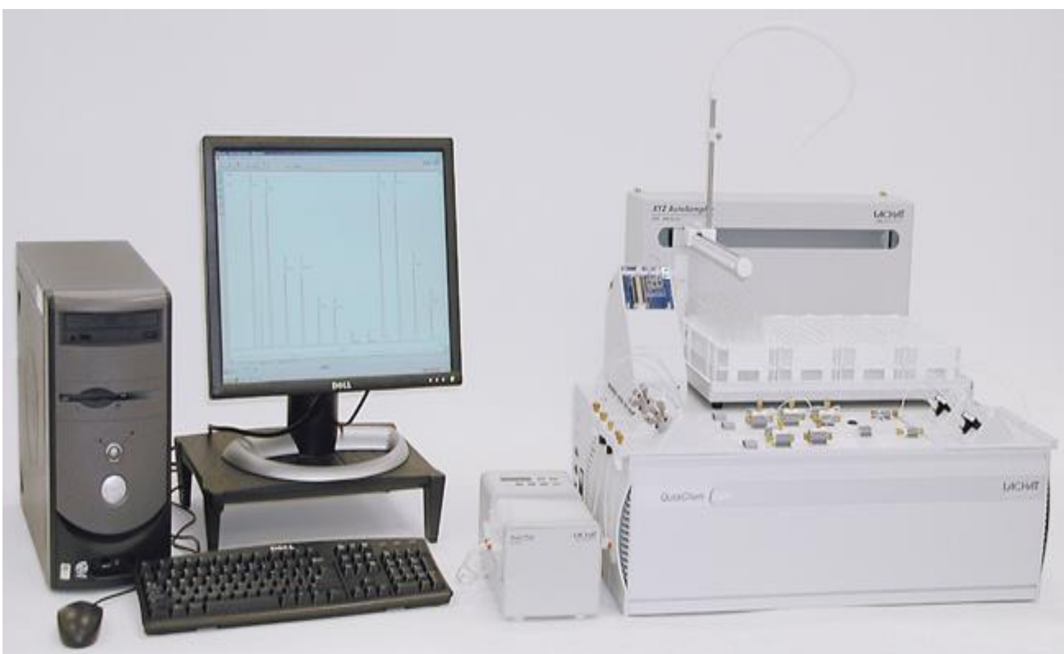
Chapter 20

Methods of Elemental Analysis

Advances in analytical chemistry have significantly improved the ease and speed for the determination of elements found in plant tissue ash or digests. Traditional wet chemistry methods to determine most elements (frequently referred to as *essential plant nutrients*) have been replaced by various automated instrumental procedures, initially by absorption spectrometry, and more recently by emission spectrometry.

Some of the classical colorimetric procedures are still in use today, although they are frequently automated with the use of a flow injection analyzer (Figure 20-1). Most colorimetric procedures require careful sample preparation and are frequently subject to both matrix and inter-element interferences.

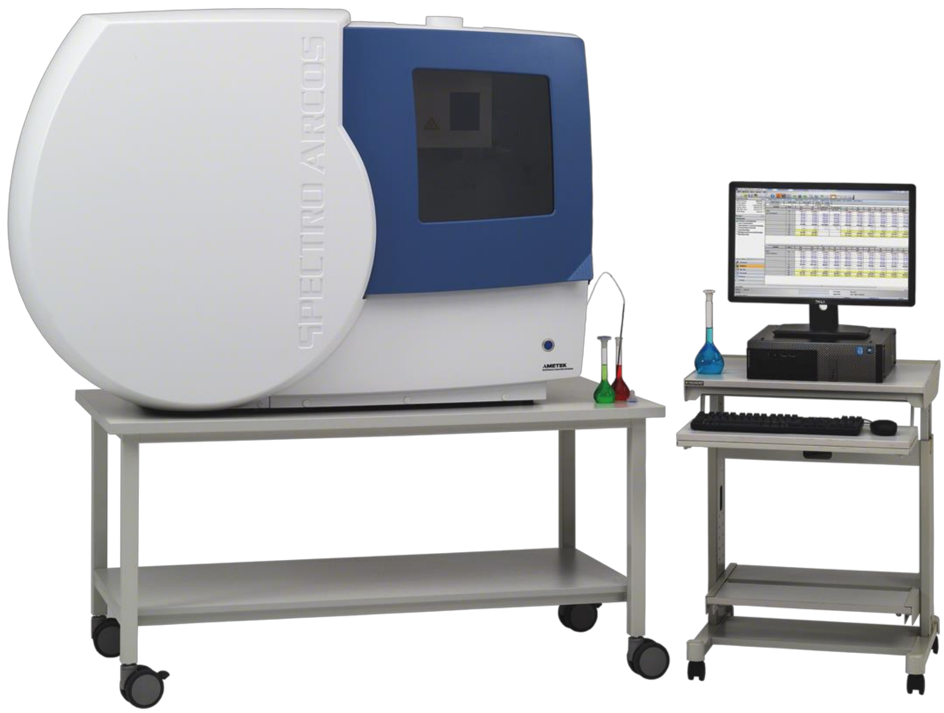
Figure 20-1. Flow Injection Analyzer (LACHAT Instruments)



Use of Ion Chromatography is increasing in use for determination of anions (nitrate, nitrite, phosphate, sulfate, chloride, fluoride, and bromide) and cations (lithium, sodium, ammonium, potassium, rubidium, cesium, magnesium, calcium, strontium, and barium) in plant petioles and as soluble ions in plant tissue.

Flame emission spectrophotometry for the determination of K and Na has had a long history of use. Similarly, flame atomic absorption spectrometry was routinely used to determine Ca, Mg, Cu, Fe, Mn, and Zn in plant tissue digests. These procedures are affected by varying degrees of matrix and concentration effects for each element in the digest. In addition, sample digests usually require considerable manipulation to bring the element concentration within the detection range of the instrument. However, these instrumental techniques are slow and cumbersome when compared to multi-element instrumental procedure in wide use today, inductively-coupled plasma emission spectrometry (frequently referred to by the acronyms ICP or ICAP). ICP spectrometry is now the analytical choice for elemental determination in plant tissue digests.

Figure 20-2. ARCOS ICP (SPECTRO ANALYTICAL INSTRUMENTS)



The ICP technique is relatively free from matrix effects and has excellent sensitivity well into the parts per billion (ppb) concentration range with a linear usable calibration range of four to five decades. Therefore, there is no need for either significant dilution or concentration requirements of a plant tissue digest in order to bring the elemental concentrations within the detection range of the ICP spectrometer. The ICP method is able to determine most of the plant essential elements (B, Ca, Cu, Fe, K, Mg, Mn, P, S, and Zn) and well as several non-essential elements, such as Al and Si, with one pass of the plant tissue digest through the excitation source.

Table 20-1. Techniques for the elemental analysis of plant tissue digests.

Method	Element ions	Speed	Sensitivity	Technical Skill	Required Supplies
Colorimetry[1]	Al, B, Cu, Fe, Mn, P, Zn, F, NO_3, NH_4	Slow	0.5 ppm	Moderate to high	Distilled/deionized. water, graduated glassware, pipettes
Turbidity[1]	K, SO_4	Slow	1.0 ppm	Moderate to high	Distilled/deionized water, graduated glassware, pipettes
Flame Photometry[1]	K, Na, Ca[2], Mg[2]	Moderate	1.0 ppm	Moderate	Distilled /deionized water, graduated glassware, pipettes
Atomic absorption spectrometry (flame)[3]	Ca, Mg, Cu, Fe, Mn, Zn	Moderate	0.5 ppm	Moderate to high	Distilled /deionized water, graduated glassware, pipettes
Plasma emission spectrometry[4]	Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, P, S, Si, Zn	Fast	0.1 ppm	Low to moderate	Low requirements for distilled/deionized. water, graduated glassware, pipettes
Specific-ion electrodes[5]	NO_3, NH_4, Cl , F	Slow	1.0 ppm	Moderate to high	Distilled/deionized. water, graduated glassware, pipettes
Liquid chromatography	NO_3, NH_4, Cl, SO_4,-S, F	Moderate	0.5 ppm	Moderate to high	Distilled/deionized water, graduated glassware, pipettes

[1]Methods can be automated using a segmented or continuous flow analyzer.
[2]Calcium and magnesium determination require special treatment of the digests to remove interfering ions.
[3]Sensitivity can be greatly increased by flameless procedures, which are tedious. Potassium and sodium are best analyzed in the emission mode.
[4]The polychromator is faster and more economical to operate, while the sequential spectrometer is not limited to a fixed number of elements.
[5] Specific-ion electrodes require the use of compensating solutions to mask interferences.

Nitrogen Determination by Kjeldahl Digestion

The Kjeldahl procedure is one method for determining the N content in plant tissue, being one of the oldest analytical procedures still in use today. Johan Kjeldahl first introduced the procedure at a meeting of the Danish Chemical Society in March 1883. The basic principle of the Kjeldahl procedure is the conversion of organic N in plant tissue to ammonium-N by digestion in boiling concentrated sulfuric acid; the digestion step is frequently modified in order to improve the accuracy and precision of the determination. Thus, the designation of the digestion step as being "Kjeldahl" is not sufficient to identify the specific procedure used. In addition a Kjeldahl N value is not necessarily the total N content in the plant tissue since not all the forms of N may not be converted to ammonium-N during the digestion step.

The Kjeldahl procedure will not recover N that exists in oxidized forms, such as nitrates (NO_3) and nitrites (NO_2), unless the plant tissue is pretreated to reduce these two anions to ammonium. In addition, *nitro-* and *azo*-compounds, in which N is directly linked to either an oxygen (O or nitrogen (N) atom, are not recovered in the digestion. The recovery of N is also related to the catalyst used. A detailed description of the Kjeldahl method is presented by Jones (1991).

Non–Kjeldahl Nitrogen Determination

The Kjeldahl-N analysis procedure has been replaced by the use of various types of Nitrogen Analyzers that use of the Dumas method for N determination, an instrumental routine used in most Plant Analysis laboratories.

Figure 20-3. LECO FP-628 Nitrogen Analyzer (LECO Corp., St. Joseph, MI)

Some instruments not only determine total N, but at the same time S and C in the plant tissue sample, see LECO Carbon/Nitrogen/Sulfur analyzer, LECO Corp., St. Joseph, MI.

Figure 20-4.LECO'S Carbon/Nitrogen/Sulfur analyzer. (LECO Corp., St. Joseph, MI.)

All of the N in the plant tissue sample is determined, and usually the N content in a plant tissue can be slightly higher than that determined by Kjeldahl digestion.

Sulfur Determination

Total S can be determined by a number of techniques with comparable results. One procedure is to determine the sulfate (SO_4-S) content in a plant tissue digest after wet-acid digestion (if the dry ashing method is used, the S will be lost due to volatilization). Sulfate content is determined using the $BaSO_4$ turbidity method. The same digest can be analyzed for S content by ICP spectrometry if equipped with a vacuum or a purged spectrometer. Automated combustion is another procedure for determining S, introducing an aliquot of dried (80^{o}C) and ground (40-mesh) plant tissue in to the S Analyzer.

Figure 20-5.LECO'S SC632 Sulfur analyzer. (LECO Corp., St. Joseph, MI.)

Standard Reference Materials (SRMs)

The use of a Standard Reference Material (SRM) for checking the accuracy of an analytical determination is very important. The United States National Institute of Standards and Technology (NIST) has a number of plant tissue Standard Reference Materials (SRMs), apple leaves, tomato leaves, peach leaves, spinach leaves and pine needles. These NIST SRMs can be useful for calibration purposes as well as for verification of accuracy. In addition, there are commercial sources of standards that can be used in place of the NIST SRMs. The analyst should develop a set of in-house standards that can be used daily during an analysis of unknowns. The nature of these standards, as well as their frequency of use, should be based on established quality assurance protocols.

Quality Assurance

In a plant analysis laboratory, quality assurance (QA) is essential to reliable performance. The Association of Official Analytical Chemists (AOAC) embracing the following management functions has established criteria for the implementation of this management technique:

1. Administration
2. Personnel Management

3. Management of Equipment and Supplies
4. Records Maintenance
5. Sample Analysis
6. Proficiency Testing
7. Audit Procedures
8. Design and Safety of Facilities

The basis for reliable performance in an analytical laboratory has been defined in terms of *Good Laboratory Practices*. These practices are organized into topics dealing with organization and personnel, standard operating procedures, study protocol and conduct, record keeping, and final reports. The AOAC has described the practical limits of acceptable variability in methods of analysis, focusing on the important aspects of reliability, reproducibility, repeatability, systematic error of bias, specificity, and limit of reliable measurement. The issues of quality control and the defining of those standards of accuracy and precision assessment with analytical measurement are applicable to all plant analysis procedures. However, no one has specifically described these requirements for the plant analysis laboratory.

Establishing a QA program in the plant analysis laboratory involves established and reliable analytical procedures and the use of reference standards. Plant tissue standards are required to monitor the precision of the analytical procedure and to verify the accuracy of the analysis result.

In place of the expensive SRMs, a set of self-prepared tissue standards can be prepared for every day use. It is desirable to have on hand a sufficient bulk of sample so that it can be used daily over a long period of time. Careful preparation, analysis, and storage are essential to ensure the reliability of these prepared standards. If possible, one or more independent laboratories using the same standard sample should analyze these reference plant tissue standardsutilizing similar analytical procedures as described in this Handbook. If at all possible, the laboratory analysts should use plant tissue standards of the same or similar type of tissue as the unknowns that are being analyzed in the laboratory.

In the normal laboratory routine, plant reference standards can also be used to monitor the analytical procedure with standards inserted into the sequence of unknowns at some predetermined interval. It is equally desirable to have a solution reference standard periodically spaced among unknowns to serve two purposes: (a) to monitor the analytical process and (b) to serve as a *marker* by identifying samples being analyzed so that no unknown sample is missed during the analytical run. The reference tissue standard serves to verify the accuracy of the analysis routine, while a series of standards and markers serve to determine the degree of precision. Reference tissue standards as well as markers must be as closely matched to the unknowns as possible. Experience has shown that middle range concentration solution standards make the best marker samples.

The laboratory quality assurance program will assist the operating technician how best to use reference and/or marker samples in terms of their placement in the analytical sequence. In general, reference tissue samples are best placed at the beginning and end of an analysis sequence. The beginning reference sample verifies the calibration and the end reference sample determines the degree of any shift in the analytical procedure during the analysis run of unknowns. Periodic marker samples can be used to measure shifts that occur during the analytical run. They also serve to warn the technician when the analysis procedure is failing. In order to verify accuracy and precision, the analysts may want to place both reference and marker samples in a sequence of unknowns, a determination that is part of the QA program. The verification process should be performed independently (without the knowledge) of the technician performing the analysis.

Another useful procedure is to use calibration standards as unknowns in an analytical sequence. For example, after calibrating an analytical system, the technician analyzes the calibration standards as unknowns. This procedure serves to verify that the method and/or instrument has been calibrated, and it also serves to establish what is the *zero* for an element. Following the analysis of a sequence of unknowns, these same calibration standards are analyzed again as unknown. If the calibration standards analyzed as unknowns fail, the entire analytical run is in question.

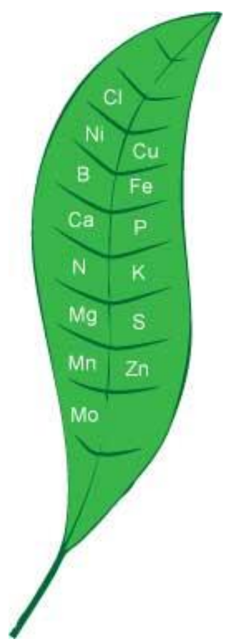
Although the analysts may not be able to choose the instrument to perform the analysis, the choice of instrument can have a significant effect on the result obtained, determining to a large degree, the level of precision that can be obtained. Without a QA program in force in an analytical laboratory, performance in terms of reliable analytical results is in question.

Methods for Expressing Elemental Content

The elemental concentration in plant tissue is expressed on a dry weight basis as a percentage (%) for the macronutrients, N, P, K, Ca, Mg, and S. The micronutrients are expressed in parts per million (ppm) for B, Cl, Cu, Fe, Mo, Mn, and Zn. Using International (SI) Units, the macronutrients are expressed as grams/kilogram (g/kg); cations may also be expressed as centimols/kilogram (cmol/kg). The micronutrients can be expressed as either micrograms/gram (μg/g) or milligrams/kilogram (mg/kg). Normally, the macronutrients are expressed as percent (%), the concentration to the nearest one-hundredth percent (0.01%). For the micronutrients, they are expressed in parts per million (ppm), with concentrations greater that 10 expressed as whole numbers, concentrations greater than 1 ppm but less than 10 ppm expressed as one-hundredth (0.01) ppm.

Table 20-2. Examples of methods of expressing nutrient concentration in plant tissue.

Element	Dry Weight Basis			
	Percent	g kg^{-1}	cmol(p+) kg^{-1}	cmol kg^{-1}
Nitrogen (N)	3.15	31.5	225	225
Potassium (K)	1.95	19.50	50	50
Calcium (Ca)	2.00	20.00	25	50
Magnesium (Mg)	0.48	4.80	10	20
	ppm	mg kg^{-1}	cmol(p+) kg^{-1}	mm of kg^{-1}
Copper (Cu)	12	12	0.09	1.85
Iron (Fe)	111	111	0.66	1.98
Manganese (Mn)	55	55	0.50	1.00
Zinc (Zn)	33	33	0.25	.50



"Plant Analysis is the Final Judge of the Success or Failure of a Fertility Program"

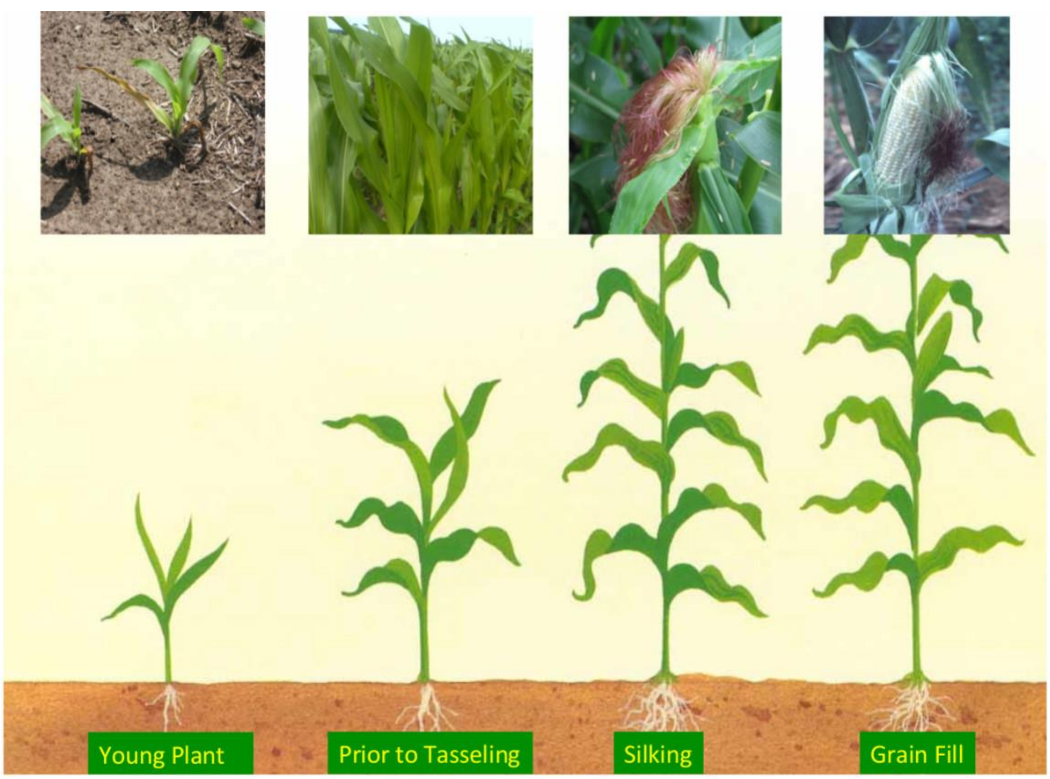
Chapter 21

Plant Tissue Sampling

This handbook addresses a number of important components of plant tissue sampling such as detailed procedures for sample collection, specific plant part and location on plants, stage of plant growth or development, time of sampling, number or quantity of samples per plant, and number of plants to select for sampling. Following these directions allows the sampler to achieve reasonable statistical reliable results.

Sampling instructions are quite specific in terms of plant part and stage of growth, because standards used for comparison of tissue test results were established using these criteria of plant samples. With corn there are at a minimum four critical stages for leaf analysis, Figure 21-1.

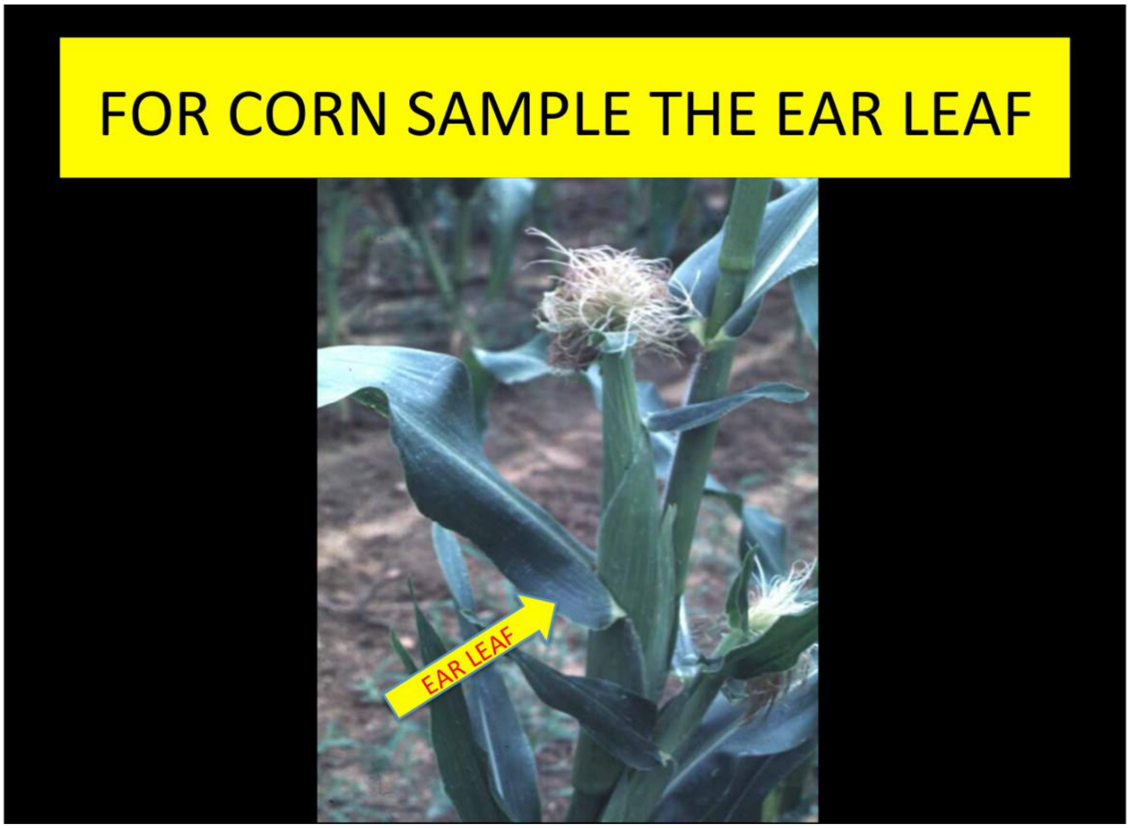
Figure 21-1. Age of the plant matters as to the level of essential plant nutrients accumulating in the plant leaf sampled and the sufficiency range chosen for a response to a reported deficiency or toxicity.



When specific sampling instructions are not given or are unknown, *the general rule of thumb is to select the upper, most recently mature leaves*.

Careful selection of plant materials is also crucial in the choice of plant samples. For some plants/crops a specific leaf to sample has been identified and the sufficiency ranges developed on that specific leaf, i.e. banana, palm oil, corn.

Figure 21-2. Corn leaf sample to test at silking.



The sampler should not select plants that have been under long climatic or nutritional stress, that are damaged mechanically or by insects, or that are infested with disease. Plants covered with dust or soil, including foliar applied spray materials, also should be avoided unless such substances can be removed effectively be removed from the tissue samples. Samples contaminated with soil can show abnormally high iron, boron, and aluminum compared to clean leaf samples. These abnormal concentrations are a warning that the samples may be contaminated although concentrations of other elements may not be affected substantially by dust/soil. Border-row plants or leaves under the canopy should not be included in the plant tissue sample. Also, dead, dying, diseased or damaged plant tissue should not be included in the collected sample.

Precision standards dictate the number of plant parts to be collected and what number of plants to sample in order to make a composite sample, or how many composite samples will be necessary to ensure sufficient replication. Various studies indicate that the number of individual leaves or plants required is correlated with the desired precision and accuracy to be obtained. When plants are under stress in a crop production area (e.g., field, greenhouse, shade house, etc.), variability is higher than under normal production, and consequently, sampling requirements must consider this variability and will be more complex.

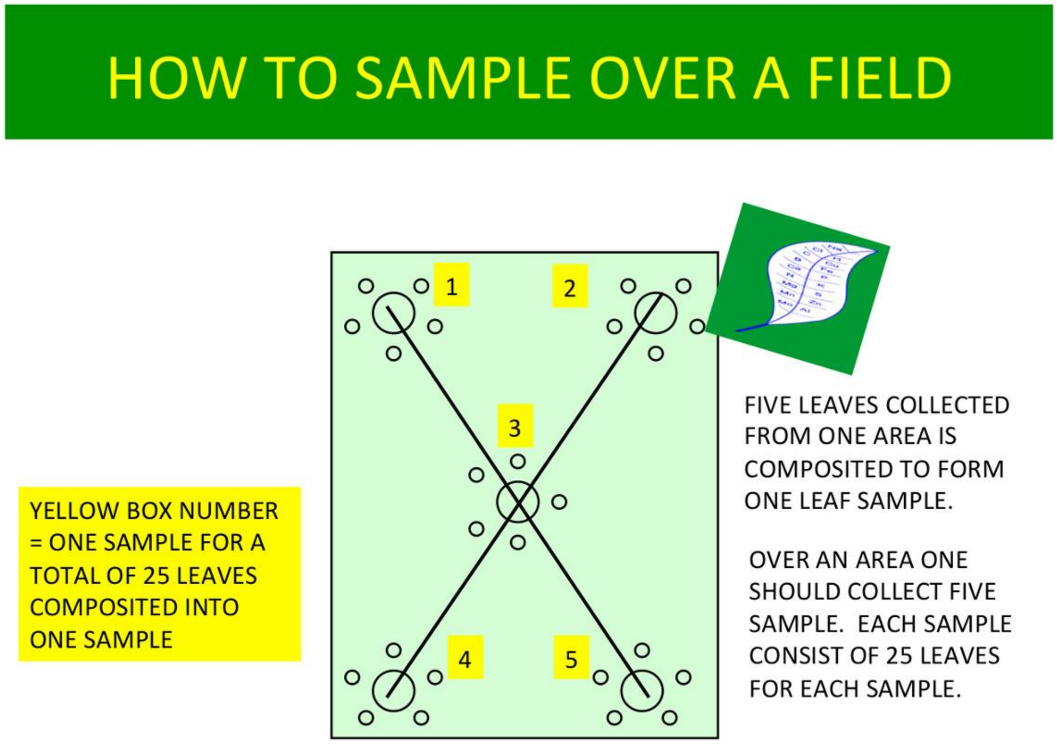
The combination of the number of plants selected for sampling plus the number of samples per plant determines the precision and accuracy associated with the final analysis result. In most cases, it is desirable to select more plants for sampling than to collect additional tissue from fewer plants. In general, the greater the number of individual plants selected for sampling and the more tissue collected, the more representative the total sample will be of the population being evaluated.

Table 21-1. Element content of a whole corn ear leaf and four equal length sections of the leaf at silking (Jones, 1970).

Equal Quarter Length Sections of the Ear Leaf					
Element	**Whole Leaf**	**Tip**	**Upper Middle**	**Lower Middle**	**Base**
N	2.93	3.20	3.65	2.75	1.95
P	0.22	0.22	0.23	0.25	0.18
K	1.22	1.26	1.19	1.44	1.23
Ca	0.48	0.75	0.58	0.48	0.35
Mg	0.39	0.40	0.41	0.45	0.40
B	11	25	14	8	6
Cu	9	12	10	10	8
Fe	96	110	102	75	57
Mn	73	124	79	62	49
Zn	22	30	22	22	18

Normally, the mean or average value of several composite sample analyses is more accurate than a single analysis based on a single composite sample that is composed of the same total number of individual samples. Choosing a composite sample to analyze is important because the distribution of the essential elements within the plant, and even within any one of its parts, is not homogeneous.

Figure 21-3. How to collect plant or soil samples over a field.



As plant tissues mature, there are changes due to (a) the movement of mobile elements from the older tissue to newly developing tissues, (b) an accumulation of non-mobile elements, and (c) a reduction in dry matter content. For example, one sign of increasing maturity is a decreasing concentration of N and P in the leaves. Another factor of variation, the relative proportion of leaf blade to midrib, affects the concentration of K detected in the whole leaf. Similarly, the relative proportion of leaf blade to margin affects the B and Mn contents of the whole leaf, since these two elements accumulate to fairly high concentrations in the leaf margin (Jones, 1970). A sampling procedure that affects the above relationships will alter the analysis of elements present in the plant part analyzed. A sampling procedure in which, for instance, only the leaf tips are sampled or blade punches are collected will produce a different interpretation from that which would result from the analysis of the whole intact leaf.

Petioles are not a part of the leaf blade and should not be included in a leaf sample for most analyses. For some crops, such as grape and sugar beet, the petiole may be the plant part to be analyzed rather than the leaf blade. Quick tests performed in fields often are conducted on petioles since the results give an indication of nutrients that are moving from the roots to leaf blades. Tables 21-2 and 21-3 contain reported values that are general measured with quick test in field determination.

Collecting the correct leaf for analysis also depends on the age of the plant in many crops. Below is an example of corn ear leaf being sampled with the age of the ear and silk being important to match to the correct sufficiency range.

Figure 21-4. Timing of leaf sampling is critical for comparison to established sufficiency ranges.

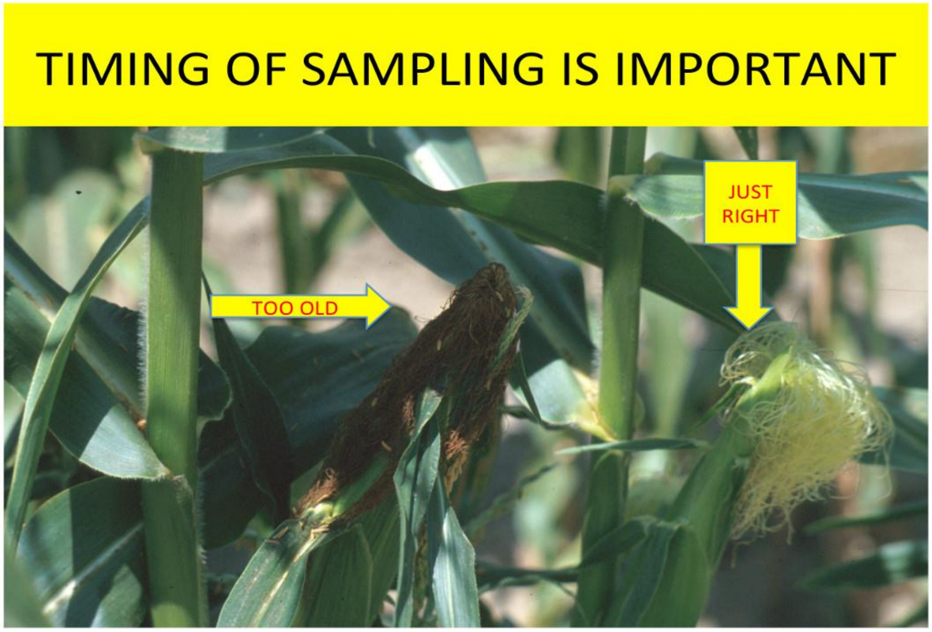


Table 21-2. Critical nitrate-N (NO_3-N) concentrations at a 10% growth restriction for various vegetable crops (Maynard et al., 1976).

Crop/Species	Sampling Time	Plant Part	NO_3-N (ppm)
Cucumber *Cucumis sativus* L.	42 days from seeding	mature petioles	2,000
Lettuce *Lactuca sativa* L.	market maturity	entire aerial portion	2,000
Potato *Solanum tuberosum* L.	18 days vegetative growth	petiole from terminal	2,000
Radish *Raphanus sativus* L.	market maturity	Root	500
Spinach *Spinacia oleracea* L.	market maturity	entire aerial portion	1,700
Squash *Cucurbita pepo* L.	42 days from seeding	mature petiole	1,000
Sweet melon *Cucumis melo* L.	42 days from seeding	mature petiole	3,000
Tomato *Lycopersicon esculentum* Mill.	42 days from seeding	petiole 2 from terminal	500

Table 21-3. Interpretive tissue analysis values for western crops (Ludwick, 1990).

Plant	Time of	Plant Part		Nutrient Level[1]

	Sampling			Deficient	Sufficient
Asparagus	Midgrowth of fern	4” tip section of new fern branch	N	100	500
			P	800	1,600
			K	1	3
Bean, bush snap	Midgrowth	Petiole of fourth leaf from growing tip	N	2,000	4,000
			P	1,000	3,000
			K	3	5
Bean, bush snap	Early bloom	Petiole of fourth leaf from growing tip	N	1,000	2,000
			P	800	2,000
			K	2	4
Broccoli	Midgrowth	Mid-rib of young, mature leaf	N	7,000	10,000
			P	2,500	5,000
			K	3	5
Broccoli	First buds	Mid-rib of young, mature leaf	N	5,000	9,000
			P	2,000	4,000
			K	2	4
Brussel sprouts	Midgrowth	Mid-rib of young, mature leaf	N	5,000	9,000
			P	2,000	3,500
			K	3	5
Brussel sprouts	Late growth	Mid-rib of young, mature leaf	N	2,000	4,000
			P	1,000	3,000
			K	2	4
Cabbage	At heading	Mid-rib of wrapper leaf	N	5,000	9,000
			P	2,500	3,500
			K	2	4
Cantaloupe	Early growth (short runners)	Petiole of sixth leaf from growing tip	N	8,000	12,000
			P	2,000	4,000
			K	4	6
Cantaloupe	Early fruit	Petiole of sixth leaf from growing tip	N	5,000	9,000
			P	1,500	2,500
			K	2	4
Cantaloupe	First mature fruit	Petiole of sixth leaf from growing tip	N	2,000	4,000
			P	1,000	2,000
			K	2	4
Carrot	Midgrowth	Petiole of young, mature leaf	N	5,000	10,000
			P	2,000	4,000
			K	4	6
Cauliflower	Buttoning	Mid-rib of young, mature leaf	N	5,000	9,000
			P	2,500	3,500
			K	2	4
Celery	Midgrowth	Petiole of newest fully elongated leaf	N	5,000	9,000
			P	2,000	4,000
			K	4	7
Celery	Midgrowth	Petiole of newest fully elongated leaf	N	4,000	6000
			P	2,000	4,000
			K	3	5
Cucumber (pickling)	Early fruit set	Petiole of sixth leaf from leaf tip	N	5,000	9,000
			P	1,500	2,500
			K	3	5
Lettuce	At heading	Mid-rib of wrapper leaf	N	4,000	8,000
			P	2,000	4,000
			K	2	4
Lettuce	At harvest	Mid-rib of wrapper leaf	N	3,000	6,000[2]
			P	1,500	2,500
			K	1.5	2.5
Pepper, chili	Early growth	Petiole of young, mature leaf	N	5,000	7,000
			P	2,000	3,000
			K	4	6
Plant	**Time of Sampling**	**Plant Part**		**Nutrient Level[1]**	
				Deficient	**Sufficient**
Pepper, chili	Early fruit-set	Petiole of young,	N	1,000	2,000
			P	1,500	2,500

		mature leaf	K	3	5
Pepper, sweet	Early growth	Petiole of young, mature leaf	N	8,000	12,000
			P	2,000	4,000
			K	4	6
Pepper, sweet	Early fruit-set	Petiole of young, mature leaf	N	3,000	5,000
			P	1,200	2,500
			K	3	5
Potatoes	Early season	Petiole of fourth leaf from growing tip	N	8,000	12,000[3]
			P	1,200	2000
			K	9	11
Potatoes	Midseason	Petiole of fourth leaf from growing tip	N	6,000	9,000[3]
			P	800	1600
			K	7	9
Potatoes	Late season	Petiole of fourth leaf from growing tip	N	3,000	6,000
			P	500	1,000
			K	4	6
Rose clover	Flowering	Leaves	N	--	--
			P	1,200	1,500
			K	0.7	1
			S	130	180
Spinach	Midgrowth	Petiole of young, mature leaf	N	4,000	8,000
			P	2,000	4,000
			K	2	4
Subclover	Third flower	Fully expanded leaf	N	--	--
			P	800	1,000[4]
			K	0.7	1
			S	150	200
Sweet Corn	Tasseling	Mid-rib of first leaf above primary ear	N	500	1,500
			P	500	1,000
			K	2	4
Sweet Potato	Midgrowth	Petiole of sixth leaf	N	1,500	3,500
			P	1,000	2,000
			K	3	5
Tomato (canning)	Early bloom	Petiole of fourth leaf from growing tip	N	8,000	12,000
			P	2,000	3,000
			K	3	6
Tomato (canning)	Fruit 1" diameter	Petiole of fourth leaf from growing tip	N	6,000	10,000
			P	2,000	3,000
			K	2	4
Tomato (canning)	First color	Petiole of fourth leaf from growing tip	N	2,000	4,000
			P	2,000	3,000
			K	1	3
Watermelon	Early fruit	Petiole of sixth leaf from growing tip	N	5,000	9,000
			P	1,500	2,500
			K	3	5

[1]Unless otherwise noted, values are: N = NO_3-N, ppm; P = acetic acid-soluble PO_4-P, ppm; K = total K, %; and S = SO_4-S, ppm.

[2]Nitrate concentrations 30% higher are suggested for winter-grown lettuce on the desert valleys of Arizona and southern California.

[3]Nitrate levels 40% to 60% higher are suggested for potatoes growing in the high valleys of Idaho and Oregon. Approximately 60% of the total P of potato petioles is extracted with 2% acetic acid.

[4]The sufficient level of P for heavily grazed subclover may be 50% higher.

Sampling of two different populations of plants for comparative purposes also can be difficult, particularly when some type of stress has caused differences in a stage of growth. When two or more sets of plants exhibit varying signs of possible nutrient elemental insufficiency, collecting tissue for comparative purposes is desirable, but can be difficult due in part to the effect of nutrient element stress on plant growth and development (Jarrell and Beverly, 1981). It should be remembered that elemental concentration is based on the dry weight of tissue. Any condition that affects the dry weight of the plant will affect its element concentration. Therefore, great care needs to be taken to ensure that representative samples are collected for such comparisons and that the interpretation of the analytical results takes into consideration the condition of the plants when they are sampled.

Plant Sampling Procedures

Plant species, age, plant part, and time samples are selected are variables that affect the interpretation of the laboratory results. In addition, the essential nutrients are not equally distributed in the plant or within its parts. The important components for proper plant tissue collection are:

- selection of a specific plant part at a specific location on the plant.
- stage of plant growth or specific time of sampling
- number of plant parts selected to form one composite sample
- area from which one composite sample will be selected

Although it is possible to analysis just about any plant part, or even the whole plant itself, the biological significance of that analysis may be limited. For example, the analysis of fruits and seeds or an analysis of the whole plant or one of its parts at maturity or harvest does not usually provide reliable information on plant nutritional status during the early growth periods. When conducting a plant analysis, the primary objective should be to obtain the plant part for which analysis results can be compared to established interpretative values.

Sampling of the most recently matured leaf should be conducted for plants in which established sufficiency ranges have not been determined. The analysis of these leaves nutritional levels would then be compared to a generic sufficiency range to gain a understanding of the nutritional status of this plant.

Table 21-4 Sufficiency levels of essential plant nutrients.

MACRONUTRIENTS

Nutrient	Symbol	Typical Concentration
Nitrogen	N	3 - 5%
Phosphorus	P	0.3 – 0.8%
Potassium	K	2.3 – 5%
Calcium	Ca	0.7 – 1.2%
Magnesium	Mg	0.3 – 0.7%

MICRONUTRIENTS

Sulfur	S	0.3 – 1.0%
Manganese	Mn	50 – 300 ppm
Boron	B	20 – 75 ppm
Copper	Cu	8 – 40 ppm
Zinc	Zn	40 -150 ppm
Molybdenum	Mo	0.5 – 5 ppm
Chlorine	Cl	<2000 ppm
Iron	Fe	70 – 400 ppm
Nickel	Ni	1 – 8 ppm

Size or Amount of Leaf Sample Matters

One of the more frequent errors in plant tissue sampling is the collection of an insufficient amount of leaf tissue for analysis.

Figure 21-5. Sample size collected for analysis is critical when sending tissue samples to a laboratory.

Figure 21-6. Seedlings below showing a nutrient deficiency require 50 plants or a full tray of seedlings to have enough leaf tissue for analysis.

Soil Sampling Procedures

Sampling tools used to collect a soil sample must not contaminate the sample submitted to the laboratory for analysis. Stainless steel or plastic probes, auger, or spade should be used. Care should be taken not to transfer soil from one sample to another through the use of the sample tool.

Generally ten to twenty sample cores are combined and mixed in a plastic container, a subsample of 250 to 500 grams is then selected and place in a plastic lined bag or container for submission to the laboratory. Soil samples being collected over a period of time and retained on the farm prior to submission to the laboratory should be air dried and ground prior to submission (this is a common practice of plantation crops, palm oil, bananas, etc.).

Collecting a soil or media sample from the plant root zone can offer considerable assistance in the plant analysis interpretation. The number of samples taken, sample depth, and field size should conform to soil sampling recommendations.

Sampling of large acreage/hactares for plantation crops and large agronomic planting requires some general considerations to determine the number of samples to collect.

1. Age of the planting should be uniform in soil sampling. Do not mix soil samples across different ages of plantings.
2. Soil samples that are analyzed yearly can be collected from larger areas (should not exceed one hundred acres). Soil samples collected ever second or third year should be collected from 10 or 20 acre blocks.

3. Uniformity of the soil type and slope of the land determines the number of samples to be collected over an area. As the soil type and composition changes, these samples should be sampled independently from another area with different composition/soil type.

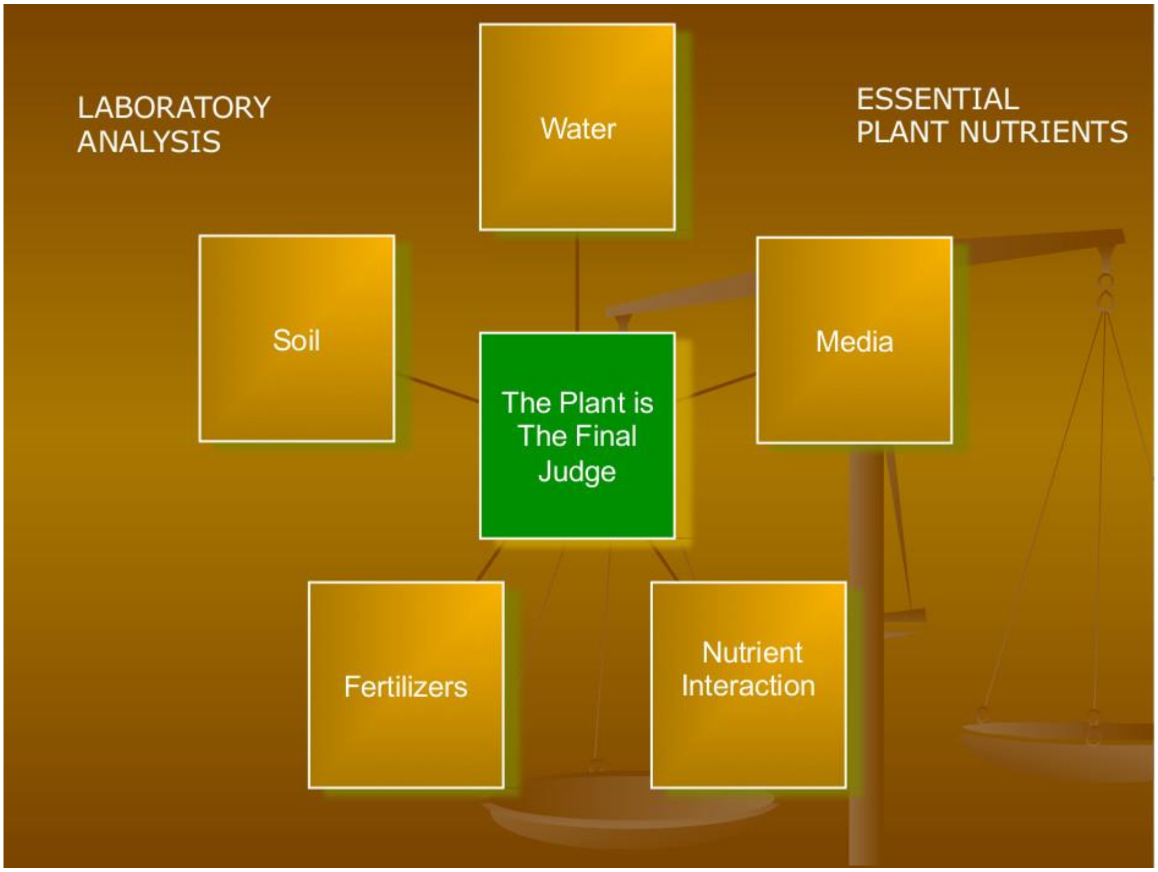
Sampling Objectives

The objective or purpose of the sampling dictates sampling protocol. If plants are experiencing symptoms of poor growth then selection of affected plants verses normal plants is the primary consideration for sample selection. If plants are being selected for fertilizer predictions then uniform samples representative of a given area should be the primary consideration for sample selection. When conducting a plant analysis the primary objective should be to obtain plant samples for which analysis results can be compared to known interpretative values developed for the plant species, age, plant part taken at a specific location on the plant, stage of plant growth, time of sampling, and number of plant samples for the best results.

Maintaining integrity in the other details of the collection procedure is also crucial to obtaining accurate analysis results. When collecting plant tissue, care should be taken to ensure that the sample is not altered chemically or contaminated by extraneous materials as a result of contact with sampling tools and containers. Most fresh plant tissue will begin to decompose and lose dry weight unless the tissue is cooled or the water in the tissue is removed. Some wilting of leaf samples should not affect the results of tissue testing as long as dry matter is not lost by a prolonged period that would allow decay of the sample. If the delivery time to the laboratory exceeds 24 hours, cool the tissue to 5°C with ice. Partially or fully drying the tissue prior to shipping to the laboratory is the normal method employed in sending samples to the laboratory for analysis. The key is to remove the water from the tissues by drying the tissue prior to shipping to the laboratory for analysis, which prevents the tissue and dry matter from decaying in transit to the laboratory. Succulent tissue, in particular, must be quickly air dried or placed into a container that has a maintained temperature of 5°C. Care should be taken that fresh plant tissue is not frozen during storage or transport, as freezing might cause rupturing of cells and loss of nutrients with the loss of water out of the ruptured cell. The conditions during transport to the laboratory, such as temperature and the water status of the tissue itself, will affect sample integrity. Here, a measure of control is required. Fresh plant tissue should not be placed in plastic bags unless the temperature is kept below 5°C. If at all possible, plant tissue should be delivered to the laboratory within 24 hours of collection, irrespective of the method used to control the loss of dry weight. When this time period is not possible then partial drying the tissue prior to shipping the tissue to the laboratory is recommended. Tissue should be placed in a paper bag for shipping to the laboratory.

It should be recognized by the grower that with all analysis available to them for improving the nutrition of their crop, the plant is the final judge of what should be adjusted in their fertility program and this can only be determined by plant analysis:

Figure 21-7. The plant is the final judge of a growers cultural program.



Chapter 22

Sample Preparation and Analysis

Preparation and Analysis

Preparing collected plant tissue for elemental content determination involves processes that will modify both the physical and chemical properties of the plant tissue. The analysts, therefore, must carefully follow those procedures necessary to prepare the plant tissue sample for elemental content determination. In the preparation process, two tasks are required. The plant tissue sample is first decontaminated and homogenized, and then put into suitable form for elemental determination.

The initial steps are decontamination and drying.Decontamination removes soil, dust, and other extraneous substances that can alter the laboratory analysis results, while drying preserves the dry weight of the plant tissue.

Decontamination

Decontamination is required when plant tissue surfaces are covered with soil growing media and dust particles, or the plant tissue may be coated with foliar applied materials that could contain elements of interest in the plant analysis determination.

Decontamination is absolutely essential if Fe and Al are elements of interest. Only fresh, fully turgid plant tissue is to be subjected to the decontamination procedure. The fresh leaf surface is quickly washed in a mild 2% P-free detergent solution, rubbing the tissue surface gently with the fingers in order to remove dust and dirt particles even if not clearly visible. The detergent solution is then quickly washed from the plant tissue surface with flowing pure water. Washing only with water or even a dilute acid will not remove many contaminants. Effective decontamination depends on the smoothness, presence of wax, and pubescence of the leaf surface as well as on the type and concentration of the contaminating substance(s). Washing is normally not necessary if the tissue collected is carefully selected and Fe and Al are not elements of primary interest.

The decontamination procedure must be done quickly with minimum exposure to the washing solution to prevent the loss of soluble elements, such as B and K from the plant tissue. In some instances, washing plant tissue may pose a contamination hazard itself by transferring contaminants from a few leaves to all those being washed. Therefore, washing does not necessarily reduce the presence of a contaminant. Tissue exposed to frequent rainfall and/or not covered with nutrient element containing spray materials need not be decontaminated.

Following an elemental determination, soil or dust contamination can be detected by observing the Al, Fe, and Si concentrations found in the plant tissue. If all three elements are at relatively high concentrations, > 100 ppm for both Al and Fe and > 1.0%

for Si, and their concentrations tend to increase and decrease together, then either dust or soil contamination is certain.

Oven Drying

Drying at the ambient temperature will remove only surface water. Oven drying at 80°C will remove essentially all combined water and preserve the tissue dry weight. Oven drying at lower temperatures will not remove all combined water in most plant tissues, while oven drying at higher temperatures can result in thermal decomposition, thereby reducing the tissue dry weight. Plant tissue high in either sugar or starch content is not easily oven-dried and is best freeze-dried. The oven-drying process is most efficiently done in a forced draft dryer with the plant tissue being placed in brown paper or cloth bags, and the bags then loosely placed in the oven dryer.

Particle Size Reduction

After oven drying, the plant tissue is reduced in particle size by either cutting (grinding in a moving blade mill) or powdered (crushed in a ball mill) in order to generate the particle size desired for conducting an elemental analysis.

Figure 22-1. Properly ground plant leaf for analysis.

The plant tissue will be contaminated by contact with the surface material used in either type of milling. This factor must be considered if mill components are made of elements that will be determined. For example, plant tissue milled in a tool steel or stainless steel mill will be contaminated with Fe during the milling process, the extent of Fe addition being dependent upon the condition of the mill and the length of time required to mill the sample.

Sample particle segregation can occur in a grinding mill, particularly if static electricity is not controlled. Sufficient time must be taken to allow the entire plant tissue sample to pass through the mill. Hygroscopic tissues may be very difficult, if not impossible, to grind. Similarly, those tissues that have considerable pubescence (apple and soybean leaves) can be difficult to grind, without sacrificing their homogeneity.

If the sample aliquot for an elemental analysis is to be no less than 1.00 grams, particle size reduction to 20-mesh is sufficient. However, if the aliquot weight is less than 0.50 grams, then finer (40-mesh) sample particle reduction is required.

If Fe is an element of major interest, significant contamination can occur if the grinding or crushing device brings steel parts in contact with the plant tissue. Experience has shown that contamination with Al, Cu, Na, or Zn is not unusual when a tissue sample is ground or crushed in some types of mills. Therefore, test samples should be analyzed to determine the level of elemental additions before the to-be-analyzed plant tissue is reduced in size by grinding. In order to avoid the addition of these elements, particularly Fe to a plant tissue sample, either hand crushing using an agate mortar and pestle or in an agate ball mill is recommended.

Once the sample has been oven dried and reduced in particle size and not to be immediately analyzed, store at 4°C in a dark and dry environment.

Organic Matter Destruction

Probably no other aspect of plant tissue preparation prior to elemental analysis has stirred as much controversy as that dealing with the destruction of the organic matter portion of the plant tissue. There are two methods, high-temperature combustion, referred to as dry ashing, and wet acid digestion, referred to as wet ashing. For most elements, both techniques will give the same analysis results. However, there are exceptions. Boron can be lost by volatilization during the wet-ashing process. Higher analysis concentrations are normally obtained for the elements Al, Fe and Zn (particularly for tissues high in Si) when plant tissue is wet ashed as compared to results obtained when tissue is dry ashed. Elements, such as As, Pb and Se, may be lost by volatilization during dry ashing; the extent of loss determined by the Ca (and possibly Mg) content of the plant tissue. Therefore, the method of organic matter destruction may be dictated by the elements to be determined as well as by the elemental content of the plant tissue.

Dry Ashing

The ashing vessel can be either a quartz or porcelain crucible, or pyrex glass beaker, that is placed into a cool muffle furnace and the temperature of the furnace brought slowly (not less than one hour) from the ambient temperature to 500°C, and then held at that temperature for no less than 4 hours. Less than 4 hours and/or a temperature less than 500°C, can result in incomplete combustion, while a longer time will have not effect, but a temperature greater than 500°C can result in the volatile loss of some elements. The ashing vessel should be so placed in the muffle furnace so that it is not in contact with a heated surface.

Plant tissues that are high in carbohydrates may require pretreatment with an ashing aid in order to combust all the carbon. A 7% solution of magnesium nitrate [$Mg(NO_3)_2.6H_2O$] or concentrated nitric acid (HNO_3) are suitable ashing aids. The plant tissue is weighed into the ashing vessel and then wetted with either reagent. Then the ashing vessel is placed on a hot plate to bring the wetted contents to dryness before placing in the muffle furnace.

After 4 hours in the muffle furnace at 500°C,the ashing vessel is removed from the muffle furnace and allowed to cool. The ash in the ashing vessel is dissolved in an aliquot of either 20% nitric and/or hydrochloric acid (HNO_3, HC1, respectively) or *aqua regia* (one part concentrated HNO_3 to three parts concentrated HC1), with or without warming, in order to bring the ash into solution. The dissolved ash is then diluted with water to bring to an appropriate volume for elemental determination.

Acid Wet Digestion

This digestion process is conducted in either a combination of nitric (HNO_3) and perchloric ($HC1O_4$) acids, or a combination of nitric acid (HNO_3) and 50% hydrogen peroxide (H_2O_2). Typically, wet digestions are performed by the use of digestion tubes inserted into ports of a temperature-controlled digestion block.

Another procedure is to conduct the digestion in either an open vessel or a closed container under pressure, such as microwave digestion, which requires a short time to complete an organic matter destruction with no loss of volatile elements.

Caution: Perchloric acid ($HC1O_4$), when hot, is a highly reactive oxidant and can act with explosive force with easily oxidizable compounds. Normally, the plant tissue to be digested is reacted first with nitric acid (HNO_3) with the addition of perchloric acid ($HC1O_4$) when the digest is cool after the initial reaction is complete. In addition, perchloric acid ($HC1O_4$) should never be brought to dryness under high heat. Laboratory operational regulations usually require the use of specially designed hood that continuously washes the fumes released during the digestion process.

Laboratory procedures for organic matter destruction by both dry combustion and wet acid digestion are given in the following tables.

Table 22-1. High Temperature Oxidation (DryAshing)

General Procedure

1. Weigh 0.5 grams dried (80°C) and ground (20- or 40-mesh) plant tissue into a 30-mL high-form porcelain crucible.
2. Place the crucible in a rack and place the rack in a cool muffle furnace.
3. Set the temperature control of the furnace at 500°C and switch on.
4. Allow the furnace temperature to reach the set temperature in about 2 hours. The muffle furnace temperature should be slowly brought up to 500°C. Plant tissue samples should never be placed into a hot furnace, nor the furnace door left opened during the ashing phase.

5. After 4 hours at 500°C, turn the muffle furnace off, remove the crucible rack from the furnace, and allow it to cool.
6. Into the ashing vessel, add 10 mL *aqua regia* solutionto dissolve the ash. Stir and allow the suspended undissolved material to settle to the bottom of the crucible. *(Agua regia* solution = 300 mL hydrochloric (HCl) and 100 mL nitric (HNO_3) acids in 1 L pure water).
7. The clear solution is ready for elemental analysis. The digest may be further diluted with water as necessary to bring an element concentration within the range of the analytical instrument.

Procedure for Tissue High in Carbon

Normally, an ashing aid is not necessary unless the plant tissue is highly carbonaceous. In such cases, the following dry ashing procedure is recommended:

1. Repeat step 1 above.
2. Moisten the plant tissue in the crucible with either concentrated nitric acid (HNO_3), or 10 mL 7% magnesium nitrate [$Mg(NO_3)_2$•$6H_20$] solution.(The latter treatment is recommended when the tissue is to be analyzed for sulfur (S) as the sulfate (SO_4) anion.)
3. Place the crucible on a hot plate and evaporate the nitric acid or magnesium nitrate solution from the sample. The residue must be completely dry before being placed in the muffle furnace.
4. Remove the crucible from the hot plate, place it in a rack and place the rack into a cool muffle furnace,
5. Repeat steps 3, 4, 5, 6, and 7 above.

Calculations:

1. The prepared plant tissue is based on a 0.5 g aliquot of ashed plant tissue dissolved in 10 mL *aqua regia* solution. To determine the milligram/kilogram (mg kg^{-1}) element content of the prepared sample, multiply the milligrams/liter (mg L^{-1}) in the prepared digest by 20 milligrams/liter (mg L^{-1}) in the digest x 20 = milligrams/kilogram (mg kg^{-1}) in tissue
2. To convert milligrams/kilogram (mg kg^{-1}) in tissue to percent (%), move the decimal point four places to the left: 1,000 milligrams/kilogram (mg kg^{-1}) = 0.1%

Table 22-2. Wet Acid Digestion Procedure Using Nitric and Perchloric Acids

1. Weigh 0.5 grams dried (80°C) and ground (20- or 40-mesh) plant tissue into a digestion tube. Place a glass funnel in the mouth of the digestion tube.
2. Add 1.5 mL concentrated nitric acid (HNO_3). Let it stand for 1 hour.
3. Place the digestion tube into a port of the digestion block and heat at 120°C for one

hour. Remove the digestion tube from the digestion block and let cool.

4. Add 1.5 mL perchloric acid ($HCIO_4$). .
5. Place the tube back into a port in the digestion block and heat at 200°C for one hour or until the digest is clear (colorless).
6. Remove the funnel from the digestion tube and set the temperature of the digestion block at 100°C. Keep the digestion tube in the block until the fumes of perchloric acid ($HClO_4$) have dissipated.
7. Remove the digestion tube from the digestion block and allow it to cool.
8. Add pure water to dilute to 10 mL, or to another appropriate volume.
9. The digest is ready for elemental analysis. The digest may be further diluted as necessary to achieve an element concentration that is within the analysis range of the analyzer.

Table 22-3. Wet Acid Digestion Procedure Using Nitric Acid and 50% Hydrogen Peroxide

1. Weigh 0.5 grams dried (80°C) and ground (20-mesh or 40-mesh) plant tissue into a digestion tube. Place a glass funnel in the mouth of the digestion tube.
2. Add 4 mL concentrated nitric acid (HNO_3). Let it stand 1 hour.
3. Place the digestion tube into a port of a digestion block and heat at 120°C for one hour. Remove the digestion tube from the digestion block and allow it to cool.
4. Add 4 mL 50% hydrogen peroxide (H_2O_2) and place the digestion tube back into a port in the digestion block. Repeat the additions of 50% hydrogen peroxide (H_2O_2) until the digest is colorless.
5. Remove the digestion tube from the digestion block and allow it to cool.
6. Add pure water to dilute to 10 mL, or to another appropriate volume.
7. The digest is ready for elemental analysis. The digest may be further diluted as necessary to bring it to an element concentration that is within the analysis range of the analyzer.

Note: Both this digestion procedure and the one using nitric (HNO_3) and perchloric ($HCIO_4$) acids can be conducted in a 200-mL tall-form beaker with the use of a hot plate. However, twice as much acid is required. The beaker must be covered during the digestion process with a watch glass. After the digestion is complete, the watch glass is removed and the residue taken to dryness at low heat (80°C). Once all the acid has been evaporated, the beaker should be immediately taken off the hot plate and allowed to cool. The residue is dissolved in either dilute (1:10) (HNO_3) or hydrochloric acids (HCI), or dilute (1:10) *aqua regia* solution(1 part HNO_3, 3 parts HC1 in one liter of water).

8. The prepared plant tissue is based on a 0.5 g aliquot of digested plant tissue dissolved in 15 mL water. To determine the milligram/kilogram (mg kg^{-1}) element content of the prepared sample, multiply the milligrams/ liter (mg L^{-1}) in the prepared digest by 50:

milligrams/liter (mg L^{-1}) in the digest x 50 = milligrams/kilogram (mg kg^{-1}) in tissue

9. To convert milligrams/kilogram (mg kg^{-1}) in tissue to percent (%), move the decimal point four places to the left: 100 milligrams/kilogram (mg kg^{-1}) = 0.1%

Table 22-4. Microwave Digestion

Procedure:

1. Weigh 0.5 grams dried (80°C) and ground (20- or 40-mesh) plant tissue into the CEM digestion vessel.
2. Add 3 mL concentrated nitric acid (HNO_3) and 2 mL 50% hydrogen peroxide (H_2O_2) Note: Perchloric acid ($HC1O_4$) may be substituted for 50% hydrogen peroxide (H_2O_2). Step 2 would read: Add 5 mL concentrated nitric acid (HNO_3) and 0.5 perchloric acid ($HC1O_4$). Precaution: The ratio of the two acids should not be less than 10 to 1.
3. Cap the digestion vessel and place it in the microwave oven.
4. Apply sufficient power to maintain the pressure at the 85 setting to on the controller for 15 minutes.
5. Remove the digestion vessel from the microwave oven and allow it to cool.
6. Remove the cap from the digestion vessel and dilute the digest to 15 mL with pure water. 7. The digest is ready for elemental analysis. The digest may be further diluted as necessary to bring an element concentration to within the analytical range of the analyzer.

Calculations:

1. The prepared plant tissue sample is based on a 0.5 g aliquot of digested tissue dissolved in 15 mL water. To determine the milligram/kilogram (mg kg^{-1}) element content of the prepared sample, multiply the milligrams/liter (mg L^{-1}) in the prepared digest by 30:

   milligrams/liter (mg/L) in the digest x 30 = milligrams/kilogram (mg kg^{-1}) in tissue

2. To convert milligrams/kilogram (mg/kg) in tissue to percent (%), move the decimal point four places to the left:

   10,000 milligrams/kilogram (mg kg^{-1}) = 1.0%

Chapter 23
Using Plant Tissue Analysis to Improve Crop Performance

Introduction

The visual appearance of plant stress symptoms has been and is still commonly used to make an initial assessment of a plants nutrient elemental deficiency or toxicity. Visual symptoms are associated with **acute nutrient deficiency**, which occurs when a nutrient is suddenly no longer available to a rapidly growing plant. Photographs and descriptions of visual deficiency and toxicity symptoms are readily available for most of the essential plant nutrient elements and for many plant species. Advantage of visual diagnostic symptoms is that they can be made on site, in the field, and provide an immediate evaluation of problems that exist in a crops nutrient status. The major failure of using visual symptoms of nutrient deficiency is that symptom expression for chlorosis and necrosis are characteristically associated with more than one essential element. One of the most important aspects to diagnosing acute nutrient deficiency is the understanding of nutrient mobility in the plant. The interaction between nutrient mobility in the plant, visual symptoms, and plant growth rate can be a major factor influencing the type and location of deficiency symptoms. Though visual nutrient deficiency symptoms continue to be a diagnostic tool for evaluating that nutritional disorders exist, use of visual symptoms alone to diagnose nutrient disorders fail as the only primary diagnostic tool in today's agricultural production programs as visual symptoms do not develop until after there has been a major effect on yield, growth and development. The plant may visually appear normal, and yet an element may be insufficient, therefore affecting growth and yield, a condition that has been referred to as *hidden hunger*[1]. Hidden hunger is associated with **chronic nutrient deficiency**, which occurs when there is a limited but continuous supply of a nutrient at a rate that is insufficient to meet the growth demands of the plant.

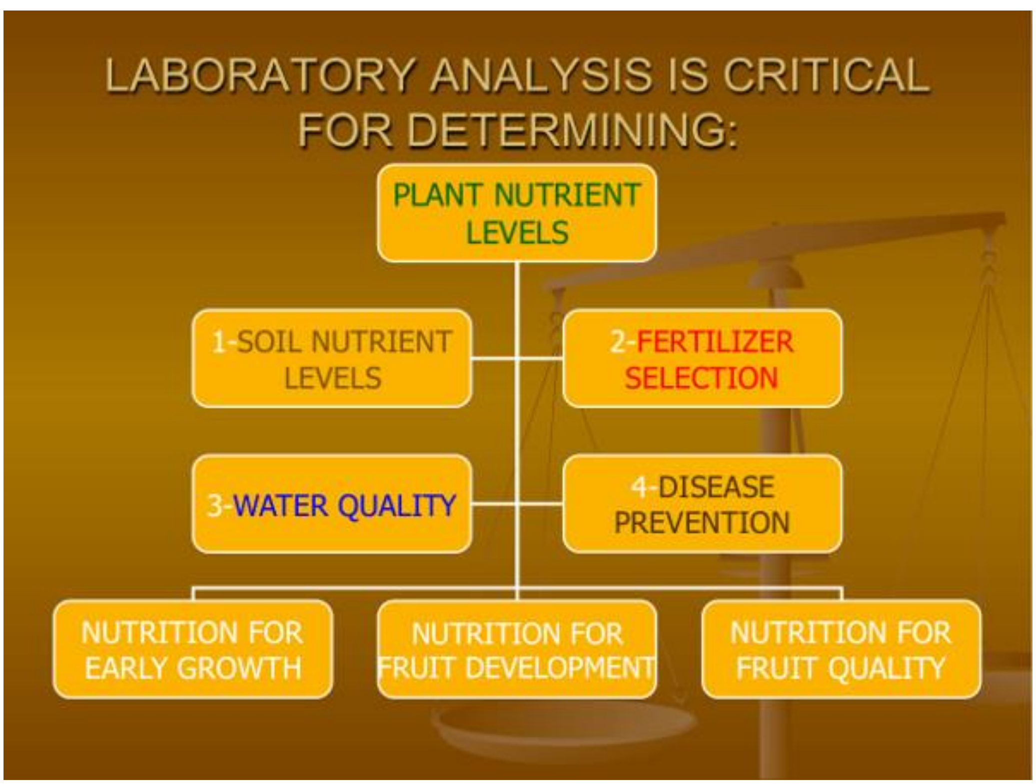
Chronic nutrient deficiencies naturally exist in natural environments including arboretum, forestry timber crops, and many plantation crops. Under these growing conditions plants are exposed to a limited nutrient supply that is renewed at an insufficient rate to support normal plant growth. Generally in this environment macronutrients, required in relatively large amounts, quickly express acute symptoms and are addressed with macro nutrient applications. Micronutrients however are required in smaller amounts and many times fall into the chronic nutrient deficiency category for the above type crops and are notaddressed with fertilizer applications until acute symptoms are expression as the plant grows and the level of micronutrients in the tissue is diluted with growth and acute symptoms appear.

Agronomic and horticultural production systems differ from natural systems in that crop plants have been selected primarily for rapid growth, high yield, enhanced foliage or flower characteristics and, these plants require reduced stress conditions. The rapid growth rates required by these selected high yielding crops results in a high nutrient demand and increased incidence of both acute and chronic nutrient deficiency unless supplemental fertilizers are supplied. Routinely one can find agricultural crops showing nutrient deficiencies, while native plants growing in the same area showing little or no indication of nutrient stress.

Approaches Using Plant Tissue Analysis

Diagnostic Tool

When a problem is observed in a field, shade house or greenhouse with a crop, a tissue sample is taken to determine if nutrition is causing the observed problem, and if so, which nutrient(s) are deficient, toxic or out of balance (both acute or chronic). While using plant tissue analysis as a diagnostic tool provides valuable information, by the time nutritional deficiency/ toxicity symptoms appear, damage has already been done to the crop, with a resulting loss of yield and quality. Most growers use plant tissue analysis only when there is a problem in their crops. While plant tissue analysis is a valid approach to determining nutritional problems, using this analysis tool alone does not provide the greatest benefits to improve plant growth and yield.



Preventative Program

Another approach to using plant tissue analysis is part of a preventative program whereby tissue samples are taken on an established schedule at certain critical points in the plants' life cycle or at established time intervals. From this information, deficiencies, toxicities and/or nutrient imbalances can be identified before symptoms appear in the plants. This allows for corrective measures to be taken before significant yield loss has occurred. This program helps to identify thecritical times in a plant's life that individual nutrients may become limiting. By having this information, fertility programs can be implemented in advance of the deficiency (or at critical plant development stages) to eliminate or reduce the severity of the deficiency, thereby preventing yield loss and a reduction in crop performance. The goal of a preventative nutritional program is that deficiency or toxic symptoms never appear in a crop.

Fertilization Decisions Using Plant Tissue Analysis Data

Factors to Consider

After tissue samples have been collected, sent to a laboratory for analysis, and results received, the next question is "What do we do now?" A simplistic answer is "If a nutrient is low, apply it, and if it is high, do not apply it." Withholding a nutrient is easy; just don't apply any. With regular tissue testing, it can be determined the quantity of nutrient that is needed to prevent deficiency, and also, as the plant grows, at what point is it necessary to apply a nutrient that was previously high, and consequently, withheld from the fertilization program. However, if a nutrient is deficient, three important decisions arise: 1) how much should be applied, 2) how (including when) should it be applied, 3) what form of fertilizer should be applied. The process of taking plant tissue analysis results and determining fertilization application rates and methods are both a science and an art. The science comes from knowledge of six things:

Nutritional needs of the plant

Without an understanding of what the plant needs, it is impossible to eliminate nutrient deficiencies of a crop. The Interpretative Data Tables contained in this book are a starting point to determine whether content of the individual nutrients of the plant are within the acceptable range for a given plant. These nutrient ranges may be modified based on specific crop, cultivar, stage of maturity, or specific growing conditions.

Knowledge of plant nutrient interactions

Just as the concentration of nutrients in plant tissues is important, the relationship of the nutrients in a fertilizer blend or solution, in the soil and within plant are important in relationship to the plants ability to take up and utilize the nutrients once inside the plant. The chapters on individual nutrients in this book give a brief overview of how nutrients interact with each other and influence how the application of one nutrient can influence the uptake and utilization of other nutrients inside the plant. Most of these nutrient interactions are based on simple chemical reactions, including effects of pH. However, other changes include microbial and biochemical reactions in the rhizosphere and in the plant as a result of the addition of a specific nutrient.

Environmental and growing conditions

Environmental conditions include any condition that can influence the uptake, movement, or utilization of any nutrient into or within a plant. A few examples are 1) soil saturated with water inhibiting the active uptake by plants because of oxygen depletion; 2) high salt (sodium chloride) content in the soil solution which competes with potassium for uptake; 3) cool, humid, cloudy conditions reducing transpiration, thus reducing passive uptake of nutrients; 4) cold soils reducing root growth which is needed to intercept nutrients like phosphorus, and also reducing microbial activity to mineralize the nutrients in organic matter; 5) certain pesticides tying up micronutrients making the nutrients unavailable for plant uptake; 6) trees growing close to crops with the tree roots taking up nutrients and water applied to the crop; 7) trees shading the crop, thus blocking sunlight and reducing photosynthesis and thus reducing the production of carbohydrates for active uptake. The list can be almost endless.

Cultural practices used

Crop production methods vary greatly depending on the type ofcrops such as rice paddies, orchards, row crops, shade houses, green houses, pot culture, hydroponics, etc. However, nutritional needs to take a seed or cutting to maturity are basically the same for a specific crop. Tillage practices (e.g., conventional plowing, minimum tillage, strip till, no-till) are just one cultural practice that influences the nutrient mineralization, interactions, movement and utilization by crops. Irrigation is another cultural factor that also has tremendous influence on nutrient availability. Nutrients can be provided in irrigation water, but irrigation water can also leach out soluble nutrients through the soil profile and even outside of the root zone. In crops grown in soilless medium (e.g., potting mixtures, rice hull, composted manure, hydroponics), the nutrient interactions with these media can be significantly different from field soils. Also, pesticide use can influence microbial populations, both in diversity and numbers, which may have an effect on nutrient mineralization and sequestration by the microbes. Some pesticides, such as glyphosate, act as strong chelating agents, binding certain nutrients making them unavailable for plant use.

Fertilizer interactions in the soil or growing medium, and influence on plant nutrient availability, uptake and utilization

When nutrients are applied to soil or growing media, numerous physical, chemical and biological reactions and processes occur. Two of the primary reactions are with other nutrients and the interaction with soil or growing medium pH. Examples of interactions of nutrients in soils or growing media include dissolving of dry fertilizers permitting uptake, but also leaching; volatilization of ammonia from surface applied nitrogen fertilizers; formation of insoluble (thus unavailable) compounds such as calcium phosphate; microbial denitrification; and microbial and pH induced redox reactions. Each of these processes influences the availability of nutrients to plants and crops, and the selection of fertilizers and application methods must be considered on how it influences nutrient uptake. Not only do interactions of fertilizers influence uptake potential of the applied nutrients, but also the chemical forms of a nutrient also influences uptake and utilization by the plant. For example, NH_4^+ and NO_3^- are the predominantly nitrogen form take up by plants.

Understanding of fertilizers as related to plant uptake and utilization

Fertilizers as sources of plant nutrients can vary greatly in reactions in the soil, chemical reactions with other nutrient, and effect on soil pH. The art comes from putting all these together to improve plant performance. Also, economic considerations must be considered based on the severity of the nutritional needs, the cause of the nutrient deficiency or imbalance, and the return on investment of the expense to correct the nutritional problem. Because crop production is a business, the cost and benefits of applying needed nutrients is a real consideration.

The first step in diagnosing a problem, or even if there is one, with a crop is observation, and obtaining background information. Observation is the foundation of all science. Even crops that look reasonably good, may still be losing yield and quality because of "hidden hunger." Plant tissue analysis results can provide a huge amount of information about a crop, but it still must be put into context of the crop growing in a field, greenhouse, shade house, or a pot. This includes environmental conditions such as temperatures, rainfall, to review the results for nutrient levels that are below the sufficiency range, or on the lower end of the sufficiency range. More than likely these will need to be applied to the crop unless the soil or growing media already has adequate nutrient levels (typically determined by a soil test). When used with interpretative tables given in this book, these values help to evaluate which nutrients, if any, may be limiting plant growth and performance. Also, with the knowledge of nutrient interactions, it is possible to determine which nutrient or nutrients are needed to correct deficiencies in the plant. In some cases, nutrients may be out of balance and while a nutrient is within the sufficiency range for the given plant, another nutrient may be and as well as to balance nutrients within the plants in an effort to prevent potential toxicities of excessively high nutrients.

Example 1 – Young corn (V2-V3).

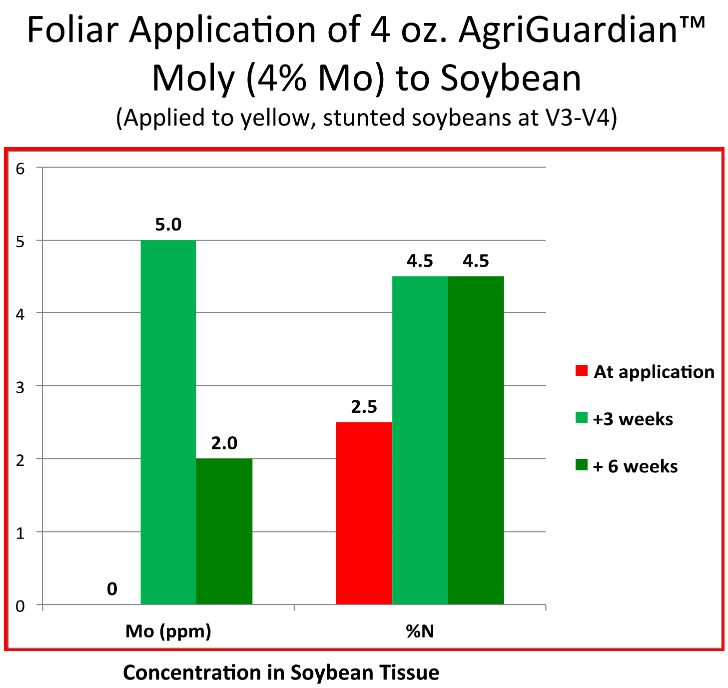
Tissue test results – most nutrients are below sufficiency range
Growing conditions – cool, wet spring, adequate nutrients already applied to soil.

This is a common condition especially in the upper Midwest. Nutrients applied in fertilizers are in the soil, but cannot be taken up by the plant. This is due to a reduction in both passive and active uptake. Passive uptake occurs as water moves into roots taking nutrient with it as the water moves up the plant and transpires from the foliage. However, frequently cool, wet springs are associated with greater cloud cover and more rainfall. The cooler temperature, higher humidity and less sunshine reduce the transpirational rates of water evaporating from the surface of the leaves. The net result is less nutrients being provided by passive uptake. Similarly, active uptake of nutrients from the soil requires energy provided by carbohydrates. These carbohydrates can come from the seed or from photosynthesis. The energy in the seed is primarily used in germination and emergence, leaving only small amounts for nutrient uptake. The majority of carbohydrates for active uptake come from photosynthesis taking place in the leaves. However, with poor nutrient transport going into the leaves, and cloudy conditions, photosynthesis is reduced. This makes a catch-22 condition in which roots are waiting on carbohydrates for active uptake, and the shoots are waiting on nutrients for growth and photosynthesis. In this case applying nutrients to soil provides no benefit since the roots cannot take them up. A foliar application is needed to get nutrients into the leaves to encourage photosynthesis and growth. Because the plants are small, a gallon of a 3-18-18 or 9-18-9 may be all that is needed as a kick-start. However, if the soil is wet, how can the nutrients be applied? A tractor may be able to go through after a day or two without rain, or an airplane may be used. Both involve a cost that must be considered. Another consideration is when was the crop planted, and how soon will the soil be warming? Was the crop planted very early (in temperate zones), and the soil just has not had time to warm up? On the other hand, are temperatures expected to rise and the soil dry out in a few days, and then nothing may need to be done. Several growers who want to push for high yields use the practice of applying a gallon of 3-18-18 to ensure the crop is not limited by nutrient deficiencies.

Example 2 – Young soybeans low in Mo and N.

Many laboratories unfortunately do not routinely test for molybdenum in tissues tests. Molybdenum is an essential plant nutrient needed for N-fixation in legumes, and for nitrate utilization by all plants. In this example, young soybeans in Iowa were slow growing and chlorotic (yellow). Tissue tests revealed that Mo was non-detectable and nitrogen levels were at 2.5%. Since Mo levels were virtually none existent, this would also mean that N-fixation would be extremely limited as well. The 2.5% nitrogen would likely come from nitrogen uptake by the roots. This grower did not apply nitrogen fertilizer to the fields, so the nitrogen being taken up by the plant would be from residual nitrogen in the soil, which a significant portion would be in the nitrate form. What this means is that since Mo was non-detectible in the tissues, then any nitrate in the plant would be virtually unusable because without Mo, there would be little or no nitrate reductase enzyme. The nitrate would be stored in the vacuoles of the plant, but the plant would get no benefit from this nitrogen. Consequently, the young soybean plants would be even more starved for nitrogen, then the 2.5% total N would indicate. To determine if Mo indeed was the limiting factor, the field was split in half with similar growth and appearance on either half. One half was sprayed with 4 oz. of a 4% molybdenum sugar-based chelate product in 10 gallons of water. After three weeks, replicated tissue samples wereagain taken from the field. As indicated in Figure 23-1 the untreated half of the field Mo levels remained non-detectable, and total N remained at 2.5%. However, where the foliar applied chelated molybdenum product was applied, Mo was at 5 ppm and nitrogen was at 4.5%. The untreated soybeans were still chlorotic and stunted, while those treated with molybdenum foliar were green, growing and starting to flower. It can be assumed that the molybdenum not only promoted N-fixation, but also allowed the soybean plants to be able to use all of the nitrogen that was taken up from the soil. As second tissue sample taken approximately three weeks later (six weeks after application) showed that total N remained at 4.5%, but Mo dropped to 2 ppm likely from a dilution effect of the growing soybean plant.

Figure 23-1. Effect of 4 oz AgriGuardian Moly™ foliar applied to soybeans low in molybdenum and nitrogen at V3-V4 on ppm Mo and %N in tissue three weeks after application. Without application, Mo and %N remained at beginning levels and had extremely poor growth.



Example #3 - Soybeans (and other crops) extremely high in iron and low in sulfur.

Sometime plant tissue analysis results can give insight into what is going on in an actual field. Tissue samples were taken from many growers across the Midwest as part of a nutritional program. An observation was made that Fe in the tissues was much higher than normal, and that S was lower than normal. Using soybean tissue as an example, Fe is normally 50 to 250 ppm, but soybean tissue analysis results increased from with in normal range to 500 ppm, to 1,000 ppm, and many 5,000-10,000 ppm. Fortunately, high Fe is not toxic like Zn or Cu, but the question was why were these numbers so high.

Another observation was that as the Fe levels increased, the S levels went down. Again using soybeans as an example, 0.20%-0.50% S is normal for soybeans. However, as Fe went up, S dropped to 0.15% to 0.10% and below. As the test results came in, the growers were contacted to find out what the conditions existed to cause these results. In each of the locations that these types of results were observed, the fields had had several weeks (3-5 weeks) of continuous rain, and the fields were perpetually wet and saturated with water. The longer the fields were wet, and the wetter they were, the higher Fe levels were and the lower the S levels were. Once the continuous rainfall diminished and the soils began to dry, the tissue samples returned to normal over a period of 2-4 weeks. The fields received less rainfall or were better drained returned too normal faster. From these observations, it was possible to look at the tissue test results alone and predict which fields were poorly drained and saturated, and which fields were moderately wet, as well as those that were well drained and had normal moisture. This could be done all by simply looking at tissue test results, and without ever seeing the fields or asking the growers. Because many of the soils in the upper Midwest are poorly drained, tiling is done to promote drainage. By comparing rainfall records and the Fe and S levels in the plant tissues, this information was able to help growers to prioritize which fields needed to tilled the most. The advantage of using this information to make such decisions was that it was based on how the plant was responding and not on how wet the soil looked. The science behind the data and how the data could be used this way is relatively simple. As soil becomes more saturated with water, especially over several days or weeks, the oxygen levels in the soil become depleted. With oxygen levels being low, the normal Fe oxides become reduced, thereby giving up their oxygen. The reduced Fe is more soluble and more readily absorbed by the plant's roots, causing an increase in concentration of Fe in the plant tissues. Also, available sulfates in the soil also lose oxygen, resulting in the formation of sulfides. When Fe and sulfides come together, Fe-sulfides are formed making the sulfur unavailable to the crop. However, once the soil drained, oxygen again returned to the soil, and reduced Fe (available) and sulfides (unavailable) again returned to Fe-oxides (unavailable) and sulfates (available). In situations such as this, even though S was low in the plant, it was understood that this was a temporary uptake problem for S, and once the soil started to oxygen into it, the problem would correct itself. Also, with saturated soil and continuous high humidity and overcast skies, both active and passive uptake for virtually all nutrients, except Fe, were reduced. S stood out because it was reduced more than the other nutrients.

Example #4 - When is "iron chlorosis" not an iron deficiency.

There are many books written on the deficiency symptoms of various crops, including photographs of what the symptoms look like in real life. Many times when a nutrient is low, the symptom may fit the deficiency exactly. As mentioned above, Mo deficiency looks like N deficiency, and can even look like S deficiency when it is severe, but there are very few examples where Mo deficiency does indeed look like Mo deficiency, e.g., whip-tail in cauliflower. Every essential plant nutrient has some interaction with at least one other nutrient. Most nutrients have interactions with several other nutrients. In the field, symptoms can help to give an indication what a nutritional problem is, but not necessarily what the real cause of the problem is. In a real-life situation in Iowa, a soybean grower complained of yellow stunted soybeans. Initially the stunted beans were visually diagnosed as "Iron chlorosis. The field was not uniform. The soybeans went from 3-4 inches tall and completely yellow, to ones 18" and acceptably green. Three soil samples and three tissue samples were taken; each from 1) severely stunted and chlorotic plants, 2) moderately stunted and chlorotic plants, and 3) with few symptoms. Soil analysis identified the iron content of all three locations (that is, in all nine soil samples), being very similar and adequate, and the iron level in the tissue samples were also similar and adequate. Immediate conclusion was that this was NOT iron deficiency. The next step was look at the other nutrients to see if any of these were high or low, and correlated with the chlorotic symptoms. Manganese was identified as high, above sufficient, on the reasonably healthy plants, well above sufficient on the moderately stunted plants and three to four times higher that the maximum sufficient upper limit for soybeans. High levels of manganese were confirmed by both the tissue and soil test results,everything matched. However, manganese is typically low in the Midwest primarily because pH's are neutral or above, so why were the manganese levels high? The soil pH influences availability of manganese, with low soil pH making higher levels of manganese available. However, based on the manganese levels, the pH levels gave a surprise. The pH of the soil with the semi-normal beans was in the neutral range. The pH with the moderately stunted plants was on the high side about 7.8, but the pH of the soil from the most stunted soybean was 8.6! This was backwards of what would be expected. Theanswer: the microbial population of the soil areas of greatest stunting contained a bacteria that flourished in high pH soils and had a propensity to reduce manganese, making it more available to soybeans to the point of inducing manganese toxicity. Manganese toxicity also happens to be a yellow chlorosis, with one exception that the manganese toxicity also produces small brown lesions (spots) on the leaves, which were missed in the first field visit. With a crop in the ground, it was not practical to try to change the pH of the soil or to try to kill the bacteria in the soil. But much of the crops would be doomed unless the manganese toxicity could be reduced. Since manganese and iron compete for uptake and utilization in crops, the way to reduce the manganese toxicity was to apply foliar chelated Fe, which was done.

Methods of Applying Fertilizers to Correct Nutritional Deficiencies and Imbalances

Typically when tissue analysis results show a nutrient deficiency or imbalance, the desire is to get that needed nutrient(s) to the plant as quickly as possible to overcome the problem, and to get the crop back on track for rapid growth and good performance. The most common methods (depending on crop and growing methods) are:

Broadcast fertilizers

Broadcast application implies a granular or dry fertilizer product, but it also pertains to liquids applied to soil with the intent that the nutrients will enter the soil and subsequently the crop takes the nutrients up from the soil. This method is infrequently used, primarily because the crop is up and growing, and granules of dry fertilizer or concentrated liquid fertilizers can easily burn the foliage. Also, nutrients that end up in the soil may face several challenges before being taken up by the plant. Any soil factor or condition that can interfere with the availability and/or uptake of nutrients by plants will influence the efficacy and effectiveness of fertilizers applied to the soil that contain those nutrients. For example, a high Ca soil will interfere with the availability and uptake of Mg applied to soil. Also, applying Zn, Fe, Cu or Mn to a high pH soils using a salt-based fertilizer will be poorly effective, as will applying sodium molybdate to an acid soil. Also, much of the fertilizer would have to move some distance to reach plants when the plants are spaced out such as between row crops, or between plants with nursery and tree crops. Broadcast fertilization is more applicable to close-spaced plants or crops where root systems permeate the bulk of the soil surface such as grasses and small grains.

Side dressing nutrients

There are two primary differences between broadcast fertilizers and side dressing. First is that both liquid and dry fertilizers are commonly used, and second is the placement of the nutrients. Side dressing literally means to apply nutrients along the side of the row of the growing crop, or close to the root zone of the growing crop. Thus side dressing is more applicable to row crops, trees, and other crops with spacing between the plants. In side dressing, the nutrients are applied to the surface of the soil, or knifed in or injected into the soil. The same issues with fertilizer-soil interactions apply as with broadcast fertilizers. Two differences when comparing to broadcast are that the side dressed nutrients are more concentrated allowing for a smaller percentage of the nutrients to react with or bound to soil particles, thus making more nutrients available to be taken up by the plants. Also, with proper placement, the distance between the nutrients and roots is less, allowing for more rapid uptake.

Figure 23-2. Side dressing fertilizer in Oil Palm plantation.

Fertigation

Applying fertilizers through irrigations systems has been used for decades. The vast majority of these are liquid fertilizers mixed with irrigation water before application such as UAN, 3-18-18, 9-18-9, etc. High-pressure injectors and siphon systems are used to get the liquid fertilizer into the water going through the irrigation system. Dry fertilizers that are very soluble can be mixed with water to form a solution to be added to the irrigation water. Regardless, most of fertigation systems deliver low concentrated solutions of fertilizers. Also, as the word fertigation implies, water is being applied to meet the needs of the crop or plants.

What this means is that the majority of the nutrients applied through these systems are washed off the foliage of the plants and end up in the soil or growing medium. In the soil, nutrients are available for uptake by the roots, especially since they are already in solution. However, the nutrients are very subject to leaching, especially if large amounts of irrigation water are applied along with or after the nutrients are applied. The result is that the nutrients drain below the root zone making them less available to the roots. This is particularly the case is nutrients are injected into the irrigation system early in the cycle, and additional nutrient-free water is applied afterwards. This is commonly done with systems using tubing, and the nutrient-free water is runthrough the lines to clear the line of nutrients which can cause clogging problems if they precipitate out, or stimulate microbial growth in the lines. One of the challenges of drip line and emitter systems is make sure the system is designed so that each emitter in the system receives not only the same amount of water, but also the same amount of injected nutrients, from those close to injector pump all the way to the last emitter on the drip line.

Figure 23-3. Example of a drip line delivery of plant nutrients from tanks containing the liquid fertilizer. In the pictures below the liquid fertilizer in the white tanks on the left is metered by a pump,delivering nutrients in measured amounts,through the underground plastic pipes under the black plastic to the root zone of the watermelon crop.

Nutrients in the irrigation water from drip or emitter systems also enter the soil are subject to all the physical, chemical and biological interactions in soil as fertilizer applied directly to the soil. These include solubility changes due to soil pH, formation of insoluble inorganic and organic complexes, absorption and transformation by microorganisms, and the potential binding onto the soil particles. All of these factors influence the ability of the plants to take up the nutrients being dispersed by the irrigation water.

With fertigation, the distribution of nutrients in the soil may be similar to either broadcast application or side dress application based the method of distribution. For example, central pivot irrigations systems cover wide areas of land, but it is more or less evenly distributed over the field, which is similar to broadcasting dry fertilizer. However, drip irrigations systems using tubes and/or emitters can control where the nutrients are applied in a field, orchard, nursery, shade house or greenhouse, or even to individual plants in pots.

Fertigation systems are more adapt to applying nutrients to the soil, and can be very useful when the soil conditions are conducive to nutrient retention in the soil as well as nutrient absorption and uptake by the crop. Since generally fertigation applies a lot of water, the nutrient solutions are very dilute, and most of the nutrients that have contact with foliage are washed off. Systems such drip irrigation, subsurface irrigation and furrow irrigation, little or no water typically comes into contact with the foliage.

Consequently, foliar absorption of nutrients is generally limited when using fertigation. Some growers do use low volume misters on the back side of central pivot or other traveling irrigation systems in which concentrated nutrients are applied to the foliage after the irrigation component of the system is not longer applying water to the plants, and the bulk of the irrigation water has run off of the foliage. These secondary systems are actually foliar fertilization, which is piggybacking onto the irrigation system.

Foliar fertilization

Foliar fertilization is the application of essential or beneficial nutrients to plants, most often as a liquid spray or mist primarily to the leaves of a crop, but stems, fruits and other structures can also absorb available nutrients (see Chapter 19 for a detailed examination of foliar fertilization). When done properly foliar fertilization is a cost effective and proven method of delivering nutrients to plants. The benefits of foliar fertilization include:

1) Nutrients can be applied when needed
2) Bypasses soil problems that can limit nutrient uptake
3) Only the nutrients needed can be applied
4) Nutrients can be quickly taken up and utilized by the plant
5) Foliar applied nutrients are often more effective than soil applied nutrients
6) Foliar applied nutrients are often more cost effective than soil applied nutrients
7) Foliar applied nutrients are easy for growers to use and apply.

Foliar fertilization is typically used as a supplement to traditional soil or growing media application of fertilizers. However, with ever increasing knowledge on foliar fertilization and with better ability to provide precise control of application of nutrients, foliar fertilization is becoming a routine practice to maximize yields with crops. There are several crop production situations that yield and quality can be improved with the use of foliar fertilization. This is even the case when adequate soil fertilization is used, but these nutrients may not be available to the shoot. These include:

1) *Drought stress* – Both passive uptake of nutrients from the soil and translocation of actively taken up nutrients require water to move these nutrients from the roots to the shoots. Stomata also close reducing transpiration of water that is available.
2) *Extended water saturated soils* – Exclusion of oxygen from the root zone inhibits respiration, reducing energy available for roots to actively uptake nutrients from the soil, or to load them into the xylem to be transported to the shoot.
3) *Extended high humidity* – Transpiration is slowed reducing the translocation of nutrients from the roots to the shoots, calcium and boron.
4) *Excessive cold soil temperature* – Root respiration is slowed reducing the amount of available energy for active uptake of nutrients and xylem loading of nutrients to be transported to the shoot.
5) *Nutrient depletion of soil* – Heavy rains can leach soluble nutrients from the soil making them unavailable to the crop. Inadequate fertilization to soil may cause nutrient depletion by a rapidly growing crop. Also, it may not be practical or economical to front-load all nutrients in the soil, but traditional side dressing of nutrients may not be feasible either.
6) *Nutrient imbalances in soil* – Certain nutrients compete for uptake by plants, and when such a nutrient combination is out of balance, the lesser nutrient may not be able to be taken up by the roots.
7) *Soil pH too high or low* – Selected nutrients become unavailable since they are not in forms that can be readily taken up by roots.
8) *Root damage* – Whenever roots are damaged, their ability to uptake nutrients is reduced. Root damage can come a number of sources such as root pruning (e.g., improper cultivation or transplanting), root diseases and rots, rootworms, nematodes, and/or insects feeding on roots, fertilizer or other chemical burn, and herbicide damage.
9) *Leaf and shoot damage* – Hail, late frost, strong winds, insect and disease damage can severely reduce leaf area and the ability of the shoot to produce carbohydrates, which are needed by the roots to provide energy for active uptake of nutrients.

Rapid Laboratory Analysis of Plant Tissue

State run and supported laboratories developed soil analysis as a routine and necessary tool for growers to address pH and some major nutrient availability. Today soil and mediaanalysis is part of the program utilized to support crop production. As the demand for higher yielding crops and new plant introduction that required a closer monitoring of a crops nutritional status was required, plant tissue analysis gained in importance. Failure to utilize or implement a tissue analysis program can be related to two major perceptions:

1) Slow turn around time at state run laboratories, and

2) Inability to interpret results from the plant analysis by user or consultant.

Tissue Analysis is Slow

While state run laboratories struggled to provide rapid tissue analysis sufficient to support grower needs, private laboratories implemented rapid analysis of plant tissue, providing 24 hour turn around time for those who needed this quick response. Unfortunately the perception still exist that tissue analysis is too slow for implementation on a regular basis as a tool to compete for high yield and high quality, this myth is slowly disappearing. While the number of state run laboratories continue to decline in numbers, private laboratories currently provide the rapid tissue analysis service required by growers in today's agronomic and horticultural production farms, nurseries, and plantation crops. The practice of utilizing plant analysis as a tool for maximizing profits in todays agricultural production is being implemented by those seeking higher yield or quality and reduced fertilizer application and waste/pollution. Today it is recognized that plant analysis, sometimes referred to a *tissue test,* is the only definitive method for evaluating the nutrient element status of a growing plant.

Plant analysis is currently utilize to determine:

1. A plant's current nutrient element status.
2. Verifying which element or elements are associated with visual symptoms of a plant stress nutritional problem.
3. The periodic monitoring of the nutrient element status of a plant as its progresses through its various stages of growth, guiding the use of supplemental fertilization in order to ensure sufficiency maintenance for each of the essential plant nutrients.

Plant Tissue Analysis - Nutrients to Include in Tests

Plant tissue analysis is an important tool to understand the nutritional status of plants. Currently, fourteen essential nutrients have been identified that are derived from soil or growing media, irrigation or rainfall, the atmosphere, and/or from applied fertilizers. Plant tissue analysis standards are a general reference as to the needs of plants and crops. Many factors such as variety or cultivar differences of a plant, age and stage of development of the plant, environmental conditions, soil or growing media properties, fertility or nutritional program, and production practices all can influence the optimum nutrient concentrations for a plant or crop. However, the plant tissue analysis data presented in this book is a starting point to refine the nutritional requirement of specific crop or cultivar grown in a specific location.

Because of the many interactions of nutrients in the plant, a complete nutrient analysis is needed, including macronutrients and micronutrients. Even when a "complete" tissue nutritional is requested, most laboratories do not include all essential nutrients. The macronutrients needed are nitrogen, phosphorus, potassium, calcium, magnesium and sulfur. Because Total N (N%) alone may not give enough information, see the discussion on nitrogen under "Molybdenum" below. Micronutrients commonly included and needed in tissue tests are boron, copper, iron, manganese and zinc. Three essential micronutrients are often missing - chlorine, nickel and molybdenum.

Chlorine

Chlorine deficiency has rarely been a problem in nutritional programs because of the many fertilizers commonly being applied that contain chloride, such as potash, KCl. Typically, if there is a chlorine problem, it is that there is too much chlorine or chloride available, especially in areas high in salt, sodium chloride. This is the only nutrient that may be excluded from a plant tissue analysis unless there is a concern.

Nickel

Ideally, nickel should be included in plant tissue analysis, but standards have been developed for this nutrient for only a few crops, because 1) it has only recently been identified as an essential plant nutrient, and 2) nickel requirements in most plants are quite low. For these reasons, research on nickel requirements of most plants is limited and relatively new. Pecan and soybean are examples of crops where nickel deficiency has been clearly identified as a real concern for the crop.

Molybdenum (and Nitrogen)

Another essential nutrient that is often ignored in tissue tests is molybdenum. The essentiality of molybdenum is well established, and is needed by all plants and crops. Molybdenum deficiency is very common in field crop production. However, growers and field agronomist routinely attribute the observed deficiency symptoms to lack of nitrogen and do not consider molybdenum as a possible cause. This is because they do not have tissue test results to know the molybdenum levels in a crop, because molybdenum deficiency looks like nitrogen deficiency (and occasionally like sulfur deficiency), and also the erroneous assumption that if the soil pH is neutral or above, then the soil can supply all the molybdenum the crop needs.

Molybdenum affects nitrogen fixation, nitrogen efficiency and utilization, and several other enzymatic reactions. One of the main reasons for testing for molybdenum in plant tissues is that when molybdenum is deficient, and Total N (%N) is the acceptable to high range, the plant could still be nitrogen deficient. Total N measures all of the nitrogen in the plant, including nitrogen in proteins and other organic compounds, ammonium (NH_4^+) and nitrate (NO_3^-). Most plants can readily take up nitrogen as ammonium, nitrate and urea. Urea rapidly converts to two ammonium molecules. Inside the plant, ammonium, whether derived from uptake or hydrolysis of urea, is toxic to the plant, and is quickly converted to amino acids and proteins. Ammonium seldom exceeds a few ppm in tissue. When ammonium does accumulate beyond a few ppm, this may be because the plant may not have enough carbohydrates in its tissues to supply the energy to complete the conversion of ammonium (from whatever source) into proteins. This can cause toxic levels of ammonium to accumulate. When seedlings of tomato and pepper plants are given too high ammonium nutrition, the resulting carbohydrate depletion can result in the death of these seedlings since their carbohydrate reserves in their small seed is very low, and because the small seedlings are small, photosynthesis is not sufficient to provide the needed carbohydrates.

Unlike ammonium, nitrate is not toxic and can easily accumulate in the plant tissues. Nitrate may be a primary source of nitrogen taken up by plants, but the plant cannot convert the nitrate directly into protein. Nitrate must be reduced to NH_4^+ by the enzyme nitrate reductase before the nitrogen can be assimilated into proteins. The enzyme nitrate reductase requires molybdenum, and the more molybdenum in the plant tissues; the more nitrate reductase is formed in the plant, thus influencing the rate of nitrate made usable by the plant. When molybdenum is deficient, nitrate reductase concentration is low, and thus nitrate reduction is slow. If nitrate uptake is faster than the rate of conversion of nitrate to ammonium by nitrate reductase, then nitrate accumulates in the plant tissues and is stored in the vacuoles.

In reference to Total N, if a significant amount of the nitrogen that makes up the Total N value is nitrate, the Total N values overestimates the available nitrogen to the crop, and indeed a crop can be nitrogen deficient, but have adequate to high Total N values. To completely understand the nitrogen status of a crop, both Total N and nitrate concentrations in the plant should be measured. Regardless, molybdenum needs to be measured to determine if the plant is capable of generating nitrate reductase. Another observation is that anytime there is an accumulation of nitrate in plant tissues, there is a good chance the plant is low in molybdenum. This is regardless of the source of nitrate in the plant. The bottom line is to test for molybdenum in every tissue test to be able to interpret the Total N data for that plant or crop. Molybdenum should also be included in every soil test as well. Nitrate determination is another value test in plant tissues, and especially in forages used for ruminant animal feed, since high levels of nitrate in their diet is toxic to animals.

Inability to Interpret Results by User

When the tissue analysis identifies a nutrient deficiency, the actions needed for correction are relatively straightforward. The first question to answer is what caused the element to be deficient or high. If the element is low or high in the soil then the answer is apparent as to the action required; if the element is low, add as a fertilizer. If the element is high, take the element out of the fertilizer program. Now once it is determined which element is deficient and the decision to add this element is made, it is important to ask if some of the other essential nutrients are at the low end of the sufficiency range that a stimulation in growth, by adding the deficient element, might also result in these other elements falling into the deficient zone. If these elements are in the bottom third of the sufficiency level then the answer is most likely yes and they should be added concurrently with the deficient element identified in the plant analysis. These simple questions, "ask and answered" would result in a positive outcome in crop growth and yield for most of the growers relying on plant analysis as a tool.

Understanding How to Interpret Sufficiency Range

It has been found that there exists a consistent significant correlation between the nutrient element concentration in a specified plant part and the plant's growth characteristics and/or yield that provide a means for making an assessment of a plant analysis result. That relationship between elemental concentrations in a plant part versus its growth or yield is graphically illustrated in Figure 23-4. In this illustration, there are 4 descriptive ranges, "severe deficiency, moderate deficiency, luxury range (defined today as the sufficiency range), and the toxic range". Many times confusion exists in the use of the descriptive word luxury range or "excess" or "excessive" which is different from identifying a nutrient level that is toxic.

Some plants can accumulate excessive levels of a given element, luxury consumption, without the plant showing adverse growth effects such as chlorosis or necrotic lesions or spots. As an example let's look at boron levels in watermelon leaves sufficiency range of 30-80 ppm in Table 23-1.

Generally leaf boron levels can exceed 80 ppm and are not toxic until 120 ppm or higher in the leaf is realized. Thus boron levels can exist in plants above the maximum sufficiency level without producing a toxic response in the plant. This level of boron above the maximum sufficiency level but not toxic would be correctly described as luxury consumption or excessive. It should be understood that the luxury/excessive range between an element that is sufficient and toxic varies greatly within plant families, genus, species, cultivar and/or variety. Some will have a very narrow range while others like watermelon has a wide range for the element boron as given in the example in Table 23-1.

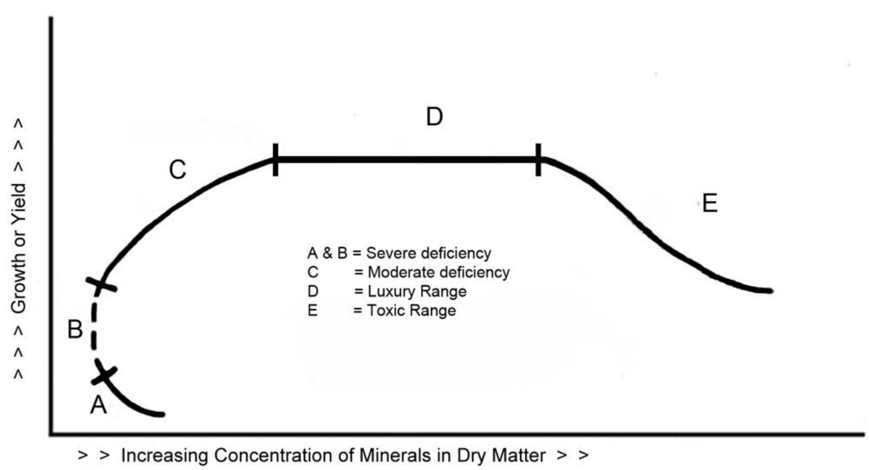
Table 23-1. Leaf sufficiency range for mature watermelons.

COMMON NAME			**Watermelon**
COLLECTED FROM			Production fields
PLANT PART			12-15 mature leaves from new growth
SEASON			Mature plants, small fruit stage
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	2.0 - 3.0	Fe	100 – 300
P	**0.2 - 0.3**	**Mn**	**60 – 240**
K	2.5 - 3.5	B	30 – 80
Ca	**2.5 - 3.5**	**Cu**	**4 – 8**
Mg	0.6 - 3.5	Zn	20 – 60
S	**0.33 - 0.47**	**Mo**	**0.05 - 1.14**

Sufficiency vs. Survey Range

Today, those involved in crop production rely upon plant analysis to determine the adequacy of essential plant nutrients by comparing the essential plant nutrients determined to established sufficiency ranges. Plants of the same species respond similarly to nutrient deficiencies, however plants of similar species will often show significant differences in their nutrient use efficiency. Plants can differ in growth rate, root distribution, phase of development, and efficiency of nutrient uptake and utilization which explains why each plant has a specific sufficiency range associated with that plant and stage of growth. It is not uncommon that plants from one species showing a nutrient-deficient may have right next to it another species growing in the same environment not show any deficiency symptoms.

Figure 23-4. Graphic illustration of the relationship between nutrient element concentrations in a plant and its growth or yield.



The ideal plant nutritional status is to have the elemental concentration determined, by means of a plant analysis/tissue test, to fall within the "sufficiency range" that has been determined by proper research or field testing. However, this correlation of nutrient level determined by plant analysis is based on the selection of a particular plant part taken at a specific time or stage of plant growth. In the example given in Table 23-1 for watermelon, the stage of plant growth that this sufficiency range is based upon is a mature plant with small fruit developing. The value of a plant analysis result is based on the degree of correction that exists between the nutrient element concentration and the stage of plant growth where the sufficiency range was determined. Therefore, sampling procedure will determine which correlation parameters are to be used for making an assessment of the nutrient element status of the sampled growing plant.

There are plant species, such as ornamentals, shade trees, bedding plants, some types of vegetables, etc., that do not have established sufficiency ranges for some or all the essential plant nutrient elements. However, there are nutrient element concentration values that have been gathered by researchers from normal-appearing plants, which have been designated as *Survey Values*.

Plant Analysis Handbook IV provides these two sets of interpretative values:

<u>Sufficiency Range:</u> a range that has been established by research, identifying that concentration range for a specified plant part and stage of plant growth of an essential plant nutrient element within which optimum plant growth and/or product yield is obtained.

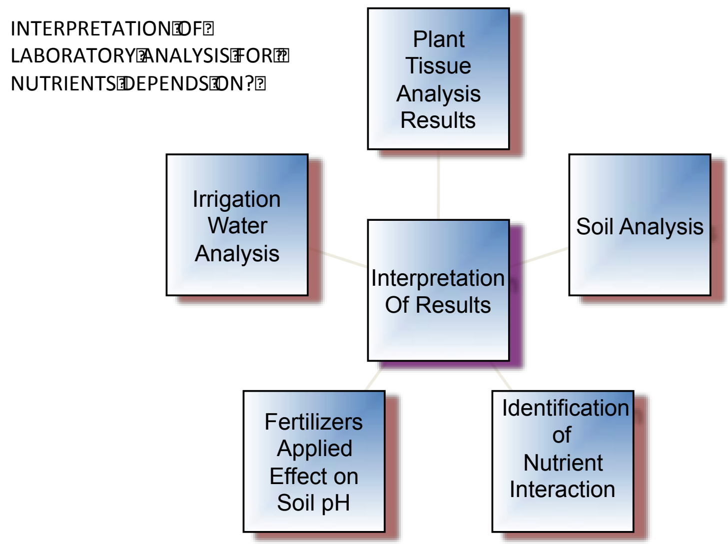
<u>Survey Value:</u> a concentration level for an essential plant nutrient element that has been determined based on an analysis of a particular plant part and stage of plant growth from a plant showing an acceptable visual appearance and or a desired economical yield. It should be understood that *Survey Values* might be modified over time as more data is obtained from additional analyses. *Survey Values* provide a workable alternative for those crop/plants currently without *Sufficiency Range* data.

It is important to remember that the *Sufficiency Ranges* and *Survey Values*given in this book are associated with a particular plant species and is related to a specific plant part and time of sampling; therefore, the application of these *Sufficiency Ranges* and *Survey Values* must be identical to the plant analysis results being evaluated.

An interpretation of a plant analysis result based on the utilization of *Sufficiency Ranges* or *Survey Values* requires skill and experience on the interpreter's part.

It should be recognized by the grower that with all analysis available to them for improving the nutrition of their crop, the plant is the final judge of what should be adjusted in their fertility program and this can only be determined from the analysis of a properly selected and shipped plant sample. To determine causation of a growth problem, all information related to cultural practices are useful to the interpreter of the tissue analysis results.

Many times growers and consultants do not use the most effective tools they have to aid in interpreting their ***plant tissue analysis*** results. Information to assist include:



In a plant analysis and the level of nutrients determined, there are no absolutes in terms of a nutrient element being sufficient or deficient or toxic, but a degree of being deficient or toxic. To illustrate this point let's assume you have submitted watermelon leaves for tissue analysis. The results show that the nitrogen level is 2.1%. This nitrogen value falls within the sufficiency range, 2-3 %, for this stage of growth for watermelons (Table 23-1). However, 2.1% N is at the low end of sufficiency range and requires action, application of this element, to maintain nitrogen in the sufficiency range. This stage of plant growth where fruit are developing and requiring nitrogen will certainly result in this mobile element moving out of the leaf with the ultimate result of nitrogen falling below the sufficiency level of 2.0%. The action required is the application of additional nitrogen to prevent a deficiency that most surely will occur. Many times the application of one essential plant nutrient element shown by an analysis to be close to or in the deficient zone will create an imbalance of another essential plant nutrient element that is sufficient but also at the lower level of the sufficiency range. It should be the goal for any interpretive response to a plant tissue analysis to have all the essential nutrients fall between the mid level range and the top value in the range. This simple practice will have as great of an impact on yield and quality as any cultural practice employed by the grower.

In an ever-increasing number of instances, identifying the excessive or toxicity concentration level of an essential plant nutrient element has become of equal importance to identifying its deficiency level. Often overlooked is the increase in disease and insect infestation in crops that express a nutrient deficiency or have toxic levels of elements present in the tissue. Imbalances in plant nutrients results in plant chemicals being given off into the air or present as exudates that attract insects that spread disease and adversely affect the health of a plant.

INSECTS ARE ATTRACTED TO NUTRIENT DEFICIENT PLANTS

Unfortunately, very little detailed information has been obtained on the toxicity level of a given nutrient that will adversely affect plant growth. Still today the use of plant analysis is the most effective means of determining the success of a growers cultural program, letting "***the plant to be the final judge"*** of the effectiveness of their cultural program**.**

Hidden hunger generally results from 1) a critical low level, not deficient but at the low end of sufficiency of a essential plant nutrient element that is unable to sustain the growth rate of the plant at a given time, and 2) a sufficient soil/media level of a given essential plant nutrient element that is suppressed in uptake and utilization when another essential plant nutrient element competes with the element and reduces it uptake and/or utilization to a point that the plant can not grow at a maximum rate (again the element limiting growth through hidden hunger is not deficient but generally at the low end of the sufficiency range). Hidden hunger is normally defined as where a 10% reduction in plant growth or yield occurs.

Chapter 24
Common Name Index to Nutritional Tables

Agronomic and Plantation Crops

Bedding Plants

Conifers

Cut Flower Crops

Ferns and Related Plants

Florist Pot Crops

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Forages and Hay Crops

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Ornamental Vines and Ground Covers

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Turfgrasses

Vegetable

Woody Ornamental Shrubs

Agronomic and Plantation Crops

A

SCIENTIFIC NAME			*Araceae c. esculenta*
COMMON NAME			**Taro**
COLLECTED FROM			Production fields
PLANT PART			Most recently matured leaf
SEASON			Mature
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	3.20 - 4.50	Fe	49–300
P	**0.24 - 0.50**	**Mn**	**49–250**
K	3.10 - 4.20	B	25–75
Ca	**0.35 - 1.20**	**Cu**	**7–15**
Mg	0.35 - 1.00	Zn	24 - 35
S	**0.24 - 0.40**	**Mo**	**0.15 - 0.40**

B

SCIENTIFIC NAME			*Araceae c. esculenta*
COMMON NAME			**Taro, dryland**
COLLECTED FROM			Production fields
PLANT PART			Most recently matured leaf
SEASON			Mid Root Development
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	4.2 - 4.5	Fe	150 - 200
P	**0.33 - 0.35**	**Mn**	**280 - 315**
K	3.7 - 4.2	B	24–26
Ca	**0.9 - 1.5**	**Cu**	**5–14**
Mg	0.36 - 0.43	Zn	22–38
S	**0.18 - 0.28**	**Mo**	**0.15–2**

C

SCIENTIFIC NAME			*Araceae c. esculenta*
COMMON NAME			**Taro, lowland**
COLLECTED FROM			Production fields
PLANT PART			Most recently matured leaf
SEASON			Mid Root Development
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	3 - 4.5	Fe	125 - 150
P	**0.3 - 0.5**	**Mn**	**300 - 400**
K	3 - 5.5	B	10 - 25
Ca	**0.75 - 1.5**	**Cu**	**6 - 12**
Mg	0.25 - 0.5	Zn	22 - 35
S	**0.2 - 0.30**	**Mo**	**0.2 - 0.6**

D

SCIENTIFIC NAME			*Arachis hypogaea*
COMMON NAME			**Peanut or Groundnut**
COLLECTED FROM			Production Fields
PLANT PART			25 whole shoots
SEASON			Early pegging
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	3.50 - 4.50	Fe	100–250
P	**0.20 - 0.35**	**Mn**	**100–350**
K	1.70 - 3.00	B	20–50
Ca	**1.25 - 1.75**	**Cu**	**10–50**
Mg	0.30 - 0.80	Zn	20–50
S	**0.20 - 0.30**	**Mo**	**0.10 - 5.00**

E

SCIENTIFIC NAME			*Arachis hypogaea*
COMMON NAME			**Peanut or Groundnut**
COLLECTED FROM			Production Fields
PLANT PART			50 whole shoots
SEASON			Prior to or at bloom stage
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	3.50 - 4.50	Fe	60 - 300
P	**0.25 - 0.50**	**Mn**	**60 - 350**
K	1.70 - 3.00	B	25 - 60
Ca	**1.25 - 2.00**	**Cu**	**5 - 20**
Mg	0.30 - 0.80	Zn	25 - 60
S	**0.20 - 0.35**	**Mo**	**0.10 - 5.00**

F

SCIENTIFIC NAME			*Avena sativa*
COMMON NAME			**Oats**
COLLECTED FROM			Production fields
PLANT PART			25 whole shoots
SEASON			Head emerges from boot
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	2.00 - 3.00	Fe	40–150
P	**0.20 - 0.50**	**Mn**	**25–100**
K	1.50 - 3.00	B	1.5–4
Ca	**0.20 - 0.50**	**Cu**	**5–25**
Mg	0.15 - 0.50	Zn	15–70
S	**0.15 - 0.40**	**Mo**	**0.20 - 0.30**

Agronomic and Plantation Crops

A

SCIENTIFIC NAME	*Beta vulgaris (Crassa group)*
COMMON NAME	**Sugar Beet**
COLLECTED FROM	Production fields
PLANT PART	25 recently matured leaves
SEASON	June-July, 50-80 days after planting
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	4.30 - 5.00	Fe	60 - 140
P	**0.45 - 1.10**	**Mn**	**26 - 360**
K	2.00 - 6.00	B	31 - 200
Ca	**0.50 - 1.50**	**Cu**	**11 - 40**
Mg	0.25 - 1.00	Zn	10 - 80
S	**0.21 - 0.50**	**Mo**	**0.20 - 2.00**

B

SCIENTIFIC NAME	*Brassica napus*
COMMON NAME	**Rapeseed for oil production**
COLLECTED FROM	Production fields
PLANT PART	50 mature leaves (5th from top) without petioles
SEASON	Rosette to pod development
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	4 - 6.4	Fe	45 - 100
P	**0.42 - 0.69**	**Mn**	**30 - 250**
K	3.5 - 5.1	B	25 - 54
Ca	**2.1 - 3**	**Cu**	**5 - 25**
Mg	0.25 - 0.62	Zn	33 - 49
S	**0.65 - 0.90**	**Mo**	**0.1 - 0.5**

C

SCIENTIFIC NAME	*Brassica napus*
COMMON NAME	**Canola or Rapeseed**
COLLECTED FROM	Production fields
PLANT PART	50 mature leaves (5th from top) without petioles
SEASON	Rosette to pod development
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.00 - 4.50	Fe	30 - 200
P	**0.28 - 0.69**	**Mn**	**25 - 250**
K	2.90 - 5.10	B	15 - 54
Ca	**1.00 - 3.00**	**Cu**	**4 - 25**
Mg	0.20 - 0.75	Zn	22 - 49
S	**0.17 - 1.04**	**Mo**	**0.25 - 0.60**

D

SCIENTIFIC NAME	*Cajanas cajan*
COMMON NAME	**Pigeonpea**
COLLECTED FROM	Production fields
PLANT PART	50 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.00 - 5.00	Fe	100 - 300
P	**0.15 - 0.40**	**Mn**	**30 - 350**
K	1.00 - 2.75	B	12 - 60
Ca	**0.75 - 1.50**	**Cu**	**10 - 20**
Mg	0.15 - 0.45	Zn	10 - 55
S	**0.15 - 0.35**	**Mo**	**0.20 - 0.45**

E

SCIENTIFIC NAME	*Camellia sinensis*
COMMON NAME	**Tea**
COLLECTED FROM	Field plantations
PLANT PART	100 leaves (3rd leaf from tip of young shoots)
SEASON	Actively-flushing plants
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.80 - 4.80	Fe	500 - 1000
P	**0.19 - 0.25**	**Mn**	**33 - 150**
K	1.80 - 2.00	B	30 - 50
Ca	**0.40 - 0.60**	**Cu**	**4 - 12**
Mg	0.15 - 0.30	Zn	30 - 50
S	**0.10 - 0.30**	**Mo**	**0.2 - 1**

F

SCIENTIFIC NAME	*Cannabis sativa*
COMMON NAME	**Cannabis**
COLLECTED FROM	Production nursery
PLANT PART	25 mature leaves from new growth
SEASON	Vegetative prior to flowering
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.3 - 4.76	Fe	100 - 150
P	**0.24 - 0.49**	**Mn**	**41 - 93**
K	1.83 - 2.35	B	56 - 105
Ca	**1.47 - 4.42**	**Cu**	**5 - 7.1**
Mg	0.4 - 0.81	Zn	24 - 52
S	**0.17 - 0.26**	**Mo**	**0.5 - 1.5**

Agronomic and Plantation Crops

A

Scientific Name	*Coffea arabica*		
Common Name	**Coffee, Arabian or Common**		
Collected From	Field plantations		
Plant Part	50 leaves (4th pair from tip)		
Season	Mature plants, flower initiation		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.30 - 3.00	Fe	70 - 125
P	**0.12 - 0.20**	**Mn**	**50 - 200**
K	2.00 - 2.50	B	40 - 75
Ca	**1.00 - 2.50**	**Cu**	**10 - 25**
Mg	0.25 - 0.40	Zn	12 - 30
S	**0.10 - 0.20**	**Mo**	**0.10 - 0.5**

B

Scientific Name	*Coffea arabica*		
Common Name	**Coffee, Arabian or Common - Non-Fruiting**		
Collected From	Field plantations		
Plant Part	50 leaves (4th pair from tip) from non-fruiting branches		
Season	Mature plants, fruiting		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.50	Fe	90–300
P	**0.15 - 0.35**	**Mn**	**50 - 300**
K	2.00 - 3.00	B	25 - 75
Ca	**1.00 - 2.20**	**Cu**	**10 - 50**
Mg	0.30 - 0.50	Zn	15 - 200
S	**0.25 - 0.50**	**Mo**	**0.16 - 0.5**

C

Scientific Name	*Coffea canephora*		
Common Name	**Robusta Coffee**		
Collected From	Field plantations		
Plant Part	50 leaves (4th pair from tip) from non-fruiting branches		
Season	Flower initiation		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.50	Fe	50 - 200
P	**0.12 - 0.15**	**Mn**	**50 - 150**
K	1.50 - 2.50	B	40 - 75
Ca	**1.00 - 2.50**	**Cu**	**10 - 40**
Mg	0.30 - 0.40	Zn	12 - 30
S	**0.15 - 0.25**	**Mo**	**0.10 - 0.50**

D

Scientific Name	*Elaeis guineensis*		
Common Name	**Oil Palm**		
Collected From	Field plantations		
Plant Part	40 leaflets from central portion of #3 frond		
Season	Young, non-fruiting trees		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.80 - 3.00	Fe	50 - 80
P	**0.17 - 0.23**	**Mn**	**150 - 200**
K	1.25 - 1.90	B	10 - 20
Ca	**0.30 - 0.65**	**Cu**	**5 - 8**
Mg	0.30 - 0.35	Zn	15 - 20
S	**0.16 - 0.26**	**Mo**	**0.50 - 1.00**

E

Scientific Name	*Elaeis guineensis*		
Common Name	**Oil Palm**		
Collected From	Field plantations		
Plant Part	40 leaflets from central portion of #17 frond		
Season	Mature fruiting trees		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 2.80	Fe	50 - 80
P	**0.15 - 0.20**	**Mn**	**80 - 200**
K	1.00 - 1.30	B	10 - 25
Ca	**0.60 - 1.00**	**Cu**	**5 - 18**
Mg	0.24 - 0.50	Zn	20 - 45
S	**0.18 - 0.24**	**Mo**	**0.50 - 1.00**

F

Scientific Name	*Glycine max*		
Common Name	**Soybean**		
Collected From	Production fields		
Plant Part	25 most recently matured trifoliate leaves		
Season	Early Growth		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.5 - 5.5	Fe	45 - 300
P	**0.3 - 0.6**	**Mn**	**23 - 133**
K	1.7 - 2.5	B	22 - 55
Ca	**1.1 - 2.2**	**Cu**	**5 - 15**
Mg	0.3 - 0.6	Zn	20 - 86
S	**0.3 - 0.80**	**Mo**	**1 - 10**

Agronomic and Plantation Crops

A

SCIENTIFIC NAME			*Glycine max*
COMMON NAME			**Soybean**
COLLECTED FROM			Production fields
PLANT PART			25 most recently matured trifoliate leaves
SEASON			Early Flowering
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	3.25 - 5	Fe	25 - 300
P	**0.3 - 0.6**	**Mn**	**17 - 100**
K	1.5 - 2.25	B	20 - 60
Ca	**0.8 - 1.4**	**Cu**	**4 - 30**
Mg	0.25 - 0.7	Zn	21 - 80
S	**0.25 - 0.60**	**Mo**	**0.1 - 2**

B

SCIENTIFIC NAME			*Glycine max*
COMMON NAME			**Soybean**
COLLECTED FROM			Production fields
PLANT PART			25 mature leaves from new growth
SEASON			Prior to pod set
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	4.00 - 5.50	Fe	50 - 350
P	**0.25 - 0.50**	**Mn**	**20 - 100**
K	1.70 - 2.50	B	20 - 55
Ca	**0.35 - 2.00**	**Cu**	**10 - 30**
Mg	0.25 - 1.00	Zn	20 - 50
S	**0.20 - 0.40**	**Mo**	**1.00 - 5.00**

C

SCIENTIFIC NAME			*Glycine max*
COMMON NAME			**Soybean**
COLLECTED FROM			Production fields
PLANT PART			25 mature leaves from new growth
SEASON			Pod-filling
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	3.5 - 5.00	Fe	45 - 200
P	**0.24 - 0.45**	**Mn**	**20 - 100**
K	1.7 - 2.5	B	20 - 50
Ca	**0.35 - 1.35**	**Cu**	**10 - 25**
Mg	0.25 - 0.6	Zn	20 - 50
S	**0.2 - 0.35**	**Mo**	**0.5 - 2.5**

D

SCIENTIFIC NAME			*Gossypium hirsutum*
COMMON NAME			**Cotton**
COLLECTED FROM			Production fields
PLANT PART			25 vegetative stems
SEASON			First squares to initial bloom
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	3.50 - 4.50	Fe	50 - 250
P	**0.30 - 0.50**	**Mn**	**25 - 350**
K	1.50 - 3.00	B	20 - 60
Ca	**2.00 - 3.00**	**Cu**	**5 - 25**
Mg	0.2 - 0.90	Zn	20 - 200
S	**0.25 - 0.80**	**Mo**	**0.22 - 1**

E

SCIENTIFIC NAME			*Gossypium hirsutum*
COMMON NAME			**Cotton**
COLLECTED FROM			Production fields
PLANT PART			25 vegetative stems
SEASON			Full bloom
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 4.30	Fe	40 - 300
P	**0.25 - 0.45**	**Mn**	**30 - 300**
K	0.90 - 2.00	B	20 - 60
Ca	**2.20 - 3.50**	**Cu**	**5 - 25**
Mg	0.30 - 0.80	Zn	20 - 100
S	**0.3 - 0.90**	**Mo**	**0.4 - 1**

F

SCIENTIFIC NAME			*Helianthus annuus*
COMMON NAME			**Sunflower**
COLLECTED FROM			Production fields
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 5.00	Fe	50 - 750
P	**0.25 - 0.60**	**Mn**	**50 - 1000**
K	2.00 - 5.00	B	35 - 150
Ca	**1.50 - 3.00**	**Cu**	**4 - 25**
Mg	0.25 - 1.00	Zn	25 - 100
S	**0.30 - 0.55**	**Mo**	**0.25 - 0.75**

Agronomic and Plantation Crops

A

Scientific Name			*Hibiscus cannabinus*
Common Name			**Kenaf or Indian Hemp**
Collected From			Production fields
Plant Part			10 stems (10 cm base section plus 10 cm section 1m from tip
Season			Summer
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.1 - 2.35	Fe	21 - 26
P	**0.12 - 0.19**	**Mn**	**14 - 23**
K	1.36 - 2.59	B	12 - 21
Ca	**0.31 - 0.41**	**Cu**	**1 - 3**
Mg	0.15 - 0.35	Zn	23 - 31
S	**0.16 - 0.28**	**Mo**	**0.80 - 0.90**

B

Scientific Name			*Hordeum vulgare*
Common Name			**Barley**
Collected From			Production fields
Plant Part			25 whole tops)
Season			Emergence of head from boot
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 3.00	Fe	30 - 200
P	**0.20 - 0.50**	**Mn**	**25 - 100**
K	1.50 - 3.00	B	1 - 5
Ca	**0.30 - 1.20**	**Cu**	**5 - 25**
Mg	0.15 - 0.50	Zn	15 - 70
S	**0.15 - 0.40**	**Mo**	**0.11 - 0.18**

C

Scientific Name			*Humulus lupulus*
Common Name			**Hops**
Collected From			Research Plots
Plant Part			25 mature leaves from new growth
Season			Reproductive stage and full flower
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.13 - 3.93	Fe	35.4 - 151
P	**0.18 - 0.43**	**Mn**	**50 - 150**
K	0.97 - 2.55	B	48 - 150
Ca	**3.09 - 6.05**	**Cu**	**5.7 - 16.6**
Mg	0.55 - 1.71	Zn	19.4 - 57.1
S	**0.18 - 0.30**	**Mo**	**1 - 5**

D

Scientific Name			*Humulus lupulus*
Common Name			**Hops**
Collected From			Production fields
Plant Part			25 mature leaves from new growth
Season			Vegetative stage prior to bloom
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.2 - 5.6	Fe	44.3 - 97.9
P	**0.27 - 0.54**	**Mn**	**45 - 125**
K	1.6 - 3.4	B	17.6 - 63.2
Ca	**1.03 - 2.57**	**Cu**	**8 - 29**
Mg	0.29 - 0.67	Zn	23.2 - 108
S	**0.2 - 0.34**	**Mo**	**0.5 - 3**

E

Scientific Name			*Manihot esculenta*
Common Name			**Cassava**
Collected From			Production fields
Plant Part			25 mature leaves from new growth
Season			Vegetative
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	5.00 - 6.00	Fe	60 - 200
P	**0.30 - 0.50**	**Mn**	**50 - 250**
K	1.20 - 2.00	B	15 - 20
Ca	**0.60 - 1.50**	**Cu**	**7 - 15**
Mg	0.25 - 0.50	Zn	40 - 100
S	**0.30 - 0.40**	**Mo**	**0.22 - 5**

F

Scientific Name			*Manihot esculenta*
Common Name			**Cassava**
Collected From			Production fields
Plant Part			25 mature leaves from new growth
Season			14 month old plants
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.8 - 1.9	Fe	82 - 150
P	**0.13 - 0.16**	**Mn**	**40 - 70**
K	1.7 - 2.7	B	33 - 40
Ca	**2.4 - 3.7**	**Cu**	**6 - 7**
Mg	0.4 - 0.6	Zn	43 - 100
S	**0.15 - 0.33**	**Mo**	**0.22 - 1**

Agronomic and Plantation Crops

A

SCIENTIFIC NAME	*Nicotiana tabacum*		
COMMON NAME	**Tobacco**		
COLLECTED FROM	Production fields		
PLANT PART	15 mature leaves from new growth		
SEASON	30-45 days after planting		
DATA TYPE	Survey Range		
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	3.50 - 6.50	Fe	430 - 1000
P	**0.10 - 0.40**	**Mn**	**26 - 200**
K	1.70 - 3.20	B	14 - 26
Ca	**1.60 - 2.40**	**Cu**	**10 - 24**
Mg	0.59 - 0.85	Zn	17 - 45
S	**0.18 - 0.28**	**Mo**	**0.22 - 1**

B

SCIENTIFIC NAME	*Nicotiana tabacum*		
COMMON NAME	**Tobacco**		
COLLECTED FROM	Production fields		
PLANT PART	15 mature leaves from new growth		
SEASON	45-60 days after planting		
DATA TYPE	Survey Range		
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	5.20 - 6.40	Fe	122 - 530
P	**0.17 - 1.00**	**Mn**	**34 - 351**
K	2.20 - 4.10	B	18 - 24
Ca	**1.70 - 2.00**	**Cu**	**17 - 34**
Mg	0.57 - 0.76	Zn	34 - 60
S	**0.18 - 0.28**	**Mo**	**0.2 - 0.5**

C

SCIENTIFIC NAME	*Nicotiana tabacum*		
COMMON NAME	**Tobacco**		
COLLECTED FROM	Production fields		
PLANT PART	15 mature leaves from new growth		
SEASON	60-80 days after planting		
DATA TYPE	Survey Range		
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	4.50 - 5.70	Fe	76 - 230
P	**0.19 - 0.37**	**Mn**	**36 - 400**
K	1.60 - 3.30	B	18 - 24
Ca	**1.60 - 2.10**	**Cu**	**12 - 30**
Mg	0.58 - 0.77	Zn	44 - 54
S	**0.18 - 0.28**	**Mo**	**0.2 - 0.5**

D

SCIENTIFIC NAME	*Nicotiana tabacum*		
COMMON NAME	**Tobacco**		
COLLECTED FROM	Production fields		
PLANT PART	15 mature leaves from new growth		
SEASON	80-100 days after planting		
DATA TYPE	Survey Range		
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	4.01 - 5.60	Fe	59 - 122
P	**0.15 - 0.34**	**Mn**	**41 - 337**
K	1.60 - 3.20	B	31 - 39
Ca	**0.80 - 2.60**	**Cu**	**15 - 23**
Mg	0.53 - 0.85	Zn	37 - 110
S	**0.18 - 0.30**	**Mo**	**0.2 - 0.5**

E

SCIENTIFIC NAME	*Nicotiana tabacum*		
COMMON NAME	**Tobacco**		
COLLECTED FROM	Production fields		
PLANT PART	15 mature leaves from new growth		
SEASON	Bloom stage		
DATA TYPE	Sufficiency Range		
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	3.50 - 4.25	Fe	50 - 200
P	**0.27 - 0.50**	**Mn**	**30 - 250**
K	2.50 - 3.20	B	20 - 50
Ca	**1.50 - 3.50**	**Cu**	**15 - 60**
Mg	0.20 - 0.65	Zn	20 - 80
S	**0.25 - 0.50**	**Mo**	**0.1 - 0.6**

F

SCIENTIFIC NAME	*Oryza sativa*		
COMMON NAME	**Rice**		
COLLECTED FROM	Production fields		
PLANT PART	25 mature leaves from new growth		
SEASON	Maximum tillering		
DATA TYPE	Sufficiency Range		
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	2.80 - 3.60	Fe	75 - 200
P	**0.10 - 0.18**	**Mn**	**200 - 800**
K	1.20 - 2.40	B	5 - 15
Ca	**0.15 - 0.30**	**Cu**	**8 - 25**
Mg	0.15 - 0.30	Zn	25 - 50
S	**0.18 - 0.33**	**Mo**	**1 - 5**

Agronomic and Plantation Crops

A

Scientific Name			*Oryza sativa*
Common Name			**Rice**
Collected From			Production fields
Plant Part			25 mature leaves from new growth
Season			Panicle initiation
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.60 - 3.20	Fe	70 - 150
P	**0.09 - 0.18**	**Mn**	**150 - 800**
K	1.00 - 2.20	B	6 - 10
Ca	**0.4 - 1.25**	**Cu**	**8 - 25**
Mg	0.20 - 0.30	Zn	18 - 50
S	**0.18 - 0.35**	**Mo**	**1 - 5**

B

Scientific Name			*Phaseolus vulgaris*
Common Name			**Black Turtle Bean**
Collected From			Production fields
Plant Part			25 most recently matured trifoliate leaves
Season			Bloom Stage
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 4.9	Fe	33 - 91
P	**0.28 - 0.45**	**Mn**	**22 - 80**
K	1.25 - 3.5	B	14 - 23
Ca	**0.78 - 2.31**	**Cu**	**5 - 18**
Mg	0.33 - 1.05	Zn	19 - 55
S	**0.23 - 0.38**	**Mo**	**0.5 - 5**

C

Scientific Name			*Phaseolus vulgaris*
Common Name			**Kidney Field Bean**
Collected From			Production fields
Plant Part			25 most recently matured trifoliate leaves
Season			Bloom Stage
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.89 - 5.5	Fe	25 - 75
P	**0.31 - 0.56**	**Mn**	**23 - 74**
K	1.56 - 3.3	B	5 - 22
Ca	**0.55 - 2**	**Cu**	**5 - 15**
Mg	0.33 - 1	Zn	21 - 78
S	**0.23 - 0.44**	**Mo**	**1.5 - 15**

D

Scientific Name			*Phaseolus vulgaris*
Common Name			**Navy Field Bean**
Collected From			Production fields
Plant Part			25 most recently matured trifoliate leaves
Season			Bloom Stage
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 5.3	Fe	25 - 75
P	**0.29 - 0.49**	**Mn**	**19 - 79**
K	1.78 - 3	B	15 - 25
Ca	**0.66 - 1.98**	**Cu**	**5 - 16**
Mg	0.33 - 1	Zn	22 - 80
S	**0.22 - 0.42**	**Mo**	**1.3 - 14**

E

Scientific Name			*Phaseolus vulgaris*
Common Name			**Pinto Field Bean**
Collected From			Production fields
Plant Part			25 most recently matured trifoliate leaves
Season			Bloom Stage
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3 - 5.5	Fe	20 - 250
P	**0.29 - 0.49**	**Mn**	**20 - 90**
K	1.5 - 2.9	B	6 - 24
Ca	**0.45 - 1.9**	**Cu**	**6 - 19**
Mg	0.25 - 1.4	Zn	15 - 69
S	**0.2 - 0.39**	**Mo**	**2 - 20**

F

Scientific Name			*Saccharum officinarum*
Common Name			**Sugarcane**
Collected From			Production fields
Plant Part			15 leaves, third leaf from tip
Season			3-5 months after planting
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.60	Fe	40 - 250
P	**0.18 - 0.30**	**Mn**	**25 - 400**
K	1.10 - 1.80	B	4 - 30
Ca	**0.20 - 0.50**	**Cu**	**5 - 15**
Mg	0.10 - 0.35	Zn	20 - 100
S	**0.14 - 0.20**	**Mo**	**0.05 - 4.00**

Agronomic and Plantation Crops

A

Scientific Name	*Secale cereale*
Common Name	**Rye**
Collected From	Production fields
Plant Part	25 whole tops
Season	Panicle initiation
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.00 - 5.00	Fe	30 - 200
P	**0.52 - 0.65**	**Mn**	**14 - 45**
K	1.90 - 2.30	B	1.5 - 4
Ca	**0.2 - 1**	**Cu**	**5 - 10**
Mg	0.20 - 0.60	Zn	18 - 70
S	**0.15 - 0.65**	**Mo**	**0.20 - 2.00**

B

Scientific Name	*Sorghum bicolor*
Common Name	**Sorghum**
Collected From	Production fields
Plant Part	25 mature leaves from new growth
Season	37-56 days after planting
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.20 - 4.20	Fe	55 - 200
P	**0.13 - 0.25**	**Mn**	**6 - 100**
K	2.00 - 3.00	B	1 - 10
Ca	**0.15 - 0.90**	**Cu**	**2 - 15**
Mg	0.20 - 0.50	Zn	20 - 40
S	**0.18 - 0.45**	**Mo**	**0.15 - 1.17**

C

Scientific Name	*Sorghum bicolor*
Common Name	**Sorghum**
Collected From	Production fields
Plant Part	25 leaves, third leaf below head
Season	Grain in dough condition
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.00 - 4.00	Fe	40 - 80
P	**0.15 - 0.25**	**Mn**	**8 - 40**
K	1.00 - 1.50	B	1 - 6
Ca	**0.20 - 0.60**	**Cu**	**1 - 3**
Mg	0.10 - 0.50	Zn	7 - 16
S	**0.16 - 0.44**	**Mo**	**0.15 - 1.17**

D

Scientific Name	*Sorghum bicolor*
Common Name	**Sorghum**
Collected From	Production fields
Plant Part	25 leaves, third leaf below head
Season	Plants at bloom stage, heads visible
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.30 - 4.00	Fe	65 - 100
P	**0.23 - 0.35**	**Mn**	**10 - 190**
K	1.40 - 1.70	B	1 - 10
Ca	**0.30 - 0.60**	**Cu**	**2 - 7**
Mg	0.10 - 0.20	Zn	15 - 30
S	**0.16 - 0.45**	**Mo**	**0.14 - 1.08**

E

Scientific Name	*Sorghum bicolor*
Common Name	**Sorghum**
Collected From	Production fields
Plant Part	25 whole tops
Season	Seedlings <30 cm tall, 23-39 days old
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.50 - 5.10	Fe	160 - 250
P	**0.30 - 0.60**	**Mn**	**40 - 150**
K	3.00 - 4.50	B	4 - 13
Ca	**0.90 - 1.30**	**Cu**	**8 - 15**
Mg	0.35 - 0.50	Zn	30 - 60
S	**0.18 - 0.38**	**Mo**	**0.14 - 1**

F

Scientific Name	*Theobroma cacao*
Common Name	**Cocoa or Chocolate**
Collected From	Field plantations
Plant Part	10 mature leaves from under canopy and tree periphery
Season	Pod-filling
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	2.00 - 2.50	Fe	60 - 200
P	**0.13 - 0.25**	**Mn**	**50 - 300**
K	1.30 - 2.20	B	25 - 70
Ca	**0.30 - 0.60**	**Cu**	**8 - 12**
Mg	0.20 - 0.50	Zn	20 - 100
S	**0.16 - 0.27**	**Mo**	**1.00 - 2.50**

Agronomic and Plantation Crops

A

Scientific Name	*Triticum aestivum*		
Common Name	**Spring Wheat**		
Collected From	Production fields		
Plant Part	25 whole tops		
Season	As head emerges from boot		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.00	Fe	25 - 100
P	**0.20 - 0.50**	**Mn**	**25 - 100**
K	1.50 - 3.00	B	6 - 10
Ca	**0.20 - 0.50**	**Cu**	**5 - 25**
Mg	0.15 - 0.50	Zn	15 - 70
S	**0.15 - 0.40**	**Mo**	**0.09 - 0.18**

B

Scientific Name	*Triticum aestivum*		
Common Name	**Winter Wheat**		
Collected From	Production fields		
Plant Part	50 leaves, top two leaves		
Season	Just before heading		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 3.00	Fe	10 - 300
P	**0.20 - 0.50**	**Mn**	**16 - 200**
K	1.50 - 3.00	B	1.5 - 4
Ca	**0.20 - 1.00**	**Cu**	**5 - 50**
Mg	0.15 - 1.00	Zn	20 - 70
S	**0.15 - 0.65**	**Mo**	**0.1 - 0.5**

C

Scientific Name	*Vicia faba*		
Common Name	**Faba or Broad Bean**		
Collected From	Production fields		
Plant Part	50 leaf blades without petioles from uppermost mature leaves		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4.80 - 5.50	Fe	22 - 175
P	**0.32 - 0.42**	**Mn**	**25 - 300**
K	2.40 - 3.20	B	5 - 22
Ca	**0.50 - 0.75**	**Cu**	**5 - 15**
Mg	0.38 - 0.42	Zn	22 - 88
S	**0.21 - 0.33**	**Mo**	**0.5 - 1.5**

D

Scientific Name	*Zea mays*		
Common Name	**Corn or Maize - <4" tall**		
Collected From	Production fields		
Plant Part	15 whole tops		
Season	Seedling less than 4 inches in height		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4 - 5	Fe	40 - 250
P	**0.4 - 0.6**	**Mn**	**25 - 160**
K	3 - 4	B	5 - 25
Ca	**0.3 - 0.8**	**Cu**	**6 - 20**
Mg	0.2 - 0.6	Zn	20 - 60
S	**0.18 - 0.50**	**Mo**	**0.1 - 0.25**

E

Scientific Name	*Zea mays*		
Common Name	**Corn or Maize - Young Plants**		
Collected From	Production fields		
Plant Part	15 whole tops		
Season	Plants <12" tall		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.50 - 5.00	Fe	30 - 250
P	**0.30 - 0.50**	**Mn**	**20 - 150**
K	2.50 - 3.5	B	5 - 25
Ca	**0.30 - 1**	**Cu**	**5 - 20**
Mg	0.15 - 0.65	Zn	20 - 70
S	**0.15 - 0.40**	**Mo**	**0.10 - 2**

F

Scientific Name	*Zea mays*		
Common Name	**Corn or Maize - Prior To Tasseling**		
Collected From	Production fields		
Plant Part	12 leaves below the whorl		
Season	Prior to tasseling		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 4	Fe	30 - 250
P	**0.25 - 0.45**	**Mn**	**20 - 150**
K	2.00 - 2.50	B	4 - 25
Ca	**0.25 - 0.50**	**Cu**	**5 - 25**
Mg	0.13 - 0.30	Zn	20 - 60
S	**0.15 - 0.50**	**Mo**	**0.10 - 0.30**

Agronomic and Plantation Crops

A

Scientific Name			*Zea mays*
Common Name			**Corn or Maize - Silking**
Collected From			Production fields
Plant Part			12 leaves from base of ear
Season			Initial silk
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.8 - 4	Fe	20 - 250
P	**0.25 - 0.5**	**Mn**	**15 - 150**
K	1.8 - 3.00	B	5 - 25
Ca	**0.25 - 0.8**	**Cu**	**6 - 25**
Mg	0.20 - 0.65	Zn	20 - 70
S	**0.15 - 0.40**	**Mo**	**0.10 - 0.20**

B

Scientific Name			*Zea mays*
Common Name			**Corn or Maize - Grain Fill**
Collected From			Production fields
Plant Part			8-12 unfurled leaves (5th leaf from tip)
Season			Grain filling stage
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 3.8	Fe	20 - 200
P	**0.24 - 0.45**	**Mn**	**20 - 180**
K	1.7 - 2.8	B	5 - 20
Ca	**0.25 - 0.9**	**Cu**	**6 - 15**
Mg	0.2 - 0.75	Zn	20 - 50
S	**0.21 - 0.44**	**Mo**	**0.15 - 0.3**

C

Scientific Name			*Zea mays*
Common Name			**Corn or Maize - Maturity**
Collected From			Production fields
Plant Part			12 leaves from base of ear
Season			Maturity
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.3 - 3.5	Fe	30 - 250
P	**0.25 - 0.4**	**Mn**	**15 - 150**
K	1.8 - 2.5	B	3 - 20
Ca	**0.2 - 0.8**	**Cu**	**5 - 25**
Mg	0.12 - 0.5	Zn	20 - 70
S	**0.12 - 0.40**	**Mo**	**0.1 - 0.2**

D

E

F

Bedding Plants

A

SCIENTIFIC NAME			*Ageratum houstonianum*
COMMON NAME			**Garden Ageratum or Flossflower**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Mature plants (36-cell packs)
DATA TYPE			Survey Range
CULTIVARS USED			Hawaii Blue'
Macronutrients %		**Micronutrients ppm**	
N	2.75 - 3.82	Fe	33 - 123
P	**0.33 - 0.42**	**Mn**	**45 - 110**
K	2.1 - 3	B	22 - 35
Ca	**.88 - 1.61**	**Cu**	**6 - 10**
Mg	.34 - .65	Zn	25 - 107
S	**0.22 - 0.73**	**Mo**	**.13 - 1.17**

B

SCIENTIFIC NAME			*Angelonia angustifolia*
COMMON NAME			**Summer Snapdragon**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Vegetative
DATA TYPE			Survey Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	4.63 - 5.06	Fe	99.6 - 110
P	**0.44 - 0.63**	**Mn**	**83.6 - 108.7**
K	2.82 - 3.47	B	29.6 - 46.2
Ca	**0.88 - 1.18**	**Cu**	**8.3 - 12.4**
Mg	0.24 - 0.3	Zn	59.4 - 86.2
S	**0.33 - 0.51**	**Mo**	**1 - 5**

C

SCIENTIFIC NAME			*Angelonia angustifolia*
COMMON NAME			**Summer Snapdragon**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Young plants/ Cutting
DATA TYPE			Survey Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	3.43 - 4.66	Fe	62.4 - 125.3
P	**0.34 - 0.5**	**Mn**	**47.7 - 184.4**
K	2.36 - 3.34	B	26.5 - 47.4
Ca	**0.3 - 0.8**	**Cu**	**2.2 - 11.2**
Mg	0.19 - 0.39	Zn	43.3 - 106.8
S	**0.13 - 0.51**	**Mo**	**1 - 5**

D

SCIENTIFIC NAME			*Annual Flowers*
COMMON NAME			**General**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			10-15 mature leaves from new growth
SEASON			Vegetative
DATA TYPE			Survey Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 5.0	Fe	50 - 200
P	**0.20 - 0.80**	**Mn**	**25 - 100**
K	1.75 - 4.50	B	10 - 32
Ca	**1.0 - 2.0**	**Cu**	**5 - 35**
Mg	0.25 - 1.0	Zn	20 - 125
S	**0.25 - 0.80**	**Mo**	**0.20 - 1.50**

E

SCIENTIFIC NAME			*Antirrhinum majus*
COMMON NAME			**Bedding Snapdragon**
COLLECTED FROM			Greenhouse nursery production
PLANT PART			50 mature leaves from new growth
SEASON			Mature plants (36-cell packs)
DATA TYPE			Survey Range
CULTIVARS USED			Liberty White', others not specified
Macronutrients %		**Micronutrients ppm**	
N	3.80 - 5.00	Fe	45 - 75
P	**0.30 - 0.50**	**Mn**	**43 - 139**
K	2.00 - 3.00	B	23 - 30
Ca	**1.00 - 1.50**	**Cu**	**6 - 9**
Mg	.34 - 0.84	Zn	35 - 56
S	**0.24 - 0.46**	**Mo**	**0.21 - 0.95**

F

SCIENTIFIC NAME			*Bedding Plants*
COMMON NAME			**General**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			10-15 mature leaves from new growth
SEASON			Vegetative
DATA TYPE			Survey Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 4.60	Fe	30 - 250
P	**0.11 - 0.67**	**Mn**	**30 - 300**
K	1.00 - 8.00	B	14 - 175
Ca	**.30 - 2.6**	**Cu**	**5 - 28**
Mg	.11 - 1.90	Zn	25 - 100
S	**0.22 - 0.38**	**Mo**	**0.2 - 5.0**

Bedding Plants

A

Scientific Name	*Bedding Plants*
Common Name	**Greenhouse Production**
Collected From	Greenhouse production nursery
Plant Part	10-15 mature leaves from new growth
Season	Vegetative
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	2.4 - 5.0	Fe	25 - 75
P	**0.20 - 0.50**	**Mn**	**20 - 60**
K	2.00 - 4.50	B	15 - 40
Ca	**0.40 - 1.50**	**Cu**	**5 - 28**
Mg	0.20 - 1.00	Zn	25 - 75
S	**0.20 - 0.35**	**Mo**	**0.20 - 2.5**

B

Scientific Name	*Begonia x semperflorens-cultorum*
Common Name	**Bedding or Waxleaf Begonia**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Sufficiency Range
Cultivars Used	Prelude Red', 'Whiskey', otheres not specified

Macronutrients %		Micronutrients ppm	
N	2.00 - 6.00	Fe	50 - 200
P	**0.29 - 0.75**	**Mn**	**45 - 200**
K	2.25 - 6.00	B	20 - 75
Ca	**1.00 - 3.10**	**Cu**	**7 - 33**
Mg	0.30 - 0.88	Zn	25 - 100
S	**0.22 - 0.70**	**Mo**	**0.50 - 0.80**

C

Scientific Name	*Brachyscome hybrid*
Common Name	**Native Daisy (Australian)**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Vegetative
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	6.99 - 7.46	Fe	116.5 - 298.3
P	**0.58 - 0.61**	**Mn**	**30 - 60**
K	4.77 - 4.95	B	34 - 67
Ca	**0.67 - 0.83**	**Cu**	**4.5 - 5.3**
Mg	0.23 - 0.26	Zn	22 - 55
S	**0.31 - 0.45**	**Mo**	**1 - 5**

D

Scientific Name	*Brachyscome hybrid (cutting)*
Common Name	**Native Daisy (Australian)**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Young Plants/Cutting
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	3.6 - 6	Fe	56.2 - 266.1
P	**0.39 - 0.7**	**Mn**	**85.1 - 353.2**
K	2.9 - 4.75	B	39.2 - 92.2
Ca	**0.53 - 1.15**	**Cu**	**5.1 - 23.5**
Mg	0.15 - 0.43	Zn	24 - 78.5
S	**0.48 - 0.98**	**Mo**	**1 - 5**

E

Scientific Name	*Bracteantha bracteata*
Common Name	**Straw Flower**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Mature leaves
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	5.51 - 6.33	Fe	61.4 - 89.9
P	**0.76 - 0.82**	**Mn**	**117.4 - 174.3**
K	6.04 - 6.74	B	28.5 - 31.2
Ca	**1.42 - 1.46**	**Cu**	**5.8 - 6.8**
Mg	0.21 - 0.29	Zn	32 - 34.4
S	**0.21 - 0.28**	**Mo**	**0.35 - 1**

F

Scientific Name	*Bracteantha bracteata (cutting)*
Common Name	**Straw Flower**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Young Plants/Cutting
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	3.83 - 5.9	Fe	57.2 - 139
P	**0.5 - 0.75**	**Mn**	**91.5 - 324**
K	3.6 - 6.31	B	37.4 - 90.7
Ca	**0.77 - 1.5**	**Cu**	**3.1 - 15.5**
Mg	0.2 - 0.52	Zn	49.4 - 130.8
S	**0.47 - 0.98**	**Mo**	**0.23 - 1**

Bedding Plants

A

Scientific Name			*Calibrachoa x hybrida*
Common Name			**Million Bells**
Collected From			Greenhouse production nursery
Plant Part			25 mature leaves from new growth
Season			Mature
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	5.04 - 5.06	Fe	68 - 110.4
P	**0.36 - 0.42**	**Mn**	**70.4 - 107.7**
K	2.95 - 4.22	B	32 - 37.4
Ca	**1.48 - 1.84**	**Cu**	**9.4 - 9.9**
Mg	0.28 - 0.39	Zn	27.4 - 43.9
S	**0.44 - 0.61**	**Mo**	**0.1 - 0.45**

B

Scientific Name			*Calibrachoa x hybrida (cutting)*
Common Name			**Million Bells**
Collected From			Greenhouse production nursery
Plant Part			25 mature leaves from new growth
Season			Young Plants/Cutting
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4.06 - 5.8	Fe	59 - 199.7
P	**0.3 - 0.63**	**Mn**	**41.4 - 166.5**
K	2.6 - 3.98	B	29.4 - 80.9
Ca	**0.48 - 1.37**	**Cu**	**4.3 - 17**
Mg	0.26 - 0.68	Zn	26 - 68.6
S	**0.23 - 1.13**	**Mo**	**0.13 - 0.5**

C

Scientific Name			*Callistephus chinensis*
Common Name			**China or Annual Aster**
Collected From			Greenhouse production nursery
Plant Part			50 mature leaves from new growth
Season			Mature plants (36-cell pack)
Data Type			Survey Range
Cultivars Used			Queen Dwarf Mix'
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 5.60	Fe	31 - 81
P	**0.22 - 0.71**	**Mn**	**0.33 - 215**
K	2.5 - 3.45	B	25 - 44
Ca	**0.45 - 0.88**	**Cu**	**4 - 19**
Mg	0.33 - 0.68	Zn	22 - 119
S	**0.16 - 0.37**	**Mo**	**0.1 - 0.35**

D

Scientific Name			*Capsicum annuum*
Common Name			**Ornamental Peppers**
Collected From			Research nursery
Plant Part			25 mature leaves from new growth
Season			Vegetative, just prior to flowering
Data Type			Sufficiency Range
Cultivars Used			Not specified
Macronutrients %		**Micronutrients ppm**	
N	3.2 - 4.8	Fe	42 - 350
P	**0.35 - 1.1**	**Mn**	**50 - 250**
K	2.7 - 4.0	B	25 - 65
Ca	**1.5 - 2.8**	**Cu**	**10 - 25**
Mg	0.35 - 1.0	Zn	25 - 45
S	**0.32 - 0.65**	**Mo**	**0.18 - 0.5**

E

Scientific Name			*Capsicum annuum*
Common Name			**Ornamental Peppers**
Collected From			Research nursery
Plant Part			25 mature leaves from new growth
Season			Vegetative
Data Type			Sufficiency Range
Cultivars Used			Not specified
Macronutrients %		**Micronutrients ppm**	
N	3.5 - 5.8	Fe	60 - 200
P	**0.35 - 0.68**	**Mn**	**50 - 250**
K	3.30 - 6.00	B	25 - 55
Ca	**1.00 - 2.80**	**Cu**	**6 - 25**
Mg	0.40 - 1.20	Zn	25 - 160
S	**0.31 - 0.50**	**Mo**	**0.15 - 0.50**

F

Scientific Name			*Catharanthus roseus*
Common Name			**Vinca or Madagascar or Rosy Periwinkle**
Collected From			Greenhouse production nursery & field research plots
Plant Part			50 mature leaves from new growth
Season			Mature plants (4" pots & 36-cell pack)
Data Type			Survey Range
Cultivars Used			Grape Cooler', 'Pacifica Red', 'Passion', others not specified
Macronutrients %		**Micronutrients ppm**	
N	2.72 - 6.28	Fe	72–277
P	**0.28 - 0.64**	**Mn**	**135–302**
K	1.88 - 3.48	B	21–49
Ca	**0.93 - 1.13**	**Cu**	**6–16**
Mg	0.32 - 0.78	Zn	30–51
S	**0.22 - 0.50**	**Mo**	**0.14 - 0.46**

Bedding Plants

A

Scientific Name	*Celosia argentea (Cristata Group)*
Common Name	**Cockscomb or Crested Celosia**
Collected From	Greenhouse production nursery
Plant Part	50 mature leaves from new growth
Season	Mature plants (36-cell pack)
Data Type	Survey Range
Cultivars Used	Fire Chief', 'Jewel Box Light Rose', 'Jewel Box Orange'

Macronutrients %		Micronutrients ppm	
N	3.71 - 4.13	Fe	88 - 189
P	**0.43 - 1.13**	**Mn**	**261 - 896**
K	3.88 - 5.06	B	23 - 50
Ca	**2.86 - 4.10**	**Cu**	**17 - 22**
Mg	1.36 - 4.05	Zn	182 - 242
S	**0.64 - 0.90**	**Mo**	**0.15 - 0.84**

B

Scientific Name	*Celosia argentea (Plumosa Group)*
Common Name	**Plumed Celosia or Feathered Amaranth**
Collected From	Greenhouse production nursery
Plant Part	50 mature leaves from new growth
Season	Mature plants (36-cell pack)
Data Type	Survey Range
Cultivars Used	New Look'

Macronutrients %		Micronutrients ppm	
N	2.1 - 5.27	Fe	34 - 130
P	**0.22 - 0.69**	**Mn**	**45 - 372**
K	1.78 - 4.53	B	18 - 53
Ca	**1.12 - 2.79**	**Cu**	**5 - 18**
Mg	0.55 - 2.54	Zn	78 - 175
S	**0.22 - 0.27**	**Mo**	**0.25 - 0.5**

C

Scientific Name	*Cleome hassleriana*
Common Name	**Spider Flower or Cleome**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Mature plants (4" pots)
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	2 - 5.54	Fe	38 - 205
P	**0.22 - 0.95**	**Mn**	**44 - 122**
K	1.11 - 3.81	B	56 - 61
Ca	**1.2 - 2.13**	**Cu**	**7 - 14**
Mg	0.35 - 0.73	Zn	78 - 142
S	**0.23 - 0.33**	**Mo**	**0.25 - 0.73**

D

Scientific Name	*Coleus x hybridus*
Common Name	**Garden Coleus**
Collected From	Greenhouse production nursery
Plant Part	40 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	2.95 - 3.88	Fe	49 - 79
P	**1.05 - 1.26**	**Mn**	**312 - 352**
K	3.66 - 4.74	B	29 - 32
Ca	**1.48 - 1.65**	**Cu**	**10 - 13**
Mg	1.27 - 1.48	Zn	35 - 48
S	**0.76 - 1.01**	**Mo**	**0.26 - 0.97**

E

Scientific Name	*Dianthus*
Common Name	**General**
Collected From	Greenhouse production nursery
Plant Part	50 mature leaves from new growth
Season	Vegetative
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	2.80 - 5.20	Fe	50 - 200
P	**0.19 - 0.80**	**Mn**	**33 - 202**
K	1.17 - 6.00	B	20 - 50
Ca	**1.00 - 2.00**	**Cu**	**8 - 15**
Mg	0.19 - 0.70	Zn	20 - 200
S	**0.25 - 0.80**	**Mo**	**0.2 - 2.5**

F

Scientific Name	*Dianthus chinensis*
Common Name	**Annual Dianthus or China Pink**
Collected From	Greenhouse production nursery
Plant Part	50 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Survey Range
Cultivars Used	Ideal Deep Violet'

Macronutrients %		Micronutrients ppm	
N	1.78 - 4.84	Fe	45 - 81
P	**0.19 - 0.48**	**Mn**	**45 - 442**
K	2.2 - 3.70	B	14 - 30
Ca	**0.65 - 1.68**	**Cu**	**4 - 10**
Mg	0.34 - 1.05	Zn	22 - 75
S	**0.19 - 0.30**	**Mo**	**0.1 - 0.77**

Bedding Plants

A

Scientific Name	*Impatiens wallerana cultivars*
Common Name	**Bedding or Garden Impatiens**
Collected From	Greenhouse production nursery
Plant Part	50 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Survey Range
Cultivars Used	Dazzler Violet', 'Super Elfin Red', others not specified

Macronutrients %		Micronutrients ppm	
N	3.64 - 5.83	Fe	107 - 130
P	**0.77 - 0.92**	**Mn**	**329 - 419**
K	1.37 - 2.35	B	23 - 25
Ca	**1.75 - 2.40**	**Cu**	**20 - 37**
Mg	0.89 - 3.64	Zn	57 - 67
S	**0.83 - 0.87**	**Mo**	**0.33 - 0.88**

B

Scientific Name	*Impatiens x New Guinea Hybrids*
Common Name	**New Guinea Impatiens**
Collected From	Greenhouse production nursery
Plant Part	40 mature leaves from new growth
Season	Mature plants (4" pots)
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	2.00 - 4.50	Fe	75 - 300
P	**0.20 - 0.80**	**Mn**	**50 - 250**
K	1.50 - 4.50	B	20 - 60
Ca	**0.50 - 2.00**	**Cu**	**5 - 15**
Mg	0.30 - 0.80	Zn	25 - 100
S	**0.24 - 0.35**	**Mo**	**0.15 - 1.00**

C

Scientific Name	*Lobularia maritima*
Common Name	**Sweet Alyssum**
Collected From	Greenhouse production nursery
Plant Part	100 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Survey Range
Cultivars Used	Royal Carpet'

Macronutrients %		Micronutrients ppm	
N	2 - 6.39	Fe	0.33 - 76
P	**0.23 - 0.68**	**Mn**	**56 - 209**
K	1.33 - 4.36	B	18 - 33
Ca	**1.22 - 2.29**	**Cu**	**6 - 11**
Mg	0.5 - 1.32	Zn	122 - 244
S	**0.27 - 0.35**	**Mo**	**0.19 - 0.5**

D

Scientific Name	*Nemesia fruticans*
Common Name	**Nemesia**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Vegetative prior to flowering
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	5.63 - 5.94	Fe	55.1 - 55.8
P	**0.51 - 0.59**	**Mn**	**81.2 - 112.5**
K	4.6 - 4.94	B	42 - 43.4
Ca	**1.5 - 1.64**	**Cu**	**5.9 - 7**
Mg	0.33 - 0.78	Zn	20 - 22
S	**0.16 - 0.23**	**Mo**	**1 - 5**

E

Scientific Name	*Nemesia fruticans (cutting)*
Common Name	**Nemesia**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Vegetative prior to flowering
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	4.3 - 6.2	Fe	66.9 - 250.1
P	**0.46 - 0.71**	**Mn**	**54.7 - 182**
K	2.5 - 3.98	B	36 - 96
Ca	**0.75 - 1.5**	**Cu**	**6.6 - 19.1**
Mg	0.21 - 0.64	Zn	44.2 - 94.6
S	**0.36 - 0.90**	**Mo**	**0.8 - 1**

F

Scientific Name	*Nicotiana alata*
Common Name	**Flowering Tobacco**
Collected From	Greenhouse production nursery
Plant Part	40 mature leaves from new growth
Season	Mature plants (4" pots)
Data Type	Survey Range
Cultivars Used	Domino White'

Macronutrients %		Micronutrients ppm	
N	2.4 - 4.67	Fe	34 - 432
P	**0.26 - 0.54**	**Mn**	**44 - 353**
K	1.11 - 4.87	B	14 - 32
Ca	**0.98 - 2.49**	**Cu**	**4 - 9**
Mg	0.33 - 0.86	Zn	24 - 54
S	**0.18 - 0.65**	**Mo**	**0.23 - 0.95**

Bedding Plants

A

Scientific Name			*Osteospermum hybrida*
Common Name			**African Daisy**
Collected From			Greenhouse production nursery
Plant Part			25 mature leaves from new growth
Season			Mature
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	5.7 - 6.5	Fe	63.2 - 65.3
P	**0.3 - 0.54**	**Mn**	**95.2 - 142**
K	4.5 - 5	B	43 - 60.2
Ca	**1.7 - 1.8**	**Cu**	**6.3 - 7**
Mg	0.29 - 0.5	Zn	14 - 23.3
S	**0.2 - 0.31**	**Mo**	**0.12 - 0.5**

B

Scientific Name			*Osteospermum hybrida (cutting)*
Common Name			**African Daisy**
Collected From			Greenhouse production nursery
Plant Part			25 mature leaves from new growth
Season			Young Plants/Cutting
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.77 - 6.53	Fe	64.8 - 190
P	**0.43 - 0.9**	**Mn**	**83.2 - 281.2**
K	2.97 - 4.67	B	34.2 - 84.2
Ca	**1.14 - 2.52**	**Cu**	**6.4 - 23.6**
Mg	0.39 - 1.02	Zn	28.2 - 80.3
S	**0.29 - 1.88**	**Mo**	**0.12 - 0.5**

C

Scientific Name			*Pelargonium x hortorum*
Common Name			**Zonal or Bedding Geranium**
Collected From			Greenhouse production nursery
Plant Part			40 mature leaves from new growth
Season			Mature plants (4" pots)
Data Type			Sufficiency Range
Cultivars Used			Not specified
Macronutrients %		**Micronutrients ppm**	
N	3.29 - 4.80	Fe	100 - 580
P	**0.30 - 1.24**	**Mn**	**40 - 325**
K	2.50 - 6.26	B	30 - 75
Ca	**0.80 - 2.40**	**Cu**	**5 - 25**
Mg	0.19 - 0.51	Zn	7 - 100
S	**0.25 - 0.70**	**Mo**	**0.14 - 0.66**

D

Scientific Name			*Petunia x hybrida*
Common Name			**Garden Petunia**
Collected From			Greenhouse production nursery
Plant Part			50 mature leaves from new growth
Season			Mature plants (36-cell packs)
Data Type			Survey Range
Cultivars Used			Carpet Red', 'Carpet Rose', others not specified
Macronutrients %		**Micronutrients ppm**	
N	3.85 - 7.60	Fe	84 - 168
P	**0.47 - 0.93**	**Mn**	**44 - 177**
K	3.13 - 6.65	B	18 - 43
Ca	**1.20 - 2.81**	**Cu**	**3 - 19**
Mg	0.36 - 1.37	Zn	33 - 85
S	**0.33 - 0.80**	**Mo**	**0.19 - 0.46**

E

Scientific Name			*Portulaca grandiflora*
Common Name			**Moss Rose or Portulaca**
Collected From			Greenhouse production nursery
Plant Part			100 mature leaves from new growth
Season			Mature plants (36-cell packs)
Data Type			Survey Range
Cultivars Used			Sundial Mix'
Macronutrients %		**Micronutrients ppm**	
N	2.45 - 5.49	Fe	45 - 115
P	**0.35 - 1.07**	**Mn**	**30 - 308**
K	2.25 - 6.74	B	15 - 32
Ca	**0.45 - 0.87**	**Cu**	**5 - 10**
Mg	0.4 - 1.28	Zn	34 - 147
S	**0.23 - 0.57**	**Mo**	**0.25 - 0.71**

F

Scientific Name			*Primula x*
Common Name			**Polyanthus Group (Garden Primrose)**
Collected From			Greenhouse production nursery
Plant Part			40 mature leaves from new growth
Season			Mature plants (4" pots)
Data Type			Sufficiency Range
Cultivars Used			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.30	Fe	75 - 155
P	**0.40 - 0.80**	**Mn**	**50 - 80**
K	1.80 - 3.00	B	30 - 35
Ca	**0.60 - 1.00**	**Cu**	**5 - 10**
Mg	0.20 - 0.40	Zn	40 - 45
S	**0.18 - 0.29**	**Mo**	**0.25 - 0.45**

Bedding Plants

A

Scientific Name	*Salvia splendens*
Common Name	**Bedding or Scarlet Salvia**
Collected From	Greenhouse production nursery
Plant Part	50 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Sufficiency Range
Cultivars Used	Hotline Red', others not specified

Macronutrients %		**Micronutrients ppm**	
N	2.38 - 5.61	Fe	60 - 300
P	**0.30 - 1.24**	**Mn**	**30 - 284**
K	2.90 - 5.86	B	25 - 75
Ca	**1.00 - 2.50**	**Cu**	**7 - 35**
Mg	0.25 - 0.86	Zn	25 - 115
S	**0.22 - 0.73**	**Mo**	**0.20 - 1.08**

B

Scientific Name	*Senecio cineraria*
Common Name	**Dusty Miller**
Collected From	Greenhouse production nursery
Plant Part	40 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Survey Range
Cultivars Used	Silverdust'

Macronutrients %		**Micronutrients ppm**	
N	2 - 3.56	Fe	45 - 79
P	**0.25 - 0.66**	**Mn**	**0.35 - 270**
K	1.22 - 2.29	B	0.17 - 0.27
Ca	**0.98 - 1.45**	**Cu**	**5 - 54**
Mg	0.22 - 0.33	Zn	22 - 73
S	**0.17 - 0.36**	**Mo**	**0.21 - 0.5**

C

Scientific Name	*Tagetes erecta*
Common Name	**African Marigold**
Collected From	Greenhouse production nursery
Plant Part	40 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Survey Range
Cultivars Used	Voyager Gold'

Macronutrients %		**Micronutrients ppm**	
N	2.2 - 5.50	Fe	45 - 454
P	**0.23 - 0.67**	**Mn**	**4 - 385**
K	1.5 - 2.19	B	15 - 39
Ca	**0.88 - 2.74**	**Cu**	**5 - 143**
Mg	0.35 - 1.56	Zn	22 - 235
S	**0.18 - 0.88**	**Mo**	**0.1 - 0.60**

D

Scientific Name	*Tagetes patula*
Common Name	**French Marigold**
Collected From	Greenhouse production nursery
Plant Part	40 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Survey Range
Cultivars Used	Aurora Yellow', 'Little Hero Yellow'

Macronutrients %		**Micronutrients ppm**	
N	3.32 - 3.62	Fe	92 - 115
P	**0.49 - 0.54**	**Mn**	**275 - 558**
K	2.79 - 2.88	B	34 - 40
Ca	**2.36 - 2.72**	**Cu**	**19 - 25**
Mg	1.33 - 1.44	Zn	76 - 97
S	**1.34 - 1.44**	**Mo**	**0.22 - 0.62**

E

Scientific Name	*Torenia fournieri*
Common Name	**Wishbone Flower or Bluewings**
Collected From	Greenhouse production nursery
Plant Part	50 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Survey Range
Cultivars Used	Normal type, 'Clown Blush'

Macronutrients %		**Micronutrients ppm**	
N	5.14 - 5.29	Fe	151 - 190
P	**0.52 - 0.62**	**Mn**	**320 - 354**
K	2.36 - 2.85	B	40 - 50
Ca	**1.26 - 1.51**	**Cu**	**11 - 14**
Mg	0.90 - 0.93	Zn	118 - 128
S	**0.29 - 0.31**	**Mo**	**0.30 - 0.55**

F

Scientific Name	*Verbena x hybrida*
Common Name	**Garden Verbena**
Collected From	Greenhouse production nursery
Plant Part	50 mature leaves from new growth
Season	Mature plants (36-cell packs)
Data Type	Sufficiency Range
Cultivars Used	Showtime Red', 'Showtime Pink', others not specified

Macronutrients %		**Micronutrients ppm**	
N	3.64 - 5.84	Fe	56 - 112
P	**0.77 - 1.19**	**Mn**	**55 - 293**
K	2.79 - 4.69	B	43 - 48
Ca	**1.60 - 2.54**	**Cu**	**3 - 13**
Mg	0.73 - 1.58	Zn	65 - 127
S	**0.58 - 0.64**	**Mo**	**0.14 - 0.80**

Bedding Plants

A

Scientific Name			*Viola x wittrockiana*
Common Name			**Pansy**
Collected From			Greenhouse production nursery
Plant Part			40 mature leaves from new growth
Season			Mature plants (36-cell packs)
Data Type			Survey Range
Cultivars Used			Not specified
Macronutrients %		**Micronutrients Ppm**	
N	3.44 - 4.20	Fe	80 - 398
P	**0.37 - 0.64**	**Mn**	**41 - 203**
K	2.39 - 2.92	B	20 - 46
Ca	**0.90 - 1.16**	**Cu**	**6 - 23**
Mg	0.36 - 0.49	Zn	44 - 137
S	**0.15 - 0.28**	**Mo**	**0.08 - 1.60**

B

Scientific Name			*Zinnia elegans*
Common Name			**Garden Zinnia**
Collected From			Greenhouse production nursery
Plant Part			40 mature leaves from new growth
Season			Mature plants (36-cell packs)
Data Type			Survey Range
Cultivars Used			Star Yellow'
Macronutrients %		**Micronutrients ppm**	
N	3.5 - 5.78	Fe	80 - 150
P	**0.4 - 0.74**	**Mn**	**200 - 300**
K	2.4 - 3.25	B	3.5 - 67
Ca	**1.75 - 2.37**	**Cu**	**5 - 23**
Mg	0.89 - 1.48	Zn	50 - 115
S	**0.25 - 0.37**	**Mo**	**0.30 - 0.50**

C

D

E

F

Conifers

A

Scientific Name	*Abies amabilis*		
Common Name	**Fir, Cascade or Pacific Silver**		
Collected From	Field research plots		
Plant Part	25 2-3" terminal cuttings from new summer growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients Ppm**	
N	0.91 - 1.65	Fe	60 - 80
P	**0.09 - 0.16**	**Mn**	**510 - 750**
K	0.41 - 1.20	B	15 - 34
Ca	**0.29 - 0.44**	**Cu**	**1 - 4**
Mg	0.07 - 0.09	Zn	22 - 43
S	**0.12 - 0.22**	**Mo**	**0.18 - 0.25**

B

Scientific Name	*Abies balsamea*		
Common Name	**Fir, Balsam**		
Collected From	Field research plots		
Plant Part	25 2-3" terminal cuttings from new summer growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	0.90 - 2.10	Fe	35 - 120
P	**0.10 - 0.26**	**Mn**	**740 - 1600**
K	0.28 - 1.08	B	15 - 35
Ca	**0.29 - 1.39**	**Cu**	**4 - 8**
Mg	0.06 - 0.16	Zn	46 - 50
S	**0.11 - 0.22**	**Mo**	**0.20 - 0.30**

C

Scientific Name	*Abies concolor*		
Common Name	**Fir, White**		
Collected From	Field research plots		
Plant Part	25 2-3" terminal cuttings from new summer growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients Ppm**	
N	1.25 - 2.22	Fe	33 - 44
P	**0.18 - 0.24**	**Mn**	**50 - 216**
K	.78 - 1.84	B	15 - 32
Ca	**.59 - 1.03**	**Cu**	**4 - 10**
Mg	.2 - .289	Zn	.23 - .34
S	**0.14 - 0.22**	**Mo**	**0.16 - 0.289**

D

Scientific Name	*Abies firma*		
Common Name	**Fir, Momi**		
Collected From	Botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings from new summer growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.149 - 2	Fe	22 - 45
P	**0.14 - 0.25**	**Mn**	**15 - 216**
K	.98 - 1.9	B	10 - 24
Ca	**.45 - 1.22**	**Cu**	**4 - 8**
Mg	.19 - .32	Zn	.2 - .44
S	**0.11 - 0.22**	**Mo**	**0.13 - 0.22**

E

Scientific Name	*Abies fraseri*		
Common Name	**Fir, Fraser**		
Collected From	Greenhouse production nursery		
Plant Part	25 2-3" terminal cuttings from new summer growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used			
Macronutrients %		**Micronutrients Ppm**	
N	0.90 - 1.45	Fe	35 - 140
P	**0.12 - 0.26**	**Mn**	**50 - 275**
K	0.70 - 1.25	B	10 - 30
Ca	**0.30 - 1.10**	**Cu**	**8 - 30**
Mg	0.10 - 0.28	Zn	15 - 25
S	**0.11 - 0.22**	**Mo**	**0.07 - 0.50**

F

Scientific Name	*Abies grandis*		
Common Name	**Fir, Giant**		
Collected From	Field research plots		
Plant Part	25 2-3" terminal cuttings from new summer growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1 - 1.40	Fe	20 - 40
P	**0.18 - 0.289**	**Mn**	**15 - 272**
K	.85 - 1.4	B	10 - 29
Ca	**.55 - 1.34**	**Cu**	**4 - 8**
Mg	.14 - .35	Zn	.22 - .34
S	**0.12 - 0.22**	**Mo**	**0.13 - 0.28**

Conifers

A

SCIENTIFIC NAME	*Abies magnifica*
COMMON NAME	**Fir, Red**
COLLECTED FROM	Field research plots
PLANT PART	25 2-3" terminal cuttings from new summer growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients Ppm	
N	1.149 - 1.98	Fe	20 - 31
P	**0.15 - 0.28**	**Mn**	**17 - 178**
K	.89 - 1.58	B	10 - 24
Ca	**.65 - 1.25**	**Cu**	**4 - 8**
Mg	.18 - .31	Zn	.23 - .35
S	**0.12 - 0.22**	**Mo**	**0.13 - 0.22**

B

SCIENTIFIC NAME	*Araucaria bidwillii*
COMMON NAME	**Bunya-bunya Pine or False Monkey Puzzle Tree**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	Needles from 10 3-4" terminal cuttings
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.20 - 2.50	Fe	50 - 300
P	**0.16 - 0.30**	**Mn**	**30 - 250**
K	1.50 - 2.50	B	15 - 40
Ca	**0.70 - 1.50**	**Cu**	**6 - 50**
Mg	0.20 - 0.50	Zn	20 - 200
S	**0.13 - 0.25**	**Mo**	**0.13 - 0.5**

C

SCIENTIFIC NAME	*Araucaria heterophylla*
COMMON NAME	**Norfolk Island Pine**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	Needles from 15 3-4" terminal cuttings
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.50 - 2.80	Fe	50 - 300
P	**0.20 - 0.30**	**Mn**	**30 - 250**
K	1.50 - 2.50	B	15 - 40
Ca	**0.70 - 1.50**	**Cu**	**6 - 50**
Mg	0.20 - 0.50	Zn	25 - 200
S	**0.15 - 0.25**	**Mo**	**0.1 - 0.5**

D

SCIENTIFIC NAME	*Cedrus deodara*
COMMON NAME	**Deodar Cedar**
COLLECTED FROM	Field production nursery
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.25 - 2.50	Fe	50 - 199
P	**0.16 - 0.34**	**Mn**	**30 - 75**
K	1.20 - 2.30	B	15 - 40
Ca	**0.50 - 1.50**	**Cu**	**8 - 15**
Mg	0.20 - 0.50	Zn	20 - 55
S	**0.18 - 0.30**	**Mo**	**0.19 - 0.22**

E

SCIENTIFIC NAME	*Cedrus libani ssp. atlantica 'Glauca'*
COMMON NAME	**Blue Atlas Cedar**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Glauca'

Macronutrients %		Micronutrients ppm	
N	1.2 - 1.60	Fe	22 - 117
P	**0.14 - 0.29**	**Mn**	**0.23 - 76**
K	0.6 - 1.11	B	19 - 40
Ca	**0.75 - 1.01**	**Cu**	**6 - 14**
Mg	0.13 - 0.28	Zn	0.38 - 30
S	**0.15 - 0.28**	**Mo**	**0.12 - 0.4**

F

SCIENTIFIC NAME	*Cephalotaxus fortunei*
COMMON NAME	**Chinese Plum-yew or Fortune's Cephalotaxus**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.14 - 1.97	Fe	27 - 42
P	**0.14 - 0.23**	**Mn**	**0.25 - 40**
K	0.99 - 1.53	B	17 - 34
Ca	**1 - 1.54**	**Cu**	**4 - 11**
Mg	0.23 - 0.34	Zn	0.4 - 30
S	**0.2 - 0.28**	**Mo**	**0.12 - 0.33**

Conifers

A

Scientific Name	*Cephalotaxus harringtonia 'Prostrata'*		
Common Name	**Spreading Japanese Plum-yew**		
Collected From	Botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Prostrata'		
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 2.07	Fe	33 - 41
P	**0.17 - 0.25**	**Mn**	**17 - 86**
K	1 - 1.81	B	4 - 36
Ca	**0.89 - 1.55**	**Cu**	**5 - 9**
Mg	0.29 - 0.34	Zn	22 - 32
S	**0.15 - 0.26**	**Mo**	**0.11 - 0.19**

B

Scientific Name	*Chamaecyparis pisifera 'Boulevard'*		
Common Name	**Boulevard' Japanese Moss or Sawara Falsecypress**		
Collected From	Botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Boulevard'		
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 1.72	Fe	31 - 40
P	**0.15 - 0.25**	**Mn**	**0.35 - 165**
K	0.96 - 1.13	B	20 - 51
Ca	**0.78 - 1.02**	**Cu**	**7 - 13**
Mg	0.2 - 0.32	Zn	0.4 - 25
S	**0.17 - 0.28**	**Mo**	**0.2 - 0.42**

C

Scientific Name	*Chamaecyparis pisifera 'Golden Mop'*		
Common Name	**Golden Thread-leaf Japanese or Sawara Falsecypress**		
Collected From	Botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Golden Mop'		
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 2.05	Fe	29 - 42
P	**0.16 - 0.25**	**Mn**	**0.34 - 1356**
K	0.74 - 1.14	B	4 - 52
Ca	**0.76 - 1.11**	**Cu**	**5 - 9**
Mg	0.17 - 0.39	Zn	16 - 27
S	**0.13 - 0.22**	**Mo**	**0.12 - 0.3**

D

Scientific Name	*Cryptomeria japonica*		
Common Name	**Japanese Cedar or Sugi**		
Collected From	Field production nursery		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Sekkan Sugi', 'Yoshino'		
Macronutrients %		**Micronutrients ppm**	
N	1.32 - 1.89	Fe	22 - 49
P	**0.11 - 0.19**	**Mn**	**26 - 61**
K	0.81 - 1.21	B	10 - 17
Ca	**0.60 - 0.99**	**Cu**	**3 - 9**
Mg	0.10 - 0.18	Zn	10 - 16
S	**0.11 - 0.16**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Cupressus arizonica var. glabra*		
Common Name	**Smooth Arizona Cypress**		
Collected From	Botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. glabra only		
Macronutrients %		**Micronutrients ppm**	
N	0.89 - 1.17	Fe	44 - 152
P	**0.12 - 0.26**	**Mn**	**15 - 42**
K	0.78 - 1.09	B	4 - 24
Ca	**0.78 - 1.14**	**Cu**	**4 - 9**
Mg	0.16 - 0.26	Zn	15 - 22
S	**0.12 - 0.17**	**Mo**	**0.11 - 0.22**

F

Scientific Name	*Cupressus sempervirens 'Stricta'*		
Common Name	**Italian Cypress**		
Collected From	Botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Stricta'		
Macronutrients %		**Micronutrients ppm**	
N	0.89 - 1.04	Fe	24 - 39
P	**0.14 - 0.23**	**Mn**	**11 - 104**
K	0.98 - 1.34	B	4 - 22
Ca	**1.11 - 2.05**	**Cu**	**3 - 7**
Mg	0.18 - 0.36	Zn	15 - 22
S	**0.11 - 0.18**	**Mo**	**0.13 - 0.25**

Conifers

A

SCIENTIFIC NAME	*Ginkgo biloba*
COMMON NAME	**Ginkgo or Maidenhair Tree**
COLLECTED FROM	Container & field production nurseries & botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Autumn Gold', 'Princeton Sentry'

Macronutrients %		Micronutrients ppm	
N	1.54 - 2.81	Fe	30 - 40
P	**0.22 - 0.36**	**Mn**	**12 - 117**
K	1.43 - 2.02	B	10 - 67
Ca	**0.88 - 1.41**	**Cu**	**2 - 20**
Mg	0.25 - 0.41	Zn	2 - 15
S	**0.18 - 0.30**	**Mo**	**0.12 - 0.90**

B

SCIENTIFIC NAME	*Juniperus communis*
COMMON NAME	**Common Juniper**
COLLECTED FROM	Field research plots
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.25 - 2.00	Fe	50 - 150
P	**0.20 - 0.35**	**Mn**	**55 - 240**
K	1.00 - 1.50	B	15 - 25
Ca	**0.75 - 1.25**	**Cu**	**3 - 15**
Mg	0.18 - 0.30	Zn	15 - 30
S	**0.15 - 0.33**	**Mo**	**0.30 - 0.50**

C

SCIENTIFIC NAME	*Juniperus conferta 'Blue Pacific'*
COMMON NAME	**Blue Pacific' Shore Juniper**
COLLECTED FROM	Container production nursery
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Blue Pacific'

Macronutrients %		Micronutrients ppm	
N	1.22 - 1.80	Fe	55 - 193
P	**0.16 - 0.20**	**Mn**	**248 - 529**
K	0.81 - 1.22	B	22 - 34
Ca	**0.61 - 0.70**	**Cu**	**3 - 5**
Mg	0.08 - 0.12	Zn	13 - 34
S	**0.10 - 0.13**	**Mo**	**0.12 - 0.50**

D

SCIENTIFIC NAME	*Juniperus davurica 'Expansa'*
COMMON NAME	**Parson's or Dahurian Juniper**
COLLECTED FROM	Container production nursery
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Expansa'

Macronutrients %		Micronutrients ppm	
N	1 - 1.63	Fe	23 - 68
P	**0.2 - 0.28**	**Mn**	**45 - 518**
K	0.79 - 1.24	B	6 - 39
Ca	**0.51 - 1.11**	**Cu**	**2 - 12**
Mg	0.13 - 0.33	Zn	22 - 73
S	**0.12 - 0.18**	**Mo**	**0.12 - 0.19**

E

SCIENTIFIC NAME	*Juniperus horizontalis*
COMMON NAME	**Creeping Juniper**
COLLECTED FROM	Container production nursery
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Plumosa Compacta', 'Bar Harbor'

Macronutrients %		Micronutrients ppm	
N	1.58 - 2.07	Fe	51 - 142
P	**0.21 - 0.39**	**Mn**	**276 - 397**
K	1.28 - 1.56	B	15 - 24
Ca	**0.71 - 1.62**	**Cu**	**6 - 9**
Mg	0.24 - 0.27	Zn	36 - 70
S	**0.18 - 0.22**	**Mo**	**0.01 - 1.57**

F

SCIENTIFIC NAME	*Juniperus horizontalis 'Wiltoni'*
COMMON NAME	**Blue Rug Creeping Juniper**
COLLECTED FROM	Container production nursery
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Wiltoni'

Macronutrients %		Micronutrients ppm	
N	1.46 - 1.76	Fe	58 - 102
P	**0.21 - 0.23**	**Mn**	**44 - 84**
K	1.11 - 1.25	B	16 - 29
Ca	**0.58 - 0.68**	**Cu**	**3 - 5**
Mg	0.16 - 0.24	Zn	20 - 25
S	**0.12 - 0.15**	**Mo**	**0.12 - 0.20**

Conifers

A

SCIENTIFIC NAME	*Juniperus procumbens 'Nana'*
COMMON NAME	**Dwarf Japanese Garden Juniper**
COLLECTED FROM	Container production nursery
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Nana'

Macronutrients %		Micronutrients ppm	
N	1.00 - 1.71	Fe	69 - 194
P	**0.13 - 0.25**	**Mn**	**104 - 203**
K	0.81 - 1.09	B	15 - 26
Ca	**0.56 - 0.66**	**Cu**	**3 - 6**
Mg	0.11 - 0.15	Zn	38 - 74
S	**0.08 - 0.15**	**Mo**	**0.12 - 0.30**

B

SCIENTIFIC NAME	*Juniperus sargentii*
COMMON NAME	**Sargent's Juniper**
COLLECTED FROM	Container production nursery
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Viridis'

Macronutrients %		Micronutrients ppm	
N	1.17 - 1.70	Fe	65 - 86
P	**0.20 - 0.21**	**Mn**	**208 - 376**
K	0.76 - 1.35	B	22 - 45
Ca	**0.49 - 0.81**	**Cu**	**3 - 4**
Mg	0.11 - 0.12	Zn	30 - 67
S	**0.11 - 0.16**	**Mo**	**0.12 - 0.31**

C

SCIENTIFIC NAME	*Juniperus virginiana*
COMMON NAME	**Eastern Red Cedar**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Glauca'

Macronutrients %		Micronutrients ppm	
N	1.35 - 1.85	Fe	49 - 73
P	**0.14 - 0.17**	**Mn**	**382 - 448**
K	0.85 - 1.28	B	26 - 29
Ca	**1.00 - 2.93**	**Cu**	**4 - 6**
Mg	0.18 - 0.20	Zn	16 - 20
S	**0.13 - 0.16**	**Mo**	**0.12 - 0.30**

D

SCIENTIFIC NAME	*Juniperus x media cultivars*
COMMON NAME	**Hybrid Chinese Junipers**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Glauca'

Macronutrients %		Micronutrients ppm	
N	1.44 - 2.26	Fe	24 - 142
P	**0.21 - 0.44**	**Mn**	**108 - 423**
K	1.09 - 2.04	B	20 - 40
Ca	**0.65 - 1.62**	**Cu**	**4 - 16**
Mg	0.13 - 0.41	Zn	18 - 62
S	**0.14 - 0.16**	**Mo**	**0.06 - 1.82**

E

SCIENTIFIC NAME	*Larix laricina*
COMMON NAME	**Eastern or American Larch or Tamarack**
COLLECTED FROM	Field research plots
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.50 - 1.80	Fe	183 - 340
P	**0.10 - 0.35**	**Mn**	**310 - 340**
K	0.46 - 1.16	B	19 - 27
Ca	**0.25 - 0.26**	**Cu**	**6 - 7**
Mg	0.11 - 0.15	Zn	32 - 40
S	**0.12 - 0.27**	**Mo**	**0.07 - 1.80**

F

SCIENTIFIC NAME	*Larix kaempferi*
COMMON NAME	**Japanese Larch**
COLLECTED FROM	Field research plots
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.00 - 3.00	Fe	22 - 31
P	**0.16 - 0.42**	**Mn**	**25 - 62**
K	0.75 - 1.35	B	8 - 15
Ca	**0.20 - 0.59**	**Cu**	**4 - 14**
Mg	0.11 - 31	Zn	17 - 29
S	**0.10 - 0.14**	**Mo**	**0.13 - 0.4**

Conifers

A

Scientific Name	*Metasequoia glyptostroboides*
Common Name	**Dawn Redwood**
Collected From	Field production nursery & botanical garden/arboretum
Plant Part	50 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.13 - 2.57	Fe	42 - 82
P	**0.19 - 0.24**	**Mn**	**40 - 274**
K	0.98 - 1.68	B	8 - 50
Ca	**0.63 - 2.31**	**Cu**	**5 - 7**
Mg	0.24 - 0.31	Zn	18 - 26
S	**0.22 - 0.27**	**Mo**	**0.12 - 0.15**

B

Scientific Name	*Microbiota decussata*
Common Name	**Russian Arborvitae**
Collected From	Botanical garden/arboretum
Plant Part	25 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	0.89 - 1.35	Fe	23 - 33
P	**0.19 - 0.24**	**Mn**	**33 - 101**
K	0.73 - 1.33	B	5 - 29
Ca	**0.66 - 0.96**	**Cu**	**4 - 9**
Mg	0.09 - 0.31	Zn	15 - 22
S	**0.11 - 0.16**	**Mo**	**0.1 - 0.55**

C

Scientific Name	*Picea abies*
Common Name	**Norway Spruce**
Collected From	Field research plots
Plant Part	25 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	0.90 - 3.00	Fe	60 - 128
P	**0.06 - 0.40**	**Mn**	**38 - 300**
K	0.45 - 1.10	B	13 - 17
Ca	**0.08 - 0.85**	**Cu**	**4 - 9**
Mg	0.09 - 0.35	Zn	19 - 33
S	**0.13 - 0.20**	**Mo**	**0.03 - 0.95**

D

Scientific Name	*Picea abies 'Pendula'*
Common Name	**Weeping Norway Spruce**
Collected From	Container production nursery
Plant Part	25 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Pendula'

Macronutrients %		Micronutrients ppm	
N	1.2 - 2.17	Fe	31 - 37
P	**0.09 - 0.29**	**Mn**	**33 - 311**
K	1 - 1.33	B	4 - 33
Ca	**0.6 - 1.21**	**Cu**	**5 - 11**
Mg	0.14 - 0.29	Zn	24 - 45
S	**0.1 - 0.14**	**Mo**	**0.2 - 0.69**

E

Scientific Name	*Picea engelmannii*
Common Name	**Engelmann Spruce**
Collected From	Field research plots
Plant Part	25 2-3" terminal cuttings
Season	Late summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	0.77 - 1.72	Fe	20 - 33
P	**0.12 - 0.29**	**Mn**	**34 - 200**
K	0.48 - 0.88	B	5 - 18
Ca	**0.28 - 1.16**	**Cu**	**4 - 8**
Mg	0.08 - 0.15	Zn	16 - 30
S	**0.08 - 0.19**	**Mo**	**0.2 - 0.5**

F

Scientific Name	*Picea glauca*
Common Name	**White Spruce**
Collected From	Field research plots
Plant Part	25 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	0.95 - 2.82	Fe	29 - 82
P	**0.12 - 0.59**	**Mn**	**188 - 1052**
K	0.45 - 1.60	B	12 - 30
Ca	**0.15 - 0.87**	**Cu**	**2 - 10**
Mg	0.08 - 0.25	Zn	35 - 117
S	**0.08 - 0.17**	**Mo**	**0.03 - 0.50**

Conifers

A

SCIENTIFIC NAME	*Picea glauca var. albertiana 'Conica'*		
COMMON NAME	**Dwarf Alberta White Spruce**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	25 2-3" terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Conica'		
Macronutrients %		**Micronutrients ppm**	
N	0.98 - 1.39	Fe	22 - 37
P	**0.18 - 0.28**	**Mn**	**33 - 628**
K	0.69 - 1.25	B	11 - 23
Ca	**0.4 - 1.28**	**Cu**	**2 - 12**
Mg	0.1 - 18	Zn	18 - 38
S	**0.15 - 0.24**	**Mo**	**0.12 - 0.33**

B

SCIENTIFIC NAME	*Picea mariana*		
COMMON NAME	**Black or Bog Spruce**		
COLLECTED FROM	Field research plots		
PLANT PART	25 2-3" terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	0.86 - 2.78	Fe	36 - 188
P	**0.08 - 0.18**	**Mn**	**196 - 760**
K	0.40 - 1.72	B	40 - 42
Ca	**0.15 - 0.64**	**Cu**	**3 - 8**
Mg	0.09 - 0.31	Zn	24 - 52
S	**0.14 - 0.22**	**Mo**	**0.05 - 1.00**

C

SCIENTIFIC NAME	*Picea pungens*		
COMMON NAME	**Colorado Spruce**		
COLLECTED FROM	Field research plots		
PLANT PART	25 2-3" terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.10	Fe	65 - 105
P	**0.12 - 0.21**	**Mn**	**22 - 32**
K	0.61 - 1.26	B	11 - 15
Ca	**0.24 - 0.63**	**Cu**	**5 - 14**
Mg	0.19 - 0.39	Zn	0.39 - 24
S	**0.19 - 0.27**	**Mo**	**0.19 - 0.37**

D

SCIENTIFIC NAME	*Picea rubens*		
COMMON NAME	**Red Spruce**		
COLLECTED FROM	Field research plots		
PLANT PART	25 2-3" terminal cuttings		
SEASON	Summer to fall		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	0.82 - 2.80	Fe	22 - 100
P	**0.13 - 0.28**	**Mn**	**50 - 1600**
K	0.40 - 1.15	B	15 - 42
Ca	**0.12 - 0.84**	**Cu**	**4 - 16**
Mg	0.07 - 0.17	Zn	23 - 56
S	**0.1 - 0.14**	**Mo**	**0.20 - 0.40**

E

SCIENTIFIC NAME	*Picea sitchensis*		
COMMON NAME	**Sitka Spruce**		
COLLECTED FROM	Field research plots		
PLANT PART	25 2-3" terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.37 - 3.12	Fe	33 - 65
P	**0.10 - 0.38**	**Mn**	**159.8 - 2043**
K	0.30 - 1.33	B	17 - 28
Ca	**0.20 - 0.35**	**Cu**	**4 - 11**
Mg	0.07 - 0.17	Zn	42 - 57
S	**0.23 - 0.29**	**Mo**	**0.12 - 0.4**

F

SCIENTIFIC NAME	*Pinus banksiana*		
COMMON NAME	**Jack Pine**		
COLLECTED FROM	Field research plots		
PLANT PART	Needles from 20 terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.24 - 2.50	Fe	70 - 262
P	**0.12 - 0.41**	**Mn**	**170 - 467**
K	0.35 - 1.20	B	17 - 31
Ca	**0.11 - 0.40**	**Cu**	**3 - 5**
Mg	0.09 - 0.31	Zn	74 - 101
S	**0.07 - 0.17**	**Mo**	**0.07 - 1.13**

Conifers

A

SCIENTIFIC NAME	*Pinus bungeana*		
COMMON NAME	**Lacebark Pine**		
COLLECTED FROM	Field production nursery & botanical garden/arboretum		
PLANT PART	Needles from 20 terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.24 - 1.63	Fe	28 - 57
P	**0.13 - 0.15**	**Mn**	**258 - 456**
K	0.42 - 0.73	B	18 - 38
Ca	**0.24 - 1.38**	**Cu**	**2 - 4**
Mg	0.10 - 0.25	Zn	28 - 100
S	**0.12 - 0.18**	**Mo**	**0.01 - 0.12**

B

SCIENTIFIC NAME	*Pinus contorta ssp. latifolia*		
COMMON NAME	**Lodgepole Pine**		
COLLECTED FROM	Field research plots		
PLANT PART	Needles from 15 terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	ssp. latifolia only		
Macronutrients %		**Micronutrients ppm**	
N	1.20 - 3.00	Fe	4 - 58
P	**0.10 - 0.40**	**Mn**	**34 - 293**
K	0.45 - 1.50	B	4 - 16
Ca	**0.08 - 0.70**	**Cu**	**3 - 9**
Mg	0.07 - 0.16	Zn	18 - 52
S	**0.12 - 0.21**	**Mo**	**0.09 - 0.24**

C

SCIENTIFIC NAME	*Pinus densiflora*		
COMMON NAME	**Japanese Red Pine**		
COLLECTED FROM	Container production nursery & botanical garden/arboretum		
PLANT PART	Needles from 15 terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species, 'Pendula', 'Umbraculifera'		
Macronutrients %		**Micronutrients ppm**	
N	1.23 - 1.39	Fe	5 - 23
P	**0.09 - 0.12**	**Mn**	**281 - 690**
K	0.76 - 0.86	B	13 - 28
Ca	**0.25 - 0.30**	**Cu**	**3 - 12**
Mg	0.09 - 0.12	Zn	22 - 45
S	**0.11 - 0.12**	**Mo**	**0.07 - 0.56**

D

SCIENTIFIC NAME	*Pinus echinata*		
COMMON NAME	**Shortleaf Pine**		
COLLECTED FROM	Field research plots & botanical garden/arboretum		
PLANT PART	Needles from 15 terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.34 - 3.02	Fe	29 - 149
P	**0.15 - 0.28**	**Mn**	**121 - 977**
K	0.78 - 1.33	B	7 - 16
Ca	**0.23 - 0.32**	**Cu**	**1 - 4**
Mg	0.09 - 0.11	Zn	19 - 51
S	**0.09 - 0.18**	**Mo**	**0.12 - 0.26**

E

SCIENTIFIC NAME	*Pinus elliottii*		
COMMON NAME	**Slash Pine**		
COLLECTED FROM	Field research plots		
PLANT PART	Needles from 10 terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 4.00	Fe	30 - 200
P	**0.15 - 0.80**	**Mn**	**50 - 400**
K	1.00 - 3.00	B	20 - 50
Ca	**0.25 - 0.90**	**Cu**	**6 - 30**
Mg	0.12 - 0.50	Zn	20 - 100
S	**0.15 - 0.30**	**Mo**	**0.12 - 0.24**

F

SCIENTIFIC NAME	*Pinus flexilis*		
COMMON NAME	**Limber Pine**		
COLLECTED FROM	Container production nursery		
PLANT PART	Needles from 20 terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Van der WoolfS Pyramid'		
Macronutrients %		**Micronutrients ppm**	
N	0.99 - 1.56	Fe	4 - 16
P	**0.13 - 0.23**	**Mn**	**44 - 552**
K	0.72 - 1.22	B	6 - 21
Ca	**0.33 - 1.03**	**Cu**	**4 - 12**
Mg	0.1 - 0.16	Zn	22 - 44
S	**0.13 - 0.23**	**Mo**	**0.15 - 0.27**

Conifers

A

Scientific Name	*Pinus halepensis*		
Common Name	**Aleppo or Jerusalem Pine**		
Collected From	Field research plots		
Plant Part	Needles from 15 terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	0.98 - 1.33	Fe	8 - 35
P	**0.10 - 0.16**	**Mn**	**23 - 34**
K	0.58 - 1.14	B	14 - 22
Ca	**0.30 - 0.91**	**Cu**	**1.11 - 3**
Mg	0.13 - 0.19	Zn	0.18 - 0.29
S	**0.14 - 0.28**	**Mo**	**0.26 - 0.55**

B

Scientific Name	*Pinus mugo var. pumilio*		
Common Name	**Dwarf Swiss Mountain Pine or Mugo Pine**		
Collected From	Container & field production nurseries		
Plant Part	Needles from 20 terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. pumilio only		
Macronutrients %		**Micronutrients ppm**	
N	1.27 - 3.06	Fe	27 - 89
P	**0.11 - 0.14**	**Mn**	**260 - 618**
K	0.71 - 1.21	B	21 - 55
Ca	**0.34 - 0.58**	**Cu**	**3 - 11**
Mg	0.11 - 0.15	Zn	20 - 117
S	**0.11 - 0.13**	**Mo**	**0.12 - 3.86**

C

Scientific Name	*Pinus nigra*		
Common Name	**Austrian Pine**		
Collected From	Container production nursery		
Plant Part	Needles from 15 terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 2.05	Fe	15 - 45
P	**0.11 - 0.27**	**Mn**	**44 - 275**
K	0.7 - 1.33	B	2 - 34
Ca	**0.35 - 0.98**	**Cu**	**7 - 12**
Mg	0.14 - 0.29	Zn	0.34 - 63
S	**0.15 - 0.24**	**Mo**	**0.2 - 0.37**

D

Scientific Name	*Pinus nigra var. maritima*		
Common Name	**Corsican Pine**		
Collected From	Field research plots		
Plant Part	Needles from 15 terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. maritima only		
Macronutrients %		**Micronutrients ppm**	
N	1 - 1.50	Fe	34 - 200
P	**0.13 - 0.29**	**Mn**	**34 - 200**
K	0.8 - 1.45	B	15 - 24
Ca	**0.55 - 1.25**	**Cu**	**4 - 12**
Mg	0.15 - 0.28	Zn	19 - 30
S	**0.16 - 0.26**	**Mo**	**0.22 - 1.00**

E

Scientific Name	*Pinus palustris*		
Common Name	**Longleaf or Southern Yellow Pine**		
Collected From	Field research plots		
Plant Part	Needles from 10 terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	0.85 - 1.27	Fe	96 - 162
P	**0.08 - 0.14**	**Mn**	**170 - 346**
K	0.60 - 1.25	B	3.00 - 15.00
Ca	**0.30 - 0.91**	**Cu**	**3.00 - 33**
Mg	0.15 - 0.39	Zn	12 - 33
S	**0.11 - 0.20**	**Mo**	**0.13 - 1.00**

F

Scientific Name	*Pinus parviflora 'Glauca'*		
Common Name	**Blue-needle Japanese White Pine**		
Collected From	Container production nursery		
Plant Part	Needles from 20 terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Glauca'		
Macronutrients %		**Micronutrients ppm**	
N	1.1 - 1.37	Fe	12 - 35
P	**0.14 - 0.28**	**Mn**	**0.34 - 535**
K	0.68 - 1.35	B	14 - 27
Ca	**0.5 - 1.29**	**Cu**	**6 - 16**
Mg	0.19 - 0.28	Zn	0.4 - 56
S	**0.13 - 0.23**	**Mo**	**0.12 - 0.35**

Conifers

A

SCIENTIFIC NAME			*Pinus ponderosa*
COMMON NAME			**Ponderosa or Western Yellow Pine**
COLLECTED FROM			Field research plots
PLANT PART			Needles from 10 terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	0.95 - 1.71	Fe	44 - 184
P	**0.08 - 0.27**	**Mn**	**38 - 102**
K	0.48 - 0.80	B	14 - 135
Ca	**0.05 - 0.29**	**Cu**	**2 - 8**
Mg	0.05 - 0.23	Zn	21 - 53
S	**0.11 - 0.24**	**Mo**	**0.11 - 0.35**

B

SCIENTIFIC NAME			*Pinus radiata*
COMMON NAME			**Monterey or Radiata Pine**
COLLECTED FROM			Field research plots
PLANT PART			Needles from 10 terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.00 - 1.96	Fe	40 - 267
P	**0.09 - 0.27**	**Mn**	**36 - 1500**
K	0.35 - 1.29	B	8 - 101
Ca	**0.10 - 0.83**	**Cu**	**2 - 46**
Mg	0.06 - 0.28	Zn	19 - 520
S	**0.02 - 0.04**	**Mo**	**0.12 - 0.40**

C

SCIENTIFIC NAME			*Pinus resinosa*
COMMON NAME			**Red or Norway Pine**
COLLECTED FROM			Field research plots
PLANT PART			Needles from 10 terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	0.89 - 3.00	Fe	66 - 206
P	**0.10 - 0.30**	**Mn**	**201 - 418**
K	0.14 - 1.10	B	10 - 34
Ca	**0.10 - 0.80**	**Cu**	**2 - 8**
Mg	0.05 - 0.21	Zn	24 - 49
S	**0.05 - 0.15**	**Mo**	**0.12 - 1.38**

D

SCIENTIFIC NAME			*Pinus strobus*
COMMON NAME			**Eastern White or Weymouth Pine**
COLLECTED FROM			Container production nursery & botanical garden/arboretum
PLANT PART			Needles from 20 terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.29 - 2.28	Fe	38 - 267
P	**0.07 - 0.30**	**Mn**	**134 - 357**
K	0.42 - 0.87	B	15 - 45
Ca	**0.22 - 0.75**	**Cu**	**3 - 22**
Mg	0.08 - 0.23	Zn	54 - 174
S	**0.08 - 0.17**	**Mo**	**0.06 - 0.93**

E

SCIENTIFIC NAME			*Pinus strobus*
COMMON NAME			**Eastern White or Weymouth Pine**
COLLECTED FROM			Field research plots
PLANT PART			Needles from 20 terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.16 - 3.20	Fe	42 - 267
P	**0.12 - 0.56**	**Mn**	**134 - 457**
K	0.32 - 1.49	B	15 - 34
Ca	**0.17 - 1.20**	**Cu**	**2 - 14**
Mg	0.05 - 0.23	Zn	52 - 82
S	**0.08 - 0.18**	**Mo**	**0.05 - 0.20**

F

SCIENTIFIC NAME			*Pinus strobus 'Nana'*
COMMON NAME			**Dwarf Eastern White or Weymouth Pine**
COLLECTED FROM			Container production nursery
PLANT PART			Needles from 20 terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Nana'
Macronutrients %		**Micronutrients ppm**	
N	1.01 - 1.47	Fe	23 - 31
P	**0.13 - 0.24**	**Mn**	**34 - 564**
K	0.71 - 1.33	B	15 - 26
Ca	**0.35 - 1.22**	**Cu**	**7 - 25**
Mg	0.11 - 22	Zn	22 - 68
S	**0.14 - 0.24**	**Mo**	**0.06 - 0.5**

Conifers

A

SCIENTIFIC NAME	*Pinus sylvestris*
COMMON NAME	**Scots Pine**
COLLECTED FROM	Container production nursery
PLANT PART	Needles from 20 terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Fastigiata', 'French Blue'

Macronutrients %		Micronutrients ppm	
N	1.42 - 1.99	Fe	45 - 98
P	**0.08 - 0.18**	**Mn**	**330 - 435**
K	0.50 - 0.72	B	25 - 39
Ca	**0.36 - 0.44**	**Cu**	**6 - 24**
Mg	0.11 - 0.12	Zn	58 - 89
S	**0.11 - 0.16**	**Mo**	**0.60 - 1.54**

B

SCIENTIFIC NAME	*Pinus sylvestris*
COMMON NAME	**Scots Pine**
COLLECTED FROM	Field research plots
PLANT PART	Needles from 20 terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.25 - 3.00	Fe	70 - 98
P	**0.08 - 0.30**	**Mn**	**87 - 898**
K	0.30 - 4.50	B	12 - 36
Ca	**0.05 - 0.69**	**Cu**	**5 - 12**
Mg	0.07 - 0.18	Zn	59 - 63
S	**0.13 - 0.20**	**Mo**	**0.05 - 0.22**

C

SCIENTIFIC NAME	*Pinus sylvestris 'Glauca Nana'*
COMMON NAME	**Dwarf Blue-needle Scots Pine**
COLLECTED FROM	Container production nursery
PLANT PART	Needles from 20 terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Glauca Nana'

Macronutrients %		Micronutrients ppm	
N	0.98 - 1.44	Fe	25 - 43
P	**0.12 - 0.25**	**Mn**	**36 - 347**
K	0.79 - 1.44	B	18 - 33
Ca	**0.34 - 1.12**	**Cu**	**8 - 67**
Mg	0.1 - 18	Zn	23 - 94
S	**0.12 - 0.22**	**Mo**	**0.11 - 0.65**

D

SCIENTIFIC NAME	*Pinus taeda*
COMMON NAME	**Loblolly or Old-field Pine**
COLLECTED FROM	Field research plots & botanical garden/arboretum
PLANT PART	Needles from 10 terminal cuttings
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	0.82 - 2.35	Fe	40 - 118
P	**0.09 - 0.17**	**Mn**	**100 - 450**
K	0.27 - 0.74	B	15 - 31
Ca	**0.13 - 0.40**	**Cu**	**3 - 8**
Mg	0.05 - 0.18	Zn	28 - 53
S	**0.08 - 0.16**	**Mo**	**0.12 - 0.56**

E

SCIENTIFIC NAME	*Pinus thunbergii*
COMMON NAME	**Japanese Black Pine**
COLLECTED FROM	Field production nursery
PLANT PART	Needles from 15 terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Monina' ('Majestic Beauty')

Macronutrients %		Micronutrients ppm	
N	0.78 - 0.91	Fe	21 - 29
P	**0.07 - 0.14**	**Mn**	**45 - 416**
K	0.45 - 1.104	B	7 - 12
Ca	**0.68 - 1.18**	**Cu**	**2 - 12**
Mg	0.12 - 0.33	Zn	13 - 21
S	**0.08 - 0.16**	**Mo**	**0.12 - 0.34**

F

SCIENTIFIC NAME	*Pinus virginiana*
COMMON NAME	**Virginia or Jersey or Scrub Pine**
COLLECTED FROM	Field research plots & botanical garden/arboretum
PLANT PART	Needles from 20 terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.32 - 2.30	Fe	35 - 44
P	**0.08 - 0.16**	**Mn**	**22 - 239**
K	0.28 - 0.75	B	4 - 22
Ca	**0.10 - 0.22**	**Cu**	**3 - 8**
Mg	0.07 - 0.18	Zn	22 - 36
S	**0.12 - 0.20**	**Mo**	**0.13 - 0.36**

Conifers

A

SCIENTIFIC NAME			*Platycladus orientalis*
COMMON NAME			**Oriental Arborvitae**
COLLECTED FROM			Container production nursery
PLANT PART			25 2-3" terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 1.89	Fe	33 - 163
P	**0.16 - 0.46**	**Mn**	**29 - 68**
K	1.09 - 1.53	B	6 - 27
Ca	**0.8 - 1.44**	**Cu**	**4.8 - 11**
Mg	0.21 - 0.39	Zn	18 - 31
S	**0.11 - 0.23**	**Mo**	**0.14 - 0.33**

B

SCIENTIFIC NAME			*Platycladus orientalis 'Aurea Nana'*
COMMON NAME			**Berckman's Golden Arborvitae or Dwarf Oriental Arborvitae**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			25 2-3" terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Aurea Nana'
Macronutrients %		**Micronutrients ppm**	
N	0.98 - 1.61	Fe	22 - 35
P	**0.16 - 0.27**	**Mn**	**0.21 - 68**
K	0.98 - 1.74	B	15 - 30
Ca	**0.75 - 1.13**	**Cu**	**5 - 12**
Mg	0.21 - 0.37	Zn	0.37 - 25
S	**0.17 - 0.26**	**Mo**	**0.12 - 0.3**

C

SCIENTIFIC NAME			*Podocarpus macrophyllus*
COMMON NAME			**Chinese Podocarpus or Yew-pine or Southern Yew**
COLLECTED FROM			Field production nursery (cut foliage)
PLANT PART			Leaves from 15 terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.50	Fe	30 - 200
P	**0.25 - 0.75**	**Mn**	**25 - 200**
K	0.80 - 2.00	B	20 - 75
Ca	**1.00 - 2.00**	**Cu**	**10 - 50**
Mg	0.25 - 0.80	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.13 - 0.33**

D

SCIENTIFIC NAME			*Podocarpus macrophyllus 'Maki'*
COMMON NAME			**Shrubby Chinese Podocarpus or Yew-pine or Southern Yew**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			Leaves from 15 terminal cuttings
SEASON			Summer
DATA TYPE			Sufficiency Range
CULTIVARS USED			'Maki'
Macronutrients %		**Micronutrients ppm**	
N	0.99 - 1.51	Fe	32 - 57
P	**0.15 - 0.22**	**Mn**	**15 - 77**
K	0.89 - 1.37	B	11 - 80
Ca	**1 - 2.14**	**Cu**	**5 - 11**
Mg	0.18 - 0.25	Zn	0.33 - 18
S	**0.12 - 0.20**	**Mo**	**0.14 - 1.04**

E

SCIENTIFIC NAME			*Pseudotsuga menziesii*
COMMON NAME			**Douglas Fir**
COLLECTED FROM			Field research plots & botanical garden/arboretum
PLANT PART			25 2-3" terminal cuttings
SEASON			Late summer to fall
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.30	Fe	70 - 200
P	**0.18 - 0.35**	**Mn**	**200 - 600**
K	0.75 - 1.10	B	4 - 15
Ca	**0.30 - 0.50**	**Cu**	**3 - 12**
Mg	0.09 - 0.15	Zn	25 - 45
S	**0.15 - 0.25**	**Mo**	**0.13 - 0.25**

F

SCIENTIFIC NAME			*Taxodium distichum*
COMMON NAME			**Baldcypress or Swamp Cypress**
COLLECTED FROM			Field research plots
PLANT PART			50 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.01 - 1.79	Fe	24 - 44
P	**0.14 - 0.24**	**Mn**	**0.23 - 48**
K	0.44 - 0.51	B	18 - 48
Ca	**1.37 - 1.98**	**Cu**	**5 - 11**
Mg	0.19 - 0.27	Zn	0.38 - 22
S	**0.17 - 0.27**	**Mo**	**0.19 - 0.3**

Conifers

A

SCIENTIFIC NAME			*Taxus baccata*
COMMON NAME			**English or Common Yew**
COLLECTED FROM			Container production nursery
PLANT PART			30 2-3" terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1 - 1.98	Fe	30 - 45
P	**0.18 - 0.28**	**Mn**	**44 - 490**
K	0.88 - 1.21	B	5 - 17
Ca	**0.55 - 0.78**	**Cu**	**4 - 8**
Mg	0.16 - 0.29	Zn	0.24 - 114
S	**0.14 - 0.14**	**Mo**	**0.12 - 0.30**

B

SCIENTIFIC NAME			*Taxus x media*
COMMON NAME			**Anglojap Hybrid Yew**
COLLECTED FROM			Container production nursery
PLANT PART			30 2-3" terminal cuttings
SEASON			Summer
DATA TYPE			Sufficiency Range
CULTIVARS USED			Hicksii', others not specified
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.65	Fe	30 - 200
P	**0.22 - 0.40**	**Mn**	**25 - 200**
K	1.60 - 2.80	B	20 - 45
Ca	**0.80 - 1.55**	**Cu**	**5 - 15**
Mg	0.25 - 0.45	Zn	25 - 50
S	**0.18 - 0.35**	**Mo**	**0.22 - 0.50**

C

SCIENTIFIC NAME			*Thuja occidentalis*
COMMON NAME			**American or Eastern Arborvitae or White Cedar**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			25 2-3" terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Holmstrup', 'Sudwelli'
Macronutrients %		**Micronutrients ppm**	
N	1.44 - 1.56	Fe	33 - 36
P	**0.17 - 0.18**	**Mn**	**524 - 586**
K	0.70 - 0.88	B	20 - 23
Ca	**0.84 - 1.17**	**Cu**	**3 - 5**
Mg	0.14 - 0.25	Zn	30 - 38
S	**0.11 - 0.13**	**Mo**	**0.13 - 0.30**

D

SCIENTIFIC NAME			*Thuja occidentalis*
COMMON NAME			**American or Eastern Arborvitae or White Cedar**
COLLECTED FROM			Field research plots
PLANT PART			25 2-3" terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	0.70 - 1.85	Fe	30 - 200
P	**0.15 - 0.40**	**Mn**	**22 - 175**
K	0.75 - 1.25	B	18 - 40
Ca	**0.52 - 1.05**	**Cu**	**2.0 - 9.0**
Mg	0.15 - 0.33	Zn	15 - 40
S	**0.13 - 0.25**	**Mo**	**0.13 - 0.50**

E

SCIENTIFIC NAME			*Thuja plicata*
COMMON NAME			**Western Red Cedar or Giant Arborvitae**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			25 2-3" terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Hogan'
Macronutrients %		**Micronutrients ppm**	
N	0.70 - 1.85	Fe	30 - 200
P	**0.15 - 0.40**	**Mn**	**22 - 175**
K	0.75 - 1.75	B	18 - 40
Ca	**0.52 - 1.05**	**Cu**	**2.0 - 9.0**
Mg	0.15 - 0.33	Zn	15 - 40
S	**0.13 - 0.25**	**Mo**	**0.13 - 0.50**

F

SCIENTIFIC NAME			*Thuja plicata*
COMMON NAME			**Western Red Cedar or Giant Arborvitae**
COLLECTED FROM			Field research plots
PLANT PART			25 2-3" terminal cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	0.70 - 1.85	Fe	80 - 200
P	**0.15 - 0.40**	**Mn**	**22 - 175**
K	0.75 - 1.75	B	18 - 40
Ca	**0.52 - 1.05**	**Cu**	**2.0 - 9.0**
Mg	0.15 - 0.33	Zn	15 - 40
S	**0.13 - 0.25**	**Mo**	**0.13 - 0.50**

Conifers

A

SCIENTIFIC NAME	*Torreya taxifolia*
COMMON NAME	**Florida Torreya or Stinking Cedar**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients Ppm	
N	1 - 1.85	Fe	33 - 103
P	**0.18 - 0.36**	**Mn**	**0.33 - 132**
K	1.13 - 2.52	B	5 - 33
Ca	**0.78 - 1.40**	**Cu**	**4 - 10**
Mg	0.22 - 0.35	Zn	17 - 31
S	**0.11 - 0.19**	**Mo**	**0.12 - 0.34**

B

SCIENTIFIC NAME	*Tsuga canadensis*
COMMON NAME	**Eastern Hemlock**
COLLECTED FROM	Field research plots & botanical garden/arboretum
PLANT PART	40 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.01 - 1.37	Fe	127 - 184
P	**0.16 - 0.27**	**Mn**	**419 - 1500**
K	0.50 - 0.69	B	40 - 53
Ca	**0.64 - 0.80**	**Cu**	**4 - 6**
Mg	0.16 - 0.26	Zn	10 - 23
S	**0.11 - 0.15**	**Mo**	**0.06 - 1.00**

C

SCIENTIFIC NAME	*Tsuga heterophylla*
COMMON NAME	**Western Hemlock**
COLLECTED FROM	Field research plots
PLANT PART	40 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients Ppm	
N	0.84 - 2.20	Fe	39 - 59
P	**0.19 - 0.50**	**Mn**	**1583 - 1876**
K	0.47 - 1.71	B	5 - 17
Ca	**0.20 - 0.32**	**Cu**	**3 - 8**
Mg	0.10 - 0.30	Zn	3 - 10
S	**0.10 - 0.15**	**Mo**	**0.05 - 0.22**

D

SCIENTIFIC NAME	*Tsuga mertensiana*
COMMON NAME	**Mountain Hemlock**
COLLECTED FROM	Field research plots
PLANT PART	40 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	0.98 - 1.22	Fe	70 - 130
P	**0.12 - 0.18**	**Mn**	**890 - 1940**
K	0.43 - 0.86	B	5 - 16
Ca	**0.22 - 0.51**	**Cu**	**2 - 4**
Mg	0.09 - 0.11	Zn	22 - 29
S	**0.18 - 0.27**	**Mo**	**0.13 - 0.24**

E

SCIENTIFIC NAME	*x Cupressocyparis leylandi*
COMMON NAME	**Leyland Cypress**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Castlewellan', 'Leighton Green'

Macronutrients %		Micronutrients Ppm	
N	1.10 - 1.50	Fe	36 - 87
P	**0.12 - 0.36**	**Mn**	**30 - 107**
K	0.67 - 1.91	B	15 - 43
Ca	**0.39 - 1.34**	**Cu**	**2 - 9**
Mg	0.07 - 0.39	Zn	17 - 98
S	**0.11 - 0.16**	**Mo**	**0.08 - 1.62**

F

Cut Flower Crops

A

SCIENTIFIC NAME			*Alpinia purpurata*
COMMON NAME			**Pink or Red Ginger**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Mature plants, visible bud stage
DATA TYPE			Survey Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients Ppm**	
N	2.19 - 2.70	Fe	31–50
P	**0.30 - 0.37**	**Mn**	**214–529**
K	2.46 - 3.34	B	10–17
Ca	**0.75 - 1.35**	**Cu**	**13–16**
Mg	0.35 - 0.47	Zn	75–176
S	**0.29 - 0.48**	**Mo**	**0.53 - 1.69**

B

SCIENTIFIC NAME			*Alstroemeria x Ligtu Hybrids*
COMMON NAME			**Florists' Alstroemeria or Peruvian Lily**
COLLECTED FROM			Greenhouse & field production nurseries
PLANT PART			30 mature leaves from new growth
SEASON			Mature plants, visible bud stage
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	3.70 - 5.60	Fe	150 - 300
P	**0.30 - 0.75**	**Mn**	**50 - 200**
K	3.52 - 7.04	B	13 - 50
Ca	**0.60 - 1.50**	**Cu**	**4 - 9**
Mg	0.20 - 0.50	Zn	30 - 45
S	**0.16 - 0.75**	**Mo**	**0.18 - 0.33**

C

SCIENTIFIC NAME			*Anthurium andraeanum*
COMMON NAME			**Florists' Anthurium or Flamingo Lily**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			15 mature leaves from new growth
SEASON			Mature plants, visible bud stage
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients Ppm**	
N	2.00 - 4.30	Fe	50–400
P	**0.15 - 0.60**	**Mn**	**50–1500**
K	1.00 - 4.90	B	25–135
Ca	**1.00 - 3.30**	**Cu**	**6–40**
Mg	0.34 - 1.00	Zn	15–280
S	**0.16 - 0.75**	**Mo**	**0.12 - 2.41**

D

SCIENTIFIC NAME			*Antirrhinum majus*
COMMON NAME			**Snapdragon**
COLLECTED FROM			Greenhouse nursery production
PLANT PART			50 mature leaves from new growth
SEASON			Mature plants, non-flowering
DATA TYPE			Sufficiency Range
CULTIVARS USED			Apache', 'Jersey City', 'Peoria', 'Philidelphia', others not specified
Macronutrients %		**Micronutrients ppm**	
N	3.20 - 5.30	Fe	70 - 450
P	**0.20 - 0.60**	**Mn**	**60 - 575**
K	2.20 - 4.60	B	15 - 60
Ca	**0.50 - 2.10**	**Cu**	**5 - 15**
Mg	0.50 - 1.05	Zn	30 - 75
S	**0.20 - 0.55**	**Mo**	**0.12 - 2.00**

E

SCIENTIFIC NAME			*Aster*
COMMON NAME			**General**
COLLECTED FROM			Field production nursery
PLANT PART			50 mature leaves from new growth
SEASON			Mature plants, non-flowering
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		**Micronutrients Ppm**	
N	2.6 - 4.9	Fe	75–130
P	**0.50 - 0.65**	**Mn**	**90–165**
K	2.1 - 3.9	B	20–35
Ca	**1.20 - 2.00**	**Cu**	**4.8–10**
Mg	0.22 - 0.58	Zn	35–70
S	**0.22 - 0.44**	**Mo**	**0.50 - 1.0**

F

SCIENTIFIC NAME			*Aster ericoides*
COMMON NAME			**September Aster**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			50 mature leaves from new growth
SEASON			Mature plants, non-flowering
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.80 - 4.90	Fe	56 - 112
P	**0.43 - 0.74**	**Mn**	**55 - 275**
K	2.55 - 3.43	B	43 - 108
Ca	**0.72 - 2.00**	**Cu**	**4 - 12**
Mg	0.22 - 0.29	Zn	26 - 78
S	**0.38 - 0.45**	**Mo**	**0.20 - 0.5**

Cut Flower Crops

A

SCIENTIFIC NAME			*Astilbe chinensis var. pumila*
COMMON NAME			**Chinese Astilbe or Lilac Rose**
COLLECTED FROM			Production fields
PLANT PART			25 mature leaves from new growth
SEASON			Young plants, 8-16 weeks old
DATA TYPE			Survey Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.94 - 4.53	Fe	117 - 306
P	**0.55 - 0.64**	**Mn**	**90 - 165**
K	1.84 - 2.27	B	20 - 35
Ca	**1.90 - 2.97**	**Cu**	**7 - 9**
Mg	0.12 - 0.28	Zn	28 - 39
S	**0.22 - 0.41**	**Mo**	**0.48 - 2.26**

B

SCIENTIFIC NAME			*Bouvardia ternifolia*
COMMON NAME			**Florists' Bouvardia**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Mature plants, visible bud stage
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	4.20 - 4.90	Fe	128 - 223
P	**0.62 - 0.93**	**Mn**	**33 - 93**
K	1.95 - 3.32	B	32 - 54
Ca	**2.00 - 2.40**	**Cu**	**5 - 10**
Mg	0.49 - 0.73	Zn	39 - 65
S	**0.19 - 0.32**	**Mo**	**0.1 - 0.26**

C

SCIENTIFIC NAME			*Clarkia x Grace series mix*
COMMON NAME			**Cut-flower Godetia or Satin Flower**
COLLECTED FROM			Experimental test plots
PLANT PART			40 mature leaves from new growth
SEASON			Mature plants, visible bud stage
DATA TYPE			Survey Range
CULTIVARS USED			Grace series mix
Macronutrients %		**Micronutrients ppm**	
N	1.17 - 3.20	Fe	44 - 189
P	**0.17 - 0.26**	**Mn**	**17 - 239**
K	1.11 - 4.18	B	4 - 23
Ca	**0.78 - 1.03**	**Cu**	**4 - 9**
Mg	0.22 - 0.34	Zn	21 - 36
S	**0.11 - 0.19**	**Mo**	**0.13 - 0.25**

D

SCIENTIFIC NAME			*Dendranthema grandiflorum*
COMMON NAME			**Florists' Chrysanthemum**
COLLECTED FROM			Production greenhouses
PLANT PART			30 leaves (4th leaf from top)
SEASON			Mature plants, visible bud stage
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	3.92 - 5.04	Fe	55 - 279
P	**0.31 - 0.62**	**Mn**	**22 - 247**
K	2.54 - 6.06	B	25 - 80
Ca	**1.00 - 3.01**	**Cu**	**4 - 8**
Mg	0.29 - 0.97	Zn	13 - 98
S	**0.14 - 0.20**	**Mo**	**0.1 - 0.25**

E

SCIENTIFIC NAME			*Dianthus caryophyllus cultivars*
COMMON NAME			**Florists' Carnation**
COLLECTED FROM			Greenhouse & field production nursery
PLANT PART			50 leaves (5th & 6th leaf pairs of non-flowering shoots)
SEASON			Mature plants, visible bud stage
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.80 - 5.20	Fe	50 - 200
P	**0.19 - 0.80**	**Mn**	**33 - 302**
K	1.17 - 6.00	B	22 - 100
Ca	**1.00 - 2.00**	**Cu**	**6 - 30**
Mg	0.19 - 0.70	Zn	20 - 200
S	**0.25 - 0.80**	**Mo**	**0.1 - 0.22**

F

SCIENTIFIC NAME			*Freesia x hybrida*
COMMON NAME			**Florists' Freesia**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			20 mature leaves from new growth
SEASON			Mature plants, bud initiated
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	1.22 - 2.80	Fe	23 - 77
P	**0.2 - 0.62**	**Mn**	**14 - 55**
K	1.5 - 5.86	B	4 - 43
Ca	**0.55 - 1**	**Cu**	**5 - 8**
Mg	0.16 - 0.24	Zn	33 - 64
S	**0.15 - 0.22**	**Mo**	**0.1 - 0.28**

Cut Flower Crops

A

Scientific Name	*Gerbera jamesonii*		
Common Name	**Gerber or Transvaal Daisy**		
Collected From	Greenhouse production nursery		
Plant Part	20 mature leaves from new growth		
Season	Mature plants, visible bud stage		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	2.52 - 4.90	Fe	56 - 112
P	**0.25 - 0.62**	**Mn**	**38 - 148**
K	3.91 - 5.00	B	30 - 40
Ca	**1.00 - 2.40**	**Cu**	**4 - 13**
Mg	0.24 - 0.63	Zn	33 - 52
S	**0.15 - 0.23**	**Mo**	**0.12 - 0.25**

B

Scientific Name	*Gladiolus x hortulanus*		
Common Name	**Garden Gladiolus**		
Collected From	Field production nursery		
Plant Part	15 mature leaves from new growth		
Season	Mature plants, visible bud stage		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 5.50	Fe	50 - 200
P	**0.25 - 1.00**	**Mn**	**50 - 200**
K	2.50 - 4.00	B	25 - 100
Ca	**0.50 - 4.50**	**Cu**	**8 - 20**
Mg	0.15 - 0.30	Zn	20 - 200
S	**0.1 - 0.20**	**Mo**	**0.2 - 0.4**

C

Scientific Name	*Gypsophila paniculata*		
Common Name	**Baby's Breath**		
Collected From	Greenhouse & field production nurseries & experimental test plots		
Plant Part	50 mature leaves from new growth		
Season	Mature plants, visible bud stage		
Data Type	Sufficiency Range		
Cultivars Used	Bristol Fairy', others not specified		
Macronutrients %		**Micronutrients Ppm**	
N	3.50 - 6.00	Fe	50–287
P	**0.25 - 0.70**	**Mn**	**33–286**
K	2.15 - 4.50	B	25–141
Ca	**2.60 - 6.41**	**Cu**	**4–25**
Mg	0.40 - 1.30	Zn	25–190
S	**0.25 - 1.28**	**Mo**	**0.12 - 0.28**

D

Scientific Name	*Lilium x Asiatic hybrids*		
Common Name	**Asiatic Hybrid Lilies**		
Collected From	Greenhouse production nursery		
Plant Part	25 mature leaves from new growth		
Season	Mature plants, visible bud stage		
Data Type	Sufficiency Range		
Cultivars Used	Enchantment', others not specified		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 4.00	Fe	32 - 63
P	**0.19 - 0.31**	**Mn**	**11 - 30**
K	1.49 - 3.91	B	4 - 17
Ca	**0.20 - 2.20**	**Cu**	**3 - 9**
Mg	0.19 - 0.30	Zn	19 - 25
S	**0.1 - 0.13**	**Mo**	**0.12 - 0.25**

E

Scientific Name	*Limonium sinuatum*		
Common Name	**Florists' or Annual Statice**		
Collected From	Production greenhouses		
Plant Part	40 mature leaves from new growth		
Season	Mature plants, visible bud stage		
Data Type	Survey Range		
Cultivars Used	Fortress Blue', 'Fortress Yellow', 'Heavenly Blue'		
Macronutrients %		**Micronutrients Ppm**	
N	1.78 - 3.50	Fe	34–159
P	**0.21 - 0.66**	**Mn**	**0.19–117**
K	1 - 3.11	B	4–20
Ca	**0.56 - 1**	**Cu**	**8–60**
Mg	0.3 - 0.92	Zn	32–70
S	**0.18 - 0.27**	**Mo**	**0.1 - 0.25**

F

Scientific Name	*Limonium sinuatum*		
Common Name	**Florists' or Annual Statice**		
Collected From	Production greenhouses		
Plant Part	40 mature leaves from new growth		
Season	Mature plants, visible bud stage		
Data Type	Survey Range		
Cultivars Used	Light blue, dark blue, white, yellow, and rose-flowering cultivars		
Macronutrients %		**Micronutrients ppm**	
N	3.42 - 6.00	Fe	50 - 355
P	**0.30 - 0.92**	**Mn**	**34 - 200**
K	3.00 - 7.32	B	20 - 51
Ca	**0.50 - 1.62**	**Cu**	**7 - 25**
Mg	0.50 - 2.13	Zn	25 - 90
S	**0.16 - 0.24**	**Mo**	**1.37 - 5.61**

Cut Flower Crops

A

Scientific Name			*Protea caffra*
Common Name			**Common Protea**
Collected From			Production fields
Plant Part			Most recentley matured leaf
Season			2-3 years
Data Type			Sufficiency Range
Cultivars Used			Common Protea
Macronutrients %		**Micronutrients ppm**	
N	1.2 - 1.3	Fe	33–45
P	**0.04 - 0.06**	**Mn**	**145 - 165**
K	0.34 - 0.73	B	14 - 24
Ca	**0.52 - 1**	**Cu**	**4 - 8**
Mg	0.1 - 0.12	Zn	22 - 35
S	**0.18 - 0.24**	**Mo**	**0.11 - 0.33**

B

Scientific Name			*Rosa x 'Dukat' & 'Emblem'*
Common Name			**Dukat' & 'Emblem' Hybrid Tea Roses (yellow**
Collected From			Production fields
Plant Part			35 leaflets (upper three leaflets from mature leaves)
Season			Mature plants, 3 - 4 years old
Data Type			Survey Range
Cultivars Used			Dukat', 'Emblem'
Macronutrients %		**Micronutrients ppm**	
N	2.56 - 4.58	Fe	73 - 278
P	**0.24 - 0.53**	**Mn**	**73 - 361**
K	1.66 - 2.39	B	43 - 78
Ca	**1.10 - 3.12**	**Cu**	**4 - 8**
Mg	0.27 - 0.43	Zn	20 - 42
S	**0.20 - 0.42**	**Mo**	**0.12 - 3.56**

C

Scientific Name			*Rosa x 'Lady Liberty' & 'Tineke'*
Common Name			**Lady Liberty' & 'Tineke' Hybrid Tea Roses (white**
Collected From			Production fields
Plant Part			35 leaflets (upper three leaflets from mature leaves)
Season			Young plants, 5-12 months old
Data Type			Survey Range
Cultivars Used			'Lady Liberty' & 'Tineke'
Macronutrients %		**Micronutrients ppm**	
N	3.66 - 4.55	Fe	93 - 208
P	**0.30 - 0.53**	**Mn**	**98 - 404**
K	1.73 - 2.88	B	37 - 81
Ca	**1.41 - 2.25**	**Cu**	**4 - 8**
Mg	0.32 - 0.45	Zn	34 - 46
S	**0.34 - 0.40**	**Mo**	**0.16 - 7.88**

D

Scientific Name			*Rosa x 'Madame'*
Common Name			**Madame' Hybrid Tea Rose (red)**
Collected From			Production fields
Plant Part			35 leaflets (upper three leaflets from mature leaves)
Season			Mature plants, 4-6 years old
Data Type			Survey Range
Cultivars Used			Madame'
Macronutrients %		**Micronutrients ppm**	
N	2.81 - 3.62	Fe	75 - 384
P	**0.24 - 0.33**	**Mn**	**91 - 179**
K	1.66 - 2.24	B	24 - 63
Ca	**1.00 - 1.77**	**Cu**	**5 - 8**
Mg	0.30 - 0.43	Zn	20 - 49
S	**0.18 - 0.23**	**Mo**	**0.12 - 4.89**

E

Scientific Name			*Rosa x 'Madame'*
Common Name			**Madame' Hybrid Tea Rose (red)**
Collected From			Production fields
Plant Part			35 leaflets (upper three leaflets from mature leaves)
Season			Young plants, 10-15 months old
Data Type			Survey Range
Cultivars Used			Madame'
Macronutrients %		**Micronutrients ppm**	
N	2.68 - 3.28	Fe	165 - 221
P	**0.19 - 0.28**	**Mn**	**137 - 496**
K	1.43 - 2.07	B	38 - 53
Ca	**1.10 - 1.54**	**Cu**	**2 - 5**
Mg	0.31 - 0.43	Zn	21 - 35
S	**0.18 - 0.23**	**Mo**	**0.19 - 0.70**

F

Scientific Name			*Rosa x 'Maikee'*
Common Name			**Maikee' Hybrid Tea Rose (champagne**
Collected From			Production fields
Plant Part			35 leaflets (upper three leaflets from mature leaves)
Season			Young plants, 6 - 12 months old
Data Type			Survey Range
Cultivars Used			Maikee'
Macronutrients %		**Micronutrients ppm**	
N	3.74 - 4.14	Fe	129 - 169
P	**0.30 - 0.36**	**Mn**	**117 - 163**
K	1.88 - 1.99	B	56 - 65
Ca	**1.32 - 1.51**	**Cu**	**5 - 7**
Mg	0.32 - 0.39	Zn	23 - 30
S	**0.29 - 0.39**	**Mo**	**0.26 - 3.72**

Cut Flower Crops

A

Scientific Name	*Rosa x 'Melody'*
Common Name	**Melody' Hybrid Tea Rose (pink)**
Collected From	Production fields
Plant Part	35 leaflets (upper three leaflets from mature leaves)
Season	Mature plants, 2 - 3 years old
Data Type	Survey Range
Cultivars Used	x 'Melody'

Macronutrients %		Micronutrients ppm	
N	4.21 - 4.73	Fe	147 - 240
P	**0.27 - 0.37**	**Mn**	**127 - 175**
K	2.21 - 2.95	B	46 - 66
Ca	**1.33 - 1.99**	**Cu**	**6 - 8**
Mg	0.34 - 0.47	Zn	26 - 42
S	**0.36 - 0.42**	**Mo**	**0.12 - 0.30**

B

Scientific Name	*Rosa x 'Osiana'*
Common Name	**Osiana' Hybrid Tea Rose (peach)**
Collected From	Production fields
Plant Part	35 leaflets (upper three leaflets from mature leaves)
Season	Mature plants, 2 - 3 years old
Data Type	Survey Range
Cultivars Used	Osiana'

Macronutrients %		Micronutrients ppm	
N	3.45 - 4.46	Fe	92 - 316
P	**0.26 - 0.43**	**Mn**	**95 - 316**
K	2.00 - 2.65	B	48 - 85
Ca	**1.01 - 2.33**	**Cu**	**4 - 8**
Mg	0.29 - 0.64	Zn	18 - 33
S	**0.18 - 0.23**	**Mo**	**0.03 - 0.12**

C

Scientific Name	*Rosa x 'Texas'*
Common Name	**Texas' Hybrid Tea Rose (yellow)**
Collected From	Production fields
Plant Part	35 leaflets (upper three leaflets from mature leaves)
Season	Young plants, 6 months old
Data Type	Survey Range
Cultivars Used	Texas'

Macronutrients %		Micronutrients ppm	
N	3.98 - 4.03	Fe	212 - 258
P	**0.30 - 0.33**	**Mn**	**237 - 419**
K	2.01 - 2.48	B	51 - 73
Ca	**1.58 - 1.85**	**Cu**	**7 - 9**
Mg	0.38 - 0.43	Zn	23 - 28
S	**0.31 - 0.35**	**Mo**	**1.01 - 1.23**

D

Scientific Name	*Rosa x 'Tineke'*
Common Name	**Tineke' Hybrid Tea Rose (white**
Collected From	Production fields
Plant Part	35 leaflets (upper three leaflets from mature leaves)
Season	Mature plants, 5 years old
Data Type	Survey Range
Cultivars Used	Tineke'

Macronutrients %		Micronutrients ppm	
N	4.20 - 4.28	Fe	136 - 171
P	**0.31 - 0.34**	**Mn**	**108 - 126**
K	2.09 - 2.17	B	42 - 48
Ca	**1.26 - 1.39**	**Cu**	**10 - 12**
Mg	0.40 - 0.43	Zn	28 - 35
S	**0.22 - 0.36**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Rosa x cultivars*
Common Name	**Hybrid Tea Roses**
Collected From	Production greenhouses
Plant Part	35 leaflets (upper three leaflets from mature leaves)
Season	Mature plants, flower buds pea size
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	2.38 - 5.00	Fe	56 - 200
P	**0.25 - 0.62**	**Mn**	**30 - 200**
K	1.50 - 3.52	B	30 - 61
Ca	**1.00 - 2.00**	**Cu**	**5 - 25**
Mg	0.22 - 0.50	Zn	18 - 100
S	**0.25 - 0.70**	**Mo**	**0.10 - 0.90**

F

Scientific Name	*Tanacetum parthenium*
Common Name	**Feverfew**
Collected From	Greenhouse production nursery
Plant Part	40 mature leaves from new growth
Season	Mature plants, non-flowering
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	4.20 - 4.90	Fe	56 - 112
P	**0.3 - 0.53**	**Mn**	**110 - 220**
K	1.11 - 7.82	B	43 - 54
Ca	**0.88 - 1.20**	**Cu**	**4 - 9**
Mg	0.19 - 0.29	Zn	29 - 85
S	**0.17 - 0.38**	**Mo**	**0.1 - 0.22**

Ferns and Related Plants

A

SCIENTIFIC NAME	*Adiantum caudatum*
COMMON NAME	**Trailing Maidenhair or Walking Fern**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	25 mature fronds from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.15 - 3.25	Fe	45 - 76
P	**0.40 - 0.80**	**Mn**	**23 - 56**
K	2.00 - 3.00	B	23 - 32
Ca	**0.89 - 1.21**	**Cu**	**3 - 10**
Mg	0.20 - 0.40	Zn	25 - 55
S	**0.2 - 0.29**	**Mo**	**0.19 - 0.34**

B

SCIENTIFIC NAME	*Adiantum pedatum*
COMMON NAME	**American or Northern Maidenhair or Five-finger Fern**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	10 mature fronds from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.5 - 2.98	Fe	31 - 109
P	**0.2 - 0.41**	**Mn**	**24 - 66**
K	1.4 - 2.45	B	24 - 35
Ca	**0.65 - 1.24**	**Cu**	**3 - 7**
Mg	.24 - .35	Zn	25 - 45
S	**0.22 - 0.39**	**Mo**	**0.14 - 0.25**

C

SCIENTIFIC NAME	*Adiantum raddianum*
COMMON NAME	**Delta Maidenhair Fern**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	25 fronds from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.80 - 2.50	Fe	50 - 300
P	**0.30 - 0.60**	**Mn**	**30 - 300**
K	2 - 2.78	B	25 - 50
Ca	**0.12 - 0.30**	**Cu**	**10 - 50**
Mg	0.25 - 0.40	Zn	25 - 200
S	**0.20 - 0.40**	**Mo**	**0.14 - .25**

D

SCIENTIFIC NAME	*Asparagus virgatus*
COMMON NAME	**Tree Fern**
COLLECTED FROM	Field production nursery
PLANT PART	10-15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	1.50 - 2.50	Fe	40 - 300
P	**0.2 - 0.65**	**Mn**	**40 - 300**
K	2.00 - 3.40	B	15 - 60
Ca	**0.25 - 0.80**	**Cu**	**5 - 30**
Mg	0.15 - 0.35	Zn	25 - 150
S	**0.15 - 0.4**	**Mo**	**0.40 - 2.05**

E

SCIENTIFIC NAME	*Asplenium nidus*
COMMON NAME	**Bird's-nest Fern**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	25 mature fronds from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.40 - 3.20	Fe	28 - 300
P	**0.30 - 0.50**	**Mn**	**27 - 300**
K	2.50 - 4.20	B	15 - 50
Ca	**0.50 - 1.00**	**Cu**	**3 - 20**
Mg	0.25 - 0.49	Zn	20 - 100
S	**0.20 - 0.35**	**Mo**	**0.07 - 0.30**

F

SCIENTIFIC NAME	*Athyrium niponicum var. pictum*
COMMON NAME	**Japanese Painted Fern**
COLLECTED FROM	Container production nursery
PLANT PART	15 mature fronds from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	var. pictum only

Macronutrients %		Micronutrients ppm	
N	2.50 - 3.34	Fe	45 - 50
P	**0.39 - 0.70**	**Mn**	**25 - 52**
K	2.88 - 3.49	B	0.15 - 24
Ca	**0.57 - 1.10**	**Cu**	**3 - 7**
Mg	0.28 - 0.32	Zn	24 - 35
S	**0.22 - 0.28**	**Mo**	**0.22 - 0.85**

Ferns and Related Plants

A

Scientific Name			*Athyrium otophorum*
Common Name			**Korean or Eared Lady Fern**
Collected From			Botanical garden/arboretum
Plant Part			20 mature fronds from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 2.55	Fe	33 - 53
P	**0.19 - 0.31**	**Mn**	**35 - 42**
K	1.78 - 2.13	B	25 - 86
Ca	**0.87 - 1.25**	**Cu**	**3 - 9**
Mg	0.31 - 0.37	Zn	20 - 33
S	**0.19 - 0.29**	**Mo**	**0.08 - 0.33**

B

Scientific Name			*Cyrtomium falcatum*
Common Name			**Holly Fern**
Collected From			Container production nursery
Plant Part			10 mature fronds from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species, 'Rochfordianum'
Macronutrients %		**Micronutrients ppm**	
N	1.45 - 2.21	Fe	37 - 66
P	**0.24 - 0.45**	**Mn**	**31 - 172**
K	2.02 - 2.73	B	23 - 40
Ca	**0.64 - 0.89**	**Cu**	**7 - 20**
Mg	0.29 - 0.42	Zn	51 - 70
S	**0.20 - 0.37**	**Mo**	**0.06 - 1.30**

C

Scientific Name			*Dennstaedtia punctilobula*
Common Name			**Hay-scented or Boulder Fern**
Collected From			Botanical garden/arboretum
Plant Part			30 mature fronds from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.26 - 2.36	Fe	34 - 151
P	**0.21 - 0.36**	**Mn**	**30 - 643**
K	1.23 - 3.24	B	8 - 30
Ca	**0.98 - 1.33**	**Cu**	**5 - 11**
Mg	0.24 - 0.58	Zn	22 - 53
S	**0.18 - 0.29**	**Mo**	**0.11 - 0.34**

D

Scientific Name			*Dryopteris erythrosora*
Common Name			**Shaggy Shield/Autumn Fern**
Collected From			Container production nursery
Plant Part			20 mature fronds from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.5	Fe	60 - 100
P	**0.25 - 0.50**	**Mn**	**40 - 200**
K	1.90 - 2.75	B	20 - 35
Ca	**0.54 - 1.75**	**Cu**	**4 - 8**
Mg	0.30 - 1.00	Zn	25 - 75
S	**0.23 - 0.51**	**Mo**	**0.1 - 0.5**

E

Scientific Name			*Dryopteris marginalis*
Common Name			**Marginal Wood or Leather Wood Fern**
Collected From			Botanical garden/arboretum
Plant Part			20 mature fronds from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 2.20	Fe	33 - 108
P	**0.21 - 0.35**	**Mn**	**34 - 178**
K	1.33 - 2.99	B	8 - 36
Ca	**0.88 - 1.21**	**Cu**	**5 - 11**
Mg	0.32 - 0.55	Zn	22 - 44
S	**0.18 - 0.29**	**Mo**	**0.09 - 0.25**

F

Scientific Name			*Equisetum hyemale*
Common Name			**Horsetail or Scouring Rush**
Collected From			Container production nursery
Plant Part			15 mature stems
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.15 - 1.55	Fe	22 - 34
P	**0.22 - 0.44**	**Mn**	**0.13 - 0.45**
K	1.78 - 3.11	B	8 - 14
Ca	**1.02 - 1.35**	**Cu**	**3 - 9**
Mg	0.19 - 0.33	Zn	33 - 61
S	**0.18 - 0.30**	**Mo**	**0.25 - 0.33**

Ferns and Related Plants

A

Scientific Name			*Nephrolepis cordifolia 'Duffii'*
Common Name			**Duffii' Sword Fern**
Collected From			Botanical garden/arboretum
Plant Part			10 mature fronds from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Duffii'
Macronutrients %		**Micronutrients ppm**	
N	1.14 - 1.89	Fe	35 - 100
P	**0.19 - 0.50**	**Mn**	**33 - 470**
K	0.98 - 1.63	B	11 - 52
Ca	**1.12 - 1.72**	**Cu**	**5 - 14**
Mg	0.32 - 1.20	Zn	21 - 76
S	**0.17 - 0.51**	**Mo**	**0.11 - 0.44**

B

Scientific Name			*Nephrolepis exaltata 'Bostoniensis'*
Common Name			**Boston Fern**
Collected From			Greenhouse production nursery
Plant Part			15 mature fronds from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			'Bostoniensis'
Macronutrients %		**Micronutrients ppm**	
N	2.10 - 3.00	Fe	28 - 300
P	**0.25 - 0.70**	**Mn**	**27 - 200**
K	1.60 - 3.80	B	20 - 70
Ca	**0.40 - 2.50**	**Cu**	**6 - 32**
Mg	0.25 - 1.00	Zn	33 - 65
S	**0.20 - 0.50**	**Mo**	**0.05 - 0.25**

C

Scientific Name			*Osmunda regalis*
Common Name			**Royal Fern**
Collected From			Botanical garden/arboretum
Plant Part			10 mature fronds from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.25 - 2.34	Fe	32 - 57
P	**0.14 - 0.26**	**Mn**	**29 - 674**
K	1 - 1.50	B	9 - 24
Ca	**0.56 - 1.11**	**Cu**	**3 - 12**
Mg	0.2 - 0.29	Zn	16 - 28
S	**0.17 - 0.27**	**Mo**	**0.05 - 0.11**

D

Scientific Name			*Polystichum acrostichoides*
Common Name			**Christmas Fern**
Collected From			Container production nursery
Plant Part			20 mature fronds from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.25 - 3.58	Fe	35 - 88
P	**0.22 - 0.69**	**Mn**	**0.28 - 73**
K	1.11 - 4.20	B	10 - 27
Ca	**0.5 - 0.90**	**Cu**	**6 - 12**
Mg	0.25 - 0.41	Zn	20 - 42
S	**0.18 - 0.32**	**Mo**	**0.14 - 0.62**

E

Scientific Name			*Polystichum polyblepharum*
Common Name			**Japanese Tassle or Bristle Fern**
Collected From			Container production nursery
Plant Part			20 mature fronds from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.34 - 2.54	Fe	33 - 59
P	**0.22 - 0.35**	**Mn**	**20 - 35**
K	1.34 - 2.96	B	8 - 14
Ca	**0.44 - 1.35**	**Cu**	**5 - 11**
Mg	0.2 - 0.33	Zn	16 - 30
S	**0.21 - 0.36**	**Mo**	**0.22 - 0.59**

F

Scientific Name			*Pteris cretica var. albolineata*
Common Name			**Variegated Cretan Brake or Table or Ribbon Fern**
Collected From			Greenhouse production nursery
Plant Part			25 mature fronds from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			var. albolineata only
Macronutrients %		**Micronutrients ppm**	
N	2.30 - 3.00	Fe	40 - 300
P	**0.21 - 0.30**	**Mn**	**70 - 300**
K	1.00 - 2.00	B	20 - 30
Ca	**2.00 - 3.00**	**Cu**	**6 - 30**
Mg	0.25 - 0.40	Zn	25 - 150
S	**0.18 - 0.29**	**Mo**	**0.22 - 1**

Ferns and Related Plants

A

Scientific Name	*Pteris quadriaurita 'Argyraea'*		
Common Name	**Silver-lace or Striped Brake or Silver Fern**		
Collected From	Botanical garden/conservatory		
Plant Part	15 mature fronds from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Argyraea'		
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 3.35	Fe	36 - 93
P	**0.22 - 0.45**	**Mn**	**32 - 53**
K	1.78 - 2.64	B	9 - 31
Ca	**0.67 - 1.14**	**Cu**	**5 - 11**
Mg	0.19 - 0.29	Zn	23 - 36
S	**0.18 - 0.29**	**Mo**	**0.05 - 1.09**

B

Scientific Name	*Rumohra adiantiformis*		
Common Name	**Leatherleaf Fern**		
Collected From	Field production nursery		
Plant Part	15 mature fronds from new growth		
Season	Spring to summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.00	Fe	20 - 200
P	**0.25 - 0.50**	**Mn**	**30 - 300**
K	2.00 - 4.00	B	20 - 50
Ca	**0.50 - 1.00**	**Cu**	**5 - 50**
Mg	0.20 - 0.80	Zn	20 - 200
S	**0.20 - 0.50**	**Mo**	**0.05 - 1**

C

Scientific Name	*Selaginella braunii*		
Common Name	**Arborvitae Fern or Sweat Plant or Chinese Lace-fern Spikemoss**		
Collected From	Botanical garden/arboretum		
Plant Part	30 fronds from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.12 - 2.42	Fe	25 - 50
P	**0.22 - 0.35**	**Mn**	**24 - 70**
K	1.22 - 1.77	B	6 - 13
Ca	**0.45 - 1**	**Cu**	**4 - 9**
Mg	0.23 - 0.32	Zn	18 - 23
S	**0.24 - 0.35**	**Mo**	**0.13 - 0.23**

D

Scientific Name	*Thelypteris hexagonoptera*		
Common Name	**Broad Beech or Southern Beech Fern**		
Collected From	Botanical garden/arboretum		
Plant Part	10 mature fronds from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 2.06	Fe	33 - 126
P	**0.18 - 0.25**	**Mn**	**30 - 180**
K	1.1 - 2.70	B	11 - 34
Ca	**1 - 1.41**	**Cu**	**6 - 12**
Mg	0.35 - 0.78	Zn	21 - 44
S	**0.22 - 0.47**	**Mo**	**0.05 - 0.25**

E

Scientific Name	*Thelypteris kunthii*		
Common Name	**Southern Maiden or River Fern**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	15 mature fronds from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.86 - 2.28	Fe	63 - 80
P	**0.35 - 0.44**	**Mn**	**71 - 83**
K	2.12 - 2.25	B	30 - 36
Ca	**0.76 - 1.18**	**Cu**	**5 - 9**
Mg	0.37 - 0.45	Zn	31 - 36
S	**0.29 - 0.34**	**Mo**	**0.08 - 0.44**

F

Scientific Name	*Thelypteris noveboracensis*		
Common Name	**New York or Tapering Fern**		
Collected From	Botanical garden/arboretum		
Plant Part	20 mature fronds from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.23 - 2.82	Fe	34 - 202
P	**0.18 - 0.26**	**Mn**	**31 - 390**
K	1.11 - 3.44	B	7 - 27
Ca	**0.89 - 1.06**	**Cu**	**6 - 14**
Mg	0.21 - 0.40	Zn	22 - 85
S	**0.19 - 0.37**	**Mo**	**0.09 - 0.22**

Ferns and Related Plants

A

SCIENTIFIC NAME	*Thelypteris torresiana*
COMMON NAME	**Marianna Maiden or Mariannas Fern**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	3 mature fronds from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.0 - 3.5	Fe	28 - 100
P	**0.25 - 0.40**	**Mn**	**25 - 50**
K	1.75 - 2.80	B	30 - 55
Ca	**0.60 - 1.25**	**Cu**	**7 - 18**
Mg	0.22 - 0.75	Zn	40 - 90
S	**0.20 - 0.35**	**Mo**	**0.2 - 0.5**

B

C

D

E

F

Florist Pot Crops

A

Scientific Name	*Aechmea fasciata*
Common Name	**Urn Plant or Pink-spike Bromeliad**
Collected From	Greenhouse production nursery
Plant Part	15 mature leaves from new growth
Season	Mature plants, non-flowering
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.33 - 2.54	Fe	35 - 300
P	**0.22 - 0.64**	**Mn**	**50 - 300**
K	0.79 - 2.21	B	25 - 58
Ca	**0.50 - 1.91**	**Cu**	**6 - 25**
Mg	0.40 - 0.80	Zn	25 - 200
S	**0.16 - 0.25**	**Mo**	**0.14 - 0.20**

B

Scientific Name	*Begonia x hiemalis cultivars*
Common Name	**Rieger-type Winter-flowering Tuberous or Elatior Begonias**
Collected From	Greenhouse production nursery
Crops Plant Part	20 mature leaves from new growth
Season	Mature plants, non-flowering
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	3.50 - 6.00	Fe	50 - 200
P	**0.30 - 0.75**	**Mn**	**50 - 200**
K	2.50 - 6.00	B	20 - 75
Ca	**1.00 - 2.50**	**Cu**	**7 - 30**
Mg	0.30 - 0.70	Zn	25 - 200
S	**0.30 - 0.70**	**Mo**	**0.09 - 0.25**

C

Scientific Name	*Begonia x tuberhybrida cultivars*
Common Name	**Tuberous Begonias**
Collected From	Greenhouse production nursery
Plant Part	20 mature leaves from new growth
Season	Mature plants, non-flowering
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	3.50 - 4.90	Fe	56 - 112
P	**0.31 - 0.62**	**Mn**	**27 - 126**
K	1.96 - 2.93	B	22 - 54
Ca	**1.00 - 2.00**	**Cu**	**6 - 13**
Mg	0.36 - 0.61	Zn	39 - 98
S	**0.21 - 0.33**	**Mo**	**0.1 - 0.23**

D

Scientific Name	*Cattleya bowringiana*
Common Name	**Bowring's Cattleya Orchid**
Collected From	Greenhouse production nursery
Plant Part	10 mature leaves and psudobulbs from new growth
Season	Mature plants, non-flowering
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.03 - 1.67	Fe	35 - 350
P	**0.16 - 0.24**	**Mn**	**31 - 180**
K	1.65 - 2.46	B	9 - 12
Ca	**1.12 - 1.78**	**Cu**	**6 - 18**
Mg	0.22 - 0.33	Zn	25 - 120
S	**0.31 - 1.33**	**Mo**	**0.09 - 0.25**

E

Scientific Name	*Cattleya gaskelliana*
Common Name	**Summer Cattleya Orchid**
Collected From	Greenhouse production nursery
Plant Part	10 mature leaves and psudobulbs from new growth
Season	Mature plants, non-flowering
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	0.31 - 0.85	Fe	40 - 250
P	**0.11 - 0.24**	**Mn**	**32 - 180**
K	1 - 1.80	B	8 - 14
Ca	**1.05 - 1.33**	**Cu**	**6 - 28**
Mg	0.22 - 0.34	Zn	23 - 120
S	**0.23 - 1.22**	**Mo**	**0.1 - 0.22**

F

Scientific Name	*Cattleya percivaliana*
Common Name	**Christmas Cattleya Orchid**
Collected From	Greenhouse production nursery
Plant Part	10 mature leaves and psudobulbs from new growth
Season	Mature plants, non-flowering
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	0.98 - 1.29	Fe	35 - 850
P	**0.15 - 0.23**	**Mn**	**29 - 66**
K	1.54 - 2.54	B	9 - 16
Ca	**1.08 - 1.71**	**Cu**	**6 - 85**
Mg	0.23 - 0.33	Zn	26 - 240
S	**0.22 - 0.83**	**Mo**	**0.09 - 0.23**

Florist Pot Crops

A

Scientific Name	*Cattleya trianaei*		
Common Name	**Christmas Orchid or Winter Cattleya Orchid**		
Collected From	Greenhouse production nursery		
Plant Part	10 mature leaves (first- through third-year leaves)		
Season	Mature plants, non-flowering		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 1.79	Fe	31 - 56
P	**0.16 - 0.24**	**Mn**	**31 - 55**
K	1.25 - 2.58	B	8 - 19
Ca	**1.09 - 2.88**	**Cu**	**6 - 12**
Mg	0.24 - 0.26	Zn	20 - 34
S	**0.17 - 0.28**	**Mo**	**0.08 - 0.29**

B

Scientific Name	*Cattleya x cultivars*		
Common Name	**Corsage or Cattleya Orchid**		
Collected From	Greenhouse production nursery		
Plant Part	5 mature leaves from new growth		
Season	Mature plants, non-flowering		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	1.00 - 2.50	Fe	50 - 200
P	**0.10 - 0.75**	**Mn**	**40 - 200**
K	2.00 - 4.24	B	25 - 75
Ca	**0.50 - 2.00**	**Cu**	**5 - 20**
Mg	0.30 - 0.70	Zn	25 - 200
S	**0.15 - 0.75**	**Mo**	**0.05 - 0.25**

C

Scientific Name	*Crossandra infundibuliformis*		
Common Name	**Crossandra or Firecracker Flower**		
Collected From	Greenhouse production nursery		
Plant Part	35 mature leaves from new growth		
Season	Mature plants, non-flowering		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 4.00	Fe	32 - 76
P	**0.25 - 0.40**	**Mn**	**32 - 66**
K	3.00 - 4.00	B	9 - 21
Ca	**1.20 - 1.60**	**Cu**	**6 - 14**
Mg	0.40 - 0.60	Zn	21 - 34
S	**0.16 - 0.26**	**Mo**	**0.09 - 0.23**

D

Scientific Name	*Cyclamen persicum*		
Common Name	**Florists' or Persian Cyclamen**		
Collected From	Greenhouse production nursery		
Plant Part	20 mature leaves from new growth		
Season	Mature plants, non-flowering		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	2.02 - 2.70	Fe	32 - 55
P	**0.14 - 0.22**	**Mn**	**31 - 49**
K	2.20 - 5.70	B	11 - 54
Ca	**0.8 - 1.28**	**Cu**	**5 - 17**
Mg	0.21 - 0.30	Zn	22 - 52
S	**0.2 - 0.29**	**Mo**	**0.07 - 0.32**

E

Scientific Name	*Cyclamen persicum*		
Common Name	**Florists' or Persian Cyclamen 6" Pots**		
Collected From	Greenhouse production nursery		
Plant Part	10-15 mature leaves from new growth		
Season	Prior to bloom		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 3.50	Fe	28 - 200
P	**0.22 - 0.40**	**Mn**	**30 - 80**
K	2.20 - 3.05	B	22 - 45
Ca	**0.50 - 1.00**	**Cu**	**3 - 20**
Mg	0.25 - 0.50	Zn	20 - 50
S	**0.20 - 0.75**	**Mo**	**0.14 - 0.20**

F

Scientific Name	*Cymbidium x cultivars*		
Common Name	**Cymbidium Orchids**		
Collected From	Greenhouse production nursery		
Plant Part	10 mature leaves from new growth		
Season	Mature plants of flowering size		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.50	Fe	50 - 133
P	**0.10 - 0.30**	**Mn**	**40 - 80**
K	2.00 - 3.00	B	25 - 50
Ca	**0.88 - 1.00**	**Cu**	**10 - 25**
Mg	0.30 - 0.60	Zn	25 - 75
S	**0.16 - 0.28**	**Mo**	**0.07 - 0.25**

Florist Pot Crops

A

Scientific Name	*Cymbidium x cultivars*
Common Name	**Cymbidium Orchids**
Collected From	Greenhouse production nursery
Plant Part	10 mature leaves from new growth
Season	Young plants, non-flowering
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	1.33 - 2.50	Fe	28 - 200
P	**0.13 - 0.75**	**Mn**	**30 - 200**
K	2.00 - 3.50	B	22 - 75
Ca	**1.23 - 2.00**	**Cu**	**5 - 20**
Mg	0.19 - 0.70	Zn	20 - 200
S	**0.15 - 0.75**	**Mo**	**0.05 - 0.11**

B

Scientific Name	*Dendranthema x grandiflorum*
Common Name	**Florists' or Pot Chrysanthemum or Garden Mum**
Collected From	Greenhouse production nursery
Plant Part	30 leaves (4th leaf from tip)
Season	Prior to bud set
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	4.00 - 6.00	Fe	20 - 750
P	**0.20 - 1.20**	**Mn**	**25 - 375**
K	1.00 - 10.00	B	20 - 200
Ca	**0.50 - 4.60**	**Cu**	**5 - 50**
Mg	0.10 - 1.50	Zn	5 - 250
S	**0.25 - 0.70**	**Mo**	**0.11 - 1.09**

C

Scientific Name	*Dendranthema x grandiflorum*
Common Name	**Florists' or Pot Chrysanthemum or Garden Mum**
Collected From	Greenhouse production nursery
Plant Part	30 leaves (4th leaf from tip)
Season	Bud set to harvest
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	4.00 - 6.30	Fe	50 - 250
P	**0.25 - 1.00**	**Mn**	**50 - 250**
K	4.00 - 7.00	B	25 - 75
Ca	**1.00 - 2.00**	**Cu**	**6 - 30**
Mg	0.25 - 1.00	Zn	20 - 250
S	**0.25 - 0.70**	**Mo**	**0.1 - 1.03**

D

Scientific Name	*Dendrobiumspp.*
Common Name	**Dendrobium orchids**
Collected From	Greenhouse production nursery
Plant Part	3rd most recently matured leaf
Season	Prior to bloom
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	1.45 - 1.9	Fe	50 - 100
P	**0.15 - 0.22**	**Mn**	**30 - 100**
K	1.75 - 2.4	B	8 - 22
Ca	**0.65 - 1.45**	**Cu**	**6 - 14**
Mg	0.4 - 0.8	Zn	21 - 37
S	**0.15 - 0.50**	**Mo**	**0.07 - 0.33**

E

Scientific Name	*Euphorbia pulcherrima*
Common Name	**Poinsettia or Christmas Flower**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Prior to bract collection
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	4.00 - 6.00	Fe	100 - 300
P	**0.30 - 1.08**	**Mn**	**45 - 300**
K	1.50 - 3.50	B	30 - 100
Ca	**0.70 - 2.4**	**Cu**	**3 - 25**
Mg	0.30 - 1.00	Zn	25 - 150
S	**0.25 - 0.70**	**Mo**	**1 - 5**

F

Scientific Name	*Euphorbia pulcherrima*
Common Name	**Poinsettia or Christmas Flower**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Bracts colored, plants flowering
Data Type	Sufficiency Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	4.00 - 6.00	Fe	100 - 300
P	**0.20 - 1.00**	**Mn**	**45 - 300**
K	1.5 - 5.00	B	20 - 200
Ca	**0.40 - 2.00**	**Cu**	**5 - 10**
Mg	0.2 - 1	Zn	25 - 150
S	**0.19 - 0.27**	**Mo**	**0.12 - 0.50**

Florist Pot Crops

A

Scientific Name		*Florist Pot Cactus*	
Common Name		**General**	
Collected From		Greenhouse production nursery	
Plant Part		10-15 mature leaves from new growth	
Season		Prior to bloom	
Data Type		Survey Range	
Cultivars Used		Not specified	
Macronutrients %		**Micronutrients ppm**	
N	3.75 - 4.75	Fe	54 - 300
P	**0.60 - 1.00**	**Mn**	**60 - 300**
K	3.00 - 6.00	B	20 - 50
Ca	**0.50 - 2.50**	**Cu**	**9 - 30**
Mg	0.68 - 2.20	Zn	25 - 100
S	**0.25 - 0.85**	**Mo**	**3.28 - 4.00**

B

Scientific Name		*Gardenia jasminoides*	
Common Name		**Common Gardenia or Cape Jasmine**	
Collected From		Greenhouse production nursery	
Plant Part		25 mature leaves from new growth	
Season		Mature plants, flowering	
Data Type		Sufficiency Range	
Cultivars Used		Not specified	
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 3.00	Fe	60 - 250
P	**0.16 - 0.40**	**Mn**	**50 - 250**
K	1.00 - 3.00	B	25 - 70
Ca	**0.50 - 1.30**	**Cu**	**6 - 40**
Mg	0.25 - 1.00	Zn	20 - 150
S	**0.20 - 0.40**	**Mo**	**0.14 - 1.15**

C

Scientific Name		*Gerbera jamesonii*	
Common Name		**Gerber or Transvaal Daisy**	
Collected From		Greenhouse production nursery	
Plant Part		20 mature leaves from new growth	
Season		Mature plants, flowering	
Data Type		Sufficiency Range	
Cultivars Used		Not specified	
Macronutrients %		**Micronutrients ppm**	
N	1.5 - 3.5	Fe	50 - 200
P	**0.2 - 0.5**	**Mn**	**40 - 250**
K	2.5 - 4.5	B	20 - 60
Ca	**1 - 3.5**	**Cu**	**6 - 50**
Mg	0.2 - 0.7	Zn	25 - 200
S	**0.25 - 0.70**	**Mo**	**0.2 - 0.6**

D

Scientific Name		*Guzmania lingulata*	
Common Name		**Scarlet or Orange Star Guzmania**	
Collected From		Greenhouse production nursery	
Plant Part		25 mature leaves from new growth	
Season		Mature plants, bud initiated	
Data Type		Sufficiency Range	
Cultivars Used		Not specified	
Macronutrients %		**Micronutrients ppm**	
N	1.96 - 2.24	Fe	56 - 112
P	**0.15 - 0.46**	**Mn**	**44 - 82**
K	2.93 - 3.52	B	11 - 22
Ca	**0.50 - 1.00**	**Cu**	**4 - 13**
Mg	0.19 - 0.34	Zn	33 - 248
S	**0.19 - 0.29**	**Mo**	**0.07 - 0.2**

E

Scientific Name		*Hippeastrum x cultivars*	
Common Name		**Garden Amaryllis**	
Collected From		Greenhouse production nursery	
Plant Part		25 mature leaves from new growth	
Season		Mature plants, non-flowering	
Data Type		Sufficiency Range	
Cultivars Used		Not specified	
Macronutrients %		**Micronutrients ppm**	
N	2.80 - 3.08	Fe	33 - 56
P	**0.18 - 0.28**	**Mn**	**33 - 55**
K	2.02 - 5.86	B	9 - 32
Ca	**0.80 - 1.00**	**Cu**	**5 - 12**
Mg	0.24 - 0.32	Zn	21 - 39
S	**0.14 - 0.23**	**Mo**	**0.14 - 0.34**

F

Scientific Name		*Hydrangea macrophylla cultivars*	
Common Name		**French Hydrangea or Hortensia**	
Collected From		Greenhouse production nursery	
Plant Part		15 mature leaves from new growth	
Season		Mature plants, non-flowering	
Data Type		Sufficiency Range	
Cultivars Used		Not specified	
Macronutrients %		**Micronutrients ppm**	
N	2.24 - 5.60	Fe	50 - 300
P	**0.25 - 0.70**	**Mn**	**38 - 300**
K	2.20 - 7.80	B	20 - 50
Ca	**0.60 - 2.00**	**Cu**	**1 - 25**
Mg	0.22 - 0.61	Zn	20 - 200
S	**0.20 - 0.70**	**Mo**	**0.09 - 0.22**

Florist Pot Crops

A

SCIENTIFIC NAME			*Kalanchoe blossfeldiana*
COMMON NAME			**Florists' Kalanchoe or Flaming Katy**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			25 leaves (4th leaf from tip)
SEASON			Prior to bloom
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	1.82 - 4.50	Fe	55 - 100
P	**0.25 - 1.00**	**Mn**	**70 - 100**
K	2.75 - 4.00	B	6 - 10
Ca	**1.22 - 4.00**	**Cu**	**4 - 10**
Mg	0.24 - 1.50	Zn	30 - 100
S	**0.21 - 0.33**	**Mo**	**0.09 - 0.29**

B

SCIENTIFIC NAME			*Lilium longiflorum*
COMMON NAME			**Easter Lily**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Prior to bud expansion
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	3.30 - 4.80	Fe	60 - 200
P	**0.25 - 0.70**	**Mn**	**35 - 200**
K	3.30 - 5.00	B	25 - 75
Ca	**0.60 - 1.50**	**Cu**	**8 - 50**
Mg	0.20 - 0.70	Zn	20 - 200
S	**0.25 - 0.70**	**Mo**	**0.15 - 0.35**

C

SCIENTIFIC NAME			*Oncidium x cultivars*
COMMON NAME			**Oncidium Orchids**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Mature plants, non-flowering
DATA TYPE			Survey Range
CULTIVARS USED			Gower Ramsey', others not specified
Macronutrients %		**Micronutrients ppm**	
N	1.54 - 2.04	Fe	16 - 61
P	**0.26 - 0.58**	**Mn**	**243 - 772**
K	2.23 - 3.95	B	11 - 21
Ca	**0.71 - 1.09**	**Cu**	**3 - 65**
Mg	0.28 - 0.48	Zn	22 - 108
S	**0.15 - 0.39**	**Mo**	**0.12 - 0.36**

D

SCIENTIFIC NAME			*Paphiopedilum x cultivars*
COMMON NAME			**Venus'-slipper Orchids**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Mature plants, non-flowering
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 3.50	Fe	50 - 200
P	**0.20 - 0.70**	**Mn**	**50 - 200**
K	2.00 - 3.50	B	25 - 75
Ca	**0.75 - 2.00**	**Cu**	**5 - 20**
Mg	0.20 - 0.75	Zn	25 - 200
S	**0.20 - 0.75**	**Mo**	**0.11 - 0.22**

E

SCIENTIFIC NAME			*Phalaenopsis x cultivars*
COMMON NAME			**Moth Orchids**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			10 mature leaves from new growth
SEASON			Mature plants of flowering size
DATA TYPE			Survey Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.50	Fe	80 - 170
P	**0.17 - 0.30**	**Mn**	**100 - 250**
K	3.90 - 7.06	B	25 - 50
Ca	**1.50 - 2.79**	**Cu**	**5 - 25**
Mg	0.40 - 1.07	Zn	20 - 94
S	**0.21 - 0.32**	**Mo**	**0.06 - 1**

F

SCIENTIFIC NAME			*Phalaenopsis x cultivars*
COMMON NAME			**Moth Orchids**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			5 mature leaves from new growth
SEASON			Young plants, non-flowering
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.50	Fe	75 - 200
P	**0.20 - 0.75**	**Mn**	**100 - 200**
K	4.00 - 6.00	B	25 - 75
Ca	**1.50 - 2.50**	**Cu**	**5 - 20**
Mg	0.40 - 1.00	Zn	20 - 200
S	**0.20 - 0.75**	**Mo**	**0.09 - 0.22**

Florist Pot Crops

A

Scientific Name	*Rhododendron indicum (Belgian Indica Hybrids)*		
Common Name	**Florists' or Belgian Indica Azaleas**		
Collected From	Greenhouse production nursery		
Plant Part	50 mature leaves from new growth		
Season	Mature plants, visible bud stage		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	1.96 - 3.00	Fe	50 - 250
P	**0.30 - 0.50**	**Mn**	**40 - 200**
K	0.78 - 2.50	B	25 - 50
Ca	**0.70 - 2.00**	**Cu**	**6 - 25**
Mg	0.17 - 0.60	Zn	20 - 250
S	**0.20 - 0.50**	**Mo**	**0.06 - 0.31**

B

Scientific Name	*Saintpaulia ionantha*		
Common Name	**African Violet**		
Collected From	Greenhouse production nursery		
Plant Part	25 mature leaves from new growth		
Season	Mature plants of flowering size		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	2.10 - 6.00	Fe	50 - 225
P	**0.30 - 1.55**	**Mn**	**27 - 200**
K	3.00 - 6.50	B	25 - 108
Ca	**1.00 - 2.00**	**Cu**	**6 - 38**
Mg	0.35 - 0.85	Zn	25 - 262
S	**0.30 - 0.70**	**Mo**	**0.07 - 0.23**

C

Scientific Name	*Schlumbergera buckleyi*		
Common Name	**Christmas Cactus**		
Collected From	Greenhouse production nursery		
Plant Part	20 2-3" terminal cuttings		
Season	Mature plants, non-flowering		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	2.80 - 4.50	Fe	54 - 300
P	**0.60 - 1.00**	**Mn**	**60 - 300**
K	4.00 - 6.00	B	20 - 50
Ca	**0.89 - 1.50**	**Cu**	**9 - 30**
Mg	0.40 - 2.00	Zn	25 - 100
S	**0.25 - 0.85**	**Mo**	**3.28 - 4.38**

D

Scientific Name	*Sinningia speciosa*		
Common Name	**Florists' Gloxinia**		
Collected From	Greenhouse production nursery		
Plant Part	15 mature leaves from new growth		
Season	Prior to floral bud expansion		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 5.00	Fe	50 - 200
P	**0.25 - 0.70**	**Mn**	**50 - 300**
K	2.50 - 5.00	B	25 - 50
Ca	**1.00 - 3.00**	**Cu**	**8 - 25**
Mg	0.35 - 0.70	Zn	20 - 50
S	**0.25 - 0.70**	**Mo**	**0.09 - 0.32**

E

Scientific Name	*x Laeliocattleya 'Aconcagua'*		
Common Name	**Aconcagua' Laeliocattleya Orchid**		
Collected From	Greenhouse production nursery		
Plant Part	10 mature leaves from new growth		
Season	Mature plants, non-flowering		
Data Type	Survey Range		
Cultivars Used	'Aconcagua'		
Macronutrients %		**Micronutrients ppm**	
N	1.68 - 1.85	Fe	295 - 405
P	**0.06 - 0.08**	**Mn**	**724 - 1047**
K	1.94 - 2.77	B	9 - 18
Ca	**1.05 - 1.63**	**Cu**	**13 - 15**
Mg	0.99 - 1.43	Zn	87 - 145
S	**0.19 - 0.27**	**Mo**	**0.08 - 0.21**

F

Scientific Name	*x Laeliocattleya 'Culminant'*		
Common Name	**Culminant' Laeliocattleya Orchid**		
Collected From	Greenhouse production nursery		
Plant Part	10 leaves (new through third year leaves)		
Season	Mature plants, non-flowering		
Data Type	Survey Range		
Cultivars Used	'Culminant'		
Macronutrients %		**Micronutrients ppm**	
N	1.90 - 2.50	Fe	93 - 150
P	**0.09 - 0.12**	**Mn**	**42 - 359**
K	0.69 - 2.41	B	8 - 18
Ca	**0.87 - 1.86**	**Cu**	**36 - 42**
Mg	0.31 - 0.79	Zn	95 - 143
S	**0.19 - 0.28**	**Mo**	**0.08 - 0.27**

Foliage Plants

A

Scientific Name	*Acalypha hispida*		
Common Name	**Chenille Plant**		
Collected From	Botanical garden/arboretum		
Plant Part	10 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.76 - 3.15	Fe	25–50
P	**0.289 - 0.51**	**Mn**	**21–73**
K	1.65 - 2.23	B	19–35
Ca	**1 - 1.96**	**Cu**	**6–13**
Mg	.34 - 0.60	Zn	0.2–39
S	**0.21 - 0.48**	**Mo**	**0.16 - 0.46**

B

Scientific Name	*Acalypha wilkesiana 'Musaica'*		
Common Name	**Copper Plant, Giant Red-leaf**		
Collected From	Botanical garden/arboretum		
Plant Part	10 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Musaica'		
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 3.89	Fe	38 - 89
P	**0.31 - 0.49**	**Mn**	**35 - 101**
K	1.79 - 3.27	B	21 - 40
Ca	**1 - 2.41**	**Cu**	**4 - 10**
Mg	0.33 - 0.96	Zn	23 - 35
S	**0.22 - 0.31**	**Mo**	**0.14 - 1.85**

C

Scientific Name	*Aeschynanthus radicans*		
Common Name	**Lipstick Plant**		
Collected From	Greenhouse production nursery and botanical garden/conservatory		
Plant Part	20 2-3" terminal cuttings		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.55 - 2.80	Fe	50–300
P	**0.20 - 0.80**	**Mn**	**40–300**
K	2.50 - 3.30	B	25–50
Ca	**0.65 - 1.60**	**Cu**	**9–30**
Mg	0.25 - 0.50	Zn	25–200
S	**0.12 - 0.30**	**Mo**	**0.50 - 1.50**

D

Scientific Name	*Aglaonema commutatum*		
Common Name	**Chinese Evergreen or Aglaonema**		
Collected From	Greenhouse production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Albovariegatum', 'Fransher', 'Pseudobracteatum', var. commutatum, var. elegans, var. maculatum		
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.80	Fe	50–300
P	**0.20 - 0.75**	**Mn**	**50–300**
K	1.50 - 2.5	B	20–75
Ca	**0.50 - 2.00**	**Cu**	**7–25**
Mg	0.30 - 1.00	Zn	20–200
S	**0.18 - 0.40**	**Mo**	**0.15 - 1.15**

E

Scientific Name	*Allamanda cathartica 'Hendersonii'*		
Common Name	**Allamanda, Yellow or Golden Trumpet Vine**		
Collected From	Container production nursery		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Hendersonii'		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 4.00	Fe	50–200
P	**0.25 - 1.00**	**Mn**	**50–200**
K	2.00 - 4.00	B	25–75
Ca	**0.76 - 1.50**	**Cu**	**8–25**
Mg	0.25 - 1.00	Zn	20–200
S	**0.20 - 0.40**	**Mo**	**0.12 - 1.00**

F

Scientific Name	*Alocasia cucullata*		
Common Name	**Chinese Taro or Chinese Ape**		
Collected From	Botanical garden/conservatory		
Plant Part	5 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.23 - 3.34	Fe	46–88
P	**0.3 - 0.45**	**Mn**	**50–179**
K	2 - 2.49	B	19–34
Ca	**1.56 - 2.29**	**Cu**	**6–16**
Mg	.45 - 0.87	Zn	31–56
S	**0.23 - 0.33**	**Mo**	**0.5 - 1.84**

Foliage Plants

A

Scientific Name	*Aloe arborescens*
Common Name	**Candleabra Aloe or Torch Plant or Octopus Plant**
Collected From	Botanical garden/conservatory
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.37 - 3.25	Fe	51 - 104
P	**0.47 - 0.52**	**Mn**	**72 - 471**
K	3.73 - 5.20	B	26 - 46
Ca	**1.52 - 1.56**	**Cu**	**4 - 6**
Mg	0.62 - 1.18	Zn	32 - 59
S	**0.18 - 0.23**	**Mo**	**0.33 - 0.45**

B

Scientific Name	*Aloe distans*
Common Name	**Jewelled Aloe**
Collected From	Botanical garden/conservatory
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.02 - 3.55	Fe	46 - 98
P	**0.289 - 0.38**	**Mn**	**46 - 189**
K	2.15 - 3.76	B	20 - 32
Ca	**1.19 - 2.12**	**Cu**	**5 - 15**
Mg	.45 - 1.27	Zn	33 - 46
S	**0.18 - 0.30**	**Mo**	**0.12 - 0.50**

C

Scientific Name	*Aloe vera*
Common Name	**Aloe Vera or Medicinal Aloe**
Collected From	Botanical garden/conservatory
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.45 - 4.05	Fe	26 - 45
P	**0.37 - 0.40**	**Mn**	**45 - 60**
K	2 - 6.46	B	21 - 33
Ca	**.98 - 1.67**	**Cu**	**3 - 13**
Mg	.4 - 1.32	Zn	34 - 40
S	**0.18 - 0.28**	**Mo**	**0.12 - 0.5**

D

Scientific Name	*Aphelandra squarrosa*
Common Name	**Zebra Plant or Aphelandra**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Dania'

Macronutrients %		Micronutrients ppm	
N	2.00 - 3.00	Fe	50 - 300
P	**0.20 - 0.40**	**Mn**	**50 - 300**
K	1.00 - 2.00	B	35 - 50
Ca	**0.40 - 2.00**	**Cu**	**10 - 50**
Mg	0.50 - 1.00	Zn	20 - 200
S	**0.20 - 0.30**	**Mo**	**0.12 - 0.50**

E

Scientific Name	*Asparagus densiflorus 'Myers'*
Common Name	**Foxtail Asparagus Fern**
Collected From	Field production nursery
Plant Part	15 mature fronds from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Myers'

Macronutrients %		Micronutrients ppm	
N	1.50 - 2.50	Fe	50 - 300
P	**0.12 - 0.50**	**Mn**	**40 - 300**
K	2.00 - 3.40	B	30 - 150
Ca	**0.25 - 0.80**	**Cu**	**5 - 30**
Mg	0.10 - 0.30	Zn	25 - 200
S	**0.15 - 0.25**	**Mo**	**0.40 - 2.05**

F

Scientific Name	*Asparagus densiflorus 'Sprengeri'*
Common Name	**Sprenger's Asparagus Fern**
Collected From	Field production nursery
Plant Part	10 mature fronds from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	'Sprengeri'

Macronutrients %		Micronutrients ppm	
N	1.75 - 3.70	Fe	40 - 300
P	**0.20 - 0.65**	**Mn**	**40 - 300**
K	2.20 - 3.90	B	15 - 60
Ca	**0.15 - 0.85**	**Cu**	**5 - 20**
Mg	0.15 - 0.40	Zn	20 - 200
S	**0.15 - 0.40**	**Mo**	**0.50 - 1.50**

Foliage Plants

A

SCIENTIFIC NAME			*Asparagus macowanii*
COMMON NAME			**Ming Asparagus Fern**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			30 branches with attached clustered 'leaves'
SEASON			Summer
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 3.10	Fe	30 - 300
P	**0.15 - 0.50**	**Mn**	**40 - 300**
K	1.40 - 3.50	B	15 - 40
Ca	**0.25 - 0.60**	**Cu**	**3 - 20**
Mg	0.10 - 0.30	Zn	15 - 200
S	**0.15 - 0.30**	**Mo**	**0.50 - 1.50**

B

SCIENTIFIC NAME			*Beaucarnea recurvata*
COMMON NAME			**Pony-tail Palm**
COLLECTED FROM			Greenhouse production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.10	Fe	40 - 200
P	**0.15 - 0.45**	**Mn**	**25 - 200**
K	1.70 - 3.00	B	12 - 35
Ca	**0.50 - 2.00**	**Cu**	**3 - 25**
Mg	0.20 - 0.50	Zn	25 - 75
S	**0.15 - 0.25**	**Mo**	**0.40 - 1.00**

C

SCIENTIFIC NAME			*Begonia foliosa*
COMMON NAME			**Fern-leaf Begonia**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			40 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.67 - 3.77	Fe	31 - 71
P	**0.23 - 0.96**	**Mn**	**26 - 79**
K	1.22 - 2.37	B	11 - 31
Ca	**0.87 - 1.23**	**Cu**	**5 - 10**
Mg	0.33 - 0.81	Zn	26 - 43
S	**0.22 - 0.40**	**Mo**	**0.32 - 1.15**

D

SCIENTIFIC NAME			*Begonia x 'Medora'*
COMMON NAME			**Miniature Angel Wing Begonia or Trout-leaf Begonia**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			40 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Medora'
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 5.13	Fe	55 - 210
P	**0.28 - 0.96**	**Mn**	**36 - 91**
K	2.25 - 6.70	B	20 - 36
Ca	**1.14 - 2**	**Cu**	**8 - 33**
Mg	0.33 - 0.68	Zn	28 - 60
S	**0.19 - 0.30**	**Mo**	**0.33 - 2.77**

E

SCIENTIFIC NAME			*Begonia x corallina 'Lucerna'*
COMMON NAME			**Lucerna' Cane-stem or Angel Wing Begonia**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Lucerna'
Macronutrients %		**Micronutrients ppm**	
N	1.55 - 2.94	Fe	44 - 141
P	**0.18 - 0.28**	**Mn**	**35 - 93**
K	0.99 - 1.50	B	21 - 55
Ca	**1.2 - 2.31**	**Cu**	**5 - 10**
Mg	0.36 - 1.05	Zn	22 - 33
S	**0.18 - 0.28**	**Mo**	**0.25 - 1.05**

F

SCIENTIFIC NAME			*Begonia x rex-cultorum*
COMMON NAME			**Rex Begonia or Beefsteak Geranium**
COLLECTED FROM			Botanical Garden/conservatory
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 3.33	Fe	55 - 173
P	**0.22 - 0.50**	**Mn**	**34 - 51**
K	1.78 - 2.86	B	24 - 50
Ca	**1 - 1.50**	**Cu**	**5 - 10**
Mg	0.34 - 0.97	Zn	34 - 76
S	**0.24 - 0.52**	**Mo**	**0.3 - 3.36**

Foliage Plants

A

Scientific Name	*Begonia x Superba Hybrids*		
Common Name	**Superba Hybrids Begonias**		
Collected From	Botanical garden/conservatory		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	2 - 3.19	Fe	55 - 130
P	**0.33 - 0.82**	**Mn**	**35 - 43**
K	1.89 - 3.22	B	22 - 49
Ca	**1.22 - 1.79**	**Cu**	**4 - 16**
Mg	0.36 - 0.84	Zn	31 - 45
S	**0.19 - 0.33**	**Mo**	**0.3 - 1.40**

B

Scientific Name	*Bougainvillea x cultivars*		
Common Name	**Bougainvillea or Paper Flower**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 4.50	Fe	50 - 300
P	**0.25 - 0.75**	**Mn**	**50 - 200**
K	3.00 - 5.50	B	25 - 75
Ca	**1.00 - 2.00**	**Cu**	**8 - 50**
Mg	0.25 - 0.75	Zn	20 - 200
S	**0.20 - 0.50**	**Mo**	**0.12 - 1.00**

C

Scientific Name	*Breynia disticha 'Rosea-picta'*		
Common Name	**Snowbush or Foliage Flower**		
Collected From	Botanical garden/arboretum		
Plant Part	40 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Rosea-picta'		
Macronutrients %		**Micronutrients ppm**	
N	2.43 - 3.02	Fe	42 - 100
P	**0.24 - 0.32**	**Mn**	**55 - 605**
K	1.72 - 3.39	B	22 - 55
Ca	**1.19 - 2.46**	**Cu**	**4 - 14**
Mg	0.37 - 0.86	Zn	33 - 85
S	**0.22 - 0.34**	**Mo**	**0.22 - 2.70**

D

Scientific Name	*Bromeliaceae Alcantarea*		
Common Name	**General**		
Collected From	Greenhouse production nursery		
Plant Part	10-15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	1.40 - 2.00	Fe	35 - 100
P	**0.15 - 0.55**	**Mn**	**40 - 150**
K	0.80 - 1.95	B	25 - 60
Ca	**0.50 - 1.60**	**Cu**	**6 - 20**
Mg	0.40 - 0.80	Zn	25 - 40
S	**0.15 - 0.25**	**Mo**	**0.20 - 0.50**

E

Scientific Name	*Caladium x hortulanum cultivars*		
Common Name	**Fancy-leaf Caladiums or Angels' Wings**		
Collected From	Greenhouse & field production nursery		
Plant Part	15 fully mature leaves		
Season	Late spring to early summer		
Data Type	Sufficiency Range		
Cultivars Used	Not specified		
Macronutrients %		**Micronutrients ppm**	
N	3.60 - 4.50	Fe	60 - 100
P	**0.30 - 0.70**	**Mn**	**50 - 210**
K	2.30 - 4.00	B	40 - 100
Ca	**1.00 - 1.50**	**Cu**	**6 - 15**
Mg	0.20 - 0.40	Zn	30 - 150
S	**0.25 - 0.50**	**Mo**	**0.12 - 1.00**

F

Scientific Name	*Calathea louisae*		
Common Name	**Feather Calathea**		
Collected From	Greenhouse production nursery		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 3.30	Fe	33 - 55
P	**0.36 - 0.50**	**Mn**	**28 - 56**
K	2.60 - 3.40	B	8 - 18
Ca	**0.40 - 0.50**	**Cu**	**5 - 12**
Mg	1.10 - 1.30	Zn	22 - 34
S	**0.19 - 0.31**	**Mo**	**0.1 - 0.24**

Foliage Plants

A

Scientific Name	*Calathea makoyana*
Common Name	**Peacock Plant or Cathedral Windows**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.50 - 4.00	Fe	30 - 200
P	**0.25 - 0.55**	**Mn**	**30 - 200**
K	2.00 - 4.50	B	18 - 50
Ca	**0.25 - 1.50**	**Cu**	**6 - 50**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.50 - 2.00**

B

Scientific Name	*Calathea picturata*
Common Name	**Silver Calathea**
Collected From	Greenhouse production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Silver Portrait', 'Vandenheckei'

Macronutrients %		Micronutrients ppm	
N	2.60 - 3.60	Fe	33 - 56
P	**0.25 - 0.50**	**Mn**	**56 - 122**
K	2.80 - 4.30	B	21 - 26
Ca	**0.30 - 0.50**	**Cu**	**4 - 14**
Mg	0.70 - 1.30	Zn	24 - 36
S	**0.18 - 0.29**	**Mo**	**0.33 - 0.5**

C

Scientific Name	*Calathea roseopicta*
Common Name	**Pink-stripe Calathea**
Collected From	Greenhouse production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.20 - 2.60	Fe	37 - 78
P	**0.34 - 0.75**	**Mn**	**35 - 77**
K	3.20 - 5.1	B	19 - 32
Ca	**0.30 - 0.40**	**Cu**	**5 - 12**
Mg	0.70 - 1.10	Zn	24 - 40
S	**0.18 - 0.29**	**Mo**	**0.1 - 0.4**

D

Scientific Name	*Calathea warscewiczii*
Common Name	**Warscewicz Zebra Calathea**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.80 - 3.80	Fe	44 - 66
P	**0.31 - 0.52**	**Mn**	**33 - 45**
K	3.10 - 3.40	B	12 - 24
Ca	**0.50 - 0.80**	**Cu**	**5 - 12**
Mg	0.90 - 1.10	Zn	21 - 34
S	**0.22 - 0.29**	**Mo**	**0.11 - 0.4**

E

Scientific Name	*Calathea zebrina*
Common Name	**Zebra Calathea or Zebra Plant**
Collected From	Botanical garden/conservatory
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.33 - 3.02	Fe	34 - 55
P	**0.17 - 0.38**	**Mn**	**45 - 108**
K	2.8 - 4.24	B	15 - 22
Ca	**0.34 - 1.54**	**Cu**	**6 - 14**
Mg	0.33 - 0.47	Zn	18 - 48
S	**0.19 - 0.40**	**Mo**	**0.09 - 1.46**

F

Scientific Name	*Cestrum elegans*
Common Name	**Crimson Jasmine or Red Cestrum or Flor del soldado**
Collected From	Botanical garden/conservatory
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.98 - 3.37	Fe	38 - 172
P	**0.21 - 0.53**	**Mn**	**33 - 278**
K	1.15 - 2.81	B	8 - 17
Ca	**0.78 - 1.44**	**Cu**	**5 - 9**
Mg	0.34 - 0.66	Zn	21 - 34
S	**0.21 - 0.39**	**Mo**	**0.3 - 0.64**

Foliage Plants

A

Scientific Name	*Chlorophytum comosum 'Vittatum'*
Common Name	**Variegated Spider Plant or Airplane Plant**
Collected From	Greenhouse production nursery and botanical garden/conservatory
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Vittatum'

Macronutrients %		Micronutrients ppm	
N	1.50 - 3.80	Fe	60 - 150
P	**0.15 - 0.50**	**Mn**	**50 - 80**
K	2.50 - 6.00	B	25 - 45
Ca	**0.90 - 2.50**	**Cu**	**4 - 25**
Mg	0.25 - 1.50	Zn	25 - 200
S	**0.20 - 0.35**	**Mo**	**0.33 - 0.75**

B

Scientific Name	*Cocculus laurifolius*
Common Name	**Laurel-leaf Moonseed or Cocculus**
Collected From	Container production nursery
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	1.25 - 2.48	Fe	44 - 78
P	**0.20 - 0.27**	**Mn**	**34 - 118**
K	1.12 - 2.10	B	32 - 92
Ca	**1.09 - 1.30**	**Cu**	**4 - 9**
Mg	0.13 - 0.21	Zn	13 - 23
S	**0.13 - 0.26**	**Mo**	**0.12 - 0.82**

C

Scientific Name	*Codiaeum variegatum var. pictum*
Common Name	**Croton or Variegated Laurel**
Collected From	Greenhouse production nursery and botanical garden/conservatory
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Banana', 'Gold Star', 'Norma', 'Petra'

Macronutrients %		Micronutrients ppm	
N	2.25 - 5.50	Fe	50 - 200
P	**0.25 - 0.55**	**Mn**	**25 - 315**
K	2.50 - 5.50	B	16 - 75
Ca	**0.90 - 2.50**	**Cu**	**5 - 50**
Mg	0.40 - 0.75	Zn	20 - 150
S	**0.12 - 0.35**	**Mo**	**0.20 - 0.50**

D

Scientific Name	*Coffea arabica*
Common Name	**Coffee Plant**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.50 - 3.50	Fe	90 - 300
P	**0.15 - 0.35**	**Mn**	**50 - 300**
K	2.00 - 3.00	B	25 - 75
Ca	**0.50 - 1.60**	**Cu**	**10 - 50**
Mg	0.30 - 0.50	Zn	15 - 200
S	**0.25 - 0.50**	**Mo**	**0.12 - 1.00**

E

Scientific Name	*Colocasia esculenta cultivars*
Common Name	**Taro or Elephant's Ear or Dasheen or Cocoyam**
Collected From	Botanical garden/conservatory
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	1.98 - 2.69	Fe	33 - 47
P	**0.31 - 0.44**	**Mn**	**41 - 50**
K	1.65 - 2.92	B	21 - 34
Ca	**1.23 - 2.29**	**Cu**	**5 - 16**
Mg	0.31 - 0.45	Zn	32 - 37
S	**0.25 - 0.43**	**Mo**	**0.22 - 0.58**

F

Scientific Name	*Cordyline fruticosa 'Firebrand'*
Common Name	**Purple-leaf Ti Plant or Hawaiian Good-luck Plant**
Collected From	Greenhouse production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Firebrand'

Macronutrients %		Micronutrients ppm	
N	1.98 - 3.50	Fe	27 - 112
P	**0.34 - 0.93**	**Mn**	**20 - 110**
K	2.37 - 4.69	B	22 - 32
Ca	**0.80 - 1.31**	**Cu**	**3 - 12**
Mg	0.23 - 0.49	Zn	44 - 131
S	**0.31 - 0.36**	**Mo**	**0.12 - 0.41**

Foliage Plants

A

Scientific Name	*Cordyline fruticosa 'Ti'*
Common Name	**Ti Plant or Hawaiian Good-luck Plant**
Collected From	Greenhouse production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Ti'

Macronutrients %		Micronutrients ppm	
N	1.86 - 2.50	Fe	19 - 38
P	**0.51 - 0.66**	**Mn**	**24 - 89**
K	0.94 - 2.02	B	9 - 28
Ca	**1.09 - 1.65**	**Cu**	**5 - 8**
Mg	0.39 - 0.49	Zn	54 - 67
S	**0.26 - 0.46**	**Mo**	**0.12 - 0.41**

B

Scientific Name	*Crassula ovata*
Common Name	**Jade Plant**
Collected From	Botanical garden/conservatory
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.14 - 2.03	Fe	41 - 45
P	**0.30 - 0.32**	**Mn**	**127 - 142**
K	1.48 - 2.69	B	20 - 31
Ca	**1.53 - 2.61**	**Cu**	**5 - 11**
Mg	0.33 - 0.82	Zn	45 - 50
S	**0.14 - 0.20**	**Mo**	**0.12 - 0.47**

C

Scientific Name	*Ctenanthe oppenheimiana 'Tricolor'*
Common Name	**Never-never Plant**
Collected From	Botanical garden/conservatory
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Tricolor'

Macronutrients %		Micronutrients ppm	
N	1.55 - 2.80	Fe	35 - 89
P	**0.21 - 0.43**	**Mn**	**44 - 94**
K	1.5 - 2.60	B	20 - 33
Ca	**0.55 - 0.79**	**Cu**	**4 - 9**
Mg	0.3 - 0.55	Zn	29 - 49
S	**0.21 - 0.37**	**Mo**	**0.33 - 3.00**

D

Scientific Name	*Dianella caerulea*
Common Name	**Australian Flax Lily or Sapphire Berry**
Collected From	Botanical garden/conservatory
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1 - 2.12	Fe	31 - 50
P	**0.18 - 0.29**	**Mn**	**30 - 75**
K	1.23 - 1.77	B	8 - 16
Ca	**0.68 - 1.41**	**Cu**	**4 - 12**
Mg	0.15 - 0.34	Zn	21 - 45
S	**0.18 - 0.29**	**Mo**	**0.2 - 0.30**

E

Scientific Name	*Dieffenbachia maculata*
Common Name	**Spotted Dumb Cane or Dieffenbachia**
Collected From	Greenhouse production nursery and botanical garden/conservatory
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species, 'Exotica', 'Rudolph Roehrs'

Macronutrients %		Micronutrients ppm	
N	2.50 - 3.95	Fe	50 - 300
P	**0.25 - 0.85**	**Mn**	**50 - 300**
K	2.75 - 6.50	B	15 - 45
Ca	**1.00 - 2.40**	**Cu**	**6 - 30**
Mg	0.30 - 1.30	Zn	40 - 200
S	**0.20 - 0.55**	**Mo**	**1.00 - 2.95**

F

Scientific Name	*Dizygotheca elegantissima*
Common Name	**False Aralia**
Collected From	Greenhouse production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.00 - 3.50	Fe	50 - 300
P	**0.25 - 0.60**	**Mn**	**50 - 300**
K	1.50 - 3.50	B	25 - 50
Ca	**0.50 - 2.00**	**Cu**	**6 - 50**
Mg	0.20 - 0.40	Zn	20 - 200
S	**0.25 - 0.50**	**Mo**	**0.20 - 1.00**

Foliage Plants

A

Scientific Name	*Dracaena deremensis 'Janet Craig Compacta'*
Common Name	**Compact Janet Craig Dracaena**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	'Janet Craig Compacta'

Macronutrients %		**Micronutrients ppm**	
N	2.30 - 5.00	Fe	50 - 300
P	**0.18 - 0.60**	**Mn**	**50 - 300**
K	2.50 - 4.50	B	15 - 50
Ca	**1.00 - 2.00**	**Cu**	**7 - 25**
Mg	0.20 - 0.60	Zn	20 - 200
S	**0.25 - 0.40**	**Mo**	**0.12 - 2.00**

B

Scientific Name	*Dracaena deremensis 'Janet Craig'*
Common Name	**Janet Craig' Dracaena**
Collected From	Greenhouse production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Janet Craig'

Macronutrients %		**Micronutrients ppm**	
N	2.50 - 4.50	Fe	50 - 300
P	**0.20 - 0.50**	**Mn**	**50 - 300**
K	2.50 - 4.00	B	15 - 50
Ca	**1.00 - 2.00**	**Cu**	**8 - 40**
Mg	0.30 - 0.60	Zn	20 - 200
S	**0.20 - 0.60**	**Mo**	**0.12 - 2.00**

C

Scientific Name	*Dracaena deremensis 'Warneckii'*
Common Name	**Warneckii' Striped Dracaena**
Collected From	Greenhouse production nursery and botanical garden/conservatory
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	'Warneckii'

Macronutrients %		**Micronutrients ppm**	
N	2.50 - 4.00	Fe	45 - 300
P	**0.15 - 0.50**	**Mn**	**50 - 300**
K	2.50 - 4.50	B	18 - 50
Ca	**0.90 - 2.00**	**Cu**	**8 - 40**
Mg	0.25 - 1.00	Zn	20 - 250
S	**0.20 - 0.45**	**Mo**	**0.50 - 2.00**

D

Scientific Name	*Dracaena fragrans 'Massangeana'*
Common Name	**Corn Plant Dracaena**
Collected From	Greenhouse production nursery
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	'Massangeana'

Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.50	Fe	50 - 300
P	**0.15 - 0.40**	**Mn**	**50 - 300**
K	1.50 - 4.00	B	20 - 50
Ca	**1.00 - 2.50**	**Cu**	**8 - 40**
Mg	0.20 - 1.00	Zn	20 - 200
S	**0.20 - 0.70**	**Mo**	**0.50 - 2.00**

E

Scientific Name	*Dracaena marginata*
Common Name	**Marginata or Red-edge Dracaena or Madagascar Dragon Tree**
Collected From	Greenhouse production nursery
Plant Part	Most recently matured leaf
Season	New growth, recently matured leaves
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.5 - 3.5	Fe	50 - 200
P	**0.15 - 0.25**	**Mn**	**20 - 200**
K	2.4 - 3.5	B	20 - 50
Ca	**1.09 - 2**	**Cu**	**5 - 14**
Mg	0.3 - 0.5	Zn	25 - 41
S	**0.25 - 0.50**	**Mo**	**0.1 - 0.55**

F

Scientific Name	*Dracaena marginata (green leaf form)*
Common Name	**Madagascar Dragontree or Red-edge Dracaena**
Collected From	Greenhouse production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.50	Fe	50 - 200
P	**0.15 - 0.25**	**Mn**	**50 - 200**
K	2.40 - 3.50	B	20 - 50
Ca	**1.00 - 2.00**	**Cu**	**5 - 20**
Mg	0.30 - 0.50	Zn	15 - 100
S	**0.25 - 0.50**	**Mo**	**0.12 - 0.50**

Foliage Plants

A

Scientific Name	*Dracaena reflexa*
Common Name	**Indian Dracaena**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.50	Fe	50 - 200
P	**0.22 - 0.40**	**Mn**	**40 - 200**
K	1.50 - 3.50	B	20 - 35
Ca	**1.50 - 2.50**	**Cu**	**6 - 25**
Mg	0.25 - 0.40	Zn	20 - 100
S	**0.25 - 0.50**	**Mo**	**0.12 - 0.50**

B

Scientific Name	*Dracaena sanderana*
Common Name	**Ribbon Plant or Belgian Evergreen**
Collected From	Greenhouse production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.50	Fe	50 - 300
P	**0.20 - 0.40**	**Mn**	**50 - 300**
K	2.00 - 3.00	B	20 - 50
Ca	**1.50 - 2.50**	**Cu**	**10 - 50**
Mg	0.30 - 0.60	Zn	20 - 250
S	**0.20 - 0.40**	**Mo**	**0.12 - 0.50**

C

Scientific Name	*Dracaena surculosa*
Common Name	**Gold-dust or Spotted Dracaena**
Collected From	Greenhouse production nursery and botanical garden/conservatory
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species, 'Flordia Beauty'

Macronutrients %		**Micronutrients ppm**	
N	2.00 - 4.00	Fe	40 - 300
P	**0.20 - 0.75**	**Mn**	**50 - 300**
K	1.50 - 4.85	B	20 - 55
Ca	**0.75 - 1.70**	**Cu**	**8 - 40**
Mg	0.20 - 0.50	Zn	20 - 150
S	**0.20 - 0.45**	**Mo**	**0.12 - 0.50**

D

Scientific Name	*Epipremnum aureum*
Common Name	**Golden Pothos or Devil's Ivy**
Collected From	Greenhouse production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.50	Fe	50 - 300
P	**0.20 - 0.50**	**Mn**	**50 - 300**
K	3.00 - 5.50	B	20 - 60
Ca	**1.00 - 2.00**	**Cu**	**6 - 25**
Mg	0.30 - 1.00	Zn	20 - 125
S	**0.20 - 0.40**	**Mo**	**0.30 - 1.25**

E

Scientific Name	*Epipremnum aureum 'Marble Queen'*
Common Name	**Marble Queen' Pothos or Devil's Ivy**
Collected From	Greenhouse production nursery and botanical garden/conservatory
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	'Marble Queen'

Macronutrients %		**Micronutrients ppm**	
N	2.70 - 4.00	Fe	50 - 300
P	**0.20 - 0.50**	**Mn**	**50 - 300**
K	3.00 - 7.00	B	20 - 60
Ca	**1.00 - 2.00**	**Cu**	**6 - 25**
Mg	0.30 - 1.00	Zn	20 - 150
S	**0.20 - 0.40**	**Mo**	**0.30 - 1.25**

F

Scientific Name	*Episcia cupreata*
Common Name	**Flame Violet**
Collected From	Botanical garden/conservatory
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	1.54 - 3.26	Fe	34 - 103
P	**0.27 - 1.45**	**Mn**	**27 - 75**
K	1.65 - 4.69	B	12 - 49
Ca	**0.96 - 1.36**	**Cu**	**6 - 25**
Mg	0.35 - 0.89	Zn	31 - 79
S	**0.25 - 0.50**	**Mo**	**0.23 - 0.50**

Foliage Plants

A

Scientific Name	*Eucharis amazonica*		
Common Name	**Amazon Lily or Eucharist Lily**		
Collected From	Botanical garden/conservatory		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 2.60	Fe	35 - 84
P	**0.22 - 0.81**	**Mn**	**28 - 44**
K	1.12 - 3.20	B	8 - 31
Ca	**1.19 - 2.14**	**Cu**	**5 - 12**
Mg	0.23 - 0.33	Zn	21 - 50
S	**0.21 - 0.46**	**Mo**	**0.2 - 2.82**

B

Scientific Name	*Euphorbia milii var. splendens*		
Common Name	**Crown-of-thorns**		
Collected From	Greenhouse production nursery		
Plant Part	40 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	var. splendens only		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 4.00	Fe	50 - 200
P	**0.25 - 1.00**	**Mn**	**25 - 200**
K	1.50 - 4.00	B	25 - 100
Ca	**1.00 - 2.50**	**Cu**	**10 - 50**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.12 - 0.50**

C

Scientific Name	*Euphorbia tirucalli*		
Common Name	**Milk Bush or Pencil Tree or Finger Tree**		
Collected From	Botanical garden/conservatory		
Plant Part	20 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.4 - 2.5	Fe	41 - 99
P	**0.24 - 0.59**	**Mn**	**33 - 271**
K	1.22 - 2.98	B	20 - 33
Ca	**1.11 - 1.85**	**Cu**	**2 - 9**
Mg	0.33 - 0.87	Zn	22 - 37
S	**0.18 - 0.26**	**Mo**	**0.12 - 0.3**

D

Scientific Name	*Ficus benjamina*		
Common Name	**Weeping Fig**		
Collected From	Container production nursery and botanical garden/conservatory		
Plant Part	40 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species, 'Exotica'		
Macronutrients %		**Micronutrients ppm**	
N	1.80 - 3.50	Fe	30 - 200
P	**0.10 - 0.40**	**Mn**	**25 - 200**
K	1.00 - 2.95	B	20 - 75
Ca	**0.85 - 3.25**	**Cu**	**5 - 25**
Mg	0.20 - 1.00	Zn	15 - 200
S	**0.15 - 0.40**	**Mo**	**0.12 - 0.50**

E

Scientific Name	*Ficus benjamina 'Hawaii'*		
Common Name	**Variegated Weeping Fig**		
Collected From	Botanical garden/conservatory		
Plant Part	40 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Hawaii'		
Macronutrients %		**Micronutrients ppm**	
N	1.01 - 1.87	Fe	45 - 57
P	**0.22 - 0.29**	**Mn**	**33 - 90**
K	1.4 - 2.75	B	17 - 52
Ca	**1.21 - 1.46**	**Cu**	**4 - 14**
Mg	0.34 - 0.45	Zn	14 - 20
S	**0.13 - 0.23**	**Mo**	**0.09 - 0.12**

F

Scientific Name	*Ficus elastica*		
Common Name	**Indian Rubber Plant**		
Collected From	Container production nursery		
Plant Part	10 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species, 'Decora'		
Macronutrients %		**Micronutrients ppm**	
N	1.30 - 2.50	Fe	30 - 200
P	**0.10 - 0.50**	**Mn**	**20 - 200**
K	0.60 - 2.10	B	20 - 50
Ca	**0.30 - 1.20**	**Cu**	**8 - 25**
Mg	0.20 - 0.50	Zn	15 - 200
S	**0.15 - 0.50**	**Mo**	**0.12 - 1.00**

Foliage Plants

A

SCIENTIFIC NAME	*Ficus elastica 'Variegata'*
COMMON NAME	**Variegated Rubber Plant**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Variegata'

Macronutrients %		Micronutrients ppm	
N	1.25 - 1.98	Fe	28 - 37
P	**0.21 - 0.34**	**Mn**	**0.25 - 0.45**
K	1.33 - 2.80	B	14 - 43
Ca	**1.11 - 1.77**	**Cu**	**4 - 11**
Mg	0.33 - 0.39	Zn	23 - 40
S	**0.07 - 0.18**	**Mo**	**0.09 - 0.32**

B

SCIENTIFIC NAME	*Ficus lyrata*
COMMON NAME	**Fiddleleaf Fig**
COLLECTED FROM	Container production nursery
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.30 - 2.75	Fe	30 - 200
P	**0.10 - 0.50**	**Mn**	**20 - 200**
K	0.60 - 3.10	B	20 - 50
Ca	**0.30 - 2.00**	**Cu**	**8 - 25**
Mg	0.20 - 0.80	Zn	15 - 200
S	**0.15 - 0.50**	**Mo**	**0.12 - 1.00**

C

SCIENTIFIC NAME	*Fittonia verschaffeltii var. argyroneura*
COMMON NAME	**Silver-nerve Plant or Mosaic Plant or Silver Fittonia**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	var. argyroneura only

Macronutrients %		Micronutrients ppm	
N	2.21 - 4.16	Fe	43 - 114
P	**0.32 - 0.76**	**Mn**	**35 - 80**
K	2.66 - 5.69	B	21 - 41
Ca	**1.5 - 2.24**	**Cu**	**5 - 9**
Mg	0.34 - 1.34	Zn	40 - 61
S	**0.23 - 0.63**	**Mo**	**0.25 - 3.00**

D

SCIENTIFIC NAME	*Foliage Plants*
COMMON NAME	**General**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	10-15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	1.9 - 3.5	Fe	49 - 300
P	**0.24 - 0.8**	**Mn**	**49 - 300**
K	1.9 - 3.5	B	19 - 50
Ca	**.7 - 2.0**	**Cu**	**7 - 60**
Mg	.2 - 1.0	Zn	24 - 250
S	**0.18 - 0.29**	**Mo**	**0.1 - 0.4**

E

SCIENTIFIC NAME	*Gynura aurantiaca 'Purple Passion'*
COMMON NAME	**Royal Velvet Plant or Purple Passion Vine**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Purple Passion'

Macronutrients %		Micronutrients ppm	
N	3.20 - 3.78	Fe	86 - 168
P	**0.32 - 0.41**	**Mn**	**192 - 239**
K	4.07 - 5.55	B	41 - 62
Ca	**1.26 - 1.60**	**Cu**	**8 - 14**
Mg	0.70 - 0.94	Zn	34 - 48
S	**0.32 - 0.41**	**Mo**	**1.57 - 3.00**

F

SCIENTIFIC NAME	*Hedera helix*
COMMON NAME	**English Ivy**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	35 mature leaves from new growth
SEASON	Mature plants
DATA TYPE	Sufficiency Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	2.50 - 4.50	Fe	50 - 375
P	**0.25 - 0.90**	**Mn**	**50 - 200**
K	1.50 - 4.50	B	20 - 50
Ca	**1.00 - 2.00**	**Cu**	**5 - 25**
Mg	0.25 - 0.70	Zn	20 - 100
S	**0.25 - 0.50**	**Mo**	**0.50 - 4.00**

Foliage Plants

A

SCIENTIFIC NAME	*Heliconia psittacorum*
COMMON NAME	**Parrot Flower or Heliconia**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	5 mid-section leaf strips
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.67 - 1.79	Fe	30 - 40
P	**0.27 - 0.38**	**Mn**	**26 - 93**
K	1.72 - 2.13	B	10 - 15
Ca	**0.75 - 0.81**	**Cu**	**5 - 8**
Mg	0.33 - 0.38	Zn	16 - 23
S	**0.36 - 0.39**	**Mo**	**1.76 - 2.05**

B

SCIENTIFIC NAME	*Heliconia wagnerana*
COMMON NAME	**Pink Lobster-claw Heliconia**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	5 mid-section leaf strips
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.77 - 2.34	Fe	35 - 77
P	**0.19 - 0.27**	**Mn**	**45 - 142**
K	1.5 - 2.22	B	19 - 31
Ca	**0.78 - 1.34**	**Cu**	**5 - 9**
Mg	0.33 - 0.74	Zn	22 - 45
S	**0.19 - 0.30**	**Mo**	**0.32 - 0.99**

C

SCIENTIFIC NAME	*Hibiscus rosa-sinensis*
COMMON NAME	**Tropical or Chinese Hibscus or Rose-of-China**
COLLECTED FROM	Container and greenhouse production nurseries
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	2.50 - 4.50	Fe	50 - 200
P	**0.25 - 1.00**	**Mn**	**40 - 200**
K	1.50 - 3.00	B	25 - 100
Ca	**1.00 - 3.00**	**Cu**	**6 - 50**
Mg	0.25 - 0.80	Zn	20 - 200
S	**0.20 - 0.50**	**Mo**	**0.12 - 1.00**

D

SCIENTIFIC NAME	*Ixora coccinea*
COMMON NAME	**Flame-of-the-woods or Indian Jasmine**
COLLECTED FROM	Container production nursery
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	1.80 - 3.00	Fe	65 - 250
P	**0.15 - 1.00**	**Mn**	**50 - 200**
K	1.00 - 2.50	B	25 - 100
Ca	**0.80 - 2.00**	**Cu**	**10 - 50**
Mg	0.20 - 1.00	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.12 - 1.00**

E

SCIENTIFIC NAME	*Jasminum nitidum*
COMMON NAME	**Angel-wing or Windmill Jasmine**
COLLECTED FROM	Container production nursery
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.00 - 4.00	Fe	50 - 200
P	**0.18 - 0.50**	**Mn**	**40 - 200**
K	1.30 - 2.50	B	25 - 75
Ca	**0.70 - 1.50**	**Cu**	**10 - 50**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.12 - 0.50**

F

SCIENTIFIC NAME	*Leea coccinea var. rubra*
COMMON NAME	**Purple-leaf Leea or West Indian Holly**
COLLECTED FROM	Greenhouse production nursery & botanical garden/conservatory
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	var. rubra only

Macronutrients %		Micronutrients ppm	
N	2.20 - 3.30	Fe	30 - 300
P	**0.20 - 0.55**	**Mn**	**20 - 200**
K	1.50 - 2.80	B	15 - 50
Ca	**0.65 - 2.00**	**Cu**	**8 - 30**
Mg	0.25 - 0.80	Zn	10 - 100
S	**0.20 - 0.50**	**Mo**	**0.12 - 0.50**

Foliage Plants

A

Scientific Name			*Mandevilla x amabilis*
Common Name			**Alice du Pont'**
Collected From			Container & greenhouse production nurseries
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Alice du Pont'
Macronutrients %		**Micronutrients ppm**	
N	1.90 - 3.00	Fe	50 - 200
P	**0.20 - 0.50**	**Mn**	**25 - 200**
K	2.00 - 4.00	B	25 - 75
Ca	**0.80 - 1.50**	**Cu**	**8 - 40**
Mg	0.25 - 0.50	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.12 - 1.00**

B

Scientific Name			*Maranta leuconeura var. kerchoviana*
Common Name			**Rabbit's-foot or Rabbit's-track Maranta or Prayer Plant**
Collected From			Greenhouse production nursery & botanical garden/conservatory
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			var. kerchoviana only
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.00	Fe	60 - 300
P	**0.20 - 0.50**	**Mn**	**50 - 200**
K	2.00 - 5.50	B	25 - 50
Ca	**0.50 - 1.50**	**Cu**	**7 - 40**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.20 - 0.50**	**Mo**	**0.50 - 2.00**

C

Scientific Name			*Monstera deliciosa*
Common Name			**Swiss-cheese Plant or Mexican Breadfruit**
Collected From			Greenhouse production nursery & botanical garden/conservatory
Plant Part			5 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 5.00	Fe	40 - 200
P	**0.20 - 0.40**	**Mn**	**40 - 450**
K	2.50 - 4.50	B	5 - 19
Ca	**0.50 - 2.50**	**Cu**	**5 - 15**
Mg	0.25 - 0.65	Zn	25 - 200
S	**0.15 - 0.45**	**Mo**	**0.50 - 2.00**

D

Scientific Name			*Murraya paniculata*
Common Name			**Orange Jasmine or Satinwood**
Collected From			Container production nursery
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.00	Fe	60 - 350
P	**0.25 - 0.50**	**Mn**	**50 - 250**
K	1.70 - 3.50	B	25 - 50
Ca	**0.80 - 1.50**	**Cu**	**7 - 50**
Mg	0.25 - 0.40	Zn	25 - 200
S	**0.20 - 0.40**	**Mo**	**0.12 - 0.50**

E

Scientific Name			*Nautilocalyx lynchii*
Common Name			**Bronze-leaf Nautilocalyx**
Collected From			Botanical garden/conservatory
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.88 - 3.57	Fe	34 - 148
P	**0.28 - 0.55**	**Mn**	**29 - 97**
K	1.5 - 3.30	B	11 - 35
Ca	**0.87 - 1.26**	**Cu**	**6 - 25**
Mg	0.34 - 0.85	Zn	29 - 88
S	**0.21 - 0.61**	**Mo**	**0.25 - 2.18**

F

Scientific Name			*Pandanus baptistii 'Aureus'*
Common Name			**Golden Screwpine**
Collected From			Greenhouse production nursery
Plant Part			10 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Aureus'
Macronutrients %		**Micronutrients ppm**	
N	1.1 - 2.24	Fe	20 - 45
P	**0.17 - 0.33**	**Mn**	**30 - 56**
K	1.75 - 2.89	B	15 - 25
Ca	**0.77 - 1.04**	**Cu**	**6 - 24**
Mg	0.28 - 0.45	Zn	22 - 39
S	**0.18 - 0.24**	**Mo**	**0.1 - 0.47**

Foliage Plants

A

SCIENTIFIC NAME			*Pandanus veitchii*
COMMON NAME			**Veitch's Variegated Screwpine**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			10 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.01 - 1.63	Fe	17 - 33
P	**0.13 - 0.21**	**Mn**	**27 - 45**
K	1.52 - 2.91	B	13 - 15
Ca	**0.64 - 0.87**	**Cu**	**5 - 18**
Mg	0.22 - 0.35	Zn	32 - 46
S	**0.15 - 0.24**	**Mo**	**0.12 - 0.30**

B

SCIENTIFIC NAME			*Peperomia argyreia*
COMMON NAME			**Watermelon Begonia or Watermelon Peperomia**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.94 - 3.77	Fe	63 - 74
P	**0.82 - 0.88**	**Mn**	**202 - 275**
K	3.33 - 5.27	B	23 - 25
Ca	**0.66 - 0.77**	**Cu**	**5 - 12**
Mg	0.35 - 0.82	Zn	14 - 41
S	**0.22 - 0.34**	**Mo**	**0.71 - 2.63**

C

SCIENTIFIC NAME			*Peperomia caperata*
COMMON NAME			**Ripple-leaf Peperomia**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Emerald Ripple', 'Little Fantasy'
Macronutrients %		**Micronutrients ppm**	
N	3.30 - 3.36	Fe	40 - 55
P	**0.52 - 0.86**	**Mn**	**153 - 160**
K	2.76 - 6.00	B	25 - 42
Ca	**0.60 - 0.86**	**Cu**	**5 - 12**
Mg	0.59 - 1.01	Zn	31 - 66
S	**0.40 - 0.66**	**Mo**	**0.52 - 1.57**

D

SCIENTIFIC NAME			*Peperomia clusiifolia*
COMMON NAME			**Red-edge Peperomia**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.33 - 2.39	Fe	44 - 155
P	**0.24 - 0.93**	**Mn**	**35 - 79**
K	2.5 - 4.95	B	24 - 31
Ca	**0.55 - 1.55**	**Cu**	**5 - 18**
Mg	0.55 - 1.25	Zn	31 - 48
S	**0.2 - 0.31**	**Mo**	**0.2 - 1.36**

E

SCIENTIFIC NAME			*Peperomia dahlstedtii*
COMMON NAME			**Vining Peperomia**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			40 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.19 - 3.60	Fe	93 - 171
P	**0.79 - 1.40**	**Mn**	**217 - 310**
K	3.67 - 5.14	B	44 - 48
Ca	**0.82 - 1.11**	**Cu**	**6 - 14**
Mg	0.85 - 0.92	Zn	38 - 107
S	**0.28 - 0.35**	**Mo**	**1.31 - 2.52**

F

SCIENTIFIC NAME			*Peperomia incana*
COMMON NAME			**Felted Pepperface or Silver-hair Peperomia**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.11 - 2.69	Fe	29 - 45
P	**0.22 - 0.92**	**Mn**	**24 - 47**
K	1.78 - 3.29	B	9 - 27
Ca	**0.58 - 1.23**	**Cu**	**5 - 9**
Mg	0.3 - 0.46	Zn	22 - 41
S	**0.18 - 0.28**	**Mo**	**0.33 - 1.46**

Foliage Plants

A

SCIENTIFIC NAME	*Peperomia obtusifolia*
COMMON NAME	**American or Baby Rubber Plant**
COLLECTED FROM	Greenhouse production nursery & botanical garden/conservatory
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.00 - 4.50	Fe	50 - 300
P	**0.25 - 1.00**	**Mn**	**50 - 300**
K	2.00 - 6.50	B	25 - 50
Ca	**1.50 - 4.00**	**Cu**	**7 - 40**
Mg	0.40 - 1.50	Zn	25 - 200
S	**0.25 - 0.75**	**Mo**	**0.50 - 2**

B

SCIENTIFIC NAME	*Peperomia obtusifolia 'Variegata'*
COMMON NAME	**Silver-edge Peperomia**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Variegata'

Macronutrients %		Micronutrients ppm	
N	1 - 2.50	Fe	34 - 52
P	**0.27 - 0.93**	**Mn**	**55 - 160**
K	2.26 - 5.67	B	18 - 41
Ca	**1.09 - 2.01**	**Cu**	**5 - 18**
Mg	0.33 - 0.96	Zn	34 - 109
S	**0.22 - 0.44**	**Mo**	**0.33 - 2.64**

C

SCIENTIFIC NAME	*Peperomia orba*
COMMON NAME	**Pixie Peperomia**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.67 - 3.48	Fe	33 - 71
P	**0.22 - 1.14**	**Mn**	**45 - 131**
K	2.66 - 7.96	B	20 - 42
Ca	**0.88 - 1.32**	**Cu**	**5 - 12**
Mg	0.34 - 1.43	Zn	35 - 88
S	**0.18 - 0.28**	**Mo**	**0.25 - 1.82**

D

SCIENTIFIC NAME	*Peperomia puteolata*
COMMON NAME	**Silver-vein Vining Peperomia**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.25 - 1.43	Fe	33 - 56
P	**0.22 - 0.35**	**Mn**	**45 - 158**
K	1.11 - 1.82	B	18 - 25
Ca	**1 - 2**	**Cu**	**4 - 14**
Mg	0.31 - 0.40	Zn	34 - 60
S	**0.24 - 0.68**	**Mo**	**0.4 - 2.60**

E

SCIENTIFIC NAME	*Peperomia serpens 'Variegata'*
COMMON NAME	**Variegated Trailing Waxleaf**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Variegata'

Macronutrients %		Micronutrients ppm	
N	2.32 - 3.05	Fe	44 - 57
P	**0.23 - 0.99**	**Mn**	**55 - 153**
K	2.3 - 3.33	B	15 - 35
Ca	**0.99 - 1.33**	**Cu**	**6 - 15**
Mg	0.33 - 0.94	Zn	24 - 55
S	**0.14 - 0.22**	**Mo**	**0.08 - 1.14**

F

SCIENTIFIC NAME	*Peperomia trinervis*
COMMON NAME	**Red-stem Creeping Peperomia**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.79 - 2.27	Fe	36 - 98
P	**0.23 - 0.83**	**Mn**	**35 - 64**
K	2.27 - 3.56	B	24 - 36
Ca	**0.43 - 1.33**	**Cu**	**5 - 14**
Mg	0.25 - 0.45	Zn	27 - 37
S	**0.13 - 0.20**	**Mo**	**0.3 - 1.14**

Foliage Plants

A

Scientific Name			*Philodendron bipennifolium*
Common Name			**Fiddle-leaf or Horsehead Philodendron or Panda Plant**
Collected From			Greenhouse production nursery
Plant Part			5 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 4.50	Fe	60 - 200
P	**0.23 - 0.45**	**Mn**	**40 - 200**
K	2.00 - 3.70	B	20 - 50
Ca	**1.00 - 2.00**	**Cu**	**7 - 50**
Mg	0.25 - 0.50	Zn	25 - 50
S	**0.20 - 0.50**	**Mo**	**0.50 - 1.50**

B

Scientific Name			*Philodendron domesticum*
Common Name			**Spade-leaf Philodendron**
Collected From			Greenhouse production nursery & botanical garden/conservatory
Plant Part			10 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 4.00	Fe	50 - 200
P	**0.25 - 0.60**	**Mn**	**50 - 200**
K	2.50 - 4.50	B	25 - 70
Ca	**0.90 - 2.50**	**Cu**	**10 - 40**
Mg	0.30 - 0.55	Zn	20 - 100
S	**0.25 - 0.60**	**Mo**	**0.50 - 2.50**

C

Scientific Name			*Philodendron hastatum*
Common Name			**Silver Sword Philodendron**
Collected From			Production nursery
Plant Part			Most recently matured leaf
Season			Summer
Data Type			Survey Range
Cultivars Used			General species
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 4	Fe	50 - 200
P	**0.25 - 0.6**	**Mn**	**50 - 200**
K	2.5 - 4.5	B	25 - 70
Ca	**0.9 - 2.5**	**Cu**	**4 - 12**
Mg	0.3 - 0.55	Zn	28 - 55
S	**0.25 - 0.60**	**Mo**	**0.3 - 0.5**

D

Scientific Name			*Philodendron scandens ssp. oxycardium*
Common Name			**Heart-leaf Philodendron or Parlor Ivy**
Collected From			Greenhouse production nursery & botanical garden/conservatory
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			ssp. oxycardium only
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.50	Fe	40 - 200
P	**0.15 - 0.50**	**Mn**	**50 - 200**
K	2.75 - 6.00	B	25 - 75
Ca	**0.35 - 2.50**	**Cu**	**6 - 40**
Mg	0.25 - 0.80	Zn	25 - 200
S	**0.20 - 0.50**	**Mo**	**0.12 - 1.50**

E

Scientific Name			*Philodendron selloum*
Common Name			**Split-leaf Philodendron**
Collected From			Greenhouse production nursery
Plant Part			5 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	3.50 - 5.00	Fe	50 - 300
P	**0.25 - 0.50**	**Mn**	**50 - 300**
K	2.00 - 4.00	B	10 - 75
Ca	**1.00 - 2.50**	**Cu**	**6 - 25**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.25 - 0.50**	**Mo**	**0.12 - 1.50**

F

Scientific Name			*Pilea cadierei*
Common Name			**Aluminum Plant**
Collected From			Botanical garden/conservatory
Plant Part			40 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Speicies only
Macronutrients %		**Micronutrients ppm**	
N	2.32 - 2.50	Fe	59 - 66
P	**0.38 - 0.55**	**Mn**	**79 - 86**
K	1.79 - 2.20	B	63 - 83
Ca	**2.93 - 3.73**	**Cu**	**8 - 12**
Mg	1.63 - 1.80	Zn	39 - 41
S	**0.71 - 0.72**	**Mo**	**1.28 - 3.70**

Foliage Plants

A

Scientific Name	*Pilea involucrata*
Common Name	**Friendship Plant or Panamiga**
Collected From	Greenhouse production nursery
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Angel Wings'

Macronutrients %		Micronutrients ppm	
N	2.00 - 3.50	Fe	34 - 55
P	**0.30 - 0.45**	**Mn**	**24 - 45**
K	1.50 - 3.00	B	2 - 4
Ca	**1.09 - 2.50**	**Cu**	**5 - 14**
Mg	1.20 - 1.40	Zn	21 - 44
S	**0.19 - 0.24**	**Mo**	**0.01 - 0.23**

B

Scientific Name	*Pilea microphylla*
Common Name	**Artillery Plant or Gunpowder Plant or Pistol Plant**
Collected From	Botanical garden/conservatory
Plant Part	30 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Speicies only

Macronutrients %		Micronutrients ppm	
N	1.21 - 2.64	Fe	27 - 55
P	**0.2 - 0.29**	**Mn**	**26 - 125**
K	1.25 - 2.42	B	8 - 37
Ca	**1.02 - 3.36**	**Cu**	**3 - 9**
Mg	0.33 - 0.75	Zn	14 - 31
S	**0.22 - 0.74**	**Mo**	**0.2 - 1.64**

C

Scientific Name	*Pilea nummulariifolia*
Common Name	**Creeping Charlie**
Collected From	Botanical garden/conservatory
Plant Part	30 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Speicies only

Macronutrients %		Micronutrients ppm	
N	1.27 - 2.60	Fe	33 - 58
P	**0.18 - 0.40**	**Mn**	**23 - 115**
K	1.12 - 1.82	B	8 - 49
Ca	**1.05 - 1.99**	**Cu**	**2 - 8**
Mg	0.34 - 0.53	Zn	20 - 34
S	**0.19 - 0.27**	**Mo**	**0.22 - 1.37**

D

Scientific Name	*Polyscias pinnata*
Common Name	**Balfour Aralia**
Collected From	Botanical garden/conservatory
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survay Range
Cultivars Used	Speicies only

Macronutrients %		Micronutrients ppm	
N	1.78 - 3.31	Fe	33 - 99
P	**0.2 - 0.34**	**Mn**	**31 - 223**
K	1.25 - 4.08	B	9 - 40
Ca	**0.88 - 1.53**	**Cu**	**5 - 11**
Mg	0.32 - 0.47	Zn	26 - 96
S	**0.17 - 0.26**	**Mo**	**0.12 - 0.3**

E

Scientific Name	*Polyscias x 'Elegans'*
Common Name	**Ming or Parsley Aralia**
Collected From	Botanical garden/conservatory
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Elegans'

Macronutrients %		Micronutrients ppm	
N	1.66 - 3.18	Fe	36 - 69
P	**0.22 - 0.31**	**Mn**	**34 - 85**
K	1.32 - 2.90	B	20 - 40
Ca	**1.11 - 1.98**	**Cu**	**5 - 11**
Mg	0.3 - 0.43	Zn	26 - 40
S	**0.21 - 0.30**	**Mo**	**0.2 - 0.46**

F

Scientific Name	*Sansevieria splendens*
Common Name	**Wide-leaf Sansevieria**
Collected From	Botanical garden/conservatory
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.23 - 3.25	Fe	33 - 55
P	**0.21 - 0.46**	**Mn**	**11 - 44**
K	2.25 - 3	B	7 - 18
Ca	**0.88 - 1.06**	**Cu**	**6 - 12**
Mg	0.31 - 0.55	Zn	26 - 44
S	**0.15 - 0.25**	**Mo**	**0.21 - 1.11**

Foliage Plants

A

Scientific Name			*Sansevieria subspicata*
Common Name			**Red-edge Sansevieria**
Collected From			Botanical garden/conservatory
Plant Part			5 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.77 - 2.42	Fe	33 - 56
P	**0.21 - 0.43**	**Mn**	**55 - 301**
K	2.22 - 2.57	B	22 - 35
Ca	**1.19 - 1.99**	**Cu**	**5 - 10**
Mg	0.33 - 1.40	Zn	35 - 60
S	**0.22 - 0.26**	**Mo**	**0.12 - 0.44**

B

Scientific Name			*Sansevieria trifasciata 'Golden Hahnii'*
Common Name			**Golden Bird's-nest Sansevieria**
Collected From			Botanical garden/conservatory
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Golden Hahnii'
Macronutrients %		**Micronutrients ppm**	
N	2.22 - 4.30	Fe	33 - 40
P	**0.33 - 0.61**	**Mn**	**45 - 125**
K	2.2 - 7.70	B	5 - 25
Ca	**0.78 - 1.24**	**Cu**	**6 - 14**
Mg	0.39 - 0.99	Zn	15 - 35
S	**0.17 - 0.24**	**Mo**	**0.12 - 0.66**

C

Scientific Name			*Sansevieria trifasciata 'Laurentii'*
Common Name			**Variegated Snake Plant or Mother-in-law's Tongue**
Collected From			Greenhouse production nursery & botanical garden/conservatory
Plant Part			5 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			'Laurentii'
Macronutrients %		**Micronutrients ppm**	
N	1.70 - 3.00	Fe	25 - 300
P	**0.15 - 0.50**	**Mn**	**40 - 440**
K	2.00 - 4.10	B	20 - 50
Ca	**0.85 - 2.00**	**Cu**	**5 - 40**
Mg	0.30 - 1.05	Zn	25 - 200
S	**0.16 - 0.40**	**Mo**	**0.12 - 0.30**

D

Scientific Name			*Sansevieria trifasciata (green form)*
Common Name			**Snake Plant or Mother-in-law's Tongue**
Collected From			Botanical garden/conservatory
Plant Part			5 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.33 - 1.57	Fe	24 - 49
P	**0.22 - 0.31**	**Mn**	**55 - 336**
K	1.25 - 1.86	B	15 - 24
Ca	**1 - 1.4**	**Cu**	**4 - 11**
Mg	0.33 - 0.67	Zn	33 - 38
S	**0.1 - 0.29**	**Mo**	**0.12 - 0.3**

E

Scientific Name			*Schefflera actinophylla*
Common Name			**Brassaia or Schefflera**
Collected From			Greenhouse production nursery
Plant Part			Most recently matured leaf
Season			Most recently matured leaf
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2 - 4.5	Fe	50 - 300
P	**0.15 - 0.5**	**Mn**	**40 - 300**
K	2 - 4.75	B	20 - 60
Ca	**0.75 - 3.65**	**Cu**	**6 - 14**
Mg	0.25 - 0.75	Zn	20 - 45
S	**0.2 - 0.80**	**Mo**	**0.12 - 0.2**

F

Scientific Name			*Schefflera actinophylla*
Common Name			**Umbrella Tree or Octopus Tree**
Collected From			Greenhouse production nursery
Plant Part			10 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 4.50	Fe	50 - 300
P	**0.15 - 0.50**	**Mn**	**40 - 300**
K	2.00 - 4.75	B	20 - 60
Ca	**0.75 - 3.65**	**Cu**	**5 - 40**
Mg	0.25 - 0.75	Zn	25 - 200
S	**0.20 - 0.80**	**Mo**	**0.12 - 1.00**

Foliage Plants

A

Scientific Name			*Schefflera arboricola*
Common Name			**Dwarf Schefflera**
Collected From			Greenhouse production nursery & botanical garden/conservatory
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.70	Fe	40 - 250
P	**0.25 - 0.55**	**Mn**	**50 - 300**
K	2.50 - 5.35	B	25 - 75
Ca	**1.20 - 2.00**	**Cu**	**6 - 25**
Mg	0.40 - 1.00	Zn	40 - 150
S	**0.15 - 0.35**	**Mo**	**0.12 - 0.50**

B

Scientific Name			*Scindapsus pictus 'Argyraeus'*
Common Name			**Satin or Silver Pothos or Silver Vine**
Collected From			Botanical garden/conservatory
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Argyraeus'
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 3.5	Fe	50 - 300
P	**0.2 - 0.5**	**Mn**	**50 - 300**
K	3 - 5.5	B	20 - 60
Ca	**1 - 2**	**Cu**	**6 - 25**
Mg	0.3 - 1	Zn	20 - 125
S	**0.2 - 0.40**	**Mo**	**0.3 - 1.25**

C

Scientific Name			*Siderasis fuscata*
Common Name			**Brazilian False Spiderwort**
Collected From			Botanical garden/conservatory
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.67 - 3.02	Fe	32 - 49
P	**0.22 - 0.39**	**Mn**	**28 - 107**
K	1.65 - 2.50	B	7 - 23
Ca	**0.89 - 1.43**	**Cu**	**5 - 14**
Mg	0.25 - 0.69	Zn	25 - 44
S	**0.17 - 0.23**	**Mo**	**0.18 - 2.15**

D

Scientific Name			*Spathiphyllum x cultivars*
Common Name			**Peace Lily or Spathiphyllum**
Collected From			Greenhouse production nursery
Plant Part			10 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Not specified
Macronutrients %		**Micronutrients ppm**	
N	3.30 - 5.00	Fe	50 - 300
P	**0.20 - 1.00**	**Mn**	**40 - 300**
K	2.30 - 6.00	B	20 - 70
Ca	**0.80 - 2.00**	**Cu**	**6 - 40**
Mg	0.20 - 1.00	Zn	25 - 200
S	**0.20 - 0.50**	**Mo**	**0.12 - 0.50**

E

Scientific Name			*Strelitzia reginae*
Common Name			**Bird-of-Paradise**
Collected From			Greenhouse production nursery & botanical garden/conservatory
Plant Part			10 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.00 - 2.50	Fe	35 - 200
P	**0.20 - 0.40**	**Mn**	**45 - 200**
K	1.50 - 3.00	B	10 - 75
Ca	**0.35 - 3.00**	**Cu**	**5 - 30**
Mg	0.18 - 0.75	Zn	20 - 200
S	**0.15 - 0.40**	**Mo**	**0.12 - 0.50**

F

Scientific Name			*Stromanthe amabilis*
Common Name			**Striped Stromanthe**
Collected From			Greenhouse production nursery
Plant Part			10 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.00	Fe	34 - 66
P	**0.20 - 0.50**	**Mn**	**35 - 77**
K	3.00 - 4.00	B	18 - 32
Ca	**0.10 - 0.20**	**Cu**	**4 - 15**
Mg	0.30 - 0.50	Zn	34 - 55
S	**0.22 - 0.28**	**Mo**	**0.2 - 0.34**

Foliage Plants

A

SCIENTIFIC NAME			*Stromanthe sanguinea*
COMMON NAME			**Scarlet Stromanthe**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			10 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.15	Fe	50 - 59
P	**0.55 - 1.16**	**Mn**	**169 - 282**
K	3.28 - 3.76	B	16 - 21
Ca	**0.30 - 0.50**	**Cu**	**4 - 6**
Mg	0.36 - 0.45	Zn	23 - 33
S	**0.15 - 0.21**	**Mo**	**1.35 - 2.75**

B

SCIENTIFIC NAME			*Synadenium grantii 'Rubra'*
COMMON NAME			**Purple-leaf African Milkbush**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Rubra'
Macronutrients %		**Micronutrients ppm**	
N	1.33 - 2.67	Fe	35 - 100
P	**0.22 - 0.79**	**Mn**	**45 - 120**
K	2.29 - 5.46	B	22 - 35
Ca	**1.11 - 1.36**	**Cu**	**3 - 15**
Mg	0.35 - 0.74	Zn	25 - 83
S	**0.2 - 0.31**	**Mo**	**0.1 - 0.5**

C

SCIENTIFIC NAME			*Syngonium podophyllum 'Variegatum'*
COMMON NAME			**Nephthytis or Arrowhead Ivy or African Evergreen**
COLLECTED FROM			Greenhouse production nursery & botanical garden/conservatory
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Sufficiency Range
CULTIVARS USED			'Variegatum'
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 4.00	Fe	50 - 300
P	**0.20 - 0.65**	**Mn**	**50 - 300**
K	3.00 - 6.50	B	25 - 50
Ca	**0.40 - 1.50**	**Cu**	**10 - 50**
Mg	0.30 - 0.65	Zn	25 - 150
S	**0.20 - 0.50**	**Mo**	**0.50 - 2.50**

D

SCIENTIFIC NAME			*Tradescantia fluminensis*
COMMON NAME			**Purple-leaf White Wandering Jew**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 3.1	Fe	55 - 133
P	**0.22 - 0.74**	**Mn**	**34 - 485**
K	1.43 - 2.52	B	24 - 45
Ca	**1.11 - 1.96**	**Cu**	**5 - 22**
Mg	0.34 - 1.4	Zn	22 - 70
S	**0.19 - 0.40**	**Mo**	**0.5 - 13.76**

E

SCIENTIFIC NAME			*Tradescantia fluminensis 'Variegata'*
COMMON NAME			**Variegated White Wandering Jew**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Variegata'
Macronutrients %		**Micronutrients ppm**	
N	2.02 - 5.06	Fe	45 - 104
P	**0.18 - 0.75**	**Mn**	**55 - 476**
K	2.76 - 5.59	B	11 - 25
Ca	**1.32 - 1.63**	**Cu**	**5 - 19**
Mg	,37 - 0.92	Zn	18 - 40
S	**0.21 - 0.36**	**Mo**	**0.22 - 2.07**

F

SCIENTIFIC NAME			*Tradescantia pallida 'Purple Heart'*
COMMON NAME			**Purple Heart Setcreasea or Spiderwort**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Purple Heart'
Macronutrients %		**Micronutrients ppm**	
N	1.25 - 2.54	Fe	32 - 88
P	**0.2 - 0.31**	**Mn**	**45 - 75**
K	1.2 - 1.89	B	25 - 38
Ca	**0.88 - 1.09**	**Cu**	**5 - 10**
Mg	0.3 - 0.41	Zn	22 - 56
S	**0.18 - 0.31**	**Mo**	**0.2 - 8.67**

Foliage Plants

A

SCIENTIFIC NAME	*Tradescantia sillamontana*
COMMON NAME	**White-velvet or White-gossamer or Silky Spiderwort**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.66 - 3.68	Fe	55 - 94
P	**0.18 - 0.56**	**Mn**	**58 - 221**
K	2.37 - 3.67	B	11 - 18
Ca	**1 - 2.59**	**Cu**	**6 - 17**
Mg	0.35 - 1.32	Zn	23 - 88
S	**0.21 - 0.42**	**Mo**	**0.11 - 0.3**

B

SCIENTIFIC NAME	*Tripogandra multiflora*
COMMON NAME	**Tahitian Bridal-veil or Fern-leaf Inch Plant**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	3.71 - 4.06	Fe	126 - 145
P	**0.70 - 0.80**	**Mn**	**142 - 251**
K	3.92 - 4.34	B	29 - 35
Ca	**0.91 - 0.99**	**Cu**	**12 - 15**
Mg	0.42 - 0.46	Zn	44 - 64
S	**0.31 - 0.35**	**Mo**	**4.56 - 15.34**

C

SCIENTIFIC NAME	*Tropical Tree/Shrubs*
COMMON NAME	**General Production**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	10-15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	0.98 - 1.75	Fe	1.00 - 2.40
P	**0.11 - 0.22**	**Mn**	**0.11 - 0.50**
K	0.5 - 1.25	B	15 - 40
Ca	**1.00 - 2.50**	**Cu**	**40 - 75**
Mg	15 - 50	Zn	4 - 28
S	**0.18 - 0.65**	**Mo**	**1.70 - 2.60**

D

SCIENTIFIC NAME	*Yucca elephantipes*
COMMON NAME	**Spineless or Soft Yucca**
COLLECTED FROM	Greenhouse production nursery & botanical garden/conservatory
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.40 - 2.50	Fe	25 - 200
P	**0.15 - 0.80**	**Mn**	**40 - 325**
K	1.20 - 3.25	B	12 - 60
Ca	**1.00 - 2.50**	**Cu**	**6 - 25**
Mg	0.20 - 1.00	Zn	20 - 200
S	**0.15 - 0.80**	**Mo**	**0.12 - 0.50**

E

SCIENTIFIC NAME	*Zamia floridana*
COMMON NAME	**Coontie Fern or Palm**
COLLECTED FROM	Greenhouse production nursery
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	0.75 - 1.90	Fe	43 - 97
P	**0.15 - 0.19**	**Mn**	**38 - 104**
K	0.43 - 1.39	B	20 - 55
Ca	**0.33 - 0.44**	**Cu**	**3 - 5**
Mg	0.22 - 0.26	Zn	20 - 61
S	**0.14 - 0.22**	**Mo**	**0.17 - 0.95**

F

SCIENTIFIC NAME	*Zingiber officinale*
COMMON NAME	**Common or Canton or Stem Ginger**
COLLECTED FROM	Botanical garden/conservatory
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.25 - 2.34	Fe	36 - 101
P	**0.21 - 0.32**	**Mn**	**26 - 167**
K	1.45 - 2.44	B	8 - 14
Ca	**0.65 - 1.41**	**Cu**	**6 - 12**
Mg	0.2 - 0.32	Zn	25 - 43
S	**0.16 - 0.22**	**Mo**	**0.22 - 1.36**

Foliage Plants

A

SCIENTIFIC NAME	*Asparagus setaceus*		
COMMON NAME	**Plumosus or Lace Asparagus Fern**		
COLLECTED FROM	Greenhouse production nursery		
PLANT PART	10 mature fronds from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.12 - 2.75	Fe	45 - 74
P	**0.17 - 0.28**	**Mn**	**34 - 124**
K	1.11 - 2.50	B	17 - 38
Ca	**0.58 - 1.25**	**Cu**	**4 - 8**
Mg	0.13 - 0.35	Zn	22 - 32
S	**0.16 - 0.25**	**Mo**	**0.10 - 0.21**

B

SCIENTIFIC NAME	*Begonia x 'Looking Glass'*		
COMMON NAME	**Looking Glass' Cane-stem or Angel Wing Begonia**		
COLLECTED FROM	Botanical garden/conservatory		
PLANT PART	15 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Looking Glass'		
Macronutrients %		**Micronutrients ppm**	
N	2.73 - 3.29	Fe	158 - 168
P	**0.33 - 0.51**	**Mn**	**76 - 99**
K	1.26 - 1.70	B	38 - 54
Ca	**1.81 - 2.20**	**Cu**	**5 - 7**
Mg	0.81 - 0.88	Zn	32 - 58
S	**0.35 - 0.37**	**Mo**	**0.12 - 4.26**

C

D

E

F

Forage and Hay Crops

A

Scientific Name	*Agropyron sibiricum*		
Common Name	**Siberian or Standard Crested Wheatgrass**		
Collected From	Field test plots		
Plant Part	Top 2 cm above soil line		
Season	Late spring		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.06 - 4.50	Fe	34 - 55
P	**0.22 - 0.38**	**Mn**	**34 - 44**
K	1.78 - 2.80	B	15 - 33
Ca	**.5 - .89**	**Cu**	**4 - 8**
Mg	.27 - .36	Zn	23 - 34
S	**0.18 - 0.24**	**Mo**	**0.14 - 0.3**

B

Scientific Name	*Bromus inermis*		
Common Name	**Smooth Bromegrass**		
Collected From	Field test plots		
Plant Part	25 fully developed stems with leaves		
Season	Summer (midway between mowings)		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.50	Fe	50 - 100
P	**0.25 - 0.35**	**Mn**	**40 - 80**
K	2.00 - 3.50	B	10 - 20
Ca	**0.25 - 0.40**	**Cu**	**5 - 10**
Mg	0.14 - 0.30	Zn	20 - 50
S	**0.17 - 0.30**	**Mo**	**0.08 - 1.11**

C

Scientific Name	*Bromus unioloides*		
Common Name	**Prairie Bromegrass or Rescue Grass**		
Collected From	Field test plots		
Plant Part	25 tops 2.5" above soil line		
Season	6-8 weeks after harvest		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.56 - 2.96	Fe	134 - 250
P	**0.31 - 0.35**	**Mn**	**84 - 136**
K	2.96 - 3.26	B	14 - 25
Ca	**0.25 - 0.36**	**Cu**	**8 - 15**
Mg	0.08 - 0.33	Zn	44 - 92
S	**0.27 - 0.44**	**Mo**	**0.08 - 0.11**

D

Scientific Name	*Calamagrostis canadensis*		
Common Name	**Bluejoint Grass**		
Collected From	Field test plots		
Plant Part	Clippings from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.96 - 3.08	Fe	41 - 134
P	**0.22 - 0.58**	**Mn**	**277 - 310**
K	1.60 - 2.06	B	5 - 10
Ca	**0.16 - 0.29**	**Cu**	**1 - 6**
Mg	0.15 - 0.28	Zn	32 - 42
S	**0.18 - 0.28**	**Mo**	**2.00 - 2.40**

E

Scientific Name	*Coronilla varia*		
Common Name	**Crownvetch**		
Collected From	Field test plots		
Plant Part	15 whole tops		
Season	Prior to planting		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 3	Fe	252 - 1820
P	**0.24 - 0.33**	**Mn**	**444 - 846**
K	1.03 - 1.62	B	27 - 45
Ca	**2.81 - 3.30**	**Cu**	**13 - 20**
Mg	0.42 - 0.65	Zn	101 - 270
S	**0.19 - 0.24**	**Mo**	**0.15 - 0.23**

F

Scientific Name	*Cynodon dactylon*		
Common Name	**Coastal Bermudagrass**		
Collected From	Field test plots		
Plant Part	40 whole tops		
Season	4-5 week-old plants		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.20 - 4.00	Fe	50 - 350
P	**0.25 - 0.60**	**Mn**	**25 - 300**
K	1.80 - 3.00	B	6 - 30
Ca	**0.25 - 0.50**	**Cu**	**5 - 25**
Mg	0.13 - 0.30	Zn	20 - 50
S	**0.18 - 0.50**	**Mo**	**0.3 - 0.5**

Forage and Hay Crops

A

SCIENTIFIC NAME			*Dactylis glomerata*
COMMON NAME			**Orchard Grass**
COLLECTED FROM			Production fields
PLANT PART			Whole plant
SEASON			5 weeks after cutting or spring green-up
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	2.5 - 3.5	Fe	50 - 250
P	**0.25 - 0.35**	**Mn**	**50 - 200**
K	2.5 - 3.5	B	5 - 20
Ca	**0.3 - 0.5**	**Cu**	**3 - 10**
Mg	0.15 - 0.3	Zn	20 - 50
S	**0.2 - 0.30**	**Mo**	**0.09 - 0.23**

B

SCIENTIFIC NAME			*Dactylis glomerata*
COMMON NAME			**Orchardgrass or Cock's-foot**
COLLECTED FROM			Field test plots
PLANT PART			15 whole tops
SEASON			3-4 weeks between clippings
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	3.20 - 4.20	Fe	50 - 200
P	**0.23 - 0.35**	**Mn**	**50 - 150**
K	2.60 - 3.50	B	8 - 12
Ca	**0.50 - 0.90**	**Cu**	**3 - 5**
Mg	0.15 - 0.30	Zn	20 - 50
S	**0.20 - 0.25**	**Mo**	**0.50 - 1.50**

C

SCIENTIFIC NAME			*Desmodium intortum*
COMMON NAME			**Greenleaf Desmodium**
COLLECTED FROM			Field test plots
PLANT PART			30 mature leaves from new growth (2nd & 3rd leaves)
SEASON			65-70 day-old plants
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	3.70 - 4.30	Fe	33 - 56
P	**0.26 - 0.28**	**Mn**	**32 - 40**
K	0.70 - 1.20	B	29 - 32
Ca	**0.58 - 0.74**	**Cu**	**4 - 12**
Mg	0.14 - 0.17	Zn	18 - 40
S	**0.24 - 0.25**	**Mo**	**0.12 - 0.5**

D

SCIENTIFIC NAME			*Digitaria decumbens*
COMMON NAME			**Pangola Grass**
COLLECTED FROM			Field test plots
PLANT PART			25 whole tops
SEASON			4-5 weeks between clippings
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	1.70 - 2.50	Fe	18 - 55
P	**0.16 - 0.28**	**Mn**	**44 - 67**
K	1.60 - 2.20	B	12 - 22
Ca	**0.56 - 1.33**	**Cu**	**4 - 13**
Mg	0.35 - 0.55	Zn	24 - 34
S	**0.20 - 0.30**	**Mo**	**0.1 - 0.2**

E

SCIENTIFIC NAME			*Lotus corniculatus*
COMMON NAME			**Bird's-foot Trefoil**
COLLECTED FROM			Field test plots
PLANT PART			50 mature leaves from new growth
SEASON			First flower
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	4.00 - 4.50	Fe	45 - 66
P	**0.28 - 0.36**	**Mn**	**50 - 80**
K	1.60 - 2.60	B	30 - 75
Ca	**1.70 - 2.00**	**Cu**	**6 - 10**
Mg	0.40 - 0.60	Zn	30 - 50
S	**0.16 - 0.27**	**Mo**	**0.15 - 0.33**

F

SCIENTIFIC NAME			*Matilium atropurpureum*
COMMON NAME			**Siratro**
COLLECTED FROM			Field test plots
PLANT PART			30 leaves (5th leaf from top)
SEASON			65 day-old plants
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	1.89 - 2.60	Fe	45 - 75
P	**0.16 - 0.28**	**Mn**	**44 - 70**
K	0.9 - 1.96	B	12 - 60
Ca	**1 - 1.40**	**Cu**	**5 - 11**
Mg	0.22 - 0.30	Zn	54 - 62
S	**0.19 - 0.27**	**Mo**	**0.09 - 0.24**

Forage and Hay Crops

A

SCIENTIFIC NAME	*Medicago sativa*
COMMON NAME	**Alfalfa or Lucerne**
COLLECTED FROM	Field test plots
PLANT PART	12 tops (6" new growth)
SEASON	Prior to flowering
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	4.50 - 5.00	Fe	30 - 250
P	**0.26 - 0.70**	**Mn**	**31 - 100**
K	2.00 - 3.50	B	30 - 80
Ca	**1.80 - 3.00**	**Cu**	**7 - 30**
Mg	0.30 - 1.00	Zn	21 - 70
S	**0.26 - 0.50**	**Mo**	**1.00 - 5.00**

B

SCIENTIFIC NAME	*Mixed Forage*
COMMON NAME	**Small Grains (wheat, oats, barley, and rye)**
COLLECTED FROM	Production fields
PLANT PART	Flag leaf
SEASON	Flowering
DATA TYPE	Survey Range
CULTIVARS USED	Wheat, oats, barley, and rye

Macronutrients %		Micronutrients ppm	
N	4 - 5	Fe	30 - 200
P	**0.2 - 0.5**	**Mn**	**20 - 150**
K	2 - 4	B	1.5 - 4
Ca	**0.2 - 1**	**Cu**	**4.5 - 15**
Mg	0.14 - 1	Zn	18 - 70
S	**0.15 - 0.65**	**Mo**	**0.1 - 2**

C

SCIENTIFIC NAME	*Mixed Forage*
COMMON NAME	**Small Grains (wheat, oats, barley, and rye)**
COLLECTED FROM	Production fields
PLANT PART	Whole plant
SEASON	Seedling (before jointing)
DATA TYPE	Survey Range
CULTIVARS USED	Wheat, oats, barley, and rye

Macronutrients %		Micronutrients ppm	
N	4 - 5	Fe	30 - 200
P	**0.2 - 0.5**	**Mn**	**20 - 150**
K	2.5 - 5	B	1.5 - 4
Ca	**0.2 - 1**	**Cu**	**4.5 - 15**
Mg	0.14 - 1	Zn	18 - 70
S	**0.15 - 0.65**	**Mo**	**0.1 - 2**

D

SCIENTIFIC NAME	*Panicum virgatum*
COMMON NAME	**Switchgrass**
COLLECTED FROM	Field test plots
PLANT PART	Tops cut 6 cm above soil
SEASON	Early anthesis
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	0.66 - 1.42	Fe	41 - 85
P	**0.08 - 0.17**	**Mn**	**50 - 209**
K	0.90 - 1.21	B	5 - 11
Ca	**0.15 - 0.24**	**Cu**	**10 - 15**
Mg	0.14 - 0.33	Zn	40 - 65
S	**0.14 - 0.32**	**Mo**	**0.12 - 0.65**

E

SCIENTIFIC NAME	*Paspalum notatum*
COMMON NAME	**Bahia Grass**
COLLECTED FROM	Field test plots
PLANT PART	50 leaf blades
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.56 - 2.80	Fe	65 - 100
P	**0.21 - 0.40**	**Mn**	**56 - 105**
K	1.26 - 1.80	B	9 - 19
Ca	**0.52 - 1.45**	**Cu**	**5 - 11**
Mg	0.32 - 0.44	Zn	22 - 31
S	**0.18 - 0.40**	**Mo**	**0.24 - 0.80**

F

SCIENTIFIC NAME	*Phleum pratense*
COMMON NAME	**Timothy**
COLLECTED FROM	Field test plots
PLANT PART	25 whole tops
SEASON	Early anthesis
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	0.53 - 1.68	Fe	22 - 54
P	**0.11 - 0.18**	**Mn**	**11 - 35**
K	1.14 - 1.70	B	1 - 10
Ca	**0.19 - 0.35**	**Cu**	**7 - 45**
Mg	0.16 - 0.25	Zn	24 - 62
S	**0.17 - 0.26**	**Mo**	**0.09 - 0.6**

Forage and Hay Crops

A

Scientific Name	*Setaria italica*		
Common Name	**Foxtail or Italian Millet or Hungarian Grass**		
Collected From	Field test plots		
Plant Part	20 whole tops		
Season	4 - 5 weeks after clipping		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 4.00	Fe	55 - 78
P	**0.22 - 0.40**	**Mn**	**44 - 66**
K	2.30 - 4.50	B	15 - 22
Ca	**1.18 - 2**	**Cu**	**5 - 15**
Mg	0.32 - 0.45	Zn	33 - 43
S	**0.14 - 0.25**	**Mo**	**0.09 - 1**

B

Scientific Name	*Sorghum sudanense*		
Common Name	**Sudangrass**		
Collected From	Field test plots		
Plant Part	15 whole tops		
Season	4 - 5 weeks between clippings		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.50	Fe	55 - 100
P	**0.20 - 0.35**	**Mn**	**43 - 65**
K	1.90 - 3.50	B	15 - 23
Ca	**1 - 1.35**	**Cu**	**5 - 14**
Mg	0.22 - 0.44	Zn	23 - 35
S	**0.23 - 0.29**	**Mo**	**0.07 - 0.2**

C

Scientific Name	*Stylosanthes humilis*		
Common Name	**Stylo**		
Collected From	Field test plots		
Plant Part	20 whole tops		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 3.50	Fe	44 - 65
P	**0.20 - 0.30**	**Mn**	**38 - 77**
K	0.60 - 1.20	B	14 - 27
Ca	**1.60 - 2.00**	**Cu**	**5 - 12**
Mg	0.30 - 0.50	Zn	35 - 50
S	**0.20 - 0.30**	**Mo**	**0.3 - 0.44**

D

Scientific Name	*Trifolium hybridum*		
Common Name	**Alsike Clover**		
Collected From	Field test plots		
Plant Part	20 whole tops		
Season	First flower		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 2.32	Fe	50 - 100
P	**0.25 - 0.50**	**Mn**	**40 - 100**
K	1.50 - 3.00	B	15 - 50
Ca	**1.00 - 1.80**	**Cu**	**3 - 15**
Mg	0.30 - 0.60	Zn	15 - 80
S	**0.21 - 0.29**	**Mo**	**0.11 - 0.4**

E

Scientific Name	*Trifolium pratense*		
Common Name	**Red Clover**		
Collected From	Field test plots		
Plant Part	15 whole tops		
Season	Prior to flowering		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 4.50	Fe	30 - 250
P	**0.28 - 0.60**	**Mn**	**30 - 120**
K	1.80 - 3.00	B	30 - 80
Ca	**2.00 - 2.60**	**Cu**	**8 - 15**
Mg	0.21 - 0.60	Zn	18 - 80
S	**0.26 - 0.30**	**Mo**	**0.50 - 1.00**

F

Scientific Name	*Trifolium repens f. lodigense*		
Common Name	**Ladino or White Clover**		
Collected From	Field test plots		
Plant Part	50 mature leaves from new growth		
Season	Prior to flowering		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	4.50 - 5.00	Fe	50 - 100
P	**0.36 - 0.45**	**Mn**	**25 - 100**
K	2.00 - 2.50	B	25 - 50
Ca	**0.50 - 1.00**	**Cu**	**5 - 8**
Mg	0.20 - 0.30	Zn	15 - 25
S	**0.25 - 0.50**	**Mo**	**0.15 - 0.25**

Forage and Hay Crops

A

SCIENTIFIC NAME	*Trifolium subterraneum*
COMMON NAME	**Subterranean Clover**
COLLECTED FROM	Field test plots
PLANT PART	75 mature leaves from new growth
SEASON	Prior to flowering
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	3.00 - 3.50	Fe	50 - 200
P	**0.25 - 0.30**	**Mn**	**50 - 120**
K	1.00 - 1.50	B	25 - 50
Ca	**1.00 - 1.50**	**Cu**	**7 - 13**
Mg	0.25 - 0.50	Zn	25 - 50
S	**0.20 - 0.50**	**Mo**	**1.50 - 2.25**

B

C

D

E

F

Fruit and Nut Crops

A

Scientific Name	*Actinidia chinensis*		
Common Name	**Kiwi-fruit or Chinese Gooseberry**		
Collected From	Research test plots		
Plant Part	30 mature leaves from new flush		
Season	Spring		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.21 - 3.33	Fe	41 - 282
P	**0.18 - 0.40**	**Mn**	**98 - 210**
K	1.25 - 2.55	B	30 - 45
Ca	**2.00 - 2.89**	**Cu**	**5 - 25**
Mg	0.35 - 0.80	Zn	23 - 79
S	**0.20 - 0.45**	**Mo**	**0.21 - 0.56**

B

Scientific Name	*Anacardium occidentale*		
Common Name	**Cashew**		
Collected From	Production orchards		
Plant Part	40 mature leaves (4th leaf) from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.45 - 2.75	Fe	33 - 77
P	**0.16 - 0.25**	**Mn**	**23 - 38**
K	0.89 - 1.44	B	15 - 45
Ca	**0.03 - 0.22**	**Cu**	**5 - 14**
Mg	0.02 - 0.15	Zn	18 - 35
S	**0.23 - 0.28**	**Mo**	**0.09 - 1.2**

C

Scientific Name	*Ananas comosus*		
Common Name	**Pineapple**		
Collected From	Production fields		
Plant Part	20 developing leaves without white leaf base		
Season	Beginning of Inflorescence		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.50	Fe	75 - 200
P	**0.10 - 0.30**	**Mn**	**50 - 400**
K	3.00 - 6.50	B	30 - 75
Ca	**0.40 - 1.20**	**Cu**	**10 - 20**
Mg	0.30 - 0.60	Zn	20 - 120
S	**0.10 - 0.30**	**Mo**	**0.14 - 0.33**

D

Scientific Name	*Annona cherimola*		
Common Name	**Cherimoya**		
Collected From	Field test plots		
Plant Part	Most recently matured leaf		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 3.1	Fe	34 - 65
P	**0.15 - 0.25**	**Mn**	**34 - 47**
K	1 - 2	B	15 - 60
Ca	**0.55 - 1.25**	**Cu**	**5 - 15**
Mg	0.3 - 0.5	Zn	26 - 33
S	**0.13 - 0.24**	**Mo**	**0.02 - 1**

E

Scientific Name	*Annona cherimola, A. muricata, and A. squamosa*		
Common Name	**Custard Apple**		
Collected From	Production orchards		
Plant Part	50 youngest mature leaves from new growth		
Season	Late summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 3.10	Fe	45 - 300
P	**0.15 - 0.25**	**Mn**	**55 - 150**
K	1.00 - 2.00	B	15 - 60
Ca	**0.55 - 1.25**	**Cu**	**7 - 14**
Mg	0.30 - 0.50	Zn	12 - 40
S	**0.16 - 0.28**	**Mo**	**0.16 - 0.289**

F

Scientific Name	*Annona squamosa x Annona cherimola*		
Common Name	**Atemoya**		
Collected From	Production fields		
Plant Part	Most recently matured leaf		
Season	Mature summer growth		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 3	Fe	45 - 100
P	**0.16 - 0.2**	**Mn**	**22 - 55**
K	1 - 1.5	B	15 - 40
Ca	**0.6 - 1**	**Cu**	**6 - 18**
Mg	0.35 - 0.5	Zn	26 - 33
S	**0.23 - 0.28**	**Mo**	**0.18 - 0.6**

Fruit and Nut Crops

A

Scientific Name	*Carica papaya*
Common Name	**Papaya**
Collected From	Production fields
Plant Part	15 petioles from most recently fully expanded mature leaves subtending flowers
Season	Spring
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.01 - 2.50	Fe	25 - 100
P	**0.22 - 0.40**	**Mn**	**25 - 150**
K	3.30 - 5.50	B	20 - 30
Ca	**1.00 - 3.00**	**Cu**	**4 - 10**
Mg	0.40 - 1.20	Zn	15 - 40
S	**0.19 - 0.24**	**Mo**	**0.03 - 1.2**

B

Scientific Name	*Carya illinoinensis*
Common Name	**Pecan**
Collected From	Production orchards
Plant Part	25 leaflet pairs from new growth
Season	56-84 days after terminal bud set
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.70 - 1.90	Fe	50 - 300
P	**0.15 - 0.20**	**Mn**	**20 - 500**
K	1.25 - 1.50	B	50 - 60
Ca	**1.00 - 1.50**	**Cu**	**8 - 40**
Mg	0.35 - 0.75	Zn	50 - 100
S	**0.18 - 0.30**	**Mo**	**0.01 - 1.0**

C

Scientific Name	*Citrus aurantiifolia 'Tahiti'*
Common Name	**Persian Lime**
Collected From	Production orchards
Plant Part	30 mature leaves from vegetative shoots
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.40 - 3.00	Fe	60 - 200
P	**0.15 - 0.50**	**Mn**	**20 - 200**
K	1.60 - 2.50	B	30 - 100
Ca	**1.50 - 5.00**	**Cu**	**5 - 35**
Mg	0.25 - 1.00	Zn	20 - 100
S	**0.15 - 0.50**	**Mo**	**0.01 - 0.05**

D

Scientific Name	*Citrus limon*
Common Name	**Lemon**
Collected From	Production orchards
Plant Part	30 mature leaves from non-fruiting branches
Season	5-7 months into growing season
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.20 - 2.70	Fe	60 - 200
P	**0.10 - 0.30**	**Mn**	**20 - 200**
K	1.00 - 2.00	B	20 - 100
Ca	**1.50 - 4.00**	**Cu**	**5 - 35**
Mg	0.20 - 0.50	Zn	20 - 75
S	**0.19 - 0.26**	**Mo**	**0.30 - 1.00**

E

Scientific Name	*Citrus paradisi cultivars*
Common Name	**Grapefruit**
Collected From	Production orchards
Plant Part	30 mature leaves
Season	Nonfruiting - most recently matured leaf
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.00 - 2.60	Fe	60 - 200
P	**0.13 - 0.50**	**Mn**	**25 - 200**
K	0.80 - 2.20	B	30 - 100
Ca	**1.50 - 5.50**	**Cu**	**5 - 20**
Mg	0.30 - 0.60	Zn	25 - 150
S	**0.15 - 0.50**	**Mo**	**0.1 - 0.3**

F

Scientific Name	*Citrus paradisi cultivars*
Common Name	**Grapefruit**
Collected From	Production orchards
Plant Part	15 mature leaves
Season	Fruiting - 6-9 months into production season
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.40 - 3.00	Fe	60 - 200
P	**0.15 - 0.50**	**Mn**	**25 - 200**
K	0.80 - 2.20	B	30 - 100
Ca	**1.50 - 5.50**	**Cu**	**5 - 35**
Mg	0.25 - 0.75	Zn	25 - 100
S	**0.15 - 0.50**	**Mo**	**0.09 - 0.22**

Fruit and Nut Crops

A

SCIENTIFIC NAME	*Citrus reticulata cultivars*		
COMMON NAME	**Mandarin or Tangerine or Satsuma Oranges**		
COLLECTED FROM	Production orchards		
PLANT PART	30 mature leaves from vegetative shoots		
SEASON	5-7 months into growing season		
DATA TYPE	Sufficiency Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	3.00 - 3.40	Fe	60 - 150
P	**0.15 - 0.25**	**Mn**	**20 - 200**
K	0.90 - 1.10	B	30 - 100
Ca	**1.50 - 4.00**	**Cu**	**5 - 35**
Mg	0.17 - 0.44	Zn	20 - 75
S	**0.14 - 0.22**	**Mo**	**0.2 - 1.00**

B

SCIENTIFIC NAME	*Citrus sinensis 'Valencia' and other cultivars*		
COMMON NAME	**Sweet and Navel Oranges**		
COLLECTED FROM	Production orchards		
PLANT PART	30 mature leaves, subtending fruit		
SEASON	5-7 months into growing season		
DATA TYPE	Sufficiency Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	2.20 - 3.50	Fe	60 - 250
P	**0.12 - 0.50**	**Mn**	**25 - 200**
K	1.20 - 3.00	B	25 - 100
Ca	**1.10 - 4.00**	**Cu**	**6 - 35**
Mg	0.30 - 0.50	Zn	25 - 150
S	**0.12 - 0.28**	**Mo**	**0.1 - 0.4**

C

SCIENTIFIC NAME	*Citrus sinensis 'Valencia' and other cultivars*		
COMMON NAME	**Sweet and Navel Oranges**		
COLLECTED FROM	Production trees		
PLANT PART	30 mature leaves, subtending fruit		
SEASON	6-9 months into production season		
DATA TYPE	Sufficiency Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	2.40 - 2.70	Fe	60 - 120
P	**0.12 - 0.16**	**Mn**	**25 - 200**
K	0.70 - 1.10	B	30 - 100
Ca	**1.50 - 2.60**	**Cu**	**5 - 20**
Mg	0.25 - 0.70	Zn	25 - 100
S	**0.20 - 0.40**	**Mo**	**0.10 - 0.90**

D

SCIENTIFIC NAME	*Citrus tangerina*		
COMMON NAME	**Tangerine**		
COLLECTED FROM	Production trees		
PLANT PART	25 mature leaves from new grwoth		
SEASON	Most recently matured leaf		
DATA TYPE	Sufficiency Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	3 - 3.4	Fe	55 - 100
P	**0.15 - 0.26**	**Mn**	**45 - 100**
K	0.9 - 1.23	B	31 - 100
Ca	**1.22 - 1.65**	**Cu**	**5 - 18**
Mg	0.17 - 0.44	Zn	23 - 73
S	**0.16 - 0.24**	**Mo**	**0.08 - 1.11**

E

SCIENTIFIC NAME	*Corylus avellana*		
COMMON NAME	**European Filbert or Hazelnut**		
COLLECTED FROM	Production orchards		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Sufficiency Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	2.30 - 2.60	Fe	50 - 350
P	**0.16 - 0.40**	**Mn**	**25 - 500**
K	0.70 - 2.40	B	30 - 75
Ca	**1.00 - 2.50**	**Cu**	**4 - 35**
Mg	0.25 - 0.50	Zn	15 - 80
S	**0.19 - 0.31**	**Mo**	**0.02 - 0.08**

F

SCIENTIFIC NAME	*Dimocarpus longana*		
COMMON NAME	**Longan**		
COLLECTED FROM	Field test plots		
PLANT PART	30 mature leaves from new growth (2nd & 3rd leaves)		
SEASON	Summer		
DATA TYPE	Sufficiency Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	1.32 - 1.69	Fe	65 - 150
P	**0.15 - 0.30**	**Mn**	**25 - 50**
K	0.95 - 1.25	B	22 - 40
Ca	**0.81 - 1.55**	**Cu**	**6 - 30**
Mg	0.20 - 0.38	Zn	6 - 30
S	**0.22 - 0.35**	**Mo**	**0.21 - 0.48**

Fruit and Nut Crops

A

SCIENTIFIC NAME			*Diospyros kaki*
COMMON NAME			**Japanese Persimmon**
COLLECTED FROM			Production orchards
PLANT PART			50 mature leaves from new growth
SEASON			Late summer
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 2.50	Fe	50 - 150
P	**0.10 - 0.25**	**Mn**	**200 - 1000**
K	2.25 - 4.50	B	45 - 100
Ca	**1.25 - 3.30**	**Cu**	**1 - 10**
Mg	0.18 - 0.50	Zn	5 - 45
S	**0.20 - 0.45**	**Mo**	**0.09 - 1.33**

B

SCIENTIFIC NAME			*Diospyros virginiana*
COMMON NAME			**Persimmon**
COLLECTED FROM			Production trees
PLANT PART			25 mature leaves from new growth
SEASON			Recently matured leaves from new growth
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 2.5	Fe	50 - 150
P	**0.1 - 0.25**	**Mn**	**200 - 1000**
K	2.25 - 4.5	B	45 - 100
Ca	**1.25 - 3.5**	**Cu**	**5 - 15**
Mg	0.18 - 0.5	Zn	20 - 45
S	**0.2 - 0.45**	**Mo**	**0.22 - 0.56**

C

SCIENTIFIC NAME			*Ficus carica*
COMMON NAME			**Fig**
COLLECTED FROM			Production orchards
PLANT PART			25 mature leaves from new growth
SEASON			Mid-summer
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.50	Fe	44 - 77
P	**0.10 - 0.30**	**Mn**	**20 - 200**
K	0.90 - 2.20	B	25 - 150
Ca	**2.00 - 4.00**	**Cu**	**4 - 20**
Mg	0.65 - 1.40	Zn	25 - 50
S	**0.17 - 0.27**	**Mo**	**0.14 - 0.67**

D

SCIENTIFIC NAME			*Fragaria x ananassa*
COMMON NAME			**Strawberry**
COLLECTED FROM			Production fields
PLANT PART			Most recently matured leaf and petiole
SEASON			Transplants
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.8 - 3.5	Fe	50 - 100
P	**0.3 - 0.4**	**Mn**	**30 - 100**
K	1.5 - 3	B	25 - 40
Ca	**0.3 - 1.5**	**Cu**	**5 - 10**
Mg	0.3 - 0.6	Zn	25 - 40
S	**0.18 - 0.25**	**Mo**	**0.025 - 1.4**

E

SCIENTIFIC NAME			*Fragaria x ananassa*
COMMON NAME			**Strawberry**
COLLECTED FROM			Production fields
PLANT PART			Most recently matured leaf and petiole
SEASON			Initial flower
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	3 - 4	Fe	50 - 100
P	**0.2 - 0.4**	**Mn**	**30 - 100**
K	1.5 - 3	B	20 - 40
Ca	**0.4 - 1.5**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	20 - 40
S	**0.2 - 0.31**	**Mo**	**0.1 - 0.3**

F

SCIENTIFIC NAME			*Fragaria x ananassa*
COMMON NAME			**Strawberry**
COLLECTED FROM			Production fields
PLANT PART			25 mature leaves from new growth
SEASON			At flowering
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.10 - 4.00	Fe	50 - 250
P	**0.20 - 0.45**	**Mn**	**30 - 350**
K	1.10 - 2.50	B	25 - 60
Ca	**0.60 - 2.50**	**Cu**	**6 - 20**
Mg	0.25 - 0.70	Zn	20 - 50
S	**0.15 - 0.30**	**Mo**	**0.01 - 0.50**

Fruit and Nut Crops

A

SCIENTIFIC NAME			*Fragaria x ananassa*
COMMON NAME			**Strawberry**
COLLECTED FROM			Production fields
PLANT PART			Most recently matured leaves only
SEASON			At flowering
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 4	Fe	50 - 200
P	**0.25 - 1**	**Mn**	**50 - 200**
K	1.3 - 3	B	23 - 50
Ca	**1 - 2.5**	**Cu**	**6 - 50**
Mg	0.25 - 1	Zn	20 - 200
S	**0.15 - 0.3**	**Mo**	**0.01 - 0.5**

B

SCIENTIFIC NAME			*Fragaria x ananassa*
COMMON NAME			**Strawberry**
COLLECTED FROM			Production fields
PLANT PART			Most recently matured leaf and petiole
SEASON			Initial harvest
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	3 - 3.5	Fe	50 - 100
P	**0.2 - 0.4**	**Mn**	**30 - 100**
K	1.5 - 2.5	B	20 - 40
Ca	**0.4 - 1.5**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	20 - 40
S	**0.19 - 0.26**	**Mo**	**0.01 - 0.43**

C

SCIENTIFIC NAME			*Fragaria x ananassa*
COMMON NAME			**Strawberry**
COLLECTED FROM			Production fields
PLANT PART			Most recently matured leaf and petiole
SEASON			Mid season
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.8 - 3	Fe	50 - 100
P	**0.2 - 0.4**	**Mn**	**25 - 100**
K	1.1 - 2.5	B	20 - 40
Ca	**0.4 - 1.5**	**Cu**	**5 - 10**
Mg	0.2 - 0.4	Zn	20 - 40
S	**0.8 - 1.00**	**Mo**	**0.5 - 0.8**

D

SCIENTIFIC NAME			*Fragaria x ananassa*
COMMON NAME			**Strawberry**
COLLECTED FROM			Production fields
PLANT PART			Most recently matured leaf and petiole
SEASON			End of seaseon
DATA TYPE			Sufficiency Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 3	Fe	50 - 100
P	**0.2 - 0.3**	**Mn**	**25 - 100**
K	1.1 - 2	B	20 - 40
Ca	**0.4 - 1.5**	**Cu**	**5 - 10**
Mg	0.2 - 0.4	Zn	20 - 40
S	**0.11 - 0.22**	**Mo**	**0.02 - 1.81**

E

SCIENTIFIC NAME			*Fruit and Nuts*
COMMON NAME			**General Fruits and Nuts**
COLLECTED FROM			Field test plots
PLANT PART			50 mature leaves from new growth
SEASON			Mid season
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.2 - 3.1	Fe	55 - 175
P	**0.18 - 0.38**	**Mn**	**30 - 255**
K	1.25 - 2.5	B	25 - 65
Ca	**0.75 - 1.67**	**Cu**	**9 - 34**
Mg	0.32 - 0.65	Zn	25 - 100
S	**0.20 - 0.40**	**Mo**	**0.11 - 0.35**

F

SCIENTIFIC NAME			*Juglans californica*
COMMON NAME			**California Walnut**
COLLECTED FROM			Field research plots
PLANT PART			5 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.44 - 2.50	Fe	35 - 120
P	**0.11 - 0.26**	**Mn**	**30 - 44**
K	1 - 1.88	B	15 - 35
Ca	**0.98 - 1.34**	**Cu**	**6 - 24**
Mg	0.3 - 0.43	Zn	20 - 30
S	**0.19 - 0.28**	**Mo**	**0.08 - 1.23**

Fruit and Nut Crops

A

Scientific Name	*Juglans cinerea*		
Common Name	**Butternut**		
Collected From	Production orchards		
Plant Part	5 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.44 - 1.79	Fe	55 - 196
P	**0.18 - 0.44**	**Mn**	**44 - 149**
K	0.82 - 1.87	B	20 - 79
Ca	**0.88 - 1.11**	**Cu**	**6 - 11**
Mg	0.32 - 0.72	Zn	33 - 58
S	**0.16 - 0.25**	**Mo**	**0.1 - 0.50**

B

Scientific Name	*Juglans nigra*		
Common Name	**Black Walnut**		
Collected From	Field research plots & orchards		
Plant Part	5 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.60	Fe	100 - 400
P	**0.18 - 0.54**	**Mn**	**80 - 190**
K	0.65 - 1.98	B	40 - 67
Ca	**0.88 - 3.23**	**Cu**	**10 - 15**
Mg	0.29 - 1.01	Zn	42 - 50
S	**0.10 - 0.25**	**Mo**	**0.10 - 0.27**

C

Scientific Name	*Juglans regia*		
Common Name	**English Walnut**		
Collected From	Production orchards		
Plant Part	25 center leaflets from mature leaves		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.25	Fe	50 - 300
P	**0.12 - 0.30**	**Mn**	**30 - 400**
K	1.20 - 3.00	B	35 - 200
Ca	**0.75 - 2.50**	**Cu**	**4 - 20**
Mg	0.30 - 1.00	Zn	20 - 200
S	**0.13 - 0.25**	**Mo**	**0.05 - 0.09**

D

Scientific Name	*Litchi chinensis*		
Common Name	**Lychee Fruit**		
Collected From	Production orchards		
Plant Part	50 central leaflets from leaves subtending fruit		
Season	Spring, after growth hardens		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.35 - 1.65	Fe	55 - 66
P	**0.15 - 0.30**	**Mn**	**40 - 100**
K	0.75 - 1.25	B	18 - 32
Ca	**0.55 - 1.00**	**Cu**	**4 - 11**
Mg	0.20 - 0.40	Zn	24 - 43
S	**0.10 - 0.20**	**Mo**	**0.16 - 0.4**

E

Scientific Name	*Macadamia integrifolia*		
Common Name	**Macadamia Nut**		
Collected From	Production orchards		
Plant Part	30 mature leaves from new growth		
Season	Late spring to mid-summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.40 - 2.50	Fe	25 - 200
P	**0.07 - 0.25**	**Mn**	**50 - 1500**
K	0.45 - 1.50	B	25 - 100
Ca	**0.50 - 1.00**	**Cu**	**4 - 12**
Mg	0.08 - 0.30	Zn	15 - 25
S	**0.10 - 0.25**	**Mo**	**0.50 - 2.50**

F

Scientific Name	*Malus domestica*		
Common Name	**Apple**		
Collected From	Experimental test plots		
Plant Part	50 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.90 - 2.60	Fe	50 - 300
P	**0.09 - 0.40**	**Mn**	**25 - 200**
K	1.20 - 2.00	B	25 - 50
Ca	**0.80 - 1.60**	**Cu**	**6 - 25**
Mg	0.25 - 0.45	Zn	20 - 100
S	**0.20 - 0.40**	**Mo**	**0.10 - 2.00**

Fruit and Nut Crops

A

Scientific Name	*Mangifera indica*		
Common Name	**Mango**		
Collected From	Production orchards		
Plant Part	15 mature leaves from new growth		
Season	Post-flowering		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.00 - 1.50	Fe	50 - 250
P	**0.08 - 0.25**	**Mn**	**50 - 250**
K	0.40 - 1.50	B	25 - 150
Ca	**2.00 - 5.00**	**Cu**	**7 - 35**
Mg	0.20 - 0.50	Zn	20 - 100
S	**0.11 - 0.28**	**Mo**	**0.01 - 0.07**

B

Scientific Name	*Musa accuminata*		
Common Name	**Plantain**		
Collected From	Production fields		
Plant Part	15 mid-section leaf strips		
Season	6-9 months into production season		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.80	Fe	75 - 200
P	**0.18 - 0.28**	**Mn**	**50 - 250**
K	2.80 - 4.00	B	10 - 25
Ca	**0.50 - 1.00**	**Cu**	**8 - 15**
Mg	0.21 - 0.35	Zn	20 - 60
S	**0.20 - 0.28**	**Mo**	**0.01 - 0.40**

C

Scientific Name	*Musa acuminata*		
Common Name	**Banana**		
Collected From	Production fields		
Plant Part	15 mid-section leaf strips		
Season	6-9 months into production season		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	3.50 - 4.50	Fe	75 - 300
P	**0.20 - 0.40**	**Mn**	**100 - 1000**
K	3.80 - 5.00	B	10 - 50
Ca	**0.80 - 1.50**	**Cu**	**6 - 25**
Mg	0.25 - 0.80	Zn	20 - 100
S	**0.25 - 0.80**	**Mo**	**0.21 - 0.33**

D

Scientific Name	*Musa acuminata*		
Common Name	**Banana**		
Collected From	Production fields		
Plant Part	15 mid-section leaf strips		
Season	At harvest stage		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.00	Fe	100 - 300
P	**0.18 - 0.40**	**Mn**	**200 - 2000**
K	2.30 - 4.00	B	15 - 50
Ca	**0.70 - 1.40**	**Cu**	**6 - 30**
Mg	0.25 - 0.40	Zn	13 - 50
S	**0.25 - 0.50**	**Mo**	**0.13 - 0.3**

E

Scientific Name	*Olea europaea*		
Common Name	**Olive**		
Collected From	Production orchards		
Plant Part	50 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.50	Fe	35 - 66
P	**0.10 - 0.30**	**Mn**	**25 - 200**
K	0.90 - 1.20	B	20 - 75
Ca	**1.00 - 2.00**	**Cu**	**4 - 9**
Mg	0.20 - 0.60	Zn	25 - 100
S	**0.16 - 0.23**	**Mo**	**0.04 - 0.09**

F

Scientific Name	*Passiflora edulis, P. laurifolia, P. ligularis, P. maliformis, P. mollissima, and P. quandrangularis*		
Common Name	**Passion fruit**		
Collected From	Production orchards		
Plant Part	75 mature leaves from actively growing lateral shoots		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	4.75 - 5.25	Fe	2.00 - 2.50
P	**0.20 - 0.40**	**Mn**	**29 - 60**
K	0.25 - 0.35	B	18 - 25
Ca	**0.5 - 1.5**	**Cu**	**5 - 20**
Mg	0.25 - 0.35	Zn	50 - 150
S	**0.45 - 0.80**	**Mo**	**4.75 - 5.25**

Fruit and Nut Crops

A

Scientific Name	*Persea americana*
Common Name	**Avocado**
Collected From	Production orchards
Plant Part	50 mature leaves from new flush
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	1.60 - 2.00	Fe	50 - 200
P	**0.08 - 0.25**	**Mn**	**30 - 500**
K	0.75 - 2.00	B	50 - 100
Ca	**1.00 - 3.00**	**Cu**	**5 - 15**
Mg	0.25 - 0.80	Zn	30 - 150
S	**0.20 - 0.60**	**Mo**	**0.05 - 1.00**

B

Scientific Name	*Pistacia vera*
Common Name	**Pistachio**
Collected From	Production orchards
Plant Part	50 terminal leaflets from leaves located midway along flushes on nonbearing branches
Season	1 month prior to harvest
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.40 - 3.00	Fe	30 - 125
P	**0.15 - 0.20**	**Mn**	**25 - 75**
K	1.00 - 2.00	B	50 - 250
Ca	**1.25 - 4.00**	**Cu**	**6 - 15**
Mg	0.50 - 1.25	Zn	7 - 20
S	**0.19 - 0.28**	**Mo**	**0.02 - 0.08**

C

Scientific Name	*Prunus armeniaca (canning varieties)*
Common Name	**Apricot**
Collected From	Production orchards
Plant Part	50 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.00	Fe	70 - 150
P	**0.13 - 0.35**	**Mn**	**25 - 100**
K	2.50 - 3.00	B	20 - 70
Ca	**1.60 - 2.50**	**Cu**	**5 - 25**
Mg	0.30 - 1.20	Zn	20 - 60
S	**0.19 - 0.28**	**Mo**	**0.03 - 0.98**

D

Scientific Name	*Prunus armeniaca (fresh fruit varieties)*
Common Name	**Apricot**
Collected From	Production orchards
Plant Part	50 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.50	Fe	70 - 150
P	**0.13 - 0.35**	**Mn**	**25 - 100**
K	2.50 - 3.00	B	25 - 70
Ca	**1.60 - 2.50**	**Cu**	**5 - 25**
Mg	0.30 - 1.20	Zn	20 - 100
S	**0.16 - 0.29**	**Mo**	**0.06 - 1.06**

E

Scientific Name	*Prunus avium*
Common Name	**Sweet Cherry**
Collected From	Production orchards
Plant Part	50 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.10 - 3.00	Fe	100 - 250
P	**0.16 - 0.50**	**Mn**	**40 - 200**
K	2.50 - 3.00	B	20 - 100
Ca	**2.00 - 3.00**	**Cu**	**5 - 30**
Mg	0.30 - 0.80	Zn	20 - 60
S	**0.19 - 0.34**	**Mo**	**0.09 - 0.24**

F

Scientific Name	*Prunus cerasus*
Common Name	**Sour Cherry**
Collected From	Production orchards
Plant Part	50 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		**Micronutrients ppm**	
N	2.60 - 3.00	Fe	100 - 200
P	**0.16 - 0.22**	**Mn**	**40 - 60**
K	1.60 - 2.10	B	20 - 55
Ca	**1.50 - 2.60**	**Cu**	**8 - 30**
Mg	0.30 - 0.75	Zn	20 - 50
S	**0.16 - 0.30**	**Mo**	**0.06 - 0.08**

Fruit and Nut Crops

A

Scientific Name			*Prunus domestica cultivars*
Common Name			**Plum or Prune**
Collected From			Production orchards
Plant Part			25 whole leaves from mid-shoot growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.40 - 3.00	Fe	100 - 250
P	**0.14 - 0.25**	**Mn**	**40 - 160**
K	1.60 - 3.00	B	25 - 60
Ca	**1.50 - 3.00**	**Cu**	**6 - 16**
Mg	0.30 - 0.80	Zn	20 - 100
S	**0.22 - 0.30**	**Mo**	**0.10 - 2.00**

B

Scientific Name			*Prunus dulcis*
Common Name			**Sweet Almond**
Collected From			Production orchards
Plant Part			50 mature leaves from new growth
Season			Mid-Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.20 - 2.50	Fe	30 - 250
P	**0.10 - 0.30**	**Mn**	**20 - 100**
K	1.00 - 1.39	B	30 - 60
Ca	**2.00 - 3.00**	**Cu**	**4 - 20**
Mg	0.25 - 0.75	Zn	18 - 75
S	**0.16 - 0.23**	**Mo**	**0.02 - 0.09**

C

Scientific Name			*Prunus persica*
Common Name			**Peach or Nectarine**
Collected From			Production orchards
Plant Part			25 midshoot leaves
Season			Spring, at fruit set
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.80 - 3.50	Fe	50 - 800
P	**0.13 - 0.25**	**Mn**	**40 - 230**
K	1.75 - 3.00	B	20 - 60
Ca	**1.50 - 2.70**	**Cu**	**5 - 20**
Mg	0.30 - 0.80	Zn	15 - 125
S	**0.20 - 0.45**	**Mo**	**1.60 - 2.80**

D

Scientific Name			*Psidium guajava*
Common Name			**Guava**
Collected From			Production orchards
Plant Part			30 leaves (third leaf pair from tip on fruiting shoots)
Season			Late summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.25 - 1.70	Fe	44 - 75
P	**0.15 - 0.20**	**Mn**	**18 - 100**
K	1.25 - 1.75	B	15 - 25
Ca	**0.80 - 1.75**	**Cu**	**3 - 9**
Mg	0.25 - 0.50	Zn	18 - 32
S	**0.21 - 0.33**	**Mo**	**0.04 - 0.2**

E

Scientific Name			*Pyrus communis*
Common Name			**Pear**
Collected From			Production orchards
Plant Part			50 mature leaves from new growth
Season			Mid-summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.20 - 2.80	Fe	60 - 250
P	**0.12 - 0.25**	**Mn**	**30 - 150**
K	1.00 - 2.00	B	20 - 70
Ca	**1.00 - 2.50**	**Cu**	**5 - 20**
Mg	0.25 - 0.50	Zn	20 - 150
S	**0.15 - 0.40**	**Mo**	**0.10 - 2.00**

F

Scientific Name			*Ribes nigrum*
Common Name			**Black or European Currant**
Collected From			Production fields
Plant Part			50 mature leaves from new growth
Season			Fruit ripening
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.50	Fe	60 - 300
P	**0.10 - 0.30**	**Mn**	**50 - 100**
K	1.40 - 1.70	B	15 - 40
Ca	**1.30 - 2.50**	**Cu**	**4 - 20**
Mg	0.20 - 0.50	Zn	20 - 50
S	**0.18 - 0.27**	**Mo**	**0.05 - 0.56**

Fruit and Nut Crops

A

Scientific Name			*Rubus fruticosus*
Common Name			**Blackberry**
Collected From			Field test plots
Plant Part			25 mature leaves from new growth
Season			Early Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.70 - 2.50	Fe	27 - 85
P	**0.15 - 0.25**	**Mn**	**25 - 150**
K	1.25 - 2.20	B	12 - 35
Ca	**0.85 - 1.10**	**Cu**	**4 - 10**
Mg	0.35 - 0.55	Zn	10 - 25
S	**0.14 - 0.23**	**Mo**	**0.08 - 0.44**

B

Scientific Name			*Rubus idaeus*
Common Name			**Red Raspberry**
Collected From			Production fields
Plant Part			50 mature leaves from mid-section of primocanes
Season			2 - 3 weeks postharvest
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.20 - 4.00	Fe	50 - 200
P	**0.20 - 0.60**	**Mn**	**25 - 300**
K	1.10 - 3.00	B	25 - 75
Ca	**0.60 - 2.50**	**Cu**	**4 - 20**
Mg	0.25 - 0.80	Zn	15 - 100
S	**0.20 - 0.30**	**Mo**	**0.21 - 1**

C

Scientific Name			*Vaccinium ashei*
Common Name			**Rabbit-eye Blueberry**
Collected From			Production fields
Plant Part			75 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Climax', 'Premier', 'Tifblue'
Macronutrients %		**Micronutrients ppm**	
N	1.08 - 1.70	Fe	27 - 85
P	**0.07 - 0.20**	**Mn**	**25 - 150**
K	0.30 - 0.60	B	12 - 35
Ca	**0.25 - 0.75**	**Cu**	**4 - 10**
Mg	0.13 - 0.22	Zn	10 - 25
S	**0.11 - 0.25**	**Mo**	**0.02 - 0.06**

D

Scientific Name			*Vaccinium corymbosum*
Common Name			**Highbush Blueberry**
Collected From			Production fields
Plant Part			75 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Bluechip', 'Croatan'
Macronutrients %		**Micronutrients ppm**	
N	1.45 - 2.20	Fe	35 - 200
P	**0.10 - 0.40**	**Mn**	**40 - 600**
K	0.40 - 0.90	B	25 - 75
Ca	**0.35 - 0.80**	**Cu**	**4 - 20**
Mg	0.12 - 0.40	Zn	10 - 100
S	**0.12 - 0.40**	**Mo**	**0.01 - 0.33**

E

Scientific Name			*Vaccinium corymbosum (Southern form)*
Common Name			**Southern Highbush Blueberry**
Collected From			Research test plots
Plant Part			75 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Cape Fear', 'Georgiagem', 'O'Neal'
Macronutrients %		**Micronutrients ppm**	
N	1.44 - 1.65	Fe	90 - 100
P	**0.09 - 0.11**	**Mn**	**186 - 253**
K	0.44 - 0.72	B	14 - 27
Ca	**0.62 - 0.73**	**Cu**	**6 - 11**
Mg	0.15 - 0.27	Zn	22 - 116
S	**0.15 - 0.17**	**Mo**	**0.02 - 0.05**

F

Scientific Name			*Vaccinium macrocarpon*
Common Name			**Cranberry**
Collected From			Production fields
Plant Part			75 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.2 - 2.21	Fe	60 - 125
P	**0.10 - 0.25**	**Mn**	**75 - 200**
K	0.40 - 0.80	B	15 - 50
Ca	**0.50 - 0.90**	**Cu**	**5 - 15**
Mg	0.15 - 0.30	Zn	25 - 40
S	**0.10 - 0.15**	**Mo**	**0.2 - 0.8**

Fruit and Nut Crops

A

Scientific Name	*Vitis labrusca cultivars (American hybrids)*		
Common Name	**American Hybrid Table Grapes**		
Collected From	Production fields		
Plant Part	50 leaf petioles opposite basal flower clusters		
Season	Full bloom		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.60 - 2.80	Fe	40 - 180
P	**0.20 - 0.60**	**Mn**	**18 - 100**
K	1.50 - 5.00	B	25 - 50
Ca	**0.40 - 2.50**	**Cu**	**5 - 10**
Mg	0.13 - 0.40	Zn	20 - 100
S	**0.17 - 0.29**	**Mo**	**0.20 - 0.40**

B

Scientific Name	*Vitis rotundifolia*		
Common Name	**Muscadine**		
Collected From	Production fields		
Plant Part	15 whole leaves opposite bunch cluster		
Season	Mid to late summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.65 - 2.15	Fe	60 - 120
P	**0.12 - 0.18**	**Mn**	**60 - 150**
K	0.80 - 1.20	B	15 - 25
Ca	**0.70 - 1.10**	**Cu**	**5 - 10**
Mg	0.15 - 0.25	Zn	18 - 35
S	**0.19 - 0.27**	**Mo**	**0.15 - 0.35**

C

Scientific Name	*Vitis vinifera cultivars*		
Common Name	**Wine grapes**		
Collected From	Production vinyards		
Plant Part	15 whole leaves opposite bunch cluster		
Season	Mid to late summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 3.25	Fe	75 - 250
P	**0.12 - 0.3**	**Mn**	**30 - 100**
K	0.5 - 1	B	30 - 100
Ca	**1 - 3**	**Cu**	**6 - 50**
Mg	0.25 - 0.5	Zn	15 - 50
S	**0.16 - 0.22**	**Mo**	**0.1 - 1**

D

Scientific Name	*Vitis vinifera cultivars*		
Common Name	**Wine or European Table Grape**		
Collected From	Production fields		
Plant Part	15 whole leaves opposite bunch cluster		
Season	Early summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.30	Fe	60 - 175
P	**0.30 - 0.40**	**Mn**	**30 - 300**
K	1.30 - 1.40	B	25 - 70
Ca	**2.00 - 2.50**	**Cu**	**5 - 50**
Mg	0.25 - 0.50	Zn	25 - 100
S	**0.18 - 0.26**	**Mo**	**0.15 - 0.35**

E

Scientific Name	*Vitis vinifera cultivars*		
Common Name	**Wine or European Table Grape**		
Collected From	Production fields		
Plant Part	50 petioles opposite basal flower clusters		
Season	Full bloom		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.70 - 3.00	Fe	40 - 300
P	**0.15 - 0.50**	**Mn**	**30 - 150**
K	1.50 - 2.00	B	30 - 100
Ca	**1.00 - 3.00**	**Cu**	**5 - 50**
Mg	0.30 - 1.50	Zn	25 - 100
S	**0.22 - 0.29**	**Mo**	**0.14 - 0.45**

F

Herbaceous Perennials

A

SCIENTIFIC NAME			*Acanthus mollis*
COMMON NAME			**Bear's Breeches or Artists' Acanthus**
COLLECTED FROM			Container production nursery
PLANT PART			10 mature leaves from new growth
SEASON			Late summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	3 - 4.56	Fe	35 - 100
P	**0.33 - 0.53**	**Mn**	**55 - 129**
K	2.78 - 4.65	B	24 - 35
Ca	**1.11 - 1.98**	**Cu**	**6 - 12**
Mg	.33 - .65	Zn	24 - 60
S	**0.13 - 0.24**	**Mo**	**0.16 - 0.22**

B

SCIENTIFIC NAME			*Achillea millefolium*
COMMON NAME			**Common Yarrow**
COLLECTED FROM			Experimental test plots & container production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Colorado', 'Lilac Beauty', 'Paprika', 'White Beauty'
Macronutrients %		Micronutrients ppm	
N	2.66 - 3.08	Fe	66 - 147
P	**0.34 - 0.56**	**Mn**	**60 - 258**
K	1.98 - 2.78	B	29 - 32
Ca	**0.75 - 0.96**	**Cu**	**4 - 8**
Mg	0.19 - 0.24	Zn	37 - 63
S	**0.2 - 0.27**	**Mo**	**0.15 - 0.24**

C

SCIENTIFIC NAME			*Achillea ptarmica*
COMMON NAME			**Sneezewort Yarrow**
COLLECTED FROM			Container production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	2.14 - 3.79	Fe	33 - 49
P	**0.27 - 0.53**	**Mn**	**50 - 105**
K	1.89 - 3.81	B	24 - 35
Ca	**.75 - 1.23**	**Cu**	**4 - 10**
Mg	.27 - .36	Zn	34 - 77
S	**0.19 - 0.29**	**Mo**	**0.14 - 0.22**

D

SCIENTIFIC NAME			*Achillea x 'Coronation Gold'*
COMMON NAME			**Coronation Gold' Yarrow**
COLLECTED FROM			Experimental test plots
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Coronation Gold'
Macronutrients %		Micronutrients ppm	
N	2.5 - 3.45	Fe	35 - 210
P	**0.24 - 0.33**	**Mn**	**33 - 44**
K	1.98 - 2.78	B	31 - 38
Ca	**.79 - 1.149**	**Cu**	**4 - 8**
Mg	0.23 - 0.35	Zn	33 - 45
S	**0.18 - 0.28**	**Mo**	**0.14 - 0.22**

E

SCIENTIFIC NAME			*Aegopodium podagraria 'Variegatum'*
COMMON NAME			**Variegated Bishop's Weed or Goutweed**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Variegatum'
Macronutrients %		Micronutrients ppm	
N	1.78 - 3.14	Fe	33 - 45
P	**0.28 - 0.42**	**Mn**	**44 - 89**
K	2.1 - 2.95	B	25 - 34
Ca	**.91 - 1.34**	**Cu**	**4 - 7**
Mg	.27 - .4	Zn	35 - 55
S	**0.22 - 0.31**	**Mo**	**0.14 - 0.34**

F

SCIENTIFIC NAME			*Alcea rosea*
COMMON NAME			**Hollyhock**
COLLECTED FROM			Container production nursery
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	2.25 - 3.94	Fe	45 - 70
P	**0.28 - 0.36**	**Mn**	**55 - 132**
K	2.66 - 3.82	B	22 - 77
Ca	**1.23 - 2.68**	**Cu**	**6 - 15**
Mg	0.44 - 0.82	Zn	35 - 49
S	**0.31 - 0.51**	**Mo**	**0.18 - 0.28**

Herbaceous Perennials

A

Scientific Name	*Alchemilla mollis*
Common Name	**Lady's Mantle**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.18 - 3.33	Fe	36 - 59
P	**0.28 - 0.44**	**Mn**	**44 - 225**
K	1.64 - 2.56	B	20 - 35
Ca	**1.22 - 2.2**	**Cu**	**4 - 12**
Mg	.289 - .43	Zn	35 - 49
S	**0.23 - 0.49**	**Mo**	**0.19 - 0.28**

B

Scientific Name	*Amsonia tabernaemontana*
Common Name	**Willow-leaf Blue Star**
Collected From	Botanical garden/arboretum
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.59 - 2.91	Fe	50 - 52
P	**0.21 - 0.30**	**Mn**	**445 - 896**
K	2.22 - 2.38	B	36 - 108
Ca	**0.66 - 1.40**	**Cu**	**3 - 5**
Mg	0.17 - 0.27	Zn	116 - 335
S	**0.36 - 0.47**	**Mo**	**0.12 - 0.30**

C

Scientific Name	*Aquilegia canadensis*
Common Name	**Wild Columbine**
Collected From	Container production nursery
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.05 - 2.68	Fe	34 - 72
P	**0.19 - 0.29**	**Mn**	**46 - 86**
K	2.34 - 3.50	B	22 - 33
Ca	**1.02 - 1.87**	**Cu**	**2 - 9**
Mg	0.24 - 0.35	Zn	36 - 51
S	**0.17 - 0.22**	**Mo**	**0.13 - 0.22**

D

Scientific Name	*Aralia racemosa*
Common Name	**American Spikenard or Life-of-Man**
Collected From	Botanical garden/arboretum
Plant Part	2 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.12 - 4.5	Fe	110 - 219
P	**0.22 - 0.32**	**Mn**	**45 - 339**
K	2.2 - 4.53	B	30 - 64
Ca	**1.5 - 2.55**	**Cu**	**7 - 11**
Mg	.38 - 0.54	Zn	20 - 38
S	**0.18 - 0.23**	**Mo**	**0.1 - 0.12**

E

Scientific Name	*Argyranthemum frutescens*
Common Name	**Marguerite Daisy**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Vegetative
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	6.53 - 7.28	Fe	56 - 66
P	**0.58 - 0.73**	**Mn**	**55 - 236**
K	6.49 - 7.05	B	45 - 58
Ca	**1.78 - 1.79**	**Cu**	**5.3 - 7.8**
Mg	0.33 - 0.34	Zn	21 - 31
S	**0.27 - 0.30**	**Mo**	**1 - 7**

F

Scientific Name	*Argyranthemum frutescens*
Common Name	**Marguerite Daisy**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Young Plants/ Cutting
Data Type	Survey Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.5 - 6.4	Fe	64 - 201.4
P	**0.37 - 0.7**	**Mn**	**82.3 - 296.8**
K	3.3 - 6.04	B	31 - 88
Ca	**0.99 - 1.67**	**Cu**	**4.6 - 25**
Mg	0.18 - 0.57	Zn	20 - 80
S	**0.45 - 1.44**	**Mo**	**1 - 5**

Herbaceous Perennials

A

Scientific Name	*Artemisia 'Powis Castle'*		
Common Name	**Powis Castle' Artemisia or Wormwood**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Powis Castle'		
Macronutrients %		**Micronutrients ppm**	
N	3.88 - 3.95	Fe	72 - 91
P	**0.45 - 0.65**	**Mn**	**140 - 244**
K	3.43 - 4.00	B	39 - 49
Ca	**1.14 - 1.35**	**Cu**	**9 - 19**
Mg	0.19 - 0.22	Zn	84 - 149
S	**0.36 - 0.45**	**Mo**	**0.12 - 0.57**

B

Scientific Name	*Artemisia dracunculus var. sativa*		
Common Name	**French Tarragon**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. sativa only		
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 4.08	Fe	41 - 52
P	**0.30 - 0.51**	**Mn**	**44 - 132**
K	1.78 - 3.68	B	18 - 21
Ca	**0.5 - 0.75**	**Cu**	**6 - 8**
Mg	0.22 - 0.31	Zn	55 - 145
S	**0.24 - 0.50**	**Mo**	**0.1 - 0.28**

C

Scientific Name	*Aruncus aethusifolius*		
Common Name	**Korean Goat's Beard**		
Collected From	Container production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.12 - 2.55	Fe	66 - 121
P	**0.34 - 0.63**	**Mn**	**25 - 458**
K	0.77 - 1.75	B	27 - 42
Ca	**0.98 - 1.62**	**Cu**	**5 - 8**
Mg	0.18 - 0.26	Zn	22 - 64
S	**0.15 - 0.30**	**Mo**	**0.30 - 0.69**

D

Scientific Name	*Asarum arifolium*		
Common Name	**Arrowhead Wild Ginger or Little Brown Jugs**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.97 - 4.11	Fe	37 - 90
P	**0.23 - 0.27**	**Mn**	**12 - 357**
K	2.14 - 6.87	B	23 - 37
Ca	**0.87 - 1.54**	**Cu**	**4 - 8**
Mg	0.31 - 0.50	Zn	45 - 148
S	**0.14 - 0.24**	**Mo**	**0.12 - 0.4**

E

Scientific Name	*Asarum canadense*		
Common Name	**Canadian Wild Ginger or Snakeroot**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.12 - 3.33	Fe	45 - 391
P	**0.32 - 0.37**	**Mn**	**33 - 142**
K	2.88 - 6.38	B	23 - 37
Ca	**1.56 - 3.02**	**Cu**	**5 - 7**
Mg	0.33 - 0.72	Zn	45 - 60
S	**0.16 - 0.28**	**Mo**	**0.12 - 0.50**

F

Scientific Name	*Asarum shut tleworthii*		
Common Name	**Mottled Wild Ginger**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.22 - 3.33	Fe	33 - 54
P	**0.17 - 0.29**	**Mn**	**25 - 399**
K	2.22 - 5.57	B	22 - 33
Ca	**0.55 - 1.25**	**Cu**	**4 - 8**
Mg	0.34 - 0.66	Zn	45 - 76
S	**0.19 - 0.28**	**Mo**	**0.12 - 0.50**

Herbaceous Perennials

A

SCIENTIFIC NAME			*Asclepias incarnata*
COMMON NAME			**Swamp Milkweed**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Ice Ballet'
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.93	Fe	32 - 40
P	**0.16 - 0.23**	**Mn**	**35 - 78**
K	1.17 - 2.18	B	17 - 25
Ca	**0.78 - 1.36**	**Cu**	**4 - 8**
Mg	0.22 - 0.34	Zn	21 - 33
S	**0.14 - 0.26**	**Mo**	**0.10 - 0.34**

B

SCIENTIFIC NAME			*Asclepias tuberosa*
COMMON NAME			**Butterfly Weed**
COLLECTED FROM			Container production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 3.01	Fe	55 - 423
P	**0.22 - 0.34**	**Mn**	**45 - 380**
K	2.11 - 3.47	B	35 - 58
Ca	**0.75 - 1.23**	**Cu**	**5 - 8**
Mg	0.33 - 0.40	Zn	33 - 68
S	**0.25 - 0.35**	**Mo**	**0.07 - 0.5**

C

SCIENTIFIC NAME			*Aster novae-angliae*
COMMON NAME			**New England Aster**
COLLECTED FROM			Experimental test plots
PLANT PART			40 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Rosa Sieger'
Macronutrients %		**Micronutrients ppm**	
N	2.21 - 3.00	Fe	55 - 168
P	**0.29 - 0.45**	**Mn**	**33 - 65**
K	2.66 - 3.29	B	21 - 37
Ca	**0.89 - 1.68**	**Cu**	**5 - 8**
Mg	0.26 - 0.35	Zn	34 - 72
S	**0.19 - 0.31**	**Mo**	**0.10 - 0.50**

D

SCIENTIFIC NAME			*Aster novi-belgii*
COMMON NAME			**New York Aster or Michaelmas Daisy**
COLLECTED FROM			Experimental test plots
PLANT PART			40 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Climax'
Macronutrients %		**Micronutrients ppm**	
N	2.20 - 3.10	Fe	162 - 180
P	**0.24 - 0.65**	**Mn**	**88 - 273**
K	3.64 - 3.67	B	39 - 46
Ca	**0.98 - 1.39**	**Cu**	**6 - 9**
Mg	0.18 - 0.35	Zn	48 - 48
S	**0.25 - 0.38**	**Mo**	**0.11 - 0.50**

E

SCIENTIFIC NAME			*Baptisia australis*
COMMON NAME			**Blue Wild Indigo**
COLLECTED FROM			Container production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.26 - 3.50	Fe	45 - 68
P	**0.22 - 0.31**	**Mn**	**34 - 461**
K	1.6 - 2.25	B	28 - 88
Ca	**0.5 - 1.45**	**Cu**	**5 - 10**
Mg	0.32 - 0.48	Zn	28 - 117
S	**0.18 - 0.29**	**Mo**	**0.12 - 0.35**

F

SCIENTIFIC NAME			*Begonia grandis*
COMMON NAME			**Hardy Begonia**
COLLECTED FROM			Container production nursery
PLANT PART			10 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.67 - 2.92	Fe	54 - 185
P	**0.17 - 0.23**	**Mn**	**55 - 157**
K	0.89 - 2.15	B	16 - 24
Ca	**0.45 - 1.26**	**Cu**	**4 - 16**
Mg	0.26 - 0.44	Zn	26 - 36
S	**0.18 - 0.26**	**Mo**	**0.06 - 0.12**

Herbaceous Perennials

A

SCIENTIFIC NAME	*Belamcanda chinensis*
COMMON NAME	**Blackberry Lily or Leopard Flower**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	0.32 - 1.37	Fe	25 - 66
P	**0.19 - 0.25**	**Mn**	**29 - 47**
K	1.78 - 2.80	B	15 - 22
Ca	**0.5 - 2.30**	**Cu**	**3 - 9**
Mg	0.27 - 0.35	Zn	9 - 33
S	**0.12 - 0.23**	**Mo**	**0.07 - 0.26**

B

SCIENTIFIC NAME	*Canna generalis*
COMMON NAME	**Hybrid Canna Lily**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	5 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.12 - 2.87	Fe	44 - 76
P	**0.24 - 0.34**	**Mn**	**55 - 675**
K	2.23 - 3.62	B	15 - 25
Ca	**0.56 - 0.84**	**Cu**	**5 - 10**
Mg	0.31 - 0.51	Zn	25 - 39
S	**0.19 - 0.26**	**Mo**	**0.07 - 0.12**

C

SCIENTIFIC NAME	*Canna lily*
COMMON NAME	**General**
COLLECTED FROM	Field/Garden Production
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	3.0 - 4.40	Fe	65 - 200
P	**0.28 - 0.40**	**Mn**	**40 - 280**
K	2.80 - 4.00	B	25 - 65
Ca	**0.60 - 1.50**	**Cu**	**10 - 30**
Mg	0.29 - 0.70	Zn	20 - 70
S	**0.25 - 0.65**	**Mo**	**0.18 - 0.55**

D

SCIENTIFIC NAME	*Centranthus ruber*
COMMON NAME	**Red Valerian or Jupiter's Beard**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.18 - 3.71	Fe	28 - 89
P	**0.19 - 0.26**	**Mn**	**44 - 75**
K	2.88 - 7.35	B	9 - 25
Ca	**0.68 - 1.55**	**Cu**	**4 - 16**
Mg	0.38 - 1.21	Zn	33 - 52
S	**0.17 - 0.26**	**Mo**	**0.04 - 0.12**

E

SCIENTIFIC NAME	*Ceratostigma plumbaginoides*
COMMON NAME	**Blue Leadwort or Hardy Plumbago**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.28 - 2.73	Fe	33 - 83
P	**0.18 - 0.27**	**Mn**	**33 - 650**
K	1.56 - 2.21	B	22 - 53
Ca	**0.5 - 1.62**	**Cu**	**4 - 9**
Mg	0.31 - 0.59	Zn	22 - 88
S	**0.19 - 0.28**	**Mo**	**0.12 - 0.3**

F

SCIENTIFIC NAME	*Chelone lyonii*
COMMON NAME	**Pink Turtlehead**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.56 - 1.85	Fe	37 - 78
P	**0.17 - 0.34**	**Mn**	**45 - 150**
K	0.83 - 2.69	B	22 - 35
Ca	**0.65 - 0.90**	**Cu**	**5 - 10**
Mg	0.32 - 0.43	Zn	23 - 36
S	**0.22 - 0.35**	**Mo**	**0.11 - 0.32**

Herbaceous Perennials

A

Scientific Name	*Chrysogonum virginianum*
Common Name	**Green & Gold or Goldenstar**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Piccadilly'

Macronutrients %		Micronutrients ppm	
N	1.84 - 2.07	Fe	65 - 271
P	**0.18 - 0.37**	**Mn**	**118 - 151**
K	3.81 - 5.15	B	61 - 174
Ca	**1.27 - 1.45**	**Cu**	**4 - 20**
Mg	0.33 - 0.44	Zn	24 - 33
S	**0.11 - 0.20**	**Mo**	**0.12 - 0.50**

B

Scientific Name	*Cimicifuga racemosa*
Common Name	**Snakeroot or Black Cohosh**
Collected From	Botanical garden/arboretum
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.45 - 2.23	Fe	38 - 87
P	**0.16 - 0.28**	**Mn**	**43 - 76**
K	2.89 - 4.62	B	25 - 42
Ca	**2 - 3.06**	**Cu**	**4 - 11**
Mg	0.28 - 0.32	Zn	11 - 34
S	**0.12 - 0.21**	**Mo**	**0.05 - 0.12**

C

Scientific Name	*Cirsium japonicum*
Common Name	**Japanese Thistle**
Collected From	Experimental test plots
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Rose Beauty'

Macronutrients %		Micronutrients ppm	
N	1.67 - 2.60	Fe	66 - 462
P	**0.19 - 0.28**	**Mn**	**55 - 130**
K	1.98 - 2.24	B	14 - 24
Ca	**0.4 - 0.60**	**Cu**	**4 - 9**
Mg	0.23 - 0.35	Zn	21 - 34
S	**0.19 - 0.30**	**Mo**	**0.08 - 0.11**

D

Scientific Name	*Clematis recta 'Purpurea'*
Common Name	**Purple-leaf Ground Clematis**
Collected From	Container production nursery
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Purpurea'

Macronutrients %		Micronutrients ppm	
N	1.55 - 2.55	Fe	38 - 125
P	**0.16 - 0.29**	**Mn**	**33 - 66**
K	1.45 - 2.24	B	20 - 30
Ca	**1.25 - 1.45**	**Cu**	**5 - 20**
Mg	0.25 - 0.33	Zn	20 - 68
S	**0.18 - 0.24**	**Mo**	**0.20 - 0.50**

E

Scientific Name	*Collinsonia canadensis*
Common Name	**Stoneroot or Citronella or Richweed**
Collected From	Botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.2 - 2.66	Fe	41 - 149
P	**0.27 - 0.36**	**Mn**	**45 - 97**
K	2.89 - 5.13	B	25 - 53
Ca	**1.98 - 3.05**	**Cu**	**7 - 24**
Mg	0.41 - 1.31	Zn	31 - 45
S	**0.16 - 0.26**	**Mo**	**0.07 - 0.12**

F

Scientific Name	*Coreopsis grandiflora*
Common Name	**Tickseed Coreopsis**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Sunray'

Macronutrients %		Micronutrients ppm	
N	3.18 - 3.33	Fe	53 - 61
P	**0.29 - 0.31**	**Mn**	**74 - 101**
K	2.73 - 3.33	B	26 - 30
Ca	**1.14 - 1.33**	**Cu**	**4 - 7**
Mg	0.49 - 0.50	Zn	64 - 75
S	**0.28 - 0.32**	**Mo**	**0.14 - 0.25**

Herbaceous Perennials

A

Scientific Name			*Coreopsis verticillata*
Common Name			**Thread-leaf Coreopsis**
Collected From			Container production nursery
Plant Part			50 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Zagreb'
Macronutrients %		**Micronutrients ppm**	
N	2.0 - 3.0	Fe	40 - 125
P	**0.18 - 0.38**	**Mn**	**50 - 150**
K	1.55 - 3.00	B	25 - 60
Ca	**1.87 - 2.65**	**Cu**	**3.0 - 6.0**
Mg	0.40 - 1.03	Zn	40 - 130
S	**0.18 - 0.35**	**Mo**	**0.20 - 2.50**

B

Scientific Name			*Cynara cardunculus*
Common Name			**Cardoon**
Collected From			Container production nursery
Plant Part			3 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.56 - 2.47	Fe	56 - 184
P	**0.28 - 0.52**	**Mn**	**31 - 38**
K	1.64 - 2.56	B	11 - 25
Ca	**0.45 - 1.00**	**Cu**	**4 - 12**
Mg	0.25 - 0.32	Zn	30 - 64
S	**0.16 - 0.23**	**Mo**	**0.09 - 0.18**

C

Scientific Name			*Daucus carota*
Common Name			**Queen Anne's Lace**
Collected From			Container production nursery
Plant Part			10 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	3.31 - 3.94	Fe	37 - 76
P	**0.21 - 0.40**	**Mn**	**43 - 93**
K	2.25 - 2.96	B	23 - 38
Ca	**1.11 - 1.59**	**Cu**	**5 - 12**
Mg	0.3 - 0.39	Zn	20 - 46
S	**0.23 - 0.39**	**Mo**	**0.14 - 0.91**

D

Scientific Name			*Delosperma brunnthaleri*
Common Name			**Rose-pink Hardy Ice Plant**
Collected From			Container production nursery
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.85 - 2.67	Fe	35 - 74
P	**0.31 - 0.58**	**Mn**	**37 - 87**
K	2 - 9.36	B	21 - 32
Ca	**2.11 - 3.57**	**Cu**	**6 - 18**
Mg	0.38 - 1.35	Zn	41 - 71
S	**0.25 - 0.50**	**Mo**	**0.33 - 0.84**

E

Scientific Name			*Delphinium x Pacific hybrids*
Common Name			**Border Delphinium**
Collected From			Experimental test plots
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2 - 3.20	Fe	55 - 617
P	**0.24 - 0.33**	**Mn**	**31 - 59**
K	2.2 - 3.52	B	14 - 18
Ca	**1.12 - 2.86**	**Cu**	**4 - 12**
Mg	0.3 - 0.70	Zn	33 - 35
S	**0.19 - 0.28**	**Mo**	**0.09 - 0.4**

F

Scientific Name			*Dendranthema 'Ryan's Daisy'*
Common Name			**Ryan's Daisy' Garden Mum**
Collected From			Container production nursery
Plant Part			35 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Ryans Daisy'
Macronutrients %		**Micronutrients ppm**	
N	2.71 - 4.20	Fe	37 - 85
P	**0.35 - 0.54**	**Mn**	**47 - 93**
K	2.46 - 4.59	B	21 - 32
Ca	**1.02 - 2.1**	**Cu**	**6 - 16**
Mg	0.29 - 0.37	Zn	37 - 82
S	**0.2 - 0.32**	**Mo**	**0.33 - 1.15**

Herbaceous Perennials

A

Scientific Name	*Dendranthema pacificum*
Common Name	**Silver and Gold Chrysanthemum**
Collected From	Container production nursery
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.36 - 2.94	Fe	29 - 92
P	**0.34 - 0.51**	**Mn**	**31 - 88**
K	2.26 - 2.99	B	19 - 31
Ca	**1.44 - 1.84**	**Cu**	**5 - 11**
Mg	0.11 - 0.35	Zn	32 - 56
S	**0.17 - 0.28**	**Mo**	**0.5 - 1.28**

B

Scientific Name	*Dianthus gratianopolitanus*
Common Name	**Cheddar Pink**
Collected From	Container production nursery
Plant Part	50 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Bath's Pink'

Macronutrients %		Micronutrients ppm	
N	1.52 - 1.63	Fe	42 - 82
P	**0.32 - 0.40**	**Mn**	**47 - 586**
K	1.96 - 2.09	B	20 - 47
Ca	**0.58 - 1.66**	**Cu**	**8 - 11**
Mg	0.22 - 0.26	Zn	109 - 148
S	**0.16 - 0.20**	**Mo**	**0.12 - 1.96**

C

Scientific Name	*Dicentra eximia*
Common Name	**Fringed Bleeding Heart or Dutchman's Breeches**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	3.71 - 5.24	Fe	74 - 79
P	**0.60 - 0.70**	**Mn**	**891 - 1504**
K	2.24 - 3.18	B	20 - 24
Ca	**0.38 - 0.64**	**Cu**	**4 - 6**
Mg	0.19 - 0.35	Zn	87 - 101
S	**0.66 - 0.69**	**Mo**	**0.66 - 1.08**

D

Scientific Name	*Digitalis purpurea*
Common Name	**Common Foxglove**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.34 - 4.40	Fe	54 - 78
P	**0.29 - 0.56**	**Mn**	**40 - 136**
K	2.22 - 3.57	B	17 - 35
Ca	**0.47 - 1.32**	**Cu**	**4 - 11**
Mg	0.31 - 0.40	Zn	33 - 111
S	**0.16 - 0.25**	**Mo**	**0.1 - 0.61**

E

Scientific Name	*Digitalis x 'Emerson'*
Common Name	**Emerson' Foxglove**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Emerson'

Macronutrients %		Micronutrients ppm	
N	2.25 - 4.04	Fe	44 - 86
P	**0.21 - 0.65**	**Mn**	**41 - 96**
K	2.34 - 3.69	B	11 - 25
Ca	**0.71 - 1.77**	**Cu**	**5 - 14**
Mg	0.24 - 0.35	Zn	34 - 71
S	**0.19 - 0.25**	**Mo**	**0.2 - 0.65**

F

Scientific Name	*Echinacea purpurea*
Common Name	**Purple Coneflower**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	White Swan'

Macronutrients %		Micronutrients ppm	
N	2.25 - 3.00	Fe	42 - 78
P	**0.25 - 0.34**	**Mn**	**55 - 81**
K	2.26 - 3.84	B	31 - 93
Ca	**1.45 - 2.17**	**Cu**	**5 - 15**
Mg	0.35 - 0.90	Zn	25 - 41
S	**0.19 - 0.28**	**Mo**	**0.09 - 0.12**

Herbaceous Perennials

A

Scientific Name			*Epimedium x versicolor*
Common Name			**Yellow Bishop's Hat or Barrenwort**
Collected From			Container production nursery
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Sulphureum'
Macronutrients %		**Micronutrients ppm**	
N	2.04 - 2.50	Fe	35 - 76
P	**0.22 - 0.27**	**Mn**	**55 - 176**
K	2.09 - 2.88	B	12 - 32
Ca	**1.1 - 1.72**	**Cu**	**4 - 8**
Mg	0.36 - 0.46	Zn	14 - 29
S	**0.19 - 0.30**	**Mo**	**0.06 - 0.21**

B

Scientific Name			*Epimedium x youngianum*
Common Name			**White Bishop's Hat or Barrenwort**
Collected From			Container production nursery
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Niveum'
Macronutrients %		**Micronutrients ppm**	
N	1.54 - 2.35	Fe	33 - 83
P	**0.19 - 0.57**	**Mn**	**54 - 301**
K	0.72 - 2.65	B	24 - 39
Ca	**1.12 - 2.03**	**Cu**	**4 - 12**
Mg	0.3 - 0.4	Zn	12 - 35
S	**0.16 - 0.22**	**Mo**	**0.1 - 0.18**

C

Scientific Name			*Eryngium planum*
Common Name			**Flat Sea Holly**
Collected From			Experimental test plots
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.33 - 4.05	Fe	55 - 257
P	**0.23 - 0.63**	**Mn**	**34 - 84**
K	2.41 - 3.36	B	16 - 28
Ca	**1.04 - 1.19**	**Cu**	**3 - 9**
Mg	0.3 - 0.47	Zn	33 - 61
S	**0.19 - 0.29**	**Mo**	**0.96 - 1.25**

D

Scientific Name			*Eupatorium maculatum*
Common Name			**Joe-Pye Weed**
Collected From			Botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.65 - 2.68	Fe	56 - 161
P	**0.21 - 0.29**	**Mn**	**26 - 78**
K	1.07 - 2.45	B	21 - 76
Ca	**0.47 - 2.61**	**Cu**	**5 - 10**
Mg	0.31 - 0.75	Zn	22 - 35
S	**0.19 - 0.97**	**Mo**	**0.09 - 0.12**

E

Scientific Name			*Galax urceolata*
Common Name			**Wand Flower or Galaxy or Coltsfoot**
Collected From			Botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.5 - 2.24	Fe	37 - 76
P	**0.17 - 0.28**	**Mn**	**55 - 2230**
K	0.7 - 2.98	B	22 - 37
Ca	**0.74 - 0.96**	**Cu**	**3 - 9**
Mg	0.33 - 0.35	Zn	19 - 37
S	**0.18 - 0.26**	**Mo**	**0.1 - 0.3**

F

Scientific Name			*Gaura lindheimeri*
Common Name			**White Gaura**
Collected From			Container production nursery
Plant Part			40 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.14 - 3.36	Fe	32 - 111
P	**0.28 - 0.50**	**Mn**	**45 - 74**
K	2.2 - 2.93	B	21 - 31
Ca	**1.67 - 2.42**	**Cu**	**5 - 13**
Mg	0.33 - 0.51	Zn	29 - 39
S	**0.18 - 0.26**	**Mo**	**0.14 - 0.31**

Herbaceous Perennials

A

SCIENTIFIC NAME			*Geranium cinereum*
COMMON NAME			**Grayleaf Cranesbill**
COLLECTED FROM			Container production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Ballerina'
Macronutrients %		Micronutrients ppm	
N	2.12 - 4.20	Fe	27 - 51
P	**0.22 - 0.47**	**Mn**	**26 - 44**
K	1.98 - 2.49	B	15 - 28
Ca	**0.4 - 0.83**	**Cu**	**5 - 10**
Mg	0.22 - 0.34	Zn	23 - 41
S	**0.17 - 0.29**	**Mo**	**0.04 - 0.15**

B

SCIENTIFIC NAME			*Geranium sanguineum*
COMMON NAME			**Bloody Cranesbill**
COLLECTED FROM			Container production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Album'
Macronutrients %		Micronutrients ppm	
N	1.35 - 2.96	Fe	33 - 51
P	**0.27 - 0.69**	**Mn**	**33 - 55**
K	1.55 - 2.95	B	18 - 25
Ca	**0.5 - 1.33**	**Cu**	**5 - 14**
Mg	0.28 - 0.34	Zn	20 - 55
S	**0.19 - 0.29**	**Mo**	**0.09 - 0.25**

C

SCIENTIFIC NAME			*Geranium x oxonianum*
COMMON NAME			**Oxford Geranium**
COLLECTED FROM			Container production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Claridge Druce'
Macronutrients %		Micronutrients ppm	
N	2.45 - 3.50	Fe	39 - 78
P	**0.29 - 0.76**	**Mn**	**54 - 84**
K	2.11 - 3.20	B	19 - 29
Ca	**1.13 - 1.76**	**Cu**	**6 - 15**
Mg	0.34 - 0.44	Zn	33 - 54
S	**0.16 - 0.25**	**Mo**	**0.12 - 0.33**

D

SCIENTIFIC NAME			*Gladiolus callianthus*
COMMON NAME			**Abysinnian Gladiolus**
COLLECTED FROM			Experimental test plots
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Muralis'
Macronutrients %		Micronutrients ppm	
N	1.78 - 2.50	Fe	45 - 110
P	**0.19 - 0.29**	**Mn**	**30 - 44**
K	1.23 - 1.54	B	15 - 25
Ca	**0.22 - 0.47**	**Cu**	**6 - 9**
Mg	0.16 - 0.33	Zn	45 - 148
S	**0.18 - 0.24**	**Mo**	**0.09 - 1.3**

E

SCIENTIFIC NAME			*Hedychium coccineum*
COMMON NAME			**Red Ginger Lily**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			10 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	1.56 - 2.6	Fe	34 - 138
P	**0.18 - 0.25**	**Mn**	**55 - 944**
K	2.33 - 3.13	B	14 - 28
Ca	**1.06 - 1.89**	**Cu**	**5 - 15**
Mg	0.33 - 0.41	Zn	19 - 41
S	**0.19 - 0.23**	**Mo**	**0.07 - 1**

F

SCIENTIFIC NAME			*Hedychium coronarium*
COMMON NAME			**Butterfly Ginger or Butterfly Lily**
COLLECTED FROM			Container production nursery
PLANT PART			10 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	1.22 - 1.56	Fe	45 - 76
P	**0.23 - 0.34**	**Mn**	**34 - 469**
K	1.87 - 2.81	B	11 - 16
Ca	**0.88 - 1.31**	**Cu**	**3 - 13**
Mg	0.29 - 0.38	Zn	28 - 45
S	**0.19 - 0.30**	**Mo**	**0.02 - 0.17**

Herbaceous Perennials

A

Scientific Name	*Helianthus angustifolius*
Common Name	**Swamp Sunflower**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.92 - 2.51	Fe	34 - 91
P	**0.24 - 0.33**	**Mn**	**57 - 369**
K	2.31 - 3.33	B	30 - 75
Ca	**1.33 - 2.11**	**Cu**	**5 - 14**
Mg	0.31 - 0.64	Zn	44 - 174
S	**0.19 - 0.37**	**Mo**	**0.1 - 0.29**

B

Scientific Name	*Heliotropium arborescens*
Common Name	**Heliotrope or Cherry-pie**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Alba', 'Mini-Marine'

Macronutrients %		Micronutrients ppm	
N	2.44 - 3.76	Fe	174 - 314
P	**0.75 - 0.80**	**Mn**	**105 - 122**
K	4.66 - 5.10	B	35 - 38
Ca	**2.14 - 2.39**	**Cu**	**5 - 13**
Mg	0.57 - 0.73	Zn	77 - 81
S	**0.30 - 0.33**	**Mo**	**0.12 - 0.19**

C

Scientific Name	*Helleborus foetidus*
Common Name	**Bearsfoot or Stinking Hellebore**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.86 - 2.88	Fe	34 - 52
P	**0.23 - 0.36**	**Mn**	**47 - 77**
K	1.55 - 1.99	B	19 - 25
Ca	**0.76 - 2.06**	**Cu**	**2 - 8**
Mg	0.21 - 0.53	Zn	22 - 33
S	**0.15 - 0.25**	**Mo**	**0.12 - 0.50**

D

Scientific Name	*Helleborus x hybridus*
Common Name	**Lenten Rose or Oriental Hellebore**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.75 - 2.97	Fe	31 - 41
P	**0.21 - 0.40**	**Mn**	**34 - 103**
K	2.52 - 3.07	B	15 - 20
Ca	**0.75 - 2.54**	**Cu**	**1 - 3**
Mg	0.21 - 0.33	Zn	16 - 31
S	**0.18 - 0.26**	**Mo**	**0.12 - 0.20**

E

Scientific Name	*Hemerocallis fulva*
Common Name	**Common Orange Daylily**
Collected From	Container production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.22 - 3.79	Fe	41 - 170
P	**0.27 - 0.35**	**Mn**	**49 - 126**
K	2.00 - 2.94	B	15 - 39
Ca	**0.45 - 0.70**	**Cu**	**2 - 8**
Mg	0.18 - 0.40	Zn	15 - 41
S	**0.15 - 0.30**	**Mo**	**0.01 - 1.00**

F

Scientific Name	*Hemerocallis x cultivars*
Common Name	**Hybrid Daylilies**
Collected From	Container production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used- Allapatah', 'Aztec Gold', 'Cradel Song', 'Dutch Treat', 'Dwarf Peach', 'Early Sunrise', 'Ming Toy', 'Sammy Russell', 'Yellow Shiner'	

Macronutrients %		Micronutrients ppm	
N	2.33 - 3.69	Fe	41 - 137
P	**0.27 - 0.42**	**Mn**	**49 - 494**
K	2.26 - 2.94	B	17 - 35
Ca	**0.45 - 1.59**	**Cu**	**3 - 8**
Mg	0.13 - 0.34	Zn	21 - 41
S	**0.15 - 0.23**	**Mo**	**0.12 - 1.33**

Herbaceous Perennials

A

Scientific Name	*Herbaceous Perennial*		
Common Name	**General**		
Collected From	Container production nursery		
Plant Part	10-15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species averaged		
Macronutrients %		**Micronutrients ppm**	
N	1.85 - 4.58	Fe	25 - 617
P	**0.18 - 0.65**	**Mn**	**20 - 220**
K	1.50 - 4.00	B	10 - 32
Ca	**0.45 - 2.50**	**Cu**	**5 - 35**
Mg	0.35 - 1.05	Zn	6 - 185
S	**0.18 - 0.75**	**Mo**	**0.20 - 1.50**

B

Scientific Name	*Heuchera micrantha 'Palace Purple'*		
Common Name	**Palace Purple' Heuchera or Small-flower Alumroot**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Palace Purple'		
Macronutrients %		**Micronutrients ppm**	
N	1.46 - 1.77	Fe	35 - 77
P	**0.2 - 0.29**	**Mn**	**34 - 77**
K	1.49 - 2.88	B	22 - 47
Ca	**1.26 - 1.88**	**Cu**	**3 - 12**
Mg	0.32 - 0.45	Zn	20 - 34
S	**0.13 - 0.25**	**Mo**	**0.01 - 0.28**

C

Scientific Name	*Heuchera sanguinea*		
Common Name	**Coral Bells**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.26 - 1.45	Fe	30 - 53
P	**0.16 - 0.28**	**Mn**	**13 - 26**
K	1.09 - 1.28	B	21 - 39
Ca	**1.47 - 2.23**	**Cu**	**1 - 4**
Mg	0.20 - 0.29	Zn	15 - 32
S	**0.10 - 0.14**	**Mo**	**0.04 - 0.79**

D

Scientific Name	*Hibiscus coccineus*		
Common Name	**Swamp Hibiscus or Scarlet Mallow**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.44	Fe	45 - 157
P	**0.25 - 0.39**	**Mn**	**56 - 291**
K	2.16 - 2.90	B	22 - 33
Ca	**1.65 - 2.48**	**Cu**	**5 - 15**
Mg	0.4 - 0.97	Zn	34 - 75
S	**0.24 - 0.82**	**Mo**	**0.06 - 0.12**

E

Scientific Name	*Hosta decorata*		
Common Name	**Blunt-leaf Hosta**		
Collected From	Botanical garden/arboretum		
Plant Part	8 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.66 - 2.02	Fe	55 - 125
P	**0.26 - 0.72**	**Mn**	**32 - 72**
K	2.41 - 3.73	B	14 - 19
Ca	**0.55 - 1.63**	**Cu**	**5 - 15**
Mg	0.25 - 0.37	Zn	34 - 60
S	**0.21 - 0.30**	**Mo**	**0.07 - 0.12**

F

Scientific Name	*Hosta fortunei 'Aureomarginata'*		
Common Name	**Gold-margin Fortune's Hosta**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	5 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Aureomarginata'		
Macronutrients %		**Micronutrients ppm**	
N	1.47 - 2.54	Fe	73 - 263
P	**0.29 - 0.39**	**Mn**	**36 - 179**
K	1.88 - 4.46	B	13 - 17
Ca	**1.12 - 2.03**	**Cu**	**2 - 5**
Mg	0.11 - 0.29	Zn	19 - 23
S	**0.18 - 0.28**	**Mo**	**0.09 - 1.25**

Herbaceous Perennials

A

Scientific Name	*Hosta fortunei cultivars*
Common Name	**Fortune's Hosta**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Aoki', 'Hyacinthina'

Macronutrients %		Micronutrients ppm	
N	1.65 - 2.35	Fe	57 - 116
P	**0.34 - 0.37**	**Mn**	**34 - 101**
K	1.62 - 2.55	B	14 - 19
Ca	**1.13 - 2.01**	**Cu**	**2 - 4**
Mg	0.13 - 0.23	Zn	16 - 24
S	**0.17 - 0.23**	**Mo**	**0.12 - 1.01**

B

Scientific Name	*Hosta lancifolia*
Common Name	**Lance-leaf Hosta**
Collected From	Container production nursery
Plant Part	8 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.85 - 2.09	Fe	69 - 149
P	**0.29 - 0.39**	**Mn**	**91 - 157**
K	1.41 - 2.48	B	15 - 18
Ca	**1.04 - 1.86**	**Cu**	**2 - 4**
Mg	0.22 - 0.39	Zn	13 - 20
S	**0.21 - 0.25**	**Mo**	**0.15 - 0.88**

C

Scientific Name	*Hosta longissima*
Common Name	**Narrow-leaf Hosta**
Collected From	Container production nursery
Plant Part	8 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.45 - 1.90	Fe	55 - 183
P	**0.24 - 0.42**	**Mn**	**56 - 307**
K	1.68 - 2.04	B	15 - 25
Ca	**1.1 - 1.64**	**Cu**	**2 - 12**
Mg	0.24 - 0.45	Zn	22 - 30
S	**0.16 - 0.23**	**Mo**	**0.28 - 0.91**

D

Scientific Name	*Hosta plantaginea*
Common Name	**Fragrant or Plantain-leaf Hosta or Old August Lily**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Aphrodite'

Macronutrients %		Micronutrients ppm	
N	1.62 - 1.68	Fe	35 - 39
P	**0.31 - 0.46**	**Mn**	**40 - 48**
K	1.92 - 2.30	B	12 - 15
Ca	**0.54 - 0.59**	**Cu**	**2 - 4**
Mg	0.18 - 0.19	Zn	14 - 21
S	**0.14 - 0.20**	**Mo**	**0.15 - 0.65**

E

Scientific Name	*Hosta sieboldiana 'Elegans'*
Common Name	**Elegans' Siebold Hosta**
Collected From	Container production nursery
Plant Part	3 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Elegans'

Macronutrients %		Micronutrients ppm	
N	1.78 - 2.33	Fe	56 - 234
P	**0.21 - 0.33**	**Mn**	**33 - 107**
K	1.45 - 2.22	B	15 - 28
Ca	**1.18 - 1.88**	**Cu**	**2 - 14**
Mg	0.25 - 0.38	Zn	12 - 28
S	**0.19 - 0.27**	**Mo**	**0.12 - 0.28**

F

Scientific Name	*Hosta sieboldiana 'Frances Williams'*
Common Name	**Frances Williams' Siebold Hosta**
Collected From	Container production nursery
Plant Part	3 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Frances Williams'

Macronutrients %		Micronutrients ppm	
N	1.33 - 1.42	Fe	34 - 107
P	**0.19 - 0.24**	**Mn**	**45 - 104**
K	0.98 - 1.36	B	13 - 20
Ca	**0.3 - 1.26**	**Cu**	**2 - 9**
Mg	0.14 - 0.34	Zn	15 - 35
S	**0.16 - 0.24**	**Mo**	**0.14 - 0.37**

Herbaceous Perennials

A

Scientific Name	*Hosta sieboldiana 'Great Expectations'*		
Common Name	**Great Expectations' Siebold Hosta**		
Collected From	Container production nursery		
Plant Part	3 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Great Expectations'		
Macronutrients %		**Micronutrients ppm**	
N	1.55 - 2.23	Fe	31 - 51
P	**0.24 - 0.33**	**Mn**	**45 - 123**
K	1.87 - 2.44	B	15 - 25
Ca	**0.45 - 2.04**	**Cu**	**2 - 12**
Mg	0.24 - 0.34	Zn	22 - 32
S	**0.16 - 0.23**	**Mo**	**0.07 - 0.28**

B

Scientific Name	*Hosta sieboldii*		
Common Name	**Seersucker Hosta**		
Collected From	Container production nursery		
Plant Part	8 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 2.15	Fe	117 - 195
P	**0.26 - 0.31**	**Mn**	**101 - 176**
K	1.55 - 1.99	B	10 - 15
Ca	**0.82 - 1.14**	**Cu**	**3 - 10**
Mg	0.28 - 0.51	Zn	19 - 27
S	**0.17 - 0.22**	**Mo**	**0.19 - 1.19**

C

Scientific Name	*Hosta sieboldii 'Kabitan'*		
Common Name	**Kabitan' Seersucker Hosta**		
Collected From	Container production nursery		
Plant Part	8 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Kabitan'		
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.78	Fe	34 - 58
P	**0.27 - 0.54**	**Mn**	**44 - 57**
K	2.57 - 4.37	B	17 - 26
Ca	**0.43 - 0.72**	**Cu**	**2 - 12**
Mg	0.24 - 0.41	Zn	24 - 40
S	**0.2 - 0.34**	**Mo**	**0.04 - 0.12**

D

Scientific Name	*Hosta undulata*		
Common Name	**Wavy-leaf Hosta**		
Collected From	Container production nursery		
Plant Part	8 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.7 - 2.48	Fe	36 - 133
P	**0.24 - 0.37**	**Mn**	**55 - 97**
K	2.16 - 2.89	B	18 - 33
Ca	**0.88 - 1.25**	**Cu**	**4 - 8**
Mg	0.34 - 0.48	Zn	20 - 38
S	**0.15 - 0.24**	**Mo**	**0.4 - 1.06**

E

Scientific Name	*Hosta undulata 'Albomarginata'*		
Common Name	**White-margin Wavy-leaf Hosta**		
Collected From	Container production nursery		
Plant Part	8 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Albomarginata'		
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 2.73	Fe	35 - 74
P	**0.31 - 0.59**	**Mn**	**55 - 624**
K	0.72 - 2.78	B	19 - 30
Ca	**1.04 - 1.78**	**Cu**	**5 - 11**
Mg	0.28 - 0.37	Zn	32 - 58
S	**0.16 - 0.22**	**Mo**	**0.1 - 0.21**

F

Scientific Name	*Hosta undulata 'Erromena'*		
Common Name	**Green-leaf Wavy-leaf Hosta**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	8 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Erromena'		
Macronutrients %		**Micronutrients ppm**	
N	1.77 - 3.44	Fe	38 - 100
P	**0.26 - 0.38**	**Mn**	**133 - 441**
K	1.56 - 3.13	B	12 - 15
Ca	**0.49 - 1.87**	**Cu**	**2 - 10**
Mg	0.25 - 0.50	Zn	16 - 30
S	**0.21 - 0.40**	**Mo**	**0.12 - 0.90**

Herbaceous Perennials

A

Scientific Name	*Hosta undulata 'Mediopicta'*
Common Name	**Variegated Wavy-leaf Hosta**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	8 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Mediopicta'

Macronutrients %		Micronutrients ppm	
N	1.34 - 2.49	Fe	62 - 165
P	**0.25 - 0.31**	**Mn**	**40 - 229**
K	1.73 - 3.22	B	15 - 24
Ca	**1.15 - 1.70**	**Cu**	**2 - 11**
Mg	0.25 - 0.44	Zn	11 - 23
S	**0.23 - 0.38**	**Mo**	**0.15 - 1.12**

B

Scientific Name	*Hosta ventricosa*
Common Name	**Blue Hosta**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.5 - 1.92	Fe	32 - 46
P	**0.21 - 0.32**	**Mn**	**34 - 155**
K	1.77 - 2.42	B	13 - 23
Ca	**0.5 - 1.45**	**Cu**	**3 - 9**
Mg	0.18 - 0.34	Zn	15 - 31
S	**0.16 - 0.28**	**Mo**	**0.08 - 0.13**

C

Scientific Name	*Hosta x 'Antioch'*
Common Name	**Antioch' Hosta**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Antioch'

Macronutrients %		Micronutrients ppm	
N	1.33 - 2.36	Fe	34 - 116
P	**0.21 - 0.36**	**Mn**	**34 - 129**
K	1.56 - 2.27	B	13 - 15
Ca	**0.25 - 1.93**	**Cu**	**2 - 11**
Mg	0.26 - 0.4	Zn	23 - 35
S	**0.18 - 0.22**	**Mo**	**0.07 - 0.13**

D

Scientific Name	*Hosta x 'Bright Lights'*
Common Name	**Bright Lights' Hosta**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Bright Lights'

Macronutrients %		Micronutrients ppm	
N	1.25 - 1.79	Fe	55 - 77
P	**0.17 - 0.29**	**Mn**	**33 - 135**
K	1.88 - 2.86	B	16 - 26
Ca	**0.88 - 1.79**	**Cu**	**2 - 10**
Mg	0.13 - 0.28	Zn	16 - 22
S	**0.19 - 0.28**	**Mo**	**0.08 - 0.16**

E

Scientific Name	*Hosta x 'Gold Standard'*
Common Name	**Gold Standard' Hosta**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Gold Standard'

Macronutrients %		Micronutrients ppm	
N	1.55 - 2.43	Fe	44 - 141
P	**0.21 - 0.34**	**Mn**	**44 - 123**
K	1.33 - 2.48	B	14 - 21
Ca	**0.5 - 2.14**	**Cu**	**3 - 14**
Mg	0.22 - 36	Zn	19 - 36
S	**0.19 - 0.29**	**Mo**	**0.23 - 1.03**

F

Scientific Name	*Hosta x 'Ground Master'*
Common Name	**Ground Master' Hosta**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Ground Master'

Macronutrients %		Micronutrients ppm	
N	1.56 - 2.43	Fe	55 - 201
P	**0.23 - 0.37**	**Mn**	**44 - 53**
K	1.98 - 2.27	B	15 - 29
Ca	**0.56 - 1.60**	**Cu**	**3 - 9**
Mg	0.25 - 0.36	Zn	34 - 49
S	**0.19 - 0.29**	**Mo**	**0.12 - 0.89**

Herbaceous Perennials

A

SCIENTIFIC NAME	*Hosta x 'Honeybells'*
COMMON NAME	**Honeybells' Hosta**
COLLECTED FROM	Container production nursery
PLANT PART	5 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Honeybells'

Macronutrients %		Micronutrients ppm	
N	1.67 - 1.98	Fe	45 - 60
P	**0.19 - 0.30**	**Mn**	**45 - 72**
K	1.37 - 1.96	B	14 - 23
Ca	**0.55 - 1.02**	**Cu**	**2 - 7**
Mg	0.289 - 0.42	Zn	21 - 36
S	**0.15 - 0.27**	**Mo**	**0.05 - 0.9**

B

SCIENTIFIC NAME	*Hosta x 'Invincible'*
COMMON NAME	**Invincible' Hosta**
COLLECTED FROM	Container production nursery
PLANT PART	5 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Invincible'

Macronutrients %		Micronutrients ppm	
N	1.24 - 1.83	Fe	34 - 50
P	**0.25 - 0.47**	**Mn**	**34 - 72**
K	1.14 - 1.48	B	12 - 22
Ca	**0.45 - 1.39**	**Cu**	**3 - 16**
Mg	0.19 - 0.37	Zn	11 - 34
S	**0.19 - 0.25**	**Mo**	**0.07 - 0.14**

C

SCIENTIFIC NAME	*Hosta x 'Royal Standard'*
COMMON NAME	**Royal Standard' Hosta**
COLLECTED FROM	Container production nursery
PLANT PART	5 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Royal Standard'

Macronutrients %		Micronutrients ppm	
N	1.5 - 2.23	Fe	32 - 66
P	**0.18 - 0.24**	**Mn**	**46 - 103**
K	2.33 - 3.54	B	20 - 30
Ca	**1.21 - 2.13**	**Cu**	**4 - 12**
Mg	0.3 - 0.41	Zn	19 - 35
S	**0.17 - 0.27**	**Mo**	**0.12 - 0.3**

D

SCIENTIFIC NAME	*Hosta x (blue-leaf) cultivars*
COMMON NAME	**Blue-leaf Hostas**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	5 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Blue Cadet', 'Bressingham Blue', 'Love Pat'

Macronutrients %		Micronutrients ppm	
N	1.66 - 2.61	Fe	60 - 161
P	**0.25 - 0.30**	**Mn**	**65 - 220**
K	1.55 - 2.55	B	14 - 22
Ca	**0.87 - 1.61**	**Cu**	**4 - 14**
Mg	0.15 - 0.27	Zn	12 - 20
S	**0.21 - 0.35**	**Mo**	**0.01 - 0.12**

E

SCIENTIFIC NAME	*Hosta x (gold-leaf) cultivars*
COMMON NAME	**Gold-leaf Hostas**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	5 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	August Moon', 'Birchwood Parky's Gold', 'Bright Glow', 'Gold Edger', 'September Sun'

Macronutrients %		Micronutrients ppm	
N	1.67 - 2.74	Fe	48 - 266
P	**0.25 - 0.49**	**Mn**	**26 - 212**
K	2.13 - 3.61	B	13 - 19
Ca	**0.89 - 2.19**	**Cu**	**1 - 4**
Mg	0.12 - 0.31	Zn	14 - 33
S	**0.23 - 0.44**	**Mo**	**0.12 - 1.02**

F

SCIENTIFIC NAME	*Houttuynia cordata 'Chameleon'*
COMMON NAME	**Chameleon Plant**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Chameleon'

Macronutrients %		Micronutrients ppm	
N	1.98 - 2.57	Fe	46 - 103
P	**0.18 - 0.24**	**Mn**	**31 - 102**
K	2.45 - 4.81	B	17 - 39
Ca	**0.45 - 0.91**	**Cu**	**6 - 14**
Mg	0.18 - 0.28	Zn	22 - 34
S	**0.17 - 0.26**	**Mo**	**0.07 - 0.27**

Herbaceous Perennials

A

Scientific Name	*Iberis sempervirens*		
Common Name	**Candytuft**		
Collected From	Container production nursery		
Plant Part	20 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Alexander's White'		
Macronutrients %		**Micronutrients ppm**	
N	3.03 - 3.70	Fe	98 - 424
P	**0.43 - 0.50**	**Mn**	**60 - 113**
K	3.29 - 4.47	B	32 - 41
Ca	**0.92 - 1.08**	**Cu**	**6 - 10**
Mg	0.36 - 0.53	Zn	118 - 194
S	**0.16 - 0.29**	**Mo**	**0.12 - 0.29**

B

Scientific Name	*Ipomoea batatas*		
Common Name	**Purple-leaf Sweet Potato Vine-Ornamental**		
Collected From	Container production nursery		
Plant Part	15-20 most recently fully-developed leaves		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species adverage		
Macronutrients %		**Micronutrients ppm**	
N	3.30 - 4.5	Fe	40 - 100
P	**0.23 - 0.5**	**Mn**	**40 - 250**
K	3.10 - 4.5	B	25 - 75
Ca	**0.70 - 1.2**	**Cu**	**4 - 10**
Mg	0.35 - 1.0	Zn	20 - 50
S	**0.25 - 0.50**	**Mo**	**0.01 - 0.4**

C

Scientific Name	*Ipomoea batatas 'Blackie'*		
Common Name	**Purple-leaf Sweet Potato Vine**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Blackie'		
Macronutrients %		**Micronutrients ppm**	
N	3.33 - 4.23	Fe	38 - 111
P	**0.32 - 0.41**	**Mn**	**55 - 208**
K	2.85 - 6.33	B	22 - 51
Ca	**1.2 - 1.97**	**Cu**	**7 - 14**
Mg	0.33 - 0.63	Zn	22 - 38
S	**0.28 - 0.45**	**Mo**	**0.11 - 0.25**

D

Scientific Name	*Iris cristata*		
Common Name	**Crested Iris**		
Collected From	Botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.33 - 1.88	Fe	55 - 76
P	**0.17 - 0.23**	**Mn**	**45 - 289**
K	1.88 - 2.46	B	17 - 32
Ca	**0.97 - 1.22**	**Cu**	**5 - 10**
Mg	0.32 - 0.45	Zn	12 - 33
S	**0.17 - 0.27**	**Mo**	**0.09 - 0.12**

E

Scientific Name	*Iris ensata cultivars*		
Common Name	**Japanese Water Iris or Japanese Iris**		
Collected From	Container production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Anna', 'Kagari Bi', 'Nikiyama'		
Macronutrients %		**Micronutrients ppm**	
N	1.33 - 3.58	Fe	27 - 48
P	**0.33 - 0.58**	**Mn**	**228 - 501**
K	2.37 - 4.98	B	26 - 36
Ca	**0.66 - 2.00**	**Cu**	**2 - 9**
Mg	0.27 - 0.34	Zn	37 - 59
S	**0.13 - 0.36**	**Mo**	**0.12 - 1.06**

F

Scientific Name	*Iris hexagona*		
Common Name	**Dixie Iris**		
Collected From	Container production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 2.28	Fe	25 - 75
P	**0.26 - 0.47**	**Mn**	**45 - 147**
K	1.8 - 2.91	B	19 - 33
Ca	**0.55 - 1.45**	**Cu**	**2 - 9**
Mg	0.27 - 0.39	Zn	22 - 35
S	**0.19 - 0.28**	**Mo**	**0.12 - 0.32**

Herbaceous Perennials

A

Scientific Name	*Iris sibirica*
Common Name	**Siberian Iris**
Collected From	Botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.85 - 2.61	Fe	33 - 73
P	**0.17 - 0.29**	**Mn**	**39 - 89**
K	1.89 - 2.87	B	18 - 30
Ca	**1.07 - 1.89**	**Cu**	**5 - 14**
Mg	0.17 - 0.39	Zn	13 - 31
S	**0.17 - 0.26**	**Mo**	**0.02 - 0.4**

B

Scientific Name	*Iris tectorum*
Common Name	**Japanese Roof Iris**
Collected From	Container production nursery
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Alba'

Macronutrients %		Micronutrients ppm	
N	1.04 - 1.85	Fe	44 - 59
P	**0.56 - 0.60**	**Mn**	**81 - 139**
K	2.71 - 3.49	B	13 - 16
Ca	**1.22 - 1.42**	**Cu**	**1 - 12**
Mg	0.30 - 0.36	Zn	8 - 35
S	**0.10 - 0.25**	**Mo**	**0.08 - 0.12**

C

Scientific Name	*Iris x nelsonii*
Common Name	**Abbeville Red Louisiana Iris**
Collected From	Botanical garden/arboretum
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.5 - 1.95	Fe	35 - 80
P	**0.22 - 0.36**	**Mn**	**33 - 81**
K	1.44 - 2.39	B	18 - 31
Ca	**0.5 - 1.83**	**Cu**	**5 - 12**
Mg	0.22 - 0.35	Zn	23 - 38
S	**0.08 - 0.14**	**Mo**	**0.14 - 0.38**

D

Scientific Name	*Kirengeshoma palmata*
Common Name	**Yellow Waxbells**
Collected From	Container production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.35 - 3.45	Fe	41 - 129
P	**0.32 - 1.75**	**Mn**	**33 - 84**
K	2.41 - 3.44	B	23 - 41
Ca	**2.01 - 3.21**	**Cu**	**3 - 9**
Mg	0.38 - 0.71	Zn	18 - 38
S	**0.23 - 0.44**	**Mo**	**0.05 - 0.14**

E

Scientific Name	*Lablab purpureus*
Common Name	**Purple Hyacinth Bean**
Collected From	Botanical garden/arboretum
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.65 - 4.09	Fe	45 - 120
P	**0.24 - 0.36**	**Mn**	**42 - 144**
K	2.28 - 3.33	B	29 - 67
Ca	**1.75 - 3.13**	**Cu**	**6 - 11**
Mg	0.24 - 0.42	Zn	33 - 40
S	**0.16 - 0.23**	**Mo**	**1 - 5.09**

F

Scientific Name	*Lamium galeobdolon*
Common Name	**Yellow Archangel**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Herman's Pride'

Macronutrients %		Micronutrients ppm	
N	3.27 - 3.76	Fe	70 - 117
P	**0.23 - 1.00**	**Mn**	**98 - 225**
K	3.97 - 4.11	B	27 - 58
Ca	**1.21 - 2.13**	**Cu**	**5 - 9**
Mg	0.48 - 0.67	Zn	21 - 24
S	**0.21 - 0.53**	**Mo**	**0.12 - 0.15**

Herbaceous Perennials

A

Scientific Name			*Lathyrus latifolius*
Common Name			**Perennial Sweet Pea or Everlasting Pea**
Collected From			Container production nursery
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.78 - 4.07	Fe	34 - 85
P	**0.22 - 0.72**	**Mn**	**42 - 116**
K	2.25 - 3.09	B	18 - 29
Ca	**0.97 - 1.88**	**Cu**	**5 - 12**
Mg	0.33 - 0.41	Zn	34 - 63
S	**0.21 - 0.33**	**Mo**	**0.21 - 0.57**

B

Scientific Name			*Lavandula x intermedia*
Common Name			**Lavandine**
Collected From			Container production nursery
Plant Part			20 2-3' terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 2.44	Fe	46 - 79
P	**0.19 - 0.36**	**Mn**	**30 - 79**
K	1.78 - 2.97	B	15 - 26
Ca	**0.45 - 0.80**	**Cu**	**5 - 10**
Mg	0.28 - 0.42	Zn	39 - 58
S	**0.21 - 0.32**	**Mo**	**0.05 - 0.12**

C

Scientific Name			*Leucanthemum vulgare*
Common Name			**Ox-eye Daisy**
Collected From			Container production nursery
Plant Part			35 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.23 - 3.90	Fe	36 - 89
P	**0.21 - 0.50**	**Mn**	**55 - 71**
K	1.89 - 3.66	B	18 - 28
Ca	**0.59 - 1.35**	**Cu**	**6 - 14**
Mg	0.28 - 0.42	Zn	36 - 69
S	**0.2 - 0.34**	**Mo**	**0.11 - 0.42**

D

Scientific Name			*Liatris spicata*
Common Name			**Spiked Blazing Star or Gayfeather**
Collected From			Experimental test plots
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.70 - 3.30	Fe	47 - 207
P	**0.19 - 0.20**	**Mn**	**163 - 178**
K	1.16 - 2.31	B	24 - 31
Ca	**1.12 - 1.49**	**Cu**	**5 - 15**
Mg	0.41 - 0.45	Zn	86 - 94
S	**0.18 - 0.29**	**Mo**	**0.1 - 0.3**

E

Scientific Name			*Ligularia dentata*
Common Name			**Bigleaf Ligularia**
Collected From			Botanical garden/arboretum
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Desdemona'
Macronutrients %		**Micronutrients ppm**	
N	1.44 - 2.04	Fe	43 - 132
P	**0.23 - 0.50**	**Mn**	**35 - 239**
K	2.12 - 3.25	B	25 - 59
Ca	**0.32 - 1.88**	**Cu**	**6 - 29**
Mg	0.32 - 0.83	Zn	24 - 183
S	**0.22 - 0.34**	**Mo**	**0.07 - 0.22**

F

Scientific Name			*Limonium altaica*
Common Name			**Altaica Statice**
Collected From			Experimental test plot
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 3.85	Fe	44 - 129
P	**0.19 - 0.40**	**Mn**	**31 - 47**
K	1.98 - 3.60	B	15 - 22
Ca	**0.48 - 1.37**	**Cu**	**5 - 15**
Mg	0.28 - 0.40	Zn	51 - 94
S	**0.19 - 0.26**	**Mo**	**0.08 - 0.3**

Herbaceous Perennials

A

SCIENTIFIC NAME			*Limonium perezii*
COMMON NAME			**Perez or Seafoam Statice**
COLLECTED FROM			Experimental test plot
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	3.18 - 3.38	Fe	86 - 123
P	**0.33 - 0.52**	**Mn**	**77 - 79**
K	2.20 - 2.33	B	17 - 28
Ca	**0.49 - 0.72**	**Cu**	**5 - 15**
Mg	0.54 - 0.56	Zn	102 - 260
S	**0.18 - 0.26**	**Mo**	**0.1 - 0.3**

B

SCIENTIFIC NAME			*Lobelia cardinalis*
COMMON NAME			**Cardinal Flower**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.87 - 2.70	Fe	55 - 92
P	**0.3 - 0.43**	**Mn**	**35 - 75**
K	2 - 2.98	B	14 - 36
Ca	**0.6 - 1.49**	**Cu**	**5 - 16**
Mg	0.31 - 0.40	Zn	22 - 57
S	**0.23 - 0.35**	**Mo**	**0.12 - 0.23**

C

SCIENTIFIC NAME			*Lobelia siphilitica*
COMMON NAME			**Big Blue Lobelia**
COLLECTED FROM			Container production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	0.89 - 3.17	Fe	33 - 47
P	**0.24 - 0.43**	**Mn**	**31 - 85**
K	2.24 - 3.56	B	15 - 29
Ca	**0.33 - 0.88**	**Cu**	**5 - 10**
Mg	0.15 - 0.34	Zn	21 - 46
S	**0.16 - 0.24**	**Mo**	**0.22 - 0.49**

D

SCIENTIFIC NAME			*Lychnis coronaria*
COMMON NAME			**Rose Campion**
COLLECTED FROM			Container production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.9 - 4.07	Fe	33 - 73
P	**0.32 - 0.45**	**Mn**	**42 - 106**
K	2.98 - 5.52	B	18 - 29
Ca	**0.83 - 1.65**	**Cu**	**5 - 17**
Mg	0.3 - 0.42	Zn	35 - 44
S	**0.19 - 0.33**	**Mo**	**0.4 - 1.59**

E

SCIENTIFIC NAME			*Lysimachia clethroides*
COMMON NAME			**Gooseneck Loosestrife**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	0.99 - 2.33	Fe	26 - 56
P	**0.14 - 0.25**	**Mn**	**12 - 24**
K	2.34 - 3.72	B	14 - 19
Ca	**0.6 - 1.71**	**Cu**	**1 - 9**
Mg	0.23 - 0.28	Zn	21 - 36
S	**0.19 - 0.28**	**Mo**	**0.12 - 0.8**

F

SCIENTIFIC NAME			*Lysimachia congestiflora*
COMMON NAME			**Creeping Loosestrife**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			20 2-3" cuttings
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Eco Dark Stain'
Macronutrients %		**Micronutrients ppm**	
N	1.65 - 2.92	Fe	54 - 164
P	**0.33 - 0.52**	**Mn**	**45 - 83**
K	2.54 - 5.71	B	22 - 43
Ca	**0.98 - 1.14**	**Cu**	**5 - 12**
Mg	0.33 - 0.54	Zn	21 - 26
S	**0.18 - 0.26**	**Mo**	**0.2 - 1.70**

Herbaceous Perennials

A

Scientific Name	*Lysimachia nummularia 'Aurea'*
Common Name	**Gold-leaf Creeping Jenny**
Collected From	Container production nursery
Plant Part	30 2-3" cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Aurea'

Macronutrients %		Micronutrients ppm	
N	1.98 - 3.61	Fe	33 - 59
P	**0.23 - 0.53**	**Mn**	**35 - 123**
K	2.33 - 4.19	B	16 - 26
Ca	**0.3 - 0.53**	**Cu**	**5 - 9**
Mg	0.28 - 0.43	Zn	29 - 36
S	**0.23 - 0.46**	**Mo**	**0.07 - 0.36**

B

Scientific Name	*Lythrum salicaria*
Common Name	**Purple or Spiked Loosestrife**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Morden Pink'

Macronutrients %		Micronutrients ppm	
N	3.12 - 5.68	Fe	35 - 158
P	**0.35 - 1.05**	**Mn**	**55 - 256**
K	2.25 - 3.00	B	16 - 29
Ca	**1.05 - 1.79**	**Cu**	**8 - 18**
Mg	0.31 - 0.42	Zn	42 - 260
S	**0.27 - 0.56**	**Mo**	**0.5 - 1.76**

C

Scientific Name	*Lythrum virgatum*
Common Name	**Smooth Loosestrife**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Morden Pink'

Macronutrients %		Micronutrients ppm	
N	2.94 - 5.42	Fe	44 - 169
P	**0.36 - 1.01**	**Mn**	**55 - 263**
K	2.24 - 3.28	B	21 - 33
Ca	**1.12 - 1.99**	**Cu**	**5 - 17**
Mg	0.34 - 0.42	Zn	44 - 173
S	**0.25 - 0.53**	**Mo**	**0.45 - 1.84**

D

Scientific Name	*Macleaya microcarpa*
Common Name	**Plume Poppy**
Collected From	Botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.45 - 2.44	Fe	34 - 111
P	**0.21 - 0.29**	**Mn**	**67 - 100**
K	2.18 - 3.21	B	25 - 51
Ca	**1.23 - 2.28**	**Cu**	**5 - 18**
Mg	0.34 - 0.4	Zn	24 - 34
S	**0.26 - 0.44**	**Mo**	**0.09 - 0.2**

E

Scientific Name	*Mertensia virginica*
Common Name	**Virginia Bluebells**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.21 - 3.43	Fe	34 - 80
P	**0.21 - 0.39**	**Mn**	**40 - 66**
K	2.65 - 3.78	B	18 - 30
Ca	**0.96 - 1.54**	**Cu**	**5 - 16**
Mg	0.21 - 0.41	Zn	26 - 43
S	**0.18 - 0.25**	**Mo**	**0.1 - 0.4**

F

Scientific Name	*Nipponanthemum nipponicum*
Common Name	**Nippon Daisy**
Collected From	Container production nursery
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.68 - 2.60	Fe	35 - 88
P	**0.23 - 0.53**	**Mn**	**44 - 72**
K	2.33 - 3.48	B	21 - 34
Ca	**1.01 - 1.78**	**Cu**	**6 - 18**
Mg	0.08 - 0.38	Zn	24 - 34
S	**0.15 - 0.23**	**Mo**	**0.33 - 1.11**

Herbaceous Perennials

A

SCIENTIFIC NAME	*Oenothera speciosa*
COMMON NAME	**Showy Evening Primrose**
COLLECTED FROM	Container production nursery
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.23 - 2.98	Fe	33 - 276
P	**0.29 - 0.39**	**Mn**	**44 - 281**
K	2.25 - 2.88	B	19 - 29
Ca	**1.35 - 2.20**	**Cu**	**6 - 17**
Mg	0.34 - 0.64	Zn	22 - 39
S	**0.23 - 0.50**	**Mo**	**0.23 - 1.95**

B

SCIENTIFIC NAME	*Ornithogalum arabicum*
COMMON NAME	**Star-of-Bethlehem or Arabian Star Flower**
COLLECTED FROM	Experimental test plots
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.85 - 2.32	Fe	34 - 82
P	**0.19 - 0.25**	**Mn**	**10 - 88**
K	2.39 - 3.59	B	22 - 34
Ca	**1.66 - 2.08**	**Cu**	**6 - 14**
Mg	0.3 - 0.39	Zn	28 - 37
S	**0.19 - 0.26**	**Mo**	**0.19 - 0.3**

C

SCIENTIFIC NAME	*Phlox glaberrima ssp. triflora*
COMMON NAME	**Smooth Phlox**
COLLECTED FROM	Container production nursery
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	ssp. triflora only

Macronutrients %		Micronutrients ppm	
N	1.67 - 2.97	Fe	39 - 83
P	**0.15 - 0.22**	**Mn**	**44 - 61**
K	1.48 - 3.01	B	22 - 39
Ca	**0.87 - 1.76**	**Cu**	**2 - 9**
Mg	0.26 - 0.36	Zn	22 - 42
S	**0.12 - 0.22**	**Mo**	**0.09 - 0.11**

D

SCIENTIFIC NAME	*Phlox maculata*
COMMON NAME	**Spotted Phlox or Wild Sweet William**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Rosalinde'

Macronutrients %		Micronutrients ppm	
N	2.7 - 3.31	Fe	42 - 259
P	**0.21 - 0.51**	**Mn**	**44 - 127**
K	1.76 - 2.64	B	23 - 36
Ca	**0 - 2.17**	**Cu**	**5 - 14**
Mg	0.35 - 0.55	Zn	33 - 103
S	**0.21 - 0.44**	**Mo**	**0.14 - 0.55**

E

SCIENTIFIC NAME	*Phlox paniculata*
COMMON NAME	**Garden Phlox**
COLLECTED FROM	Container production nursery
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'David', 'Fujiyama', 'Purple Puff'

Macronutrients %		Micronutrients ppm	
N	3.38 - 3.85	Fe	49 - 142
P	**0.41 - 0.54**	**Mn**	**72 - 150**
K	2.41 - 2.86	B	28 - 39
Ca	**1.41 - 2.35**	**Cu**	**4 - 10**
Mg	0.22 - 0.57	Zn	71 - 81
S	**0.18 - 0.30**	**Mo**	**0.59 - 1.16**

F

SCIENTIFIC NAME	*Phlox subulata*
COMMON NAME	**Moss Phlox or Thrift**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.55 - 1.93	Fe	35 - 59
P	**0.22 - 0.32**	**Mn**	**44 - 75**
K	1.55 - 1.61	B	17 - 28
Ca	**1 - 1.25**	**Cu**	**5 - 15**
Mg	0.16 - 0.45	Zn	25 - 83
S	**0.14 - 0.24**	**Mo**	**0.02 - 0.11**

Herbaceous Perennials

A

Scientific Name	*Physostegia virginiana*
Common Name	**Obedient Plant or False Dragonhead**
Collected From	Experimental test plots
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Alba'

Macronutrients %		Micronutrients ppm	
N	2.2 - 2.72	Fe	44 - 242
P	**0.23 - 0.32**	**Mn**	**45 - 66**
K	1.25 - 3.1	B	19 - 27
Ca	**1 - 1.87**	**Cu**	**5 - 16**
Mg	0.3 - 0.37	Zn	34 - 198
S	**0.17 - 0.25**	**Mo**	**0.09 - 0.43**

B

Scientific Name	*Platycodon grandiflorus*
Common Name	**Balloonflower**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Fuji Blue'

Macronutrients %		Micronutrients ppm	
N	1.01 - 3.72	Fe	55 - 363
P	**0.25 - 0.64**	**Mn**	**32 - 137**
K	2.11 - 4.12	B	18 - 29
Ca	**0.45 - 1.09**	**Cu**	**5 - 15**
Mg	0.24 - 0.32	Zn	22 - 141
S	**0.18 - 0.28**	**Mo**	**0.1 - 0.34**

C

Scientific Name	*Platycodon grandiflorus var. mariesii*
Common Name	**Dwarf Balloonflower**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	var. mariesii only

Macronutrients %		Micronutrients ppm	
N	1.88 - 2.69	Fe	55 - 176
P	**0.17 - 0.21**	**Mn**	**38 - 118**
K	1.88 - 2.40	B	21 - 38
Ca	**1.12 - 1.66**	**Cu**	**9 - 24**
Mg	0.26 - 0.39	Zn	33 - 96
S	**0.17 - 0.29**	**Mo**	**0.9 - 0.24**

D

Scientific Name	*Prunella grandiflora*
Common Name	**Self-heal**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.69 - 3.85	Fe	42 - 230
P	**0.32 - 0.57**	**Mn**	**63 - 107**
K	2.39 - 5.14	B	18 - 32
Ca	**0.57 - 1.49**	**Cu**	**3 - 14**
Mg	0.35 - 0.43	Zn	33 - 80
S	**0.19 - 0.34**	**Mo**	**0.09 - 0.12**

E

Scientific Name	*Pulmonaria longifolia 'Bertram Anderson'*
Common Name	**Bertram Anderson' Lungwort**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Bertram Anderson'

Macronutrients %		Micronutrients ppm	
N	1.33 - 2.52	Fe	44 - 85
P	**0.25 - 1.20**	**Mn**	**41 - 159**
K	2.23 - 5.12	B	22 - 36
Ca	**0.44 - 1.82**	**Cu**	**3 - 8**
Mg	0.18 - 0.33	Zn	21 - 40
S	**0.19 - 0.24**	**Mo**	**0.21 - 0.59**

F

Scientific Name	*Pulmonaria saccharata 'Mrs. Moon'*
Common Name	**Mrs. Moon' Lungwort or Bethelehem Sage**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Mrs. Moon'

Macronutrients %		Micronutrients ppm	
N	1.78 - 2.61	Fe	34 - 63
P	**0.21 - 1.64**	**Mn**	**55 - 113**
K	2.25 - 5.43	B	24 - 43
Ca	**1.01 - 1.65**	**Cu**	**8 - 16**
Mg	0.27 - 0.55	Zn	34 - 76
S	**0.18 - 0.29**	**Mo**	**0.25 - 1.49**

Herbaceous Perennials

A

SCIENTIFIC NAME	*Pulsatilla vulgaris*
COMMON NAME	**Pasque Flower**
COLLECTED FROM	Container production nursery
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.12 - 2.43	Fe	41 - 98
P	**0.21 - 0.31**	**Mn**	**54 - 85**
K	2.25 - 2.85	B	18 - 28
Ca	**1 - 2.01**	**Cu**	**5 - 10**
Mg	0.32 - 0.41	Zn	34 - 111
S	**0.18 - 0.25**	**Mo**	**0.14 - 0.29**

B

SCIENTIFIC NAME	*Pycnanthemum incanum*
COMMON NAME	**Mountain Mint**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	35 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.58 - 2.24	Fe	35 - 67
P	**0.18 - 0.22**	**Mn**	**45 - 111**
K	1.45 - 2.16	B	21 - 35
Ca	**1.11 - 1.89**	**Cu**	**6 - 14**
Mg	0.36 - 0.56	Zn	33 - 63
S	**0.21 - 0.36**	**Mo**	**0.11 - 0.19**

C

SCIENTIFIC NAME	*Ranunculus repens 'Flore Pleno'*
COMMON NAME	**Butter Daisy or Creeping Buttercup**
COLLECTED FROM	Container production nursery
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Flore Pleno'

Macronutrients %		Micronutrients ppm	
N	2.40 - 4.00	Fe	75 - 120
P	**0.25 - 0.35**	**Mn**	**40 - 175**
K	2.00 - 3.85	B	20 - 35
Ca	**0.85 - 2.50**	**Cu**	**8 - 15**
Mg	0.33 - 0.88	Zn	35 - 60
S	**0.24 - 0.40**	**Mo**	**0.15 - 1.00**

D

SCIENTIFIC NAME	*Rohdea japonica*
COMMON NAME	**Sacred Lily-of-China or Nippon Lily**
COLLECTED FROM	Container production nursery
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.69 - 2.49	Fe	38 - 83
P	**0.21 - 0.32**	**Mn**	**56 - 145**
K	1.45 - 2.79	B	18 - 33
Ca	**0.83 - 1.57**	**Cu**	**3 - 12**
Mg	0.21 - 0.34	Zn	28 - 40
S	**0.2 - 0.28**	**Mo**	**0.08 - 0.21**

E

SCIENTIFIC NAME	*Rudbeckia fulgida var. sullivantii 'Goldsturm'*
COMMON NAME	**Goldsturm' Orange Coneflower**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Goldsturm'

Macronutrients %		Micronutrients ppm	
N	1.88 - 2.41	Fe	34 - 78
P	**0.17 - 0.25**	**Mn**	**34 - 145**
K	1.78 - 2.11	B	19 - 66
Ca	**0.6 - 3.26**	**Cu**	**4 - 14**
Mg	0.33 - 0.69	Zn	29 - 60
S	**0.22 - 0.81**	**Mo**	**0.12 - 0.7**

F

SCIENTIFIC NAME	*Rudbeckia laciniata*
COMMON NAME	**Cut-leaf Coneflower**
COLLECTED FROM	Container production nursery
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.56 - 2.77	Fe	55 - 77
P	**0.19 - 0.31**	**Mn**	**55 - 227**
K	1.78 - 2.84	B	15 - 69
Ca	**1.19 - 1.70**	**Cu**	**4 - 14**
Mg	0.29 - 0.51	Zn	32 - 52
S	**0.21 - 0.62**	**Mo**	**0.08 - 0.11**

Herbaceous Perennials

A

Scientific Name	*Salvia leucantha*
Common Name	**Mexican Bush Sage**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.75 - 4.64	Fe	44 - 260
P	**0.24 - 0.71**	**Mn**	**55 - 349**
K	1.57 - 3.34	B	20 - 47
Ca	**1.25 - 2.46**	**Cu**	**5 - 10**
Mg	0.33 - 0.63	Zn	23 - 62
S	**0.18 - 0.28**	**Mo**	**0.2 - 1.59**

B

Scientific Name	*Salvia nemorosa 'East Friesland'*
Common Name	**East Friesland' Salvia**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'East Friesland'

Macronutrients %		Micronutrients ppm	
N	2.21 - 3.92	Fe	56 - 123
P	**0.18 - 0.21**	**Mn**	**45 - 199**
K	1.99 - 3.72	B	23 - 41
Ca	**1.07 - 1.40**	**Cu**	**9 - 35**
Mg	0.33 - 0.46	Zn	34 - 129
S	**0.18 - 0.28**	**Mo**	**0.2 - 1.81**

C

Scientific Name	*Salvia officinalis 'Aurea'*
Common Name	**Golden Sage**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Aurea'

Macronutrients %		Micronutrients ppm	
N	2.70 - 3.42	Fe	104 - 121
P	**0.31 - 0.44**	**Mn**	**36 - 63**
K	2.88 - 4.47	B	29 - 38
Ca	**0.48 - 0.65**	**Cu**	**7 - 21**
Mg	0.27 - 0.44	Zn	72 - 139
S	**0.25 - 0.32**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Salvia officinalis 'Tricolor'*
Common Name	**Tricolor' Sage**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Tricolor'

Macronutrients %		Micronutrients ppm	
N	2.3 - 4.23	Fe	32 - 88
P	**0.23 - 0.46**	**Mn**	**46 - 107**
K	2.39 - 4.62	B	21 - 40
Ca	**0.89 - 1.45**	**Cu**	**5 - 16**
Mg	0.35 - 0.48	Zn	46 - 175
S	**0.23 - 0.46**	**Mo**	**0.09 - 0.12**

E

Scientific Name	*Saxifraga stolonifera*
Common Name	**Strawberry Begonia or Strawberry Geranium**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Fred Galle'

Macronutrients %		Micronutrients ppm	
N	2.05 - 3.70	Fe	74 - 177
P	**0.59 - 1.13**	**Mn**	**19 - 34**
K	2.17 - 2.68	B	14 - 29
Ca	**1.75 - 3.65**	**Cu**	**3 - 10**
Mg	0.45 - 0.66	Zn	33 - 108
S	**0.10 - 0.14**	**Mo**	**0.08 - 0.12**

F

Scientific Name	*Scabiosa caucasica*
Common Name	**Perennial Scabious**
Collected From	Experimental test plots
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Fama'

Macronutrients %		Micronutrients ppm	
N	2.25 - 2.81	Fe	43 - 400
P	**0.22 - 0.31**	**Mn**	**44 - 116**
K	2.11 - 2.98	B	22 - 27
Ca	**0.65 - 1.11**	**Cu**	**6 - 15**
Mg	0.36 - 0.48	Zn	19 - 37
S	**0.17 - 0.23**	**Mo**	**0.1 - 0.33**

Herbaceous Perennials

A

SCIENTIFIC NAME	*Sedum kamtschaticum*
COMMON NAME	**Kamschatka Stonecrop**
COLLECTED FROM	Container production nursery
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.3 - 3.54	Fe	65 - 114
P	**0.22 - 0.47**	**Mn**	**34 - 138**
K	1.65 - 2.3	B	19 - 28
Ca	**0.65 - 1.84**	**Cu**	**5 - 15**
Mg	0.28 - 0.62	Zn	34 - 119
S	**0.23 - 0.38**	**Mo**	**0.08 - 0.32**

B

SCIENTIFIC NAME	*Sedum pilosum*
COMMON NAME	**Caucasian Stonecrop**
COLLECTED FROM	Container production nursery
PLANT PART	35 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.98 - 2.90	Fe	43 - 72
P	**0.25 - 0.48**	**Mn**	**33 - 101**
K	2.11 - 3.31	B	11 - 18
Ca	**1.04 - 3.38**	**Cu**	**5 - 10**
Mg	0.33 - 0.52	Zn	28 - 78
S	**0.19 - 0.22**	**Mo**	**0.14 - 0.63**

C

SCIENTIFIC NAME	*Sedum reflexum*
COMMON NAME	**Stone Orpine**
COLLECTED FROM	Container production nursery
PLANT PART	35 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.46 - 3.72	Fe	37 - 95
P	**0.26 - 0.51**	**Mn**	**27 - 87**
K	2.25 - 4.95	B	21 - 42
Ca	**1.78 - 2.46**	**Cu**	**7 - 16**
Mg	0.36 - 0.52	Zn	44 - 184
S	**0.25 - 0.55**	**Mo**	**0.11 - 0.28**

D

SCIENTIFIC NAME	*Sedum sarmentosum*
COMMON NAME	**Japanese Stonecrop**
COLLECTED FROM	Container production nursery
PLANT PART	35 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.4 - 4.08	Fe	55 - 221
P	**0.28 - 0.71**	**Mn**	**34 - 102**
K	2.28 - 4.90	B	17 - 27
Ca	**1.04 - 2.14**	**Cu**	**6 - 18**
Mg	0.33 - 0.62	Zn	34 - 191
S	**0.22 - 0.50**	**Mo**	**0.04 - 0.12**

E

SCIENTIFIC NAME	*Sedum sieboldii 'Mediovariegatum'*
COMMON NAME	**Variegated October Daphne or October Plant**
COLLECTED FROM	Container production nursery
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Mediovariegatum'

Macronutrients %		Micronutrients ppm	
N	2.59 - 4.54	Fe	33 - 76
P	**0.33 - 0.84**	**Mn**	**44 - 78**
K	2.31 - 3.57	B	20 - 31
Ca	**2.22 - 5.84**	**Cu**	**6 - 13**
Mg	0.3 - 0.46	Zn	47 - 115
S	**0.23 - 0.46**	**Mo**	**0.23 - 0.76**

F

SCIENTIFIC NAME	*Sedum spectabile*
COMMON NAME	**Showy Stonecrop**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Brillant'

Macronutrients %		Micronutrients ppm	
N	0.87 - 4.09	Fe	58 - 69
P	**0.38 - 0.69**	**Mn**	**63 - 99**
K	1.31 - 3.22	B	19 - 27
Ca	**1.43 - 2.66**	**Cu**	**6 - 10**
Mg	0.24 - 0.67	Zn	47 - 119
S	**0.16 - 0.32**	**Mo**	**0.12 - 0.30**

Herbaceous Perennials

A

Scientific Name	*Sedum x 'Autumn Joy'*
Common Name	**Autumn Joy' Sedum or Stonecrop**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Autumn Joy'

Macronutrients %		Micronutrients ppm	
N	1.78 - 2.48	Fe	33 - 201
P	**0.29 - 0.43**	**Mn**	**51 - 94**
K	1.80 - 3.00	B	24 - 31
Ca	**2.75 - 3.07**	**Cu**	**6 - 9**
Mg	0.43 - 0.45	Zn	51 - 94
S	**0.12 - 0.31**	**Mo**	**0.12 - 1.60**

B

Scientific Name	*Sempervivum tectorum*
Common Name	**Common Houseleek**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2 - 2.67	Fe	37 - 100
P	**0.27 - 0.50**	**Mn**	**30 - 67**
K	2 - 3.02	B	19 - 29
Ca	**1.25 - 3.35**	**Cu**	**5 - 10**
Mg	0.33 - 0.42	Zn	31 - 71
S	**0.18 - 0.37**	**Mo**	**0.2 - 0.74**

C

Scientific Name	*Senecio aureus*
Common Name	**Golden Ragwort**
Collected From	Botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.45 - 2.07	Fe	36 - 106
P	**0.19 - 0.28**	**Mn**	**55 - 125**
K	2.35 - 3.96	B	16 - 41
Ca	**0.5 - 1.53**	**Cu**	**5 - 16**
Mg	0.33 - 0.41	Zn	22 - 31
S	**0.22 - 0.31**	**Mo**	**0.09 - 0.16**

D

Scientific Name	*Silphium dentatum*
Common Name	**Rosinweed**
Collected From	Container production nursery
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.85 - 2.43	Fe	36 - 58
P	**0.17 - 0.23**	**Mn**	**44 - 119**
K	1.82 - 2.69	B	30 - 70
Ca	**1.77 - 2.26**	**Cu**	**3 - 13**
Mg	0.36 - 0.56	Zn	26 - 38
S	**0.18 - 0.27**	**Mo**	**0.06 - 0.12**

E

Scientific Name	*Sisyrinchium montanum*
Common Name	**Blue-eyed Grass**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.89 - 2.42	Fe	36 - 122
P	**0.22 - 0.32**	**Mn**	**31 - 44**
K	2.11 - 3.27	B	15 - 22
Ca	**0.35 - 0.77**	**Cu**	**5 - 15**
Mg	0.23 - 0.38	Zn	20 - 41
S	**0.19 - 0.28**	**Mo**	**0.09 - 0.37**

F

Scientific Name	*Smilacina racemosa*
Common Name	**False Solomon's Seal**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.67 - 2.37	Fe	55 - 145
P	**0.22 - 0.34**	**Mn**	**44 - 228**
K	2.5 - 3.16	B	10 - 23
Ca	**1.14 - 1.55**	**Cu**	**5 - 15**
Mg	0.31 - 0.39	Zn	12 - 31
S	**0.18 - 0.22**	**Mo**	**0.09 - 0.12**

Herbaceous Perennials

A

SCIENTIFIC NAME	*Solidago x 'Crown of Rays' and Solidaster x 'Super'*
COMMON NAME	**Goldenrods**
COLLECTED FROM	Experimental test plots
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Crown of Rays' (or 'Strahlenkrone'), 'Super'

Macronutrients %		Micronutrients ppm	
N	2.70 - 3.60	Fe	200 - 202
P	**0.27 - 0.46**	**Mn**	**115 - 282**
K	3.82 - 4.71	B	24 - 30
Ca	**0.87 - 1.23**	**Cu**	**6 - 16**
Mg	0.30 - 0.43	Zn	25 - 68
S	**0.2 - 0.28**	**Mo**	**0.09 - 0.22**

B

SCIENTIFIC NAME	*Spigelia marilandica*
COMMON NAME	**Indian Pink or Pinkroot**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	35 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.20 - 2.62	Fe	88 - 128
P	**0.20 - 0.51**	**Mn**	**188 - 394**
K	2.50 - 3.01	B	31 - 49
Ca	**1.07 - 2.00**	**Cu**	**4 - 24**
Mg	0.57 - 1.43	Zn	26 - 46
S	**0.27 - 0.30**	**Mo**	**0.17 - 0.20**

C

SCIENTIFIC NAME	*Stachys byzantina*
COMMON NAME	**Lamb's Ears**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.46 - 5.41	Fe	108 - 139
P	**0.30 - 0.39**	**Mn**	**88 - 271**
K	2.37 - 3.38	B	14 - 26
Ca	**0.46 - 0.68**	**Cu**	**2 - 6**
Mg	0.28 - 0.31	Zn	37 - 42
S	**0.18 - 0.36**	**Mo**	**0.12 - 0.30**

D

SCIENTIFIC NAME	*Stokesia laevis*
COMMON NAME	**Stokes' Aster**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.92 - 2.45	Fe	33 - 104
P	**0.18 - 0.289**	**Mn**	**55 - 506**
K	2.4 - 3.37	B	23 - 51
Ca	**1.21 - 1.45**	**Cu**	**5 - 14**
Mg	0.31 - 0.44	Zn	32 - 152
S	**0.2 - 0.28**	**Mo**	**0.07 - 0.12**

E

SCIENTIFIC NAME	*Stylophorum diphyllum*
COMMON NAME	**Celandine Poppy**
COLLECTED FROM	Container production nursery
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.33 - 3.71	Fe	44 - 81
P	**0.34 - 0.79**	**Mn**	**34 - 241**
K	2.34 - 4.05	B	11 - 22
Ca	**0.65 - 1.40**	**Cu**	**5 - 15**
Mg	0.24 - 0.33	Zn	26 - 43
S	**0.15 - 0.22**	**Mo**	**0.2 - 0.98**

F

SCIENTIFIC NAME	*Teucrium chamaedrys*
COMMON NAME	**Wall Germander**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.72 - 2.91	Fe	35 - 48
P	**0.16 - 0.34**	**Mn**	**92 - 147**
K	1.71 - 2.83	B	26 - 38
Ca	**0.29 - 0.69**	**Cu**	**5 - 16**
Mg	0.05 - 0.14	Zn	34 - 103
S	**0.15 - 0.26**	**Mo**	**0.75 - 1.17**

Herbaceous Perennials

A

Scientific Name	*Thalictrum aquilegiifolium*
Common Name	**Columbine Meadow-rue**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.78 - 2.94	Fe	44 - 76
P	**0.33 - 0.53**	**Mn**	**24 - 33**
K	1.97 - 3.21	B	16 - 36
Ca	**0.88 - 1.50**	**Cu**	**4 - 10**
Mg	0.27 - 0.37	Zn	22 - 29
S	**0.17 - 0.22**	**Mo**	**0.09 - 0.22**

B

Scientific Name	*Thalictrum flavum ssp. glaucum*
Common Name	**Dusty Meadow-rue**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	ssp. glaucum only

Macronutrients %		Micronutrients ppm	
N	3.12 - 4.27	Fe	38 - 54
P	**0.44 - 0.82**	**Mn**	**37 - 48**
K	2.28 - 3.21	B	25 - 31
Ca	**0.75 - 1.60**	**Cu**	**4 - 8**
Mg	0.26 - 0.31	Zn	48 - 81
S	**0.29 - 0.35**	**Mo**	**0.12 - 0.84**

C

Scientific Name	*Thermopsis lupinoides*
Common Name	**Lanceleaf False Lupine**
Collected From	Container production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.45 - 4.56	Fe	45 - 85
P	**0.23 - 0.42**	**Mn**	**42 - 90**
K	1.98 - 2.42	B	18 - 27
Ca	**0.31 - 0.66**	**Cu**	**5 - 12**
Mg	0.28 - 0.40	Zn	38 - 96
S	**0.18 - 0.29**	**Mo**	**0.2 - 1.07**

D

Scientific Name	*Thymus vulgaris*
Common Name	**Common or French Thyme**
Collected From	Container production nursery
Plant Part	35 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.45 - 2.61	Fe	85 - 118
P	**0.25 - 0.29**	**Mn**	**38 - 98**
K	2.17 - 3.15	B	17 - 28
Ca	**0.50 - 1.25**	**Cu**	**6 - 9**
Mg	0.29 - 0.40	Zn	68 - 99
S	**0.24 - 0.29**	**Mo**	**0.12 - 0.55**

E

Scientific Name	*Tiarella wherryi*
Common Name	**Clumping Foamflower**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Oakleaf'

Macronutrients %		Micronutrients ppm	
N	1.67 - 2.41	Fe	44 - 67
P	**0.24 - 0.32**	**Mn**	**33 - 82**
K	1.8 - 2.61	B	14 - 25
Ca	**1 - 2.06**	**Cu**	**2 - 8**
Mg	0.24 - 0.32	Zn	28 - 40
S	**0.2 - 0.29**	**Mo**	**0.12 - 0.24**

F

Scientific Name	*Tradescantia andersoniana*
Common Name	**Virginia Spiderwort**
Collected From	Container production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	2.45 - 4.84	Fe	38 - 127
P	**0.23 - 0.52**	**Mn**	**59 - 1069**
K	2.73 - 5.41	B	20 - 33
Ca	**1.56 - 2.07**	**Cu**	**5 - 10**
Mg	0.31 - 0.36	Zn	22 - 63
S	**0.23 - 0.31**	**Mo**	**0.2 - 0.43**

Herbaceous Perennials

A

Scientific Name			*Tricyrtis hirta*
Common Name			**Common Toad-lily**
Collected From			Container production nursery
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.5 - 2.50	Fe	55 - 159
P	**0.21 - 0.49**	**Mn**	**55 - 166**
K	2.43 - 4.06	B	20 - 33
Ca	**1 - 1.55**	**Cu**	**4 - 9**
Mg	0.36 - 0.60	Zn	24 - 36
S	**0.19 - 0.29**	**Mo**	**0.09 - 0.37**

B

Scientific Name			*Typha latifolia*
Common Name			**Greenhouse Production**
Collected From			Container production nursery
Plant Part			10-15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species adverage
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 4.00	Fe	45 - 100
P	**0.30 - 0.75**	**Mn**	**35 - 125**
K	2.00 - 3.80	B	20 - 40
Ca	**0.50 - 1.80**	**Cu**	**7 - 15**
Mg	0.30 - 0.60	Zn	40 - 75
S	**0.20 - 0.45**	**Mo**	**0.40 - 0.80**

C

Scientific Name			*Verbena bonariensis*
Common Name			**Blue Vervain**
Collected From			Container production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.12 - 3.53	Fe	44 - 54
P	**0.18 - 0.56**	**Mn**	**30 - 55**
K	1.66 - 2.79	B	18 - 26
Ca	**0.66 - 2.89**	**Cu**	**5 - 8**
Mg	0.33 - 0.47	Zn	23 - 42
S	**0.23 - 0.58**	**Mo**	**0.22 - 0.67**

D

Scientific Name			*Verbena tenuisecta*
Common Name			**Moss Verbena**
Collected From			Container production nursery
Plant Part			30 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			var. alba only
Macronutrients %		**Micronutrients ppm**	
N	2.26 - 3.00	Fe	131 - 204
P	**0.35 - 0.46**	**Mn**	**66 - 100**
K	2.27 - 2.91	B	25 - 29
Ca	**1.17 - 1.76**	**Cu**	**13 - 16**
Mg	0.53 - 0.63	Zn	77 - 285
S	**0.36 - 0.45**	**Mo**	**0.12 - 1.15**

E

Scientific Name			*Verbena x 'Homestead Purple'*
Common Name			**Homestead Purple' Verbena**
Collected From			Container production nursery
Plant Part			40 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Homestead Purple'
Macronutrients %		**Micronutrients ppm**	
N	2.71 - 3.99	Fe	76 - 142
P	**0.44 - 0.76**	**Mn**	**59 - 124**
K	2.24 - 4.75	B	37 - 48
Ca	**1.18 - 1.25**	**Cu**	**9 - 23**
Mg	0.55 - 0.79	Zn	59 - 141
S	**0.35 - 0.51**	**Mo**	**0.12 - 0.39**

F

Scientific Name			*Veronica longifolia or V. spicata*
Common Name			**Long-leaf or Spiked Veronica or Speedwell**
Collected From			Experimental test plots & container production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Icicle' (Veronica spicata), 'Schneeriesen' (Veronica longifolia)
Macronutrients %		**Micronutrients ppm**	
N	2.90 - 3.74	Fe	82 - 147
P	**0.35 - 0.84**	**Mn**	**30 - 35**
K	1.2 - 3.50	B	11 - 25
Ca	**0.58 - 1.70**	**Cu**	**5 - 14**
Mg	0.23 - 0.61	Zn	57 - 59
S	**0.19 - 0.34**	**Mo**	**0.13 - 0.70**

Herbaceous Perennials

A

SCIENTIFIC NAME			*Veronica subsessilis*
COMMON NAME			**Japanese Veronica or Speedwell**
COLLECTED FROM			Botanical garden/conservatory
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.14 - 1.51	Fe	33 - 47
P	**0.25 - 0.48**	**Mn**	**44 - 138**
K	1.97 - 2.55	B	16 - 23
Ca	**0.56 - 2.43**	**Cu**	**5 - 12**
Mg	0.23 - 0.41	Zn	37 - 80
S	**0.17 - 0.30**	**Mo**	**0.07 - 0.12**

B

SCIENTIFIC NAME			*Veronica x 'Goodness Grows'*
COMMON NAME			**Goodness Grows' Veronica or Speedwell**
COLLECTED FROM			Container production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Goodness Grows'
Macronutrients %		**Micronutrients ppm**	
N	1.87 - 2.69	Fe	31 - 49
P	**0.23 - 0.27**	**Mn**	**15 - 45**
K	1.85 - 2.11	B	13 - 18
Ca	**0.3 - 0.42**	**Cu**	**4 - 12**
Mg	0.26 - 0.34	Zn	24 - 32
S	**0.19 - 0.25**	**Mo**	**0.23 - 0.42**

C

SCIENTIFIC NAME			*Veronica x 'Sunny Border Blue'*
COMMON NAME			**Sunny Border Blue' Veronica or Speedwell**
COLLECTED FROM			Container production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Sunny Border Blue'
Macronutrients %		**Micronutrients ppm**	
N	2.70 - 3.53	Fe	56 - 79
P	**0.32 - 0.49**	**Mn**	**40 - 159**
K	2.60 - 2.73	B	19 - 33
Ca	**0.73 - 1.76**	**Cu**	**4 - 22**
Mg	0.40 - 0.72	Zn	55 - 95
S	**0.20 - 0.29**	**Mo**	**0.36 - 1.12**

D

SCIENTIFIC NAME			*x Pardancanda norrisii*
COMMON NAME			**Candy Lily**
COLLECTED FROM			Container production nursery
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.06 - 2.25	Fe	45 - 139
P	**0.23 - 0.37**	**Mn**	**34 - 128**
K	2 - 3.17	B	15 - 24
Ca	**0.56 - 1.86**	**Cu**	**1 - 14**
Mg	0.26 - 0.37	Zn	11 - 23
S	**0.18 - 0.29**	**Mo**	**0.12 - 0.33**

E

SCIENTIFIC NAME			*Astilbe chinensis var. pumila*
COMMON NAME			**Chinese Astilbe or Lilac Rose**
COLLECTED FROM			Container production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			var. pumila only
Macronutrients %		**Micronutrients ppm**	
N	2.29 - 4.24	Fe	45 - 245
P	**0.37 - 0.54**	**Mn**	**65 - 111**
K	1.28 - 2.41	B	18 - 27
Ca	**1.19 - 2.46**	**Cu**	**4 - 8**
Mg	0.21 - 0.38	Zn	45 - 100
S	**0.29 - 0.49**	**Mo**	**0.12 - 0.29**

F

Herbs

A

Scientific Name	*Amethrum graveoleus*		
Common Name	**Dill**		
Collected From	Field/garden production		
Plant Part	25 mature leaves + stem		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		Micronutrients ppm	
N	4.5 - 5.5	Fe	60 - 300
P	**0.31 - 0.45**	**Mn**	**50 - 250**
K	3.50 - 5.00	B	25 - 55
Ca	**1.25 - 2.20**	**Cu**	**5 - 15**
Mg	0.25 - 0.40	Zn	25 - 100
S	**0.30 - 0.40**	**Mo**	**0.4 - 1.00**

B

Scientific Name	*Hydrastis canadensis*		
Common Name	**Goldenseal or Turmeric**		
Collected From	Botanical garden/arboretum		
Plant Part	10 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		Micronutrients ppm	
N	1.88 - 2.14	Fe	55 - 132
P	**0.18 - 0.52**	**Mn**	**35 - 48**
K	2 - 3.36	B	22 - 55
Ca	**0.5 - 2.37**	**Cu**	**6 - 15**
Mg	0.33 - 0.68	Zn	34 - 44
S	**0.28 - 0.86**	**Mo**	**0.12 - 0.88**

C

Scientific Name	*Mentha spicata*		
Common Name	**Mint**		
Collected From	Field/garden production		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		Micronutrients ppm	
N	3.25 - 4.60	Fe	60 - 250
P	**0.20 - 0.40**	**Mn**	**50 - 300**
K	2.25 - 3.80	B	18 - 30
Ca	**0.50 - 1.25**	**Cu**	**5 - 15**
Mg	0.35 - 0.88	Zn	25 - 100
S	**0.18 - 0.35**	**Mo**	**0.5 - 1.00**

D

Scientific Name	*Ocimum basilicum*		
Common Name	**Basil**		
Collected From	Field/garden production		
Plant Part	10-15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		Micronutrients ppm	
N	4 - 6	Fe	75 - 200
P	**0.62 - 1.00**	**Mn**	**30 - 150**
K	1.55 - 2.05	B	25 - 60
Ca	**1.25 - 2.00**	**Cu**	**5 - 10**
Mg	0.60 - 1.0	Zn	30 - 70
S	**0.2 - 0.6**	**Mo**	**0.1 - 0.5**

E

Scientific Name	*Origanum vulgare*		
Common Name	**Oregano**		
Collected From	Field/garden production		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		Micronutrients ppm	
N	2.50 - 3.60	Fe	50 - 75
P	**0.15 - 0.24**	**Mn**	**40 - 60**
K	2.00 - 3.20	B	20 - 30
Ca	**0.55 - 0.85**	**Cu**	**5 - 12**
Mg	0.35 - 0.55	Zn	20 - 50
S	**0.15 - 0.25**	**Mo**	**0.40 - 1.00**

F

Scientific Name	*Petroselinum crispum*		
Common Name	**Parsley**		
Collected From	Field/garden production		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		Micronutrients ppm	
N	3.50 - 5.50	Fe	55 - 95
P	**0.22 - 0.40**	**Mn**	**46 - 80**
K	3.00 - 5.00	B	25 - 45
Ca	**0.60 - 1.25**	**Cu**	**6 - 12**
Mg	0.35 - 0.70	Zn	40 - 75
S	**0.15 - 0.25**	**Mo**	**0.40 - 1.0**

Herbs

A

Scientific Name	*Rosmarinus officinalis*
Common Name	**Rosemary**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	25 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Arp', 'Tuscan Blue'

Macronutrients %		Micronutrients ppm	
N	2.09 - 2.52	Fe	39 - 106
P	**0.26 - 0.35**	**Mn**	**22 - 76**
K	2.36 - 2.55	B	30 - 41
Ca	**0.48 - 0.69**	**Cu**	**3 - 23**
Mg	0.28 - 0.40	Zn	45 - 64
S	**0.22 - 0.34**	**Mo**	**0.5 - 1.40**

B

Scientific Name	*Thymus citriodorus 'Aureus'*
Common Name	**Golden Lemon Thyme**
Collected From	Container production nursery
Plant Part	35 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Aureus'

Macronutrients %		Micronutrients ppm	
N	2.71 - 3.08	Fe	73 - 134
P	**0.28 - 0.41**	**Mn**	**38 - 204**
K	2.35 - 3.61	B	19 - 26
Ca	**0.48 - 0.88**	**Cu**	**9 - 12**
Mg	0.31 - 0.40	Zn	50 - 72
S	**0.25 - 0.29**	**Mo**	**0.40 - 0.72**

C

Scientific Name	*Thymus praecox ssp. arcticus 'Splendens'*
Common Name	**Creeping Thyme or Mother-of-Thyme**
Collected From	Container production nursery
Plant Part	35 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Splendens'

Macronutrients %		Micronutrients ppm	
N	1.25 - 1.82	Fe	54 - 161
P	**0.18 - 0.30**	**Mn**	**33 - 54**
K	1.33 - 2.67	B	15 - 24
Ca	**0.35 - 0.62**	**Cu**	**6 - 14**
Mg	0.25 - 0.31	Zn	25 - 56
S	**0.18 - 0.23**	**Mo**	**0.21 - 0.56**

D

Scientific Name	*Thymus vulgaris 'Argenteus'*
Common Name	**Silver Thyme**
Collected From	Container production nursery
Plant Part	35 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Argenteus'

Macronutrients %		Micronutrients ppm	
N	1.75 - 2.71	Fe	58 - 156
P	**0.18 - 0.34**	**Mn**	**35 - 64**
K	2.21 - 3.50	B	15 - 21
Ca	**0.33 - 0.65**	**Cu**	**5 - 14**
Mg	0.25 - 0.38	Zn	23 - 78
S	**0.18 - 0.28**	**Mo**	**0.16 - 0.75**

E

Scientific Name	*Zingiber officinale*
Common Name	**Ginger**
Collected From	Field/garden production
Plant Part	4th leaf blade
Season	2-3 months after planting
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	4 - 4.5	Fe	111 - 161
P	**1.24 - 1.33**	**Mn**	**126 - 251**
K	4.9 - 6.7	B	81 - 113
Ca	**2.1 - 2.3**	**Cu**	**6 - 18**
Mg	1.5 - 1.8	Zn	22 - 55
S	**1.35 - 1.40**	**Mo**	**0.21 - 1**

F

Scientific Name	*Allium schoenoprasum*
Common Name	**Chives**
Collected From	Production fields/garden
Plant Part	12-15 whole tops (green portion only), 1/3-1/2 maturity
Season	1/3 to 1/2 maturity
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	3.5 - 5	Fe	60 - 200
P	**0.25 - 0.45**	**Mn**	**45 - 252**
K	3.5 - 5.5	B	22 - 60
Ca	**1.00 - 3.5**	**Cu**	**8 - 25**
Mg	0.3 - 0.5	Zn	25 - 75
S	**0.45 - 0.75**	**Mo**	**1 - 5**

Herbs

A

SCIENTIFIC NAME	*Cariandrum sativum*
COMMON NAME	**Cilantro**
COLLECTED FROM	Field/garden production
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients Ppm	
N	4 - 6	Fe	55 - 95
P	**0.42 - 0.85**	**Mn**	**46 - 80**
K	3.8 - 5.0	B	25 - 45
Ca	**0.85 - 1.25**	**Cu**	**5 - 15**
Mg	0.40 - 0.75	Zn	40 - 70
S	**0.22 - 0.35**	**Mo**	**0.40 - 1.00**

B

C

D

E

F

Landscape and Forest Trees

A

Scientific Name	*Acer buergerianum*		
Common Name	**Maple, Trident**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.88 - 2.88	Fe	41 - 56
P	**0.18 - 0.33**	**Mn**	**156 - 253**
K	1.25 - 1.39	B	19 - 74
Ca	**0.62 - 2.32**	**Cu**	**5 - 16**
Mg	0.22 - 0.44	Zn	11 - 31
S	**0.21 - 0.26**	**Mo**	**0.12 - 0.25**

B

Scientific Name	*Acer campestre*		
Common Name	**Maple, Hedge or Field**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Evelyn' ('Queen Elisabeth')		
Macronutrients %		**Micronutrients ppm**	
N	1.99 - 3.19	Fe	47 - 83
P	**0.23 - 0.31**	**Mn**	**79 - 589**
K	1.24 - 2.07	B	36 - 80
Ca	**0.84 - 1.79**	**Cu**	**5 - 10**
Mg	0.21 - 0.44	Zn	31 - 61
S	**0.20 - 0.24**	**Mo**	**0.05 - 0.12**

C

Scientific Name	*Acer capillipes*		
Common Name	**Maple, Japanese Snakebark**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.2 - 2.98	Fe	52 - 87
P	**0.21 - 0.34**	**Mn**	**121 - 1171**
K	1.5 - 2.02	B	35 - 57
Ca	**.88 - 2.06**	**Cu**	**5 - 11**
Mg	.25 - .55	Zn	33 - 579
S	**0.16 - 0.22**	**Mo**	**0.14 - 0.44**

D

Scientific Name	*Acer griseum*		
Common Name	**Maple, Paperbark**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.70 - 2.40	Fe	50 - 60
P	**0.13 - 0.15**	**Mn**	**137 - 365**
K	0.72 - 1.01	B	40 - 65
Ca	**0.80 - 1.06**	**Cu**	**5 - 8**
Mg	0.16 - 0.18	Zn	15 - 25
S	**0.17 - 0.19**	**Mo**	**0.12 - 0.27**

E

Scientific Name	*Acer negundo*		
Common Name	**Box-elder**		
Collected From	Botanical garden/arboretum & field research plots		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.73	Fe	30 - 125
P	**0.22 - 0.32**	**Mn**	**30 - 147**
K	1.88 - 3.10	B	20 - 118
Ca	**1.10 - 2.36**	**Cu**	**8 - 20**
Mg	0.25 - 0.64	Zn	10 - 23
S	**0.16 - 0.30**	**Mo**	**0.12 - 0.40**

F

Scientific Name	*Acer palmatum 'Senkaki' ('Sango-kaku')*		
Common Name	**Coral-bark Japanese Maple**		
Collected From	Containers & field production nurseries		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Senkaki' ('Sango-kaku')		
Macronutrients %		**Micronutrients ppm**	
N	1.79 - 2.13	Fe	55 - 70
P	**0.13 - 0.18**	**Mn**	**298 - 1469**
K	0.53 - 1.07	B	28 - 49
Ca	**1.30 - 2.16**	**Cu**	**1 - 6**
Mg	0.22 - 0.33	Zn	27 - 54
S	**0.19 - 0.23**	**Mo**	**0.12 - 0.21**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Acer palmatum cultivars*
COMMON NAME	**Japanese Maple--green-leaf forms**
COLLECTED FROM	Containers & field production nurseries
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Seedlings, 'Seriyu', 'Viride'

Macronutrients %		Micronutrients ppm	
N	2.04 - 2.34	Fe	67 - 85
P	**0.14 - 0.15**	**Mn**	**233 - 1020**
K	0.39 - 1.41	B	27 - 63
Ca	**0.95 - 1.02**	**Cu**	**1 - 6**
Mg	0.17 - 0.42	Zn	23 - 41
S	**0.20 - 0.26**	**Mo**	**0.12 - 0.30**

B

SCIENTIFIC NAME	*Acer palmatum var. atropurpureum*
COMMON NAME	**Purple-leaf Japanese Maple**
COLLECTED FROM	Containers & field production nurseries
PLANT PART	35 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	var. atropurpureum seedlings

Macronutrients %		Micronutrients ppm	
N	1.90 - 1.96	Fe	33 - 53
P	**0.17 - 0.42**	**Mn**	**144 - 597**
K	0.58 - 0.68	B	39 - 57
Ca	**1.08 - 2.03**	**Cu**	**3 - 5**
Mg	0.38 - 0.45	Zn	40 - 116
S	**0.19 - 0.28**	**Mo**	**0.12 - 0.55**

C

SCIENTIFIC NAME	*Acer palmatum var. atropurpureum 'Bloodgood'*
COMMON NAME	**Bloodgood' Japanese Maple**
COLLECTED FROM	Containers & field production nurseries
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Bloodgood'

Macronutrients %		Micronutrients ppm	
N	2.16 - 2.39	Fe	68 - 73
P	**0.13 - 0.18**	**Mn**	**226 - 1827**
K	0.41 - 1.38	B	38 - 47
Ca	**0.89 - 1.13**	**Cu**	**1 - 5**
Mg	0.20 - 0.36	Zn	20 - 50
S	**0.22 - 0.25**	**Mo**	**0.12 - 1.50**

D

SCIENTIFIC NAME	*Acer palmatum var. dissectum*
COMMON NAME	**Purple-, Cut-leaf Japanese Maple**
COLLECTED FROM	Containers & field production nurseries & botanical garden/arboretum
PLANT PART	35 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED - Burgundy Lace', 'Dissectum Atropurpureum', 'Filiferum Purpureum', 'Oshio-Beni'	

Macronutrients %		Micronutrients ppm	
N	1.74 - 2.81	Fe	59 - 294
P	**0.11 - 0.46**	**Mn**	**131 - 2271**
K	0.73 - 1.51	B	45 - 93
Ca	**0.73 - 2.02**	**Cu**	**1 - 6**
Mg	0.17 - 0.77	Zn	48 - 109
S	**0.18 - 0.30**	**Mo**	**0.12 - 2.89**

E

SCIENTIFIC NAME	*Acer pensylvanicum*
COMMON NAME	**Striped Maple or Moosewood or Whistlewood**
COLLECTED FROM	Field research plots
PLANT PART	25 mature leaves from new growth
SEASON	Spring to summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.65 - 2.98	Fe	45 - 65
P	**0.18 - 0.46**	**Mn**	**478 - 708**
K	.9 - 1.75	B	32 - 65
Ca	**.71 - 1.9**	**Cu**	**5 - 8**
Mg	.3 - .55	Zn	19 - 37
S	**0.18 - 0.28**	**Mo**	**0.13 - 0.33**

F

SCIENTIFIC NAME	*Acer platanoides*
COMMON NAME	**Norway Maple**
COLLECTED FROM	Field production nursery
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Princeton Gold'

Macronutrients %		Micronutrients ppm	
N	2 - 2.65	Fe	44 - 70
P	**0.22 - 0.33**	**Mn**	**22 - 44**
K	1.7 - 2.25	B	30 - 41
Ca	**.9 - 1.45**	**Cu**	**5 - 14**
Mg	.26 - .48	Zn	22 - 45
S	**0.21 - 0.29**	**Mo**	**0.14 - 0.22**

Landscape and Forest Trees

A

Scientific Name	*Acer rubrum*		
Common Name	**Red Maple**		
Collected From	Field research plots		
Plant Part	25 mature leaves from new growth		
Season	Spring to summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.25 - 2.68	Fe	52 - 683
P	**0.19 - 0.42**	**Mn**	**20 - 765**
K	.9 - 1.65	B	30 - 57
Ca	**.65 - 2.24**	**Cu**	**5 - 18**
Mg	.21 - 0.63	Zn	22 - 50
S	**0.16 - 0.29**	**Mo**	**0.14 - 0.24**

B

Scientific Name	*Acer rubrum 'Franksred' ('Red Sunset')*		
Common Name	**Red Sunset' Red Maple**		
Collected From	Field production nursery		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Franksred' ('Red Sunset')		
Macronutrients %		**Micronutrients ppm**	
N	1.99 - 2.25	Fe	34 - 40
P	**0.17 - 0.20**	**Mn**	**254 - 305**
K	0.68 - 0.97	B	14 - 20
Ca	**0.28 - 0.45**	**Cu**	**3 - 5**
Mg	0.15 - 0.20	Zn	11 - 15
S	**0.16 - 0.20**	**Mo**	**0.12 - 0.30**

C

Scientific Name	*Acer rubrum 'October Glory'*		
Common Name	**October Glory' Red Maple**		
Collected From	Field production nursery		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'October Glory'		
Macronutrients %		**Micronutrients ppm**	
N	1.45 - 2.98	Fe	36 - 296
P	**0.22 - 0.50**	**Mn**	**20 - 220**
K	0.95 - 1.71	B	14 - 39
Ca	**.45 - 1.23**	**Cu**	**5 - 18**
Mg	.22 - 0.35	Zn	21 - 45
S	**0.18 - 0.24**	**Mo**	**0.13 - 0.28**

D

Scientific Name	*Acer rubrum cultivars*		
Common Name	**Red Maple**		
Collected From	Container & field production nurseries		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Edna Davis', 'Fairview Flame'		
Macronutrients %		**Micronutrients ppm**	
N	1.91 - 2.35	Fe	38 - 67
P	**0.15 - 0.25**	**Mn**	**50 - 1062**
K	.89 - 1.92	B	18 - 72
Ca	**.56 - 1.97**	**Cu**	**5 - 45**
Mg	.21 - 0.37	Zn	22 - 70
S	**0.14 - 0.18**	**Mo**	**0.18 - 0.69**

E

Scientific Name	*Acer rubrum var. drummondii*		
Common Name	**Drummond's Red Maple**		
Collected From	Field production nursery		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. drummondii only		
Macronutrients %		**Micronutrients ppm**	
N	1.97 - 2.25	Fe	27 - 37
P	**0.18 - 0.27**	**Mn**	**55 - 230**
K	1 - 1.87	B	16 - 22
Ca	**.89 - 1.56**	**Cu**	**4 - 8**
Mg	.22 - .33	Zn	18 - 34
S	**0.17 - 0.26**	**Mo**	**0.13 - 0.22**

F

Scientific Name	*Acer saccharinum*		
Common Name	**Silver Maple**		
Collected From	Field production nursery		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.30 - 2.78	Fe	35 - 74
P	**0.18 - 0.24**	**Mn**	**50 - 496**
K	1.25 - 1.79	B	25 - 54
Ca	**.65 - 1.29**	**Cu**	**4 - 8**
Mg	0.33 - 0.55	Zn	34 - 95
S	**0.18 - 0.25**	**Mo**	**0.14 - 0.3**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Acer saccharum*
COMMON NAME	**Sugar Maple**
COLLECTED FROM	Field research plots
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.25 - 2.85	Fe	81 - 220
P	**0.2 - 0.30**	**Mn**	**80 - 761**
K	.89 - 1.42	B	29 - 62
Ca	**1.01 - 2.42**	**Cu**	**5 - 12**
Mg	.22 - 0.45	Zn	26 - 54
S	**0.18 - 0.25**	**Mo**	**0.19 - 0.26**

B

SCIENTIFIC NAME	*Acer saccharum cultivars*
COMMON NAME	**Sugar Maple**
COLLECTED FROM	Field production nursery & botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED -	Species, 'Astis' ('Steeple'), 'Bonfire', 'Commemoration', 'Endowment', 'Green Mountian', 'Legacy'

Macronutrients %		Micronutrients ppm	
N	1.49 - 2.56	Fe	35 - 144
P	**0.19 - 0.29**	**Mn**	**111 - 740**
K	.75 - 1.34	B	16 - 43
Ca	**0.57 - 1.77**	**Cu**	**4 - 8**
Mg	.18 - 0.33	Zn	21 - 27
S	**0.18 - 0.28**	**Mo**	**0.14 - 0.30**

C

SCIENTIFIC NAME	*Acer saccharum ssp. floridanum*
COMMON NAME	**Southern Sugar Maple or Florida Maple**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	ssp. floridanum only

Macronutrients %		Micronutrients ppm	
N	1.35 - 2.25	Fe	45 - 80
P	**0.21 - 0.29**	**Mn**	**50 - 490**
K	.98 - 1.25	B	18 - 46
Ca	**.75 - 1.97**	**Cu**	**5 - 12**
Mg	0.23 - 0.31	Zn	22 - 33
S	**0.18 - 0.27**	**Mo**	**0.14 - 0.22**

D

SCIENTIFIC NAME	*Acer saccharum ssp. grandidentatum*
COMMON NAME	**Bigtooth Maple**
COLLECTED FROM	Field production nursery
PLANT PART	25 mature leaves from new summer growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Schmidt' ('Rocky Mountian Glow')

Macronutrients %		Micronutrients ppm	
N	1.85 - 2.85	Fe	35 - 88
P	**0.22 - 0.44**	**Mn**	**62 - 103**
K	1.85 - 2.55	B	24 - 50
Ca	**1 - 1.76**	**Cu**	**6 - 15**
Mg	.22 - .4	Zn	19 - 66
S	**0.18 - 0.33**	**Mo**	**0.1 - 0.21**

E

SCIENTIFIC NAME	*Acer saccharum ssp. leucoderme*
COMMON NAME	**Chalkbark Maple**
COLLECTED FROM	Field production nursery & botanical garden/arboretum
PLANT PART	25 mature leaves from new summer growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	ssp. leucoderme only

Macronutrients %		Micronutrients ppm	
N	1.73 - 3.00	Fe	34 - 92
P	**0.18 - 0.24**	**Mn**	**60 - 786**
K	0.65 - 1.47	B	16 - 71
Ca	**0.83 - 1.68**	**Cu**	**2 - 5**
Mg	0.15 - 0.23	Zn	13 - 20
S	**0.14 - 0.18**	**Mo**	**0.12 - 0.26**

F

SCIENTIFIC NAME	*Acer saccharum ssp. nigrum*
COMMON NAME	**Black Maple**
COLLECTED FROM	Field research plots
PLANT PART	20 mature leaves from new summer growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	ssp. nigrum only

Macronutrients %		Micronutrients ppm	
N	1.78 - 2.95	Fe	33 - 122
P	**0.21 - 0.33**	**Mn**	**30 - 244**
K	1.22 - 2.33	B	23 - 55
Ca	**1.1 - 2.91**	**Cu**	**6 - 15**
Mg	0.25 - 0.43	Zn	22 - 38
S	**0.22 - 0.41**	**Mo**	**0.77 - 2.93**

Landscape and Forest Trees

A

SCIENTIFIC NAME			*Acer spicatum*
COMMON NAME			**Mountain Maple**
COLLECTED FROM			Field research plots
PLANT PART			25 mature leaves from new summer growth
SEASON			Spring to Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	1.55 - 2.24	Fe	32 - 150
P	**0.22 - 0.41**	**Mn**	**15 - 348**
K	1.3 - 1.89	B	16 - 55
Ca	**.88 - 1.78**	**Cu**	**9 - 18**
Mg	.21 - .37	Zn	23 - 37
S	**0.21 - 0.35**	**Mo**	**0.5 - 1**

B

SCIENTIFIC NAME			*Acer tataricum ssp. ginnala*
COMMON NAME			**Amur Maple**
COLLECTED FROM			Field production nursery & botanical garden/arboretum
PLANT PART			30 mature leaves from new summer growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			ssp. ginnala only
Macronutrients %		Micronutrients ppm	
N	1.59 - 2.18	Fe	45 - 91
P	**0.13 - 0.15**	**Mn**	**134 - 1186**
K	0.76 - 0.90	B	19 - 36
Ca	**0.92 - 1.34**	**Cu**	**3 - 6**
Mg	0.18 - 0.23	Zn	14 - 82
S	**0.14 - 0.18**	**Mo**	**0.12 - 0.30**

C

SCIENTIFIC NAME			*Acer truncatum*
COMMON NAME			**Purpleblow or Shantung Maple**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			25 mature leaves from new summer growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		Micronutrients ppm	
N	1.6 - 2.5	Fe	32 - 51
P	**0.2 - 0.35**	**Mn**	**33 - 231**
K	1.5 - 2.23	B	20 - 36
Ca	**1.02 - 2.11**	**Cu**	**6 - 12**
Mg	.22 - 0.39	Zn	.14 - .24
S	**0.14 - 0.22**	**Mo**	**0.15 - 0.4**

D

SCIENTIFIC NAME			*Acer truncatum*
COMMON NAME			**Purpleblow or Shantung Maple**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	1.78 - 2.549	Fe	22 - 45
P	**0.28 - 0.42**	**Mn**	**45 - 145**
K	1.24 - 1.98	B	19 - 34
Ca	**.78 - 1.34**	**Cu**	**6 - 15**
Mg	.23 - .34	Zn	33 - 65
S	**0.21 - 0.29**	**Mo**	**0.14 - 0.24**

E

SCIENTIFIC NAME			*Acer x 'Keithsform' ('Norwegian Sunset')*
COMMON NAME			**Norwegian Sunset' Maple**
COLLECTED FROM			Field production nursery
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Keithsform' ('Norwegian Sunset')
Macronutrients %		Micronutrients ppm	
N	2.2 - 3.15	Fe	25 - 127
P	**0.21 - 0.35**	**Mn**	**50 - 148**
K	1.09 - 1.45	B	25 - 33
Ca	**.86 - 1.34**	**Cu**	**5 - 9**
Mg	.24 - 0.29	Zn	23 - 34
S	**0.18 - 0.29**	**Mo**	**0.14 - 0.21**

F

SCIENTIFIC NAME			*Acer x freemanii 'Autumn Blaze'*
COMMON NAME			**Autumn Blaze' Red Maple**
COLLECTED FROM			Field production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Autumn Blaze'
Macronutrients %		Micronutrients ppm	
N	1.77 - 2.42	Fe	34 - 74
P	**0.22 - 0.29**	**Mn**	**74 - 186**
K	0.88 - 1.07	B	17 - 20
Ca	**0.27 - 0.93**	**Cu**	**8 - 11**
Mg	0.11 - 0.28	Zn	19 - 32
S	**0.14 - 0.20**	**Mo**	**0.12 - 0.30**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Acer x freemanii cultivars*
COMMON NAME	**Columnar or Upright Red Maple**
COLLECTED FROM	Container & field production nurseries
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Armstrong', 'Scarsen' ('Scarlet Sentinel')

Macronutrients %		Micronutrients ppm	
N	2.1 - 2.64	Fe	60 - 104
P	**0.15 - 0.21**	**Mn**	**27 - 1646**
K	0.71 - 1.1	B	16 - 34
Ca	**0.79 - 1.01**	**Cu**	**4 - 15**
Mg	0.26 - 0.28	Zn	19 - 44
S	**0.19 - 0.22**	**Mo**	**0.13 - 0.30**

B

SCIENTIFIC NAME	*Aesculus flava*
COMMON NAME	**Yellow Buckeye**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.27 - 3.77	Fe	35 - 132
P	**0.27 - 0.45**	**Mn**	**44 - 76**
K	2 - 2.88	B	17 - 27
Ca	**1.65 - 2.22**	**Cu**	**6 - 25**
Mg	.31 - 0.50	Zn	22 - 33
S	**0.21 - 0.30**	**Mo**	**0.18 - 0.24**

C

SCIENTIFIC NAME	*Aesculus glabra*
COMMON NAME	**Ohio Buckeye**
COLLECTED FROM	Botanical garden/arboretum & field research plots
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2 - 3.24	Fe	55 - 340
P	**0.29 - 0.93**	**Mn**	**81 - 120**
K	1.1 - 2.8	B	26 - 35
Ca	**1.78 - 2.23**	**Cu**	**5 - 7**
Mg	0.31 - 0.65	Zn	22 - 54
S	**0.15 - 0.20**	**Mo**	**0.13 - 0.22**

D

SCIENTIFIC NAME	*Aesculus hippocastanum*
COMMON NAME	**Common Horsechestnut**
COLLECTED FROM	Field research plots
PLANT PART	5 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.22 - 3.44	Fe	55 - 506
P	**0.19 - 0.28**	**Mn**	**128 - 226**
K	1.1 - 2.29	B	14 - 26
Ca	**0.86 - 1.21**	**Cu**	**4 - 12**
Mg	0.17 - 0.29	Zn	20 - 35
S	**0.16 - 0.25**	**Mo**	**0.25 - 0.33**

E

SCIENTIFIC NAME	*Aesculus pavia*
COMMON NAME	**Red Buckeye**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.1 - 3.24	Fe	44 - 168
P	**0.19 - 0.28**	**Mn**	**44 - 98**
K	1.18 - 2.23	B	23 - 34
Ca	**1.89 - 2.44**	**Cu**	**5 - 9**
Mg	.35 - 0.61	Zn	15 - 23
S	**0.21 - 0.28**	**Mo**	**0.13 - 0.22**

F

SCIENTIFIC NAME	*Aesculus x carnea*
COMMON NAME	**Red Horsechestnut**
COLLECTED FROM	Container production nursery
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	O'Neill Red'

Macronutrients %		Micronutrients ppm	
N	2.5 - 3.6	Fe	45 - 81
P	**0.21 - 0.29**	**Mn**	**25 - 350**
K	.98 - 1.88	B	14 - 22
Ca	**1.44 - 2.40**	**Cu**	**6 - 12**
Mg	.33 - .5	Zn	12 - 25
S	**0.16 - 0.23**	**Mo**	**0.18 - 0.3**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Albizia julibrissin*		
COMMON NAME	**Mimosa or Silk Tree**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	10 mature leaves from new summer growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	2.21 - 4.29	Fe	55 - 98
P	**0.14 - 0.38**	**Mn**	**45 - 105**
K	1.28 - 2.78	B	18 - 26
Ca	**.75 - 1.76**	**Cu**	**7 - 15**
Mg	.33 - 0.50	Zn	15 - 45
S	**0.19 - 0.26**	**Mo**	**0.14 - 0.23**

B

SCIENTIFIC NAME	*Alnus glutinosa*		
COMMON NAME	**Black or European Alder**		
COLLECTED FROM	Field research plots		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	1.65 - 2.30	Fe	55 - 404
P	**0.14 - 0.27**	**Mn**	**45 - 1014**
K	0.78 - 1.53	B	21 - 31
Ca	**.78 - 1.24**	**Cu**	**5 - 12**
Mg	.21 - 0.29	Zn	29 - 36
S	**0.18 - 0.27**	**Mo**	**0.19 - 0.48**

C

SCIENTIFIC NAME	*Alnus rubra*		
COMMON NAME	**Red Alder**		
COLLECTED FROM	Field research plots		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	1.92 - 2.69	Fe	48 - 133
P	**0.17 - 0.29**	**Mn**	**130 - 294**
K	.65 - 1.95	B	20 - 30
Ca	**.87 - 1.09**	**Cu**	**8 - 10**
Mg	.21 - .33	Zn	35 - 47
S	**0.15 - 0.28**	**Mo**	**0.17 - 0.33**

D

SCIENTIFIC NAME	*Alnus serrulata*		
COMMON NAME	**Tag Or Hazel Alder**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	1.5 - 2.95	Fe	46 - 55
P	**0.11 - 0.29**	**Mn**	**55 - 566**
K	1.15 - 2.88	B	21 - 44
Ca	**1.05 - 2.00**	**Cu**	**5 - 9**
Mg	.13 - 35	Zn	35 - 53
S	**0.16 - 0.24**	**Mo**	**0.12 - 0.4**

E

SCIENTIFIC NAME	*Alnus x viridis ssp. crispa*		
COMMON NAME	**American Green Alder**		
COLLECTED FROM	Field research plots		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	ssp. crispa only		
Macronutrients %		Micronutrients ppm	
N	1.98 - 2.28	Fe	115 - 316
P	**0.17 - 0.3**	**Mn**	**33 - 318**
K	.65 - 1.56	B	21 - 35
Ca	**.89 - 1.07**	**Cu**	**3 - 7**
Mg	0.13 - 0.24	Zn	19 - 38
S	**0.16 - 0.27**	**Mo**	**0.33 - 7.60**

F

SCIENTIFIC NAME	*Amelanchier laevis*		
COMMON NAME	**Allegheny Serviceberry or Shadbush**		
COLLECTED FROM	Field production nursery & botanical garden/arboretum		
PLANT PART	30 leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Cumulus'		
Macronutrients %		Micronutrients ppm	
N	2.30 - 2.60	Fe	34 - 44
P	**0.19 - 0.26**	**Mn**	**476 - 563**
K	0.95 - 1.36	B	21 - 32
Ca	**0.48 - 1.42**	**Cu**	**3 - 5**
Mg	0.22 - 0.24	Zn	33 - 51
S	**0.17 - 0.20**	**Mo**	**0.05 - 0.30**

Landscape and Forest Trees

A

Scientific Name			*Amelanchier x 'Ballerina'*
Common Name			**Ballerina' Serviceberry**
Collected From			Field production nursery
Plant Part			30 leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Ballerina'
Macronutrients %		**Micronutrients ppm**	
N	2.11 - 2.78	Fe	45 - 66
P	**0.21 - 0.3**	**Mn**	**44 - 2224**
K	0.74 - 1.68	B	21 - 31
Ca	**1.12 - 1.45**	**Cu**	**3 - 9**
Mg	0.3 - 0.41	Zn	22 - 34
S	**0.15 - 0.24**	**Mo**	**0.15 - 0.4**

B

Scientific Name			*Aralia spinosa*
Common Name			**Devil's Walkingstick**
Collected From			Botanical garden/arboretum
Plant Part			8 mature leaves
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.76 - 3.46	Fe	87 - 125
P	**0.32 - 0.62**	**Mn**	**228 - 611**
K	2.49 - 3.78	B	59 - 76
Ca	**2.59 - 3.02**	**Cu**	**7 - 14**
Mg	0.14 - 0.55	Zn	103 - 109
S	**0.11 - 0.19**	**Mo**	**0.56 - 1.09**

C

Scientific Name			*Betula alleghaniensis*
Common Name			**Yellow Birch**
Collected From			Field research plots
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.30 - 2.82	Fe	44 - 101
P	**0.10 - 0.53**	**Mn**	**51 - 862**
K	0.53 - 1.88	B	16 - 31
Ca	**0.48 - 2.50**	**Cu**	**7 - 15**
Mg	0.24 - 0.96	Zn	59 - 228
S	**0.12 - 0.22**	**Mo**	**0.19 - 2.2**

D

Scientific Name			*Betula nigra*
Common Name			**River Birch**
Collected From			Field research plots
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.48 - 2.26	Fe	107 - 233
P	**0.18 - 0.30**	**Mn**	**29 - 73**
K	0.92 - 1.62	B	38 - 100
Ca	**0.98 - 1.51**	**Cu**	**8 - 23**
Mg	0.21 - 0.58	Zn	23 - 212
S	**0.14 - 0.22**	**Mo**	**0.33 - 0.96**

E

Scientific Name			*Betula nigra*
Common Name			**River Birch**
Collected From			Field production nursery & botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species, 'Cully' ('Heritage')
Macronutrients %		**Micronutrients ppm**	
N	2.07 - 2.74	Fe	43 - 72
P	**0.13 - 0.21**	**Mn**	**151 - 1345**
K	0.69 - 1.21	B	11 - 65
Ca	**0.51 - 0.95**	**Cu**	**4 - 11**
Mg	0.21 - 0.31	Zn	16 - 200
S	**0.14 - 0.20**	**Mo**	**0.07 - 0.30**

F

Scientific Name			*Betula papyrifera*
Common Name			**Paper or Canoe Birch**
Collected From			Field research plots
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.12 - 2.52	Fe	72 - 140
P	**0.12 - 0.51**	**Mn**	**166 - 578**
K	0.84 - 1.46	B	31 - 63
Ca	**0.37 - 1.87**	**Cu**	**5 - 16**
Mg	0.16 - 0.58	Zn	51 - 146
S	**0.18 - 0.22**	**Mo**	**0.02 - 1.04**

Landscape and Forest Trees

A

Scientific Name	*Betula pendula*
Common Name	**European White Birch**
Collected From	Field research plots
Plant Part	20 whole seedlings
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	4.00 - 4.60	Fe	37 - 77
P	**0.36 - 0.59**	**Mn**	**54 - 111**
K	1.70 - 2.90	B	15 - 29
Ca	**0.20 - 0.31**	**Cu**	**5 - 15**
Mg	0.26 - 0.38	Zn	19 - 34
S	**0.17 - 0.24**	**Mo**	**0.2 - 0.54**

B

Scientific Name	*Betula pendula 'Youngii'*
Common Name	**Weeping European White Birch**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Youngii'

Macronutrients %		Micronutrients ppm	
N	2.19 - 3.20	Fe	45 - 101
P	**0.12 - 0.16**	**Mn**	**236 - 477**
K	0.9 - 1.86	B	18 - 33
Ca	**0.98 - 1.23**	**Cu**	**5 - 12**
Mg	0.27 - 0.33	Zn	33 - 296
S	**0.18 - 0.24**	**Mo**	**0.55 - 2.33**

C

Scientific Name	*Betula populifolia*
Common Name	**Gray or Old-field or Fire Birch**
Collected From	Field research plots
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.22 - 2.87	Fe	33 - 71
P	**0.11 - 0.23**	**Mn**	**173 - 354**
K	1.00 - 1.37	B	14 - 42
Ca	**0.47 - 0.61**	**Cu**	**9 - 23**
Mg	0.22 - 0.42	Zn	64 - 131
S	**0.18 - 0.27**	**Mo**	**0.05 - 2.1**

D

Scientific Name	*Betula utilis var. jacquemontii*
Common Name	**Himalayan Whitebark Birch**
Collected From	Container production nursery
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	var. jacquemontii only

Macronutrients %		Micronutrients ppm	
N	2.28 - 3.71	Fe	34 - 183
P	**0.14 - 0.18**	**Mn**	**55 - 703**
K	1.14 - 1.93	B	22 - 82
Ca	**1.12 - 1.51**	**Cu**	**5 - 79**
Mg	0.32 - 0.38	Zn	33 - 354
S	**0.18 - 0.26**	**Mo**	**0.43 - 2.62**

E

Scientific Name	*Bucida buceras*
Common Name	**Black Olive**
Collected From	Container production nursery
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.60 - 3.00	Fe	50 - 200
P	**0.15 - 0.75**	**Mn**	**40 - 200**
K	0.70 - 3.50	B	25 - 75
Ca	**0.25 - 1.00**	**Cu**	**5 - 25**
Mg	0.25 - 1.00	Zn	20 - 100
S	**0.20 - 0.75**	**Mo**	**0.1 - 0.3**

F

Scientific Name	*Carpinus betulus cultivars*
Common Name	**Upright or Columnar European Hornbeam**
Collected From	Container & field production nursery & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Columnaris', 'Fastigiata'

Macronutrients %		Micronutrients ppm	
N	2.14 - 2.84	Fe	53 - 131
P	**0.14 - 0.20**	**Mn**	**233 - 2094**
K	0.68 - 0.92	B	23 - 203
Ca	**1.18 - 2.98**	**Cu**	**3 - 8**
Mg	0.27 - 0.40	Zn	18 - 32
S	**0.19 - 0.21**	**Mo**	**0.09 - 2.51**

Landscape and Forest Trees

A

Scientific Name	*Carpinus caroliniana*
Common Name	**American Hornbeam or Blue Beech or Musclewood**
Collected From	Field production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.85 - 2.55	Fe	36 - 78
P	**0.11 - 0.23**	**Mn**	**56 - 257**
K	0.52 - 1.87	B	21 - 33
Ca	**0.85 - 1.46**	**Cu**	**5 - 12**
Mg	0.18 - 0.18	Zn	12 - 22
S	**0.15 - 0.23**	**Mo**	**0.1 - 0.18**

B

Scientific Name	*Carpinus japonica*
Common Name	**Japanese Hornbeam**
Collected From	Field production nursery
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.99 - 2.25	Fe	42 - 77
P	**0.14 - 0.19**	**Mn**	**123 - 873**
K	0.69 - 1.89	B	20 - 36
Ca	**0.79 - 1.35**	**Cu**	**5 - 15**
Mg	0.19 - 0.29	Zn	21 - 31
S	**0.18 - 0.23**	**Mo**	**0.09 - 0.27**

C

Scientific Name	*Carya glabra*
Common Name	**Pignut Hickory**
Collected From	Botanical garden/arboretum & field research plots
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.60 - 2.42	Fe	38 - 72
P	**0.14 - 0.17**	**Mn**	**179 - 1250**
K	0.58 - 1.10	B	21 - 79
Ca	**0.95 - 1.60**	**Cu**	**5 - 17**
Mg	0.48 - 0.82	Zn	27 - 53
S	**0.15 - 0.21**	**Mo**	**0.11 - 0.33**

D

Scientific Name	*Carya ovata*
Common Name	**Shagbark Hickory**
Collected From	Field research plots
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.23 - 2.22	Fe	55 - 183
P	**0.12 - 0.18**	**Mn**	**266 - 727**
K	0.52 - 1.45	B	26 - 110
Ca	**1.09 - 1.45**	**Cu**	**5 - 9**
Mg	0.33 - 0.57	Zn	23 - 63
S	**0.15 - 0.23**	**Mo**	**0.19 - 0.34**

E

Scientific Name	*Carya tomentosa*
Common Name	**Mockernut Hickory**
Collected From	Botanical garden/arboretum
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.78 - 2.12	Fe	37 - 65
P	**0.09 - 0.16**	**Mn**	**221 - 1247**
K	0.76 - 1.77	B	36 - 134
Ca	**0.97 - 2.47**	**Cu**	**6 - 12**
Mg	0.38 - 0.47	Zn	21 - 34
S	**0.15 - 0.22**	**Mo**	**0.11 - 0.27**

F

Scientific Name	*Catalpa bignonioides*
Common Name	**Southern Catalpa or Indian BeanTree**
Collected From	Botanical garden/arboretum
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.11 - 2.32	Fe	41 - 119
P	**0.13 - 0.19**	**Mn**	**67 - 131**
K	0.93 - 1.25	B	29 - 56
Ca	**1.19 - 1.75**	**Cu**	**5 - 10**
Mg	0.3 - 0.36	Zn	21 - 31
S	**0.15 - 0.24**	**Mo**	**0.09 - 0.12**

Landscape and Forest Trees

A

Scientific Name	*Catalpa speciosa*		
Common Name	**Northern Catalpa**		
Collected From	Field research plots		
Plant Part	5 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.92 - 2.25	Fe	55 - 680
P	**0.2 - 0.30**	**Mn**	**103 - 130**
K	1.31 - 2.21	B	15 - 27
Ca	**1.15 - 2.26**	**Cu**	**7 - 19**
Mg	0.28 - 0.34	Zn	23 - 50
S	**0.23 - 0.48**	**Mo**	**0.1 - 0.3**

B

Scientific Name	*Celtis occidentalis*		
Common Name	**Northern Hackberry**		
Collected From	Field research plots		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.61 - 2.77	Fe	202 - 550
P	**0.17 - 0.27**	**Mn**	**170 - 184**
K	0.60 - 1.75	B	28 - 45
Ca	**1.08 - 7.81**	**Cu**	**6 - 8**
Mg	0.47 - 0.53	Zn	18 - 32
S	**0.12 - 0.29**	**Mo**	**0.07 - 0.23**

C

Scientific Name	*Cercidiphyllum japonicum*		
Common Name	**Katsuratree**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.69 - 2.23	Fe	35 - 73
P	**0.15 - 0.23**	**Mn**	**29 - 156**
K	1.4 - 2.01	B	17 - 28
Ca	**1.78 - 3.24**	**Cu**	**5 - 15**
Mg	0.19 - 0.33	Zn	7 - 22
S	**0.15 - 0.21**	**Mo**	**0.09 - 0.3**

D

Scientific Name	*Cercis canadenis*		
Common Name	**Eastern Redbud**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.14 - 2.86	Fe	20 - 56
P	**0.09 - 0.82**	**Mn**	**7 - 76**
K	0.76 - 1.43	B	10 - 67
Ca	**0.72 - 2.67**	**Cu**	**2 - 8**
Mg	0.12 - 0.36	Zn	7 - 30
S	**0.16 - 0.22**	**Mo**	**0.01 - 0.45**

E

Scientific Name	*Cercis canadensis 'Flame'*		
Common Name	**Rosebud - or Double-flowered Eastern Redbud**		
Collected From	Field production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Flame'		
Macronutrients %		**Micronutrients ppm**	
N	1.87 - 2.16	Fe	36 - 63
P	**0.14 - 0.18**	**Mn**	**156 - 210**
K	0.84 - 1.74	B	16 - 31
Ca	**1.1 - 1.52**	**Cu**	**5 - 17**
Mg	0.29 - 0.34	Zn	20 - 31
S	**0.15 - 0.23**	**Mo**	**0.08 - 0.34**

F

Scientific Name	*Cercis canadensis 'Forest Pansy'*		
Common Name	**Purple-leaf Eastern Redbud**		
Collected From	Field production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Forest Pansy'		
Macronutrients %		**Micronutrients ppm**	
N	1.99 - 2.15	Fe	32 - 45
P	**0.14 - 0.17**	**Mn**	**27 - 230**
K	1.47 - 1.82	B	20 - 33
Ca	**0.50 - 0.93**	**Cu**	**3 - 9**
Mg	0.16 - 0.28	Zn	10 - 20
S	**0.12 - 0.16**	**Mo**	**0.12 - 0.30**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Cercis canadensis var. alba*
COMMON NAME	**White-flowered Eastern Redbud**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	var. alba only

Macronutrients %		Micronutrients ppm	
N	2.19 - 2.29	Fe	35 - 78
P	**0.23 - 0.37**	**Mn**	**37 - 100**
K	1.27 - 1.89	B	25 - 46
Ca	**0.89 - 1.39**	**Cu**	**5 - 11**
Mg	0.22 - 0.33	Zn	17 - 24
S	**0.18 - 0.28**	**Mo**	**0.11 - 0.24**

B

SCIENTIFIC NAME	*Cercis canandensis ssp. texensis*
COMMON NAME	**Texas Redbud**
COLLECTED FROM	Field production nursery & botanical garden/arboretum
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Oklahoma', 'Texas White'

Macronutrients %		Micronutrients ppm	
N	1.90 - 2.40	Fe	31 - 46
P	**0.13 - 0.31**	**Mn**	**31 - 130**
K	0.77 - 1.65	B	28 - 78
Ca	**1.14 - 2.00**	**Cu**	**4 - 8**
Mg	0.26 - 0.34	Zn	15 - 20
S	**0.13 - 0.18**	**Mo**	**0.12 - 0.16**

C

SCIENTIFIC NAME	*Cercis chinensis*
COMMON NAME	**Chinese Redbud**
COLLECTED FROM	Field production nursery
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Avondale'

Macronutrients %		Micronutrients ppm	
N	2.03 - 2.50	Fe	29 - 52
P	**0.2 - 0.29**	**Mn**	**43 - 88**
K	0.87 - 1.86	B	23 - 66
Ca	**1.14 - 2.27**	**Cu**	**5 - 12**
Mg	0.31 - 0.39	Zn	11 - 16
S	**0.14 - 0.22**	**Mo**	**0.1 - 0.34**

D

SCIENTIFIC NAME	*Chionanthus retusus*
COMMON NAME	**Chinese Fringetree**
COLLECTED FROM	Field production nursery
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.81 - 2.73	Fe	46 - 59
P	**0.12 - 0.18**	**Mn**	**108 - 333**
K	0.84 - 1.36	B	16 - 19
Ca	**0.93 - 1.16**	**Cu**	**3 - 18**
Mg	0.13 - 0.18	Zn	13 - 48
S	**0.18 - 0.20**	**Mo**	**0.12 - 0.30**

E

SCIENTIFIC NAME	*Chionanthus virginicus*
COMMON NAME	**White Fringetree or Grancy Graybeard**
COLLECTED FROM	Field production nursery
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.81 - 1.97	Fe	32 - 56
P	**0.11 - 0.17**	**Mn**	**25 - 38**
K	0.60 - 0.85	B	6 - 11
Ca	**0.80 - 0.89**	**Cu**	**3 - 7**
Mg	0.23 - 0.31	Zn	12 - 26
S	**0.14 - 0.16**	**Mo**	**0.12 - 0.30**

F

SCIENTIFIC NAME	*Chrysobalanus icaco*
COMMON NAME	**Coco Plum**
COLLECTED FROM	Container production nursery
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.00 - 3.00	Fe	50 - 200
P	**0.25 - 1.00**	**Mn**	**40 - 200**
K	1.00 - 2.50	B	25 - 100
Ca	**0.80 - 2.00**	**Cu**	**10 - 25**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.14 - 0.32**

Landscape and Forest Trees

A

Scientific Name	*Cladrastis kentukea*
Common Name	**American Yellowwood**
Collected From	Field production nursery & botanical garden/arboretum & field research plots
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.92 - 2.88	Fe	42 - 250
P	**0.28 - 0.78**	**Mn**	**15 - 87**
K	1.20 - 1.88	B	14 - 49
Ca	**2.02 - 3.68**	**Cu**	**4 - 14**
Mg	0.24 - 0.32	Zn	15 - 36
S	**0.11 - 0.27**	**Mo**	**0.12 - 0.30**

B

Scientific Name	*Cornus alternifolia*
Common Name	**Pagoda Dogwood**
Collected From	Botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.81 - 2.33	Fe	37 - 56
P	**0.2 - 0.33**	**Mn**	**49 - 78**
K	1.4 - 2.18	B	18 - 47
Ca	**1.68 - 2.59**	**Cu**	**5 - 15**
Mg	0.34 - 0.81	Zn	19 - 31
S	**0.23 - 0.60**	**Mo**	**0.11 - 0.45**

C

Scientific Name	*Cornus controversa*
Common Name	**Giant Dogwood**
Collected From	Botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.69 - 2.24	Fe	33 - 63
P	**0.19 - 0.60**	**Mn**	**48 - 123**
K	0.99 - 1.89	B	18 - 24
Ca	**1.25 - 2.60**	**Cu**	**4 - 13**
Mg	0.22 - 0.34	Zn	11 - 24
S	**0.22 - 0.35**	**Mo**	**0.16 - 0.37**

D

Scientific Name	*Cornus florida*
Common Name	**Flowering Dogwood**
Collected From	Field research plots
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.37 - 1.79	Fe	41 - 210
P	**0.14 - 0.18**	**Mn**	**50 - 90**
K	0.37 - 1.18	B	22 - 31
Ca	**1.60 - 4.21**	**Cu**	**5 - 17**
Mg	0.51 - 0.90	Zn	23 - 28
S	**0.26 - 0.70**	**Mo**	**0.2 - 0.43**

E

Scientific Name	*Cornus florida 'Cherokee Sunset'*
Common Name	**Variegated Flowering Dogwood**
Collected From	Botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Cherokee Sunset'

Macronutrients %		Micronutrients ppm	
N	1.91 - 2.23	Fe	34 - 62
P	**0.18 - 0.31**	**Mn**	**33 - 155**
K	0.92 - 1.78	B	21 - 44
Ca	**1.87 - 2.80**	**Cu**	**5 - 14**
Mg	0.25 - 0.34	Zn	15 - 35
S	**0.21 - 0.35**	**Mo**	**0.11 - 0.35**

F

Scientific Name	*Cornus florida cultivars*
Common Name	**Flowering Dogwood**
Collected From	Botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Barton', 'Cherokee Princess', 'Pendula', 'Plena', 'Welch's Bay Beauty'

Macronutrients %		Micronutrients ppm	
N	1.57 - 2.11	Fe	43 - 74
P	**0.20 - 0.35**	**Mn**	**27 - 63**
K	0.68 - 1.06	B	34 - 44
Ca	**2.39 - 3.17**	**Cu**	**4 - 15**
Mg	0.26 - 0.62	Zn	10 - 25
S	**0.41 - 0.58**	**Mo**	**0.12 - 0.30**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Cornus florida var. rubra cultivars*
COMMON NAME	**Pink or Red Flowering Dogwood**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	var. rubra seedlings, 'Cherokee Chief', 'Junior Miss', 'Prosser Red'

Macronutrients %		Micronutrients ppm	
N	1.71 - 2.13	Fe	45 - 126
P	**0.14 - 0.37**	**Mn**	**38 - 60**
K	0.72 - 0.99	B	40 - 52
Ca	**2.06 - 3.16**	**Cu**	**5 - 6**
Mg	0.30 - 0.56	Zn	16 - 19
S	**0.34 - 0.50**	**Mo**	**0.06 - 0.30**

B

SCIENTIFIC NAME	*Cornus kousa*
COMMON NAME	**Kousa or Japanese Flowering Dogwood**
COLLECTED FROM	Container & field production nurseries
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	1.63 - 1.94	Fe	22 - 49
P	**0.14 - 0.46**	**Mn**	**13 - 117**
K	0.77 - 1.13	B	11 - 29
Ca	**1.96 - 2.71**	**Cu**	**3 - 5**
Mg	0.23 - 0.34	Zn	10 - 17
S	**0.21 - 0.32**	**Mo**	**0.02 - 0.12**

C

SCIENTIFIC NAME	*Cornus kousa var. chinensis*
COMMON NAME	**Chinese Flowering Dogwood**
COLLECTED FROM	Container & field production nurseries & botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	var. chinensis, 'Milky Way', 'Morning Star'

Macronutrients %		Micronutrients ppm	
N	1.32 - 1.95	Fe	47 - 60
P	**0.13 - 0.15**	**Mn**	**25 - 96**
K	0.62 - 1.49	B	11 - 102
Ca	**2.05 - 2.78**	**Cu**	**2 - 19**
Mg	0.24 - 0.43	Zn	13 - 19
S	**0.18 - 0.42**	**Mo**	**0.12 - 0.35**

D

SCIENTIFIC NAME	*Cornus mas*
COMMON NAME	**Cornelian Cherry**
COLLECTED FROM	Container production nurseries & botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.63 - 2.07	Fe	28 - 106
P	**0.11 - 0.45**	**Mn**	**9 - 32**
K	1.00 - 1.45	B	38 - 100
Ca	**2.08 - 2.45**	**Cu**	**3 - 6**
Mg	0.30 - 0.37	Zn	26 - 30
S	**0.25 - 0.30**	**Mo**	**0.13 - 0.16**

E

SCIENTIFIC NAME	*Cornus officinalis*
COMMON NAME	**Japanese Cornel**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.47 - 1.98	Fe	41 - 59
P	**0.14 - 0.19**	**Mn**	**44 - 66**
K	1.62 - 1.86	B	33 - 82
Ca	**1.12 - 1.59**	**Cu**	**5 - 15**
Mg	0.3 - 0.39	Zn	15 - 27
S	**0.15 - 0.27**	**Mo**	**0.1 - 0.33**

F

SCIENTIFIC NAME	*Corylus americana*
COMMON NAME	**American Filbert**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.43 - 2.23	Fe	33 - 75
P	**0.11 - 0.28**	**Mn**	**55 - 1894**
K	0.67 - 2.38	B	32 - 55
Ca	**1.11 - 2.23**	**Cu**	**5 - 15**
Mg	0.37 - 0.59	Zn	21 - 34
S	**0.13 - 0.21**	**Mo**	**0.14 - 0.45**

Landscape and Forest Trees

A

Scientific Name	*Corylus maxima 'Purpurea'*		
Common Name	**Purple-leaf Giant Filbert**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Purpurea'		
Macronutrients %		**Micronutrients ppm**	
N	2.12 - 2.48	Fe	42 - 159
P	**0.11 - 0.15**	**Mn**	**205 - 298**
K	1.18 - 1.86	B	34 - 104
Ca	**0.99 - 1.86**	**Cu**	**5 - 7**
Mg	0.23 - 0.35	Zn	22 - 37
S	**0.15 - 0.22**	**Mo**	**0.06 - 0.12**

B

Scientific Name	*Cotinus coggygria cultivars*		
Common Name	**Purple Smoketree or Smokebush**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Foliis Purpureis', 'Royal Purple'		
Macronutrients %		**Micronutrients ppm**	
N	2.08 - 2.27	Fe	66 - 72
P	**0.15 - 0.16**	**Mn**	**26 - 40**
K	1.21 - 1.29	B	131 - 148
Ca	**1.86 - 2.76**	**Cu**	**4 - 5**
Mg	0.19 - 0.24	Zn	10 - 11
S	**0.17 - 0.20**	**Mo**	**0.06 - 0.20**

C

Scientific Name	*Cotinus obovatus*		
Common Name	**American Smoketree**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.77 - 2.35	Fe	34 - 74
P	**0.14 - 0.24**	**Mn**	**22 - 89**
K	0.88 - 2.01	B	33 - 78
Ca	**2.12 - 3.15**	**Cu**	**4 - 11**
Mg	0.33 - 0.41	Zn	17 - 29
S	**0.14 - 0.22**	**Mo**	**0.1 - 0.2**

D

Scientific Name	*Crataegus phaenopyrum*		
Common Name	**Washington Hawthorn**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.32 - 1.48	Fe	40 - 158
P	**0.21 - 0.26**	**Mn**	**45 - 75**
K	0.74 - 1.05	B	14 - 21
Ca	**1.38 - 2.24**	**Cu**	**6 - 14**
Mg	0.29 - 0.33	Zn	23 - 29
S	**0.11 - 0.15**	**Mo**	**0.05 - 1.14**

E

Scientific Name	*Cupaniopsis anacardiopsis*		
Common Name	**Carrotwood**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.85 - 2.23	Fe	38 - 132
P	**0.14 - 0.25**	**Mn**	**45 - 153**
K	1.01 - 2.11	B	13 - 28
Ca	**0.91 - 1.45**	**Cu**	**3 - 9**
Mg	0.21 - 0.31	Zn	13 - 24
S	**0.14 - 0.21**	**Mo**	**0.43 - 1.77**

F

Scientific Name	*Diospyros virginiana*		
Common Name	**Common Persimmon**		
Collected From	Botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.24 - 2.28	Fe	51 - 210
P	**0.12 - 0.14**	**Mn**	**220 - 812**
K	1.26 - 1.98	B	24 - 86
Ca	**1.63 - 2.19**	**Cu**	**5 - 5**
Mg	0.36 - 0.74	Zn	19 - 36
S	**0.18 - 0.27**	**Mo**	**0.1 - 0.12**

Landscape and Forest Trees

A

Scientific Name	*Eucalyptus deglupta*		
Common Name	**Mindanao Gum or Bagras**		
Collected From	Field research plots		
Plant Part	30 mature leaves from previous year's growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.20 - 3.36	Fe	44 - 77
P	**0.10 - 0.69**	**Mn**	**45 - 143**
K	0.44 - 1.78	B	15 - 28
Ca	**0.46 - 1.40**	**Cu**	**7 - 15**
Mg	0.13 - 0.42	Zn	17 - 25
S	**0.18 - 0.23**	**Mo**	**0.09 - 0.19**

B

Scientific Name	*Eucalyptus globulus*		
Common Name	**Southern or Tasmanian Blue Gum**		
Collected From	Field research plots		
Plant Part	30 mature leaves from new growth		
Season	Late summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.15 - 1.21	Fe	88 - 120
P	**0.14 - 0.21**	**Mn**	**855 - 1041**
K	0.54 - 0.72	B	14 - 28
Ca	**1.90 - 2.30**	**Cu**	**8 - 11**
Mg	0.25 - 0.29	Zn	16 - 18
S	**0.16 - 0.24**	**Mo**	**0.07 - 0.23**

C

Scientific Name	*Eucalyptus grandis*		
Common Name	**Rose Gum**		
Collected From	Field research plots		
Plant Part	30 mature leaves from new growth		
Season	Late summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.05 - 1.49	Fe	41 - 69
P	**0.14 - 0.30**	**Mn**	**54 - 177**
K	1.29 - 1.68	B	15 - 31
Ca	**0.87 - 1.26**	**Cu**	**5 - 15**
Mg	0.28 - 0.37	Zn	21 - 32
S	**0.21 - 0.26**	**Mo**	**0.09 - 0.32**

D

Scientific Name	*Fagus grandifolia*		
Common Name	**American Beech**		
Collected From	Botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.69 - 2.35	Fe	29 - 222
P	**0.09 - 0.23**	**Mn**	**236 - 565**
K	0.55 - 0.68	B	35 - 47
Ca	**0.63 - 1.03**	**Cu**	**10 - 20**
Mg	0.13 - 0.34	Zn	19 - 41
S	**0.17 - 0.20**	**Mo**	**0.06 - 1.9**

E

Scientific Name	*Fagus grandifolia*		
Common Name	**American Beech**		
Collected From	Field research plots		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.72 - 2.85	Fe	84 - 222
P	**0.11 - 0.23**	**Mn**	**236 - 435**
K	0.68 - 1.55	B	20 - 47
Ca	**0.40 - 1.03**	**Cu**	**10 - 20**
Mg	0.17 - 0.34	Zn	22 - 41
S	**0.17 - 0.22**	**Mo**	**0.06 - 1.9**

F

Scientific Name	*Fagus sylvatica*		
Common Name	**European Beech**		
Collected From	Field research plots		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.50	Fe	58 - 190
P	**0.06 - 0.20**	**Mn**	**250 - 931**
K	0.53 - 0.84	B	18 - 40
Ca	**0.55 - 1.10**	**Cu**	**4 - 11**
Mg	0.13 - 0.36	Zn	18 - 30
S	**0.18 - 0.25**	**Mo**	**0.03 - 0.09**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Fagus sylvatica 'Pendula'*		
COMMON NAME	**Weeping European Beech**		
COLLECTED FROM	Container production nursery		
PLANT PART	20 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Pendula'		
Macronutrients %		**Micronutrients ppm**	
N	2.01 - 2.55	Fe	32 - 65
P	**0.11 - 0.17**	**Mn**	**58 - 176**
K	0.51 - 1.75	B	20 - 61
Ca	**0.99 - 1.23**	**Cu**	**5 - 11**
Mg	0.24 - 0.36	Zn	19 - 31
S	**0.16 - 0.22**	**Mo**	**0.44 - 1.42**

B

SCIENTIFIC NAME	*Firmiana simplex*		
COMMON NAME	**Chinese Parasol Tree**		
COLLECTED FROM	Botanical garden/conservatory		
PLANT PART	5 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.11 - 3.15	Fe	41 - 119
P	**0.2 - 0.29**	**Mn**	**44 - 181**
K	1.78 - 2.27	B	27 - 102
Ca	**1.89 - 3.74**	**Cu**	**4 - 9**
Mg	0.41 - 0.77	Zn	14 - 22
S	**0.18 - 0.21**	**Mo**	**0.1 - 0.27**

C

SCIENTIFIC NAME	*Franklinia alatamaha*		
COMMON NAME	**Franklin Tree or Lost Gordonia**		
COLLECTED FROM	Botanical garden/conservatory		
PLANT PART	20 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2 - 2.24	Fe	32 - 65
P	**0.1 - 0.16**	**Mn**	**56 - 384**
K	1.1 - 2.14	B	20 - 29
Ca	**0.38 - 1.66**	**Cu**	**4 - 12**
Mg	0.17 - 0.34	Zn	13 - 24
S	**0.16 - 0.23**	**Mo**	**0.1 - 0.32**

D

SCIENTIFIC NAME	*Fraxinus american*		
COMMON NAME	**White Ash**		
COLLECTED FROM	Field research plots		
PLANT PART	10 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	0.72 - 2.86	Fe	91 - 173
P	**0.16 - 0.48**	**Mn**	**38 - 111**
K	0.80 - 2.01	B	23 - 38
Ca	**0.94 - 2.39**	**Cu**	**11 - 19**
Mg	0.25 - 0.41	Zn	15 - 21
S	**0.15 - 0.29**	**Mo**	**0.11 - 2.2**

E

SCIENTIFIC NAME	*Fraxinus nigra*		
COMMON NAME	**Black Ash**		
COLLECTED FROM	Field research plots		
PLANT PART	10 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.83 - 2.32	Fe	45 - 288
P	**0.17 - 0.29**	**Mn**	**43 - 96**
K	1.78 - 2.70	B	19 - 29
Ca	**1.45 - 2.01**	**Cu**	**7 - 20**
Mg	0.28 - 0.47	Zn	22 - 32
S	**0.17 - 0.27**	**Mo**	**0.13 - 2.7**

F

SCIENTIFIC NAME	*Fraxinus pennsylvanica*		
COMMON NAME	**Green Ash**		
COLLECTED FROM	Field research plots		
PLANT PART	10 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.93 - 2.13	Fe	42 - 105
P	**0.17 - 0.37**	**Mn**	**44 - 71**
K	0.95 - 2.70	B	48 - 59
Ca	**1.15 - 2.01**	**Cu**	**13 - 17**
Mg	0.22 - 0.47	Zn	21 - 32
S	**0.19 - 0.24**	**Mo**	**0.14 - 2.0**

Landscape and Forest Trees

A

SCIENTIFIC NAME			*Fraxinus pennsylvanica*
COMMON NAME			**Green Ash**
COLLECTED FROM			Field production nursery & botanical garden/arboretum
PLANT PART			10 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species, 'Summit'
Macronutrients %		**Micronutrients ppm**	
N	1.97 - 2.68	Fe	48 - 51
P	**0.15 - 0.25**	**Mn**	**24 - 75**
K	0.92 - 1.50	B	17 - 82
Ca	**0.61 - 1.57**	**Cu**	**13 - 18**
Mg	0.29 - 0.49	Zn	9 - 28
S	**0.20 - 0.27**	**Mo**	**0.12 - 0.30**

B

SCIENTIFIC NAME			*Fraxinus quadrangulata*
COMMON NAME			**Blue Ash**
COLLECTED FROM			Field research plots
PLANT PART			10 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.81 - 2.28	Fe	55 - 360
P	**0.22 - 0.42**	**Mn**	**43 - 80**
K	1.11 - 1.69	B	13 - 23
Ca	**1.16 - 1.98**	**Cu**	**4 - 13**
Mg	0.28 - 0.30	Zn	24 - 34
S	**0.11 - 0.18**	**Mo**	**0.13 - 0.25**

C

SCIENTIFIC NAME			*Fraxinus sieboldiana*
COMMON NAME			**Japanese Flowering Ash**
COLLECTED FROM			Field production nursery
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 2.26	Fe	37 - 72
P	**0.15 - 0.19**	**Mn**	**45 - 157**
K	1.3 - 1.96	B	13 - 44
Ca	**0.74 - 1.36**	**Cu**	**4 - 11**
Mg	0.17 - 0.37	Zn	17 - 32
S	**0.17 - 0.26**	**Mo**	**0.05 - 0.21**

D

SCIENTIFIC NAME			*Gleditsia triacanthos var. inermis*
COMMON NAME			**Thornless Honeylocust**
COLLECTED FROM			Field production nursery
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			var. inermis seedlings, 'Moraine'
Macronutrients %		**Micronutrients ppm**	
N	2.40 - 3.95	Fe	35 - 106
P	**0.15 - 0.32**	**Mn**	**68 - 273**
K	1.10 - 2.65	B	16 - 28
Ca	**0.67 - 3.75**	**Cu**	**3 - 6**
Mg	0.22 - 0.35	Zn	17 - 25
S	**0.21 - 0.26**	**Mo**	**0.12 - 0.30**

E

SCIENTIFIC NAME			*Gordonia lasianthus*
COMMON NAME			**Loblolly Bay**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.2 - 2.14	Fe	29 - 72
P	**0.13 - 0.21**	**Mn**	**221 - 592**
K	0.72 - 1.87	B	18 - 33
Ca	**0.87 - 1.24**	**Cu**	**2 - 12**
Mg	0.21 - 0.36	Zn	8 - 21
S	**0.11 - 0.17**	**Mo**	**0.11 - 0.42**

F

SCIENTIFIC NAME			*Gymnocladus dioica*
COMMON NAME			**Kentucky Coffeetree**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			5 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.02 - 2.81	Fe	34 - 57
P	**0.23 - 0.34**	**Mn**	**7 - 79**
K	1.35 - 2.05	B	21 - 89
Ca	**1.62 - 2.46**	**Cu**	**5 - 16**
Mg	0.18 - 0.29	Zn	19 - 29
S	**0.14 - 0.19**	**Mo**	**0.06 - 0.21**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Halesia tetraptera*		
COMMON NAME	**Carolina Silverbell or Snowdrop Tree**		
COLLECTED FROM	Field production nursery & botanical garden/arboretum		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.14 - 3.12	Fe	51 - 66
P	**0.13 - 0.22**	**Mn**	**108 - 713**
K	1.25 - 1.80	B	8 - 46
Ca	**0.45 - 1.27**	**Cu**	**3 - 13**
Mg	0.14 - 0.37	Zn	12 - 17
S	**0.18 - 0.24**	**Mo**	**0.12 - 0.30**

B

SCIENTIFIC NAME	*Idesia polycarpa*		
COMMON NAME	**Igiri Tree**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	10 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.97 - 2.28	Fe	39 - 56
P	**0.14 - 0.22**	**Mn**	**221 - 399**
K	1.59 - 2.11	B	26 - 57
Ca	**1.22 - 1.81**	**Cu**	**5 - 9**
Mg	0.33 - 0.44	Zn	13 - 22
S	**0.19 - 0.37**	**Mo**	**0.1 - 0.37**

C

SCIENTIFIC NAME	*Juglans nigra*		
COMMON NAME	**Black Walnut**		
COLLECTED FROM	Field production nursery & botanical garden/arboretum		
PLANT PART	5 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.47 - 2.98	Fe	69 - 129
P	**0.16 - 0.24**	**Mn**	**207 - 274**
K	1.32 - 1.47	B	66 - 81
Ca	**1.9 - 2.01**	**Cu**	**10 - 12**
Mg	0.51 - 0.64	Zn	33 - 55
S	**0.15 - 0.21**	**Mo**	**0.12 - 0.3**

D

SCIENTIFIC NAME	*Koelreuteria bipinnata*		
COMMON NAME	**Pink or Bougainvillea Goldenraintree**		
COLLECTED FROM	Field production nursery & botanical garden/arboretum		
PLANT PART	10 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.28 - 2.62	Fe	63 - 71
P	**0.18 - 0.20**	**Mn**	**47 - 90**
K	1.14 - 1.44	B	26 - 88
Ca	**1.68 - 2.28**	**Cu**	**5 - 7**
Mg	0.29 - 0.31	Zn	11 - 12
S	**0.22 - 0.23**	**Mo**	**0.9 - 0.30**

E

SCIENTIFIC NAME	*Koelreuteria paniculata*		
COMMON NAME	**Panicled Goldenraintree**		
COLLECTED FROM	Field production nursery		
PLANT PART	15 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species, 'Fastigiata'		
Macronutrients %		**Micronutrients ppm**	
N	2.45 - 2.75	Fe	48 - 64
P	**0.21 - 0.26**	**Mn**	**49 - 96**
K	0.97 - 1.37	B	15 - 18
Ca	**0.68 - 0.95**	**Cu**	**4 - 9**
Mg	0.21 - 0.22	Zn	13 - 17
S	**0.21 - 0.23**	**Mo**	**0.12 - 0.30**

F

SCIENTIFIC NAME	*Lagerstroemia 'Natchez'*		
COMMON NAME	**Natchez' Hybrid Crepe Myrtle**		
COLLECTED FROM	Field production nursery		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Natchez'		
Macronutrients %		**Micronutrients ppm**	
N	2.11 - 2.76	Fe	45 - 134
P	**0.13 - 0.19**	**Mn**	**179 - 573**
K	1.13 - 2.07	B	17 - 28
Ca	**0.96 - 1.75**	**Cu**	**8 - 16**
Mg	0.33 - 0.45	Zn	18 - 28
S	**0.21 - 0.27**	**Mo**	**0.11 - 0.34**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Lagerstroemia (dwarf) cultivars*
COMMON NAME	**Dwarf Hybrid Crepe Myrtles**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Ocmulgee', 'Victor'

Macronutrients %		Micronutrients ppm	
N	2.29 - 2.44	Fe	55 - 114
P	**0.18 - 0.20**	**Mn**	**165 - 712**
K	0.90 - 2.01	B	74 - 79
Ca	**1.69 - 2.34**	**Cu**	**5 - 11**
Mg	0.32 - 0.58	Zn	14 - 37
S	**0.21 - 0.23**	**Mo**	**0.12 - 0.15**

B

SCIENTIFIC NAME	*Lagerstroemia (semi-dwarf) cultivars*
COMMON NAME	**Semi-dwarf Hybrid Crepe Myrtles**
COLLECTED FROM	Field production nursery & botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Acoma', 'Hopi', 'Pecos', 'Zuni'

Macronutrients %		Micronutrients ppm	
N	2.12 - 2.44	Fe	42 - 138
P	**0.16 - 0.23**	**Mn**	**368 - 572**
K	0.80 - 1.28	B	11 - 92
Ca	**0.64 - 2.65**	**Cu**	**3 - 6**
Mg	0.23 - 0.57	Zn	17 - 61
S	**0.20 - 0.34**	**Mo**	**0.12 - 1.25**

C

SCIENTIFIC NAME	*Lagerstroemia cultivars*
COMMON NAME	**Hybrid Crepe Myrtles**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Apalachee', 'Biloxi', 'Lipan', 'Miami', 'Osage', 'Sioux', 'Tuscarora', 'Tuskegee', 'Wichita'

Macronutrients %		Micronutrients ppm	
N	1.69 - 2.54	Fe	47 - 134
P	**0.15 - 0.29**	**Mn**	**221 - 828**
K	0.65 - 1.28	B	22 - 126
Ca	**1.13 - 3.10**	**Cu**	**2 - 18**
Mg	0.28 - 0.65	Zn	14 - 151
S	**0.17 - 0.48**	**Mo**	**0.12 - 0.30**

D

SCIENTIFIC NAME	*Lagerstroemia fauriei*
COMMON NAME	**Japanese Crepe Myrtle**
COLLECTED FROM	Field production nursery
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Fantasy'

Macronutrients %		Micronutrients ppm	
N	1.45 - 2.72	Fe	43 - 147
P	**0.15 - 0.22**	**Mn**	**234 - 697**
K	0.85 - 1.79	B	20 - 39
Ca	**1.68 - 2.94**	**Cu**	**5 - 9**
Mg	0.33 - 0.55	Zn	27 - 73
S	**0.19 - 0.27**	**Mo**	**0.1 - 0.33**

E

SCIENTIFIC NAME	*Lagerstroemia indica 'Carolina Beauty'*
COMMON NAME	**Carolina Beauty' Crepe Myrtle**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Carolina Beauty'

Macronutrients %		Micronutrients ppm	
N	2.01 - 2.32	Fe	38 - 122
P	**0.21 - 0.31**	**Mn**	**52 - 508**
K	1.61 - 2.46	B	18 - 32
Ca	**0.67 - 1.25**	**Cu**	**5 - 13**
Mg	0.33 - 0.46	Zn	33 - 205
S	**0.15 - 0.21**	**Mo**	**0.15 - 0.25**

F

SCIENTIFIC NAME	*Lagerstroemia indica cultivars*
COMMON NAME	**Indian or Common Crepe Myrtle**
COLLECTED FROM	Container & field production nurseries & botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Catawba', 'Hardy Lavender', 'Peppermint Lace'

Macronutrients %		Micronutrients ppm	
N	1.56 - 2.06	Fe	43 - 109
P	**0.11 - 0.23**	**Mn**	**105 - 708**
K	0.45 - 1.53	B	37 - 65
Ca	**1.12 - 2.10**	**Cu**	**7 - 25**
Mg	0.43 - 0.72	Zn	35 - 194
S	**0.14 - 0.27**	**Mo**	**0.10 - 0.12**

Landscape and Forest Trees

A

Scientific Name	*Liquidambar formosana*
Common Name	**Formosan Sweet Gum**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.5 - 2.25	Fe	37 - 78
P	**0.15 - 0.24**	**Mn**	**55 - 239**
K	0.53 - 1.86	B	32 - 100
Ca	**1.35 - 2.11**	**Cu**	**3 - 9**
Mg	0.31 - 0.53	Zn	17 - 31
S	**0.1 - 0.19**	**Mo**	**0.1 - 0.34**

B

Scientific Name	*Liquidambar styraciflua*
Common Name	**Sweet Gum**
Collected From	Field production nursery & botanical garden/arboretum & field research plots
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Burgundy', 'Palo Alto'

Macronutrients %		Micronutrients ppm	
N	1.50 - 2.02	Fe	37 - 200
P	**0.13 - 0.35**	**Mn**	**476 - 700**
K	0.40 - 0.85	B	7 - 51
Ca	**0.68 - 1.97**	**Cu**	**1 - 9**
Mg	0.22 - 0.43	Zn	27 - 39
S	**0.10 - 0.16**	**Mo**	**0.12 - 0.30**

C

Scientific Name	*Liquidambar styraciflua 'Rotundiloba'*
Common Name	
Collected From	Field production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Rotundiloba'

Macronutrients %		Micronutrients ppm	
N	1.94 - 2.14	Fe	44 - 60
P	**0.13 - 0.16**	**Mn**	**450 - 540**
K	0.52 - 0.61	B	14 - 18
Ca	**0.52 - 0.73**	**Cu**	**1 - 5**
Mg	0.19 - 0.25	Zn	25 - 30
S	**0.16 - 0.17**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Liriodendron tulipifera*
Common Name	**Tuliptree or Tulip or Yellow Poplar**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.31 - 3.20	Fe	67 - 79
P	**0.15 - 0.17**	**Mn**	**85 - 101**
K	0.62 - 0.92	B	35 - 46
Ca	**1.66 - 3.00**	**Cu**	**9 - 28**
Mg	0.30 - 0.33	Zn	13 - 22
S	**0.17 - 0.20**	**Mo**	**0.24 - 1.61**

E

Scientific Name	*Liriodendron tulipifera*
Common Name	**Tuliptree or Tulip or Yellow Poplar**
Collected From	Field research plots
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.90 - 4.28	Fe	122 - 280
P	**0.10 - 0.34**	**Mn**	**90 - 471**
K	0.86 - 2.00	B	25 - 72
Ca	**1.39 - 3.52**	**Cu**	**5 - 10**
Mg	0.21 - 0.61	Zn	28 - 32
S	**0.18 - 0.37**	**Mo**	**0.45 - 1.20**

F

Scientific Name	*Liriodendron tulipifera 'Arnold'*
Common Name	**Upright or Columnar Tuliptree**
Collected From	Field production nursery & botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Arnold'

Macronutrients %		Micronutrients ppm	
N	2.30 - 2.66	Fe	50 - 60
P	**0.13 - 0.20**	**Mn**	**40 - 318**
K	0.83 - 1.39	B	27 - 38
Ca	**1.46 - 2.78**	**Cu**	**5 - 7**
Mg	0.23 - 0.28	Zn	14 - 18
S	**0.18 - 0.20**	**Mo**	**0.08 - 0.44**

Landscape and Forest Trees

A

Scientific Name	*Liriodendron tulipifera 'Aureomarginata'*		
Common Name	**Variegated Tuliptree**		
Collected From	Container production nursery		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Aureomarginata'		
Macronutrients %		**Micronutrients ppm**	
N	2.15 - 3.23	Fe	38 - 82
P	**0.12 - 0.19**	**Mn**	**87 - 117**
K	1.16 - 1.87	B	20 - 47
Ca	**1.11 - 1.49**	**Cu**	**5 - 12**
Mg	0.29 - 0.35	Zn	15 - 26
S	**0.18 - 0.21**	**Mo**	**0.5 - 1.40**

B

Scientific Name	*Maackia amurensis*		
Common Name	**Amur Maackia**		
Collected From	Field production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.29 - 3.08	Fe	37 - 68
P	**0.18 - 0.21**	**Mn**	**55 - 305**
K	1.49 - 2.11	B	24 - 50
Ca	**0.87 - 1.30**	**Cu**	**5 - 15**
Mg	0.28 - 0.39	Zn	22 - 34
S	**0.19 - 0.25**	**Mo**	**0.1 - 0.3**

C

Scientific Name	*Maclura pomifera*		
Common Name	**Osage Orange or Hedge-apple or Bois d'Arc**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.62 - 2.23	Fe	41 - 79
P	**0.15 - 0.21**	**Mn**	**28 - 76**
K	1.78 - 2.22	B	38 - 81
Ca	**2.22 - 4.86**	**Cu**	**5 - 14**
Mg	0.32 - 0.45	Zn	17 - 27
S	**0.18 - 0.23**	**Mo**	**0.09 - 0.37**

D

Scientific Name	*Magnolia acuminata*		
Common Name	**Cucumbertree Magnolia**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.82 - 2.53	Fe	37 - 67
P	**0.12 - 0.15**	**Mn**	**55 - 163**
K	1.13 - 2.23	B	28 - 79
Ca	**1.45 - 2.13**	**Cu**	**5 - 16**
Mg	0.3 - 0.38	Zn	12 - 21
S	**0.17 - 0.23**	**Mo**	**0.09 - 0.23**

E

Scientific Name	*Magnolia ashei*		
Common Name	**Ashe or Dwarf Bigleaf Magnolia**		
Collected From	Botanical garden/arboretum		
Plant Part	3 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.37	Fe	38 - 115
P	**0.12 - 0.21**	**Mn**	**41 - 114**
K	1.68 - 1.90	B	21 - 36
Ca	**1.12 - 1.63**	**Cu**	**5 - 14**
Mg	0.36 - 0.45	Zn	18 - 29
S	**0.15 - 0.22**	**Mo**	**0.1 - 0.2**

F

Scientific Name	*Magnolia denudata*		
Common Name	**Yulan Magnolia**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 2.78	Fe	45 - 62
P	**0.14 - 0.19**	**Mn**	**163 - 726**
K	1.38 - 1.66	B	28 - 117
Ca	**0.85 - 2.12**	**Cu**	**5 - 7**
Mg	0.26 - 0.39	Zn	12 - 15
S	**0.16 - 0.20**	**Mo**	**0.12 - 0.30**

Landscape and Forest Trees

A

Scientific Name	*Magnolia fraseri*
Common Name	**Fraser Magnolia**
Collected From	Botanical garden/arboretum
Plant Part	3 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.75 - 2.25	Fe	34 - 74
P	**0.13 - 0.23**	**Mn**	**65 - 483**
K	1.25 - 2.34	B	19 - 31
Ca	**1.14 - 1.61**	**Cu**	**4 - 13**
Mg	0.31 - 0.35	Zn	11 - 25
S	**0.2 - 0.39**	**Mo**	**0.1 - 0.32**

B

Scientific Name	*Magnolia grandiflora 'Little Gem'*
Common Name	**Little Gem' Southern Magnolia**
Collected From	Field production nursery
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Little Gem'

Macronutrients %		Micronutrients ppm	
N	1.62 - 2.12	Fe	37 - 74
P	**0.14 - 0.2**	**Mn**	**131 - 197**
K	0.61 - 1.88	B	10 - 25
Ca	**0.63 - 1.46**	**Cu**	**4 - 14**
Mg	0.14 - 0.29	Zn	15 - 25
S	**0.15 - 0.21**	**Mo**	**0.1 - 0.31**

C

Scientific Name	*Magnolia grandiflora 'MGTIG' ('Greenback')*
Common Name	**Greenback' Southern Magnolia**
Collected From	Field production nursery
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'MGTIG' ('Greenback')

Macronutrients %		Micronutrients ppm	
N	1.91 - 2.31	Fe	26 - 66
P	**0.13 - 0.21**	**Mn**	**45 - 59**
K	0.93 - 1.94	B	13 - 28
Ca	**0.24 - 1.25**	**Cu**	**5 - 10**
Mg	0.17 - 0.37	Zn	18 - 25
S	**0.16 - 0.23**	**Mo**	**0.1 - 0.34**

D

Scientific Name	*Magnolia grandiflora 'Select #3'*
Common Name	**Select #3' Southern Magnolia**
Collected From	Field production nursery
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Select #3'

Macronutrients %		Micronutrients ppm	
N	1.71 - 2.19	Fe	27 - 31
P	**0.12 - 0.22**	**Mn**	**196 - 227**
K	1.04 - 1.10	B	10 - 15
Ca	**0.35 - 0.40**	**Cu**	**6 - 10**
Mg	0.17 - 0.20	Zn	7 - 19
S	**0.12 - 0.18**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Magnolia grandiflora 'Victoria'*
Common Name	**Victoria' Southern Magnolia**
Collected From	Field production nursery
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Victoria'

Macronutrients %		Micronutrients ppm	
N	1.73 - 2.35	Fe	39 - 72
P	**0.1 - 0.18**	**Mn**	**203 - 860**
K	0.91 - 1.88	B	15 - 28
Ca	**0.68 - 1.23**	**Cu**	**5 - 16**
Mg	0.22 - 0.33	Zn	9 - 24
S	**0.12 - 0.19**	**Mo**	**0.11 - 0.33**

F

Scientific Name	*Magnolia grandiflora cultivars*
Common Name	**Southern Magnolia**
Collected From	Field production nursery & botanical garden/arboretum
Plant Part	10 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Claudia Wannamaker', 'D.D. Blanchard', 'Glen St. Mary', 'Majestic Beauty', 'Phyllis Barow', 'Russet'

Macronutrients %		Micronutrients ppm	
N	1.15 - 2.43	Fe	20–52
P	**0.09 - 0.28**	**Mn**	**50–585**
K	0.65 - 1.30	B	11–21
Ca	**0.20 - 0.84**	**Cu**	**3–10**
Mg	0.12 - 0.29	Zn	7–22
S	**0.12 - 0.20**	**Mo**	**0.05 - 0.12**

Landscape and Forest Trees

A

Scientific Name	*Magnolia kobus*		
Common Name	**Kobus Magnolia**		
Collected From	Botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, var. boealis		
Macronutrients %		**Micronutrients ppm**	
N	2.30 - 2.83	Fe	51 - 65
P	**0.13 - 0.15**	**Mn**	**233 - 585**
K	1.04 - 2.10	B	89 - 96
Ca	**2.15 - 2.43**	**Cu**	**5 - 9**
Mg	0.29 - 0.33	Zn	10 - 12
S	**0.18 - 0.20**	**Mo**	**0.12 - 0.30**

B

Scientific Name	*Magnolia liliiflora*		
Common Name	**Lily Magnolia**		
Collected From	Botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.42 - 2.01	Fe	34–57
P	**0.14 - 0.17**	**Mn**	**101–213**
K	1.75 - 2.15	B	31–71
Ca	**1.14 - 1.81**	**Cu**	**5–11**
Mg	0.26 - 0.34	Zn	16–26
S	**0.16 - 0.23**	**Mo**	**0.13 - 0.27**

C

Scientific Name	*Magnolia macrophylla*		
Common Name	**Bigleaf Magnolia**		
Collected From	Field production nursery & botanical garden/arboretum & field research plots		
Plant Part	3 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.74 - 2.94	Fe	53 - 280
P	**0.18 - 0.20**	**Mn**	**191 - 654**
K	1.04 - 1.33	B	11 - 30
Ca	**1.00 - 2.38**	**Cu**	**6 - 11**
Mg	0.28 - 0.33	Zn	15 - 28
S	**0.20 - 0.25**	**Mo**	**0.09 - 0.30**

D

Scientific Name	*Magnolia stellata*		
Common Name	**Star Magnolia**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Royal Star'		
Macronutrients %		**Micronutrients ppm**	
N	2.02 - 2.18	Fe	41 - 77
P	**0.10 - 0.28**	**Mn**	**140 - 148**
K	0.99 - 1.47	B	55 - 79
Ca	**1.52 - 1.77**	**Cu**	**9 - 15**
Mg	0.18 - 0.27	Zn	12 - 14
S	**0.17 - 0.19**	**Mo**	**0.12 - 1.37**

E

Scientific Name	*Magnolia tripetala*		
Common Name	**Umbrella Magnolia**		
Collected From	Botanical garden/arboretum		
Plant Part	3 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.19 - 2.33	Fe	43 - 132
P	**0.21 - 0.30**	**Mn**	**55 - 340**
K	2.18 - 2.75	B	21 - 36
Ca	**1.48 - 1.89**	**Cu**	**5 - 12**
Mg	0.29 - 0.39	Zn	14 - 24
S	**0.18 - 0.27**	**Mo**	**0.09 - 0.36**

F

Scientific Name	*Magnolia virginiana*		
Common Name	**Sweet Bay or Swamp Magnolia**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.06 - 3.64	Fe	39 - 52
P	**0.11 - 0.31**	**Mn**	**111 - 496**
K	0.61 - 1.66	B	11 - 47
Ca	**0.50 - 2.25**	**Cu**	**3 - 13**
Mg	0.12 - 0.25	Zn	11 - 28
S	**0.15 - 0.26**	**Mo**	**0.06 - 0.20**

Landscape and Forest Trees

A

Scientific Name	*Magnolia x 'Elizabeth'*		
Common Name	**Yellow-flowered Magnolia**		
Collected From	Field production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Elizabeth'		
Macronutrients %		**Micronutrients ppm**	
N	2.21 - 2.70	Fe	36 - 62
P	**0.14 - 0.19**	**Mn**	**89 - 729**
K	1.48 - 2.13	B	14 - 23
Ca	**0.99 - 1.3**	**Cu**	**5 - 12**
Mg	0.27 - 0.31	Zn	18 - 26
S	**0.17 - 0.22**	**Mo**	**0.14 - 0.34**

B

Scientific Name	*Magnolia x 'Galaxy' and 'Spectrum'*		
Common Name	**Galaxy' and 'Spectrum' Magnolias**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Galaxy', 'Spectrum'		
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.44	Fe	46 - 70
P	**0.14 - 0.22**	**Mn**	**236 - 426**
K	1.34 - 1.61	B	38 - 124
Ca	**1.15 - 2.07**	**Cu**	**6 - 16**
Mg	0.36 - 0.37	Zn	12 - 15
S	**0.18 - 0.23**	**Mo**	**0.12 - 0.30**

C

Scientific Name	*Magnolia x 'Jane'*		
Common Name	**Jane' (Little Girl) Magnolia**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Jane'		
Macronutrients %		**Micronutrients ppm**	
N	2.18 - 3.29	Fe	42 - 63
P	**0.14 - 0.28**	**Mn**	**388 - 629**
K	1.55 - 2.65	B	32 - 96
Ca	**1.15 - 2.04**	**Cu**	**9 - 13**
Mg	0.18 - 0.25	Zn	15 - 22
S	**0.16 - 0.21**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Magnolia x 'Pink Stardust'*		
Common Name	**Pink Stardust' Magnolia**		
Collected From	Field production nursery		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Pink Stardust'		
Macronutrients %		**Micronutrients ppm**	
N	2.75 - 3.18	Fe	58 - 103
P	**0.16 - 0.19**	**Mn**	**382 - 854**
K	1.09 - 1.55	B	30 - 45
Ca	**1.00 - 1.48**	**Cu**	**12 - 15**
Mg	0.21 - 0.30	Zn	12 - 14
S	**0.22 - 0.23**	**Mo**	**0.06 - 0.75**

E

Scientific Name	*Magnolia x 'White Stardust'*		
Common Name	**White Stardust' Magnolia**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'White Stardust'		
Macronutrients %		**Micronutrients ppm**	
N	1.79 - 2.78	Fe	44 - 74
P	**0.13 - 0.16**	**Mn**	**485 - 658**
K	0.97 - 1.48	B	17 - 59
Ca	**1.00 - 1.75**	**Cu**	**7 - 9**
Mg	0.17 - 0.24	Zn	9 - 13
S	**0.13 - 0.21**	**Mo**	**0.12 - 0.30**

F

Scientific Name	*Magnolia x (Kosar-deVos Hybrids) cultivars*		
Common Name	**Little Girl Magnolias**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Ann', 'Betty'		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.54	Fe	60 - 70
P	**0.14 - 0.23**	**Mn**	**362 - 616**
K	2.13 - 2.34	B	66 - 71
Ca	**1.07 - 1.50**	**Cu**	**8 - 16**
Mg	0.18 - 0.25	Zn	16 - 21
S	**0.15 - 0.25**	**Mo**	**0.12 - 0.30**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Magnolia x cultivars*
COMMON NAME	**Hybrid Magnolia cultivars**
COLLECTED FROM	Field production nursery
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Jon Jon', 'Sayonara'

Macronutrients %		Micronutrients ppm	
N	2.74 - 3.05	Fe	60 - 70
P	**0.19 - 0.21**	**Mn**	**240 - 261**
K	1.63 - 1.94	B	29 - 39
Ca	**0.89 - 1.37**	**Cu**	**5 - 8**
Mg	0.27 - 0.42	Zn	11 - 14
S	**0.18 - 0.19**	**Mo**	**0.12 - 0.53**

B

SCIENTIFIC NAME	*Magnolia x loebneri 'Leonard Messel'*
COMMON NAME	**Leonard Messel' Magnolia**
COLLECTED FROM	Container production nursery
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Leonard Messel'

Macronutrients %		Micronutrients ppm	
N	2.11 - 2.84	Fe	38 - 59
P	**0.11 - 0.15**	**Mn**	**188 - 316**
K	1.65 - 1.96	B	17 - 36
Ca	**0.66 - 0.94**	**Cu**	**5 - 40**
Mg	0.24 - 0.34	Zn	11 - 24
S	**0.15 - 0.24**	**Mo**	**0.22 - 0.78**

C

SCIENTIFIC NAME	*Magnolia x loebneri 'Merrill'*
COMMON NAME	**Merrill' Magnolia**
COLLECTED FROM	Container & field production nurseries
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Merrill'

Macronutrients %		Micronutrients ppm	
N	2.31 - 2.51	Fe	59 - 68
P	**0.14 - 0.17**	**Mn**	**179 - 230**
K	1.49 - 1.65	B	15 - 35
Ca	**1.05 - 1.22**	**Cu**	**6 - 10**
Mg	0.20 - 0.22	Zn	10 - 16
S	**0.17 - 0.18**	**Mo**	**0.12 - 0.76**

D

SCIENTIFIC NAME	*Magnolia x soulangiana*
COMMON NAME	**Saucer or Tulip Magnolia**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.66 - 2.26	Fe	39 - 61
P	**0.14 - 0.20**	**Mn**	**54 - 241**
K	1.38 - 1.78	B	28 - 145
Ca	**1.98 - 3.99**	**Cu**	**5 - 16**
Mg	0.23 - 0.33	Zn	23 - 30
S	**0.12 - 0.19**	**Mo**	**0.18 - 0.40**

E

SCIENTIFIC NAME	*Magnolia zenii*
COMMON NAME	**Zen Magnolia**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.14 - 2.55	Fe	35 - 66
P	**0.13 - 0.2**	**Mn**	**187 - 393**
K	1.65 - 1.80	B	31 - 84
Ca	**1.25 - 1.85**	**Cu**	**5 - 9**
Mg	0.25 - 0.29	Zn	15 - 27
S	**0.14 - 0.18**	**Mo**	**0.11 - 0.34**

F

SCIENTIFIC NAME	*Malus floribunda*
COMMON NAME	**Japanese Flowering Crabapple**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.88 - 1.94	Fe	41 - 65
P	**0.13 - 0.18**	**Mn**	**43 - 109**
K	1.55 - 2.07	B	35 - 104
Ca	**1.02 - 1.56**	**Cu**	**5 - 12**
Mg	0.21 - 0.32	Zn	17 - 28
S	**0.2 - 0.27**	**Mo**	**0.03 - 0.19**

Landscape and Forest Trees

A

Scientific Name	*Malus x 'Callaway'*		
Common Name	**Callaway' Flowering Crabapple**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Callaway'		
Macronutrients %		**Micronutrients ppm**	
N	1.81 - 2.3	Fe	35 - 89
P	**0.13 - 0.23**	**Mn**	**41 - 124**
K	1.19 - 2.75	B	18 - 37
Ca	**1.25 - 1.87**	**Cu**	**6 - 16**
Mg	0.26 - 0.32	Zn	14 - 25
S	**0.14 - 0.18**	**Mo**	**0.1 - 0.45**

B

Scientific Name	*Melia azedarach*		
Common Name	**Chinaberry or Pride-of-India or Persian Lilac**		
Collected From	Field production nursery		
Plant Part	10 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.13 - 4.22	Fe	35 - 91
P	**0.19 - 0.41**	**Mn**	**37 - 52**
K	1.53 - 1.97	B	25 - 53
Ca	**1.02 - 1.62**	**Cu**	**5 - 11**
Mg	0.25 - 0.30	Zn	21 - 37
S	**0.21 - 0.33**	**Mo**	**0.1 - 0.43**

C

Scientific Name	*Morus rubra*		
Common Name	**Red Mulberry**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.32 - 3.35	Fe	43 - 120
P	**0.14 - 0.26**	**Mn**	**62 - 98**
K	1.45 - 1.67	B	34 - 106
Ca	**1.88 - 3.12**	**Cu**	**7 - 14**
Mg	0.35 - 0.44	Zn	16 - 25
S	**0.16 - 0.21**	**Mo**	**0.11 - 0.31**

D

Scientific Name	*Nyssa sylvatica*		
Common Name	**Black Tupelo or Black or Sour Gum**		
Collected From	Field production nursery & field research plots		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.65 - 2.85	Fe	30 - 55
P	**0.10 - 0.25**	**Mn**	**154 - 634**
K	0.41 - 1.37	B	17 - 20
Ca	**0.30 - 1.04**	**Cu**	**2 - 13**
Mg	0.23 - 0.51	Zn	9 - 23
S	**0.16 - 0.21**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Ostrya virginiana*		
Common Name	**American Hophornbeam or Ironwood**		
Collected From	Botanical garden/arboretum & field research plots		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.49 - 1.96	Fe	64 - 278
P	**0.10 - 0.23**	**Mn**	**320 - 1450**
K	0.50 - 1.30	B	25 - 53
Ca	**1.06 - 2.42**	**Cu**	**4 - 9**
Mg	0.11 - 0.54	Zn	12 - 23
S	**0.13 - 0.17**	**Mo**	**0.12 - 1.10**

F

Scientific Name	*Oxydendrum arboreum*		
Common Name	**Sourwood or Sorrel Tree or Lily-of-the-Valley Tree**		
Collected From	Botanical garden/arboretum & field research plots		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.53 - 2.38	Fe	41 - 68
P	**0.10 - 0.19**	**Mn**	**271 - 878**
K	0.44 - 0.98	B	66 - 182
Ca	**0.96 - 1.46**	**Cu**	**3 - 5**
Mg	0.24 - 0.29	Zn	20 - 26
S	**0.14 - 0.17**	**Mo**	**0.12 - 0.30**

Landscape and Forest Trees

A

SCIENTIFIC NAME			*Parrotia persica*
COMMON NAME			**Persian Ironwood or Parrotia**
COLLECTED FROM			Container & field production nurseries
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.64 - 2.51	Fe	40 - 60
P	**0.09 - 0.23**	**Mn**	**139 - 202**
K	0.82 - 1.03	B	10 - 42
Ca	**0.62 - 1.04**	**Cu**	**3 - 5**
Mg	0.09 - 0.17	Zn	7 - 10
S	**0.12 - 0.20**	**Mo**	**0.12 - 0.30**

B

SCIENTIFIC NAME			*Paulownia tomentosa*
COMMON NAME			**Royal Paulownia or Empress or Princess Tree**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			5 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 2.46	Fe	45 - 119
P	**0.15 - 0.23**	**Mn**	**33 - 201**
K	1.35 - 1.65	B	18 - 37
Ca	**1.23 - 1.86**	**Cu**	**4 - 15**
Mg	0.28 - 0.39	Zn	23 - 31
S	**0.19 - 0.24**	**Mo**	**0.17 - 0.30**

C

SCIENTIFIC NAME			*Persea borbonia*
COMMON NAME			**Redbay or Swamp Bay**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.59 - 2.34	Fe	36 - 64
P	**0.12 - 0.15**	**Mn**	**131 - 193**
K	0.72 - 1.68	B	19 - 28
Ca	**0.48 - 1.23**	**Cu**	**5 - 17**
Mg	0.1 - 0.29	Zn	31 - 116
S	**0.14 - 0.24**	**Mo**	**0.08 - 0.38**

D

SCIENTIFIC NAME			*Pinckneya pubens*
COMMON NAME			**Feverbark or Georgia Bark**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.85 - 2.33	Fe	34 - 104
P	**0.12 - 0.18**	**Mn**	**46 - 62**
K	1.73 - 2.45	B	22 - 33
Ca	**1.15 - 1.78**	**Cu**	**5 - 14**
Mg	0.31 - 0.36	Zn	31 - 49
S	**0.12 - 0.19**	**Mo**	**0.1 - 0.34**

E

SCIENTIFIC NAME			*Pistacia chinensis*
COMMON NAME			**Chinese Pistache**
COLLECTED FROM			Field production nursery & botanical garden/arboretum
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.13 - 2.81	Fe	24 - 60
P	**0.16 - 0.25**	**Mn**	**14 - 98**
K	1.02 - 1.58	B	15 - 65
Ca	**0.60 - 1.41**	**Cu**	**3 - 14**
Mg	0.18 - 0.38	Zn	11 - 15
S	**0.14 - 0.16**	**Mo**	**0.12 - 0.30**

F

SCIENTIFIC NAME			*Platanus occidentalis*
COMMON NAME			**Sycamore or American Planetree**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			5 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.84 - 2.32	Fe	50 - 55
P	**0.13 - 0.15**	**Mn**	**127 - 167**
K	0.92 - 1.01	B	15 - 32
Ca	**1.31 - 1.52**	**Cu**	**6 - 9**
Mg	0.17 - 0.23	Zn	11 - 14
S	**0.27 - 0.30**	**Mo**	**0.12 - 0.30**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Platanus occidentalis*
COMMON NAME	**Sycamore or American Planetree**
COLLECTED FROM	Field research plots
PLANT PART	5 mature leaves from new growth
SEASON	Late summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.62 - 2.07	Fe	202 - 450
P	**0.12 - 0.19**	**Mn**	**36 - 150**
K	0.71 - 1.25	B	65 - 86
Ca	**0.96 - 2.36**	**Cu**	**4 - 8**
Mg	0.15 - 0.30	Zn	18 - 42
S	**0.21 - 0.29**	**Mo**	**0.07 - 0.14**

B

SCIENTIFIC NAME	*Platanus x acerifolia 'Bloodgood'*
COMMON NAME	**Bloodgood' London Planetree**
COLLECTED FROM	Field production nursery
PLANT PART	5 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Bloodgood'

Macronutrients %		Micronutrients ppm	
N	1.96 - 2.73	Fe	34 - 42
P	**0.19 - 0.24**	**Mn**	**95 - 110**
K	1.07 - 1.12	B	13 - 15
Ca	**0.44 - 0.52**	**Cu**	**5 - 7**
Mg	0.19 - 0.21	Zn	17 - 19
S	**0.24 - 0.30**	**Mo**	**0.12 - 0.13**

C

SCIENTIFIC NAME	*Populus deltoides*
COMMON NAME	**Eastern Cottonwood**
COLLECTED FROM	Field research plots
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.36 - 2.40	Fe	34 - 104
P	**0.17 - 0.28**	**Mn**	**43 - 106**
K	0.92 - 1.30	B	35 - 84
Ca	**1.11 - 2.30**	**Cu**	**7 - 9**
Mg	0.18 - 0.72	Zn	35 - 199
S	**0.22 - 0.37**	**Mo**	**0.13 - 0.45**

D

SCIENTIFIC NAME	*Populus grandidentata*
COMMON NAME	**Bigtooth Aspen**
COLLECTED FROM	Field research plots
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.11 - 2.93	Fe	91 - 106
P	**0.12 - 0.52**	**Mn**	**49 - 229**
K	1.78 - 2.37	B	31 - 77
Ca	**0.35 - 1.41**	**Cu**	**8 - 45**
Mg	0.24 - 0.33	Zn	32 - 213
S	**0.14 - 0.20**	**Mo**	**0.04 - 0.72**

E

SCIENTIFIC NAME	*Populus tremuloides*
COMMON NAME	**Quaking or Trembling Aspen**
COLLECTED FROM	Field research plots
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.00 - 2.77	Fe	62 - 105
P	**0.14 - 0.40**	**Mn**	**41 - 460**
K	0.16 - 2.59	B	30 - 89
Ca	**1.41 - 2.21**	**Cu**	**8 - 17**
Mg	0.14 - 0.22	Zn	56 - 192
S	**0.17 - 0.23**	**Mo**	**0.06 - 0.70**

F

SCIENTIFIC NAME	*Prunus campanulata*
COMMON NAME	**Taiwan Cherry**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Rnage
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.89 - 2.55	Fe	37 - 64
P	**0.16 - 0.22**	**Mn**	**42 - 108**
K	1.44 - 1.62	B	22 - 38
Ca	**1.32 - 2.02**	**Cu**	**2 - 12**
Mg	0.31 - 0.46	Zn	14 - 24
S	**0.14 - 0.18**	**Mo**	**0.05 - 0.34**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Prunus caroliniana*
COMMON NAME	**Carolina Cherrylaurel**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Monus' ('Bright 'n Tight')

Macronutrients %		Micronutrients ppm	
N	1.33 - 2.07	Fe	48 - 126
P	**0.12 - 0.18**	**Mn**	**960 - 1056**
K	0.72 - 0.83	B	32 - 44
Ca	**1.66 - 2.90**	**Cu**	**4 - 11**
Mg	0.37 - 0.63	Zn	27 - 32
S	**0.07 - 0.10**	**Mo**	**0.12 - 0.30**

B

SCIENTIFIC NAME	*Prunus mume*
COMMON NAME	**Japanese Flowering Apricot**
COLLECTED FROM	Field production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Peggy Clarke'

Macronutrients %		Micronutrients ppm	
N	2.1 - 2.88	Fe	34 - 71
P	**0.14 - 0.23**	**Mn**	**55 - 106**
K	2.01 - 3.49	B	33 - 61
Ca	**1.33 - 2.06**	**Cu**	**5 - 11**
Mg	0.26 - 0.37	Zn	16 - 25
S	**0.18 - 0.24**	**Mo**	**0.19 - 0.28**

C

SCIENTIFIC NAME	*Prunus pensylvanica*
COMMON NAME	**Pin or Wild Red or Fire Cherry**
COLLECTED FROM	Field research plots
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.76 - 2.34	Fe	36 - 77
P	**0.11 - 0.21**	**Mn**	**27 - 61**
K	1.69 - 1.99	B	15 - 44
Ca	**0.40 - 0.88**	**Cu**	**8 - 22**
Mg	0.28 - 0.38	Zn	19 - 37
S	**0.15 - 0.24**	**Mo**	**0.03 - 0.13**

D

SCIENTIFIC NAME	*Prunus persica 'Alba Plena'*
COMMON NAME	**Ornamental Flowering Peach**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Alba Plena'

Macronutrients %		Micronutrients ppm	
N	2.22 - 2.47	Fe	43 - 78
P	**0.14 - 0.21**	**Mn**	**40 - 249**
K	2.25 - 3.13	B	35 - 64
Ca	**1.25 - 1.76**	**Cu**	**7 - 11**
Mg	0.33 - 0.38	Zn	11 - 23
S	**0.14 - 0.21**	**Mo**	**0.1 - 0.17**

E

SCIENTIFIC NAME	*Prunus serotina*
COMMON NAME	**Black Cherry**
COLLECTED FROM	Botanical garden/arboretum & field research plots
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.99 - 2.24	Fe	49 - 290
P	**0.13 - 0.40**	**Mn**	**230 - 585**
K	0.76 - 1.60	B	22 - 50
Ca	**0.40 - 2.62**	**Cu**	**4 - 8**
Mg	0.17 - 0.53	Zn	16 - 27
S	**0.11 - 0.19**	**Mo**	**0.12 - 2.91**

F

SCIENTIFIC NAME	*Prunus serrulata 'Royal Burgundy'*
COMMON NAME	**Purple-leaf Japanese Flowering Cherry**
COLLECTED FROM	Field production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Royal Burgundy'

Macronutrients %		Micronutrients ppm	
N	1.75 - 2.45	Fe	37 - 57
P	**0.1 - 0.14**	**Mn**	**134 - 213**
K	1.54 - 2.14	B	17 - 31
Ca	**0.77 - 1.74**	**Cu**	**5 - 9**
Mg	0.16 - 0.36	Zn	12 - 22
S	**0.11 - 0.19**	**Mo**	**0.11 - 0.38**

Landscape and Forest Trees

A

Scientific Name			*Prunus subhirtella 'Autumnalis'*
Common Name			**Autumn-flowering Higan Cherry**
Collected From			Field production nursery & botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Autumnalis'
Macronutrients %		**Micronutrients ppm**	
N	1.85 - 2.47	Fe	30 - 80
P	**0.14 - 0.20**	**Mn**	**153 - 532**
K	1.23 - 1.45	B	55 - 71
Ca	**1.12 - 1.79**	**Cu**	**4 - 6**
Mg	0.23 - 0.31	Zn	16 - 24
S	**0.11 - 0.16**	**Mo**	**0.12 - 0.30**

B

Scientific Name			*Prunus subhirtella 'Pendula'*
Common Name			**Weeping Higan Cherry**
Collected From			Field production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Pendula'
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 2.58	Fe	45 - 66
P	**0.20 - 0.25**	**Mn**	**27 - 119**
K	1.39 - 1.87	B	16 - 29
Ca	**0.82 - 1.10**	**Cu**	**6 - 9**
Mg	0.25 - 0.28	Zn	10 - 22
S	**0.13 - 0.16**	**Mo**	**0.08 - 0.36**

C

Scientific Name			*Prunus tomentosa*
Common Name			**Manchu or Nanking Cherry**
Collected From			Field production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.00	Fe	42 - 64
P	**0.13 - 0.19**	**Mn**	**39 - 177**
K	1.56 - 2.15	B	19 - 34
Ca	**0.68 - 1.28**	**Cu**	**5 - 14**
Mg	0.29 - 0.35	Zn	13 - 23
S	**0.13 - 0.23**	**Mo**	**0.11 - 0.4**

D

Scientific Name			*Prunus virginiana*
Common Name			**Common Chokecherry**
Collected From			Field production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.11 - 2.78	Fe	36 - 67
P	**0.12 - 0.16**	**Mn**	**150 - 298**
K	1.88 - 2.19	B	18 - 28
Ca	**0.95 - 1.27**	**Cu**	**25 - 29**
Mg	0.27 - 0.36	Zn	20 - 44
S	**0.15 - 0.23**	**Mo**	**0.06 - 0.12**

E

Scientific Name			*Prunus x 'Okame'*
Common Name			**Okame' Flowering Cherry**
Collected From			Field production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Okame'
Macronutrients %		**Micronutrients ppm**	
N	1.91 - 2.16	Fe	37 - 77
P	**0.12 - 0.23**	**Mn**	**48 - 466**
K	1.03 - 1.71	B	9 - 34
Ca	**0.45 - 1.50**	**Cu**	**3 - 9**
Mg	0.27 - 0.35	Zn	11 - 15
S	**0.13 - 0.15**	**Mo**	**0.12 - 0.30**

F

Scientific Name			*Prunus x 'Snow Goose'*
Common Name			**Snow Goose' Flowering Cherry**
Collected From			Field production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Snow Goose'
Macronutrients %		**Micronutrients ppm**	
N	2.15 - 2.34	Fe	40 - 94
P	**0.14 - 0.18**	**Mn**	**250 - 730**
K	1.25 - 1.66	B	21 - 55
Ca	**0.98 - 1.61**	**Cu**	**5 - 16**
Mg	0.19 - 0.34	Zn	16 - 27
S	**0.13 - 0.22**	**Mo**	**0.11 - 0.31**

Landscape and Forest Trees

A

Scientific Name	*Prunus yedoensis*		
Common Name	**Yoshino Cherry**		
Collected From	Container & field production nurseries & botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.79 - 2.27	Fe	64 - 82
P	**0.13 - 0.19**	**Mn**	**110 - 268**
K	1.40 - 1.67	B	41 - 63
Ca	**1.82 - 2.22**	**Cu**	**6 - 12**
Mg	0.28 - 0.41	Zn	12 - 17
S	**0.12 - 0.13**	**Mo**	**0.11 - 0.12**

B

Scientific Name	*Prunus yedoensis 'Akebono'*		
Common Name	**Akebone' Yoshino Cherry**		
Collected From	Field production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Akebono'		
Macronutrients %		**Micronutrients ppm**	
N	2.26 - 2.98	Fe	36 - 118
P	**0.15 - 0.21**	**Mn**	**55 - 496**
K	1.41 - 2.45	B	22 - 44
Ca	**0.78 - 1.62**	**Cu**	**5 - 12**
Mg	0.17 - 0.37	Zn	15 - 34
S	**0.17 - 0.25**	**Mo**	**0.1 - 0.4**

C

Scientific Name	*Prunus yedoensis 'Shidare Yoshino'*		
Common Name	**Weeping Yoshino Cherry**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Shidare Yoshino'		
Macronutrients %		**Micronutrients ppm**	
N	2.16 - 2.64	Fe	32 - 63
P	**0.13 - 0.16**	**Mn**	**55 - 90**
K	1.44 - 1.67	B	14 - 57
Ca	**1.04 - 1.32**	**Cu**	**5 - 15**
Mg	0.28 - 0.33	Zn	15 - 27
S	**0.14 - 0.25**	**Mo**	**0.11 - 0.44**

D

Scientific Name	*Pterocarya stenoptera*		
Common Name	**Chinese Wingnut**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.12 - 2.65	Fe	35 - 83
P	**0.2 - 0.26**	**Mn**	**60 - 185**
K	1.16 - 2.23	B	26 - 56
Ca	**1.15 - 1.65**	**Cu**	**5 - 9**
Mg	0.28 - 0.34	Zn	18 - 33
S	**0.14 - 0.21**	**Mo**	**0.1 - 0.28**

E

Scientific Name	*Pyrus calleryana 'Bradford'*		
Common Name	**Bradford' Flowering Pear**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Bradford'		
Macronutrients %		**Micronutrients ppm**	
N	1.77 - 2.24	Fe	37 - 76
P	**0.13 - 0.31**	**Mn**	**44 - 79**
K	1.56 - 2.34	B	18 - 26
Ca	**1.35 - 1.99**	**Cu**	**5 - 12**
Mg	0.22 - 0.34	Zn	28 - 53
S	**0.11 - 0.18**	**Mo**	**0.1 - 0.3**

F

Scientific Name	*Pyrus calleryana cultivars*		
Common Name	**Flowering or Callery Pear**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Aristocrat', 'Redspire'		
Macronutrients %		**Micronutrients ppm**	
N	1.60 - 2.46	Fe	45 - 112
P	**0.11 - 0.17**	**Mn**	**51 - 54**
K	1.12 - 1.74	B	39 - 44
Ca	**1.79 - 2.42**	**Cu**	**6 - 17**
Mg	0.21 - 0.41	Zn	27 - 57
S	**0.10 - 0.15**	**Mo**	**0.12 - 0.70**

Landscape and Forest Trees

A

Scientific Name	*Quercus*
Common Name	**General Oak**
Collected From	Field research plots
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.85 - 2.65	Fe	60 - 125
P	**0.14 - 0.25**	**Mn**	**40 - 455**
K	1.10 - 1.72	B	12 - 45
Ca	**0.50 - 1.25**	**Cu**	**7 - 14**
Mg	0.33 - 0.65	Zn	15 - 35
S	**0.18 - 0.30**	**Mo**	**0.10 - 0.30**

B

Scientific Name	*Quercus acutissima*
Common Name	**Sawtooth Oak**
Collected From	Field production nursery & botanical garden/arboretum
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.84 - 2.62	Fe	54 - 108
P	**0.12 - 0.16**	**Mn**	**286 - 739**
K	0.74 - 1.13	B	20 - 171
Ca	**0.59 - 1.16**	**Cu**	**4 - 6**
Mg	0.13 - 0.15	Zn	17 - 28
S	**0.14 - 0.20**	**Mo**	**0.12 - 0.25**

C

Scientific Name	*Quercus agrifolia*
Common Name	**California Live Oak**
Collected From	Field research plots
Plant Part	25 mature leaves from previous year's growth
Season	Spring
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.15 - 1.21	Fe	99 - 120
P	**0.11 - 0.17**	**Mn**	**855 - 1040**
K	0.64 - 0.72	B	15 - 33
Ca	**1.90 - 2.30**	**Cu**	**8 - 11**
Mg	0.25 - 0.29	Zn	15 - 18
S	**0.14 - 0.18**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Quercus alba*
Common Name	**White Oak**
Collected From	Field research plots
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.78 - 2.80	Fe	45 - 126
P	**0.12 - 0.19**	**Mn**	**345 - 1374**
K	0.66 - 1.42	B	19 - 38
Ca	**0.58 - 1.36**	**Cu**	**5 - 8**
Mg	0.17 - 0.36	Zn	15 - 22
S	**0.13 - 0.27**	**Mo**	**0.06 - 0.27**

E

Scientific Name	*Quercus alba*
Common Name	**White Oak**
Collected From	Field production nursery & botanical garden/arboretum
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.82 - 2.43	Fe	38 - 57
P	**0.12 - 0.16**	**Mn**	**323 - 623**
K	0.59 - 1.17	B	22 - 35
Ca	**0.66 - 0.97**	**Cu**	**4 - 7**
Mg	0.17 - 0.19	Zn	15 - 38
S	**0.12 - 0.20**	**Mo**	**0.08 - 0.30**

F

Scientific Name	*Quercus bicolor*
Common Name	**Swamp White Oak**
Collected From	Field production nursery & field research plots
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.02 - 2.29	Fe	47 - 149
P	**0.15 - 0.26**	**Mn**	**121 - 323**
K	1.15 - 1.20	B	23 - 52
Ca	**0.33 - 1.07**	**Cu**	**8 - 10**
Mg	0.13 - 0.31	Zn	16 - 26
S	**0.13 - 0.16**	**Mo**	**0.05 - 0.12**

Landscape and Forest Trees

A

SCIENTIFIC NAME			*Quercus coccinea*
COMMON NAME			**Scarlet Oak**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.40 - 2.26	Fe	50 - 68
P	**0.09 - 0.11**	**Mn**	**142 - 771**
K	0.57 - 0.64	B	26 - 50
Ca	**0.44 - 0.87**	**Cu**	**2 - 5**
Mg	0.13 - 0.16	Zn	19 - 28
S	**0.09 - 0.13**	**Mo**	**0.07 - 0.12**

B

SCIENTIFIC NAME			*Quercus dentata*
COMMON NAME			**Japanese Emperor or Daimyo Oak**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			10 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.65 - 1.91	Fe	42 - 114
P	**0.1 - 0.16**	**Mn**	**324 - 1363**
K	1.6 - 1.84	B	26 - 74
Ca	**0.98 - 1.29**	**Cu**	**4 - 12**
Mg	0.23 - 0.31	Zn	15 - 27
S	**0.12 - 0.20**	**Mo**	**0.09 - 0.26**

C

SCIENTIFIC NAME			*Quercus falcata*
COMMON NAME			**Southern Red or Spanish Oak**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 2.35	Fe	47 - 99
P	**0.13 - 0.19**	**Mn**	**321 - 324**
K	0.54 - 1.65	B	30 - 51
Ca	**0.86 - 1.35**	**Cu**	**5 - 8**
Mg	0.2 - 0.32	Zn	20 - 29
S	**0.15 - 0.23**	**Mo**	**0.09 - 0.23**

D

SCIENTIFIC NAME			*Quercus frainetto*
COMMON NAME			**Hungarian Oak**
COLLECTED FROM			Field production nursery
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Schmidt', ('Forest Green')
Macronutrients %		**Micronutrients ppm**	
N	2.01 - 2.61	Fe	32 - 76
P	**0.16 - 0.22**	**Mn**	**324 - 1115**
K	1.05 - 2.05	B	17 - 25
Ca	**1.1 - 1.55**	**Cu**	**5 - 11**
Mg	0.26 - 0.35	Zn	18 - 37
S	**0.17 - 0.24**	**Mo**	**0.1 - 0.37**

E

SCIENTIFIC NAME			*Quercus georgiana*
COMMON NAME			**Georgia or Stone Mountain Oak**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.56 - 2.23	Fe	35 - 78
P	**0.11 - 0.21**	**Mn**	**55 - 1362**
K	0.73 - 1.78	B	25 - 51
Ca	**1.01 - 1.18**	**Cu**	**5 - 16**
Mg	0.18 - 0.29	Zn	21 - 38
S	**0.13 - 0.18**	**Mo**	**0.1 - 0.29**

F

SCIENTIFIC NAME			*Quercus glauca*
COMMON NAME			**Blue Japanese Evergreen Oak**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.25 - 2.33	Fe	37 - 87
P	**0.09 - 0.26**	**Mn**	**44 - 895**
K	0.84 - 2.13	B	20 - 31
Ca	**1.03 - 1.22**	**Cu**	**3 - 12**
Mg	0.2 - 0.32	Zn	11 - 22
S	**0.14 - 0.20**	**Mo**	**0.1 - 0.3**

Landscape and Forest Trees

A

Scientific Name	*Quercus hemisphaerica*		
Common Name	**Laurel or Darlington Oak**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 2.25	Fe	48 - 104
P	**0.14 - 0.21**	**Mn**	**44 - 280**
K	0.98 - 1.58	B	15 - 35
Ca	**0.50 - 0.88**	**Cu**	**4 - 8**
Mg	0.18 - 0.25	Zn	18 - 30
S	**0.14 - 0.21**	**Mo**	**0.05 - 0.5**

B

Scientific Name	*Quercus imbricaria*		
Common Name	**Shingle Oak**		
Collected From	Field production nursery		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.99 - 2.17	Fe	34 - 64
P	**0.1 - 0.14**	**Mn**	**169 - 498**
K	0.68 - 1.78	B	17 - 29
Ca	**0.54 - 1.13**	**Cu**	**3 - 12**
Mg	0.18 - 0.36	Zn	19 - 29
S	**0.17 - 0.22**	**Mo**	**0.09 - 0.23**

C

Scientific Name	*Quercus lyrata*		
Common Name	**Overcup Oak**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.38 - 2.35	Fe	50 - 85
P	**0.12 - 0.20**	**Mn**	**55 - 600**
K	0.85 - 1.50	B	25 - 60
Ca	**1.00 - 1.85**	**Cu**	**5 - 15**
Mg	0.21 - 0.35	Zn	20 - 30
S	**0.15 - 0.25**	**Mo**	**0.12 - 0.50**

D

Scientific Name	*Quercus macrocarpa*		
Common Name	**Bur or Mossycup Oak**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.95 - 2.31	Fe	32 - 54
P	**0.08 - 0.16**	**Mn**	**57 - 225**
K	0.73 - 1.24	B	12 - 115
Ca	**0.39 - 0.48**	**Cu**	**6 - 15**
Mg	0.17 - 0.26	Zn	13 - 23
S	**0.14 - 0.15**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Quercus macrolepis*		
Common Name	**Vallonea Oak**		
Collected From	Field research plots		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 2.24	Fe	37 - 73
P	**0.08 - 0.15**	**Mn**	**77 - 201**
K	0.18 - 0.48	B	14 - 25
Ca	**1.59 - 2.28**	**Cu**	**5 - 10**
Mg	0.27 - 0.42	Zn	23 - 34
S	**0.17 - 0.22**	**Mo**	**0.09 - 0.32**

F

Scientific Name	*Quercus nigra*		
Common Name	**Water Oak**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.7 - 2.32	Fe	22 - 63
P	**0.1 - 0.21**	**Mn**	**229 - 654**
K	0.9 - 1.85	B	18 - 55
Ca	**1.11 - 1.26**	**Cu**	**5 - 14**
Mg	0.22 - 0.31	Zn	32 - 50
S	**0.12 - 0.19**	**Mo**	**0.11 - 0.23**

Landscape and Forest Trees

A

Scientific Name	*Quercus nuttallii*		
Common Name	**Nuttall Oak**		
Collected From	Field research plots		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.37 - 1.81	Fe	24 - 46
P	**0.13 - 0.14**	**Mn**	**62 - 642**
K	0.74 - 0.91	B	13 - 20
Ca	**0.83 - 1.03**	**Cu**	**2 - 6**
Mg	0.22 - 0.27	Zn	21 - 29
S	**0.19 - 0.24**	**Mo**	**0.12 - 0.30**

B

Scientific Name	*Quercus pagoda*		
Common Name	**Cherrybark or Swamp Spanish Oak**		
Collected From	Field production nursery & field research plots		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.52 - 2.30	Fe	34 - 132
P	**0.13 - 0.14**	**Mn**	**55 - 1010**
K	0.54 - 0.78	B	20 - 27
Ca	**0.59 - 1.26**	**Cu**	**4 - 16**
Mg	0.15 - 0.32	Zn	21 - 31
S	**0.16 - 0.22**	**Mo**	**0.1 - 0.25**

C

Scientific Name	*Quercus palustris*		
Common Name	**Pin or Swamp Oak**		
Collected From	Field research plots		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.00 - 2.33	Fe	45 - 180
P	**0.16 - 0.39**	**Mn**	**218 - 633**
K	0.76 - 1.25	B	19 - 122
Ca	**0.40 - 1.36**	**Cu**	**7 - 38**
Mg	0.14 - 0.28	Zn	29 - 88
S	**0.16 - 0.23**	**Mo**	**0.02 - 1.58**

D

Scientific Name	*Quercus palustris*		
Common Name	**Pin or Swamp Oak**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.79 - 2.85	Fe	35 - 68
P	**0.13 - 0.15**	**Mn**	**274 - 797**
K	0.85 - 0.97	B	12 - 98
Ca	**0.28 - 0.64**	**Cu**	**2 - 7**
Mg	0.13 - 0.19	Zn	27 - 97
S	**0.17 - 0.19**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Quercus petraea 'Columna'*		
Common Name	**Upright or Columnar Durmast Oak**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Columna'		
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 2.35	Fe	38 - 65
P	**0.14 - 0.22**	**Mn**	**74 - 193**
K	2.09 - 2.33	B	24 - 54
Ca	**1.01 - 1.68**	**Cu**	**5 - 14**
Mg	0.26 - 0.32	Zn	20 - 28
S	**0.15 - 0.24**	**Mo**	**0.04 - 0.34**

F

Scientific Name	*Quercus phellos*		
Common Name	**Willow Oak**		
Collected From	Field production nursery		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.66 - 2.65	Fe	24 - 46
P	**0.13 - 0.17**	**Mn**	**62 - 642**
K	0.69 - 0.95	B	13 - 20
Ca	**0.41 - 0.81**	**Cu**	**2 - 6**
Mg	0.17 - 0.22	Zn	15 - 37
S	**0.12 - 0.18**	**Mo**	**0.12 - 0.30**

Landscape and Forest Trees

A

SCIENTIFIC NAME			*Quercus prinus*
COMMON NAME			**Chestnut or Basket or Rock Chestnut Oak**
COLLECTED FROM			Botanical garden/arboretum & field research plots
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.22 - 2.80	Fe	37 - 62
P	**0.14 - 0.18**	**Mn**	**54 - 455**
K	1.10 - 1.25	B	22 - 144
Ca	**0.59 - 1.20**	**Cu**	**5 - 10**
Mg	0.19 - 0.25	Zn	21 - 22
S	**0.15 - 0.23**	**Mo**	**0.1 - 0.23**

B

SCIENTIFIC NAME			*Quercus robur 'Fastigiata'*
COMMON NAME			**Upright or Columnar English Oak**
COLLECTED FROM			Container & field production nurseries
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Fastigiata'
Macronutrients %		**Micronutrients ppm**	
N	1.55 - 2.65	Fe	24 - 77
P	**0.12 - 0.16**	**Mn**	**95 - 332**
K	0.54 - 1.16	B	9 - 79
Ca	**0.31 - 1.39**	**Cu**	**3 - 9**
Mg	0.13 - 0.33	Zn	25 - 54
S	**0.10 - 0.21**	**Mo**	**0.06 - 1.56**

C

SCIENTIFIC NAME			*Quercus rubra*
COMMON NAME			**Red or Northern Red Oak**
COLLECTED FROM			Field research plots
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.87 - 2.70	Fe	63 - 125
P	**0.11 - 0.25**	**Mn**	**240 - 1736**
K	0.95 - 1.72	B	36 - 70
Ca	**0.55 - 0.95**	**Cu**	**5 - 14**
Mg	0.20 - 0.40	Zn	16 - 30
S	**0.18 - 0.24**	**Mo**	**0.05 - 0.70**

D

SCIENTIFIC NAME			*Quercus rubra*
COMMON NAME			**Red or Northern Red Oak**
COLLECTED FROM			Field production nursery
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.46 - 2.62	Fe	60 - 69
P	**0.15 - 0.16**	**Mn**	**236 - 1103**
K	0.83 - 0.85	B	23 - 25
Ca	**0.69 - 0.75**	**Cu**	**5 - 7**
Mg	0.17 - 0.23	Zn	33 - 37
S	**0.17 - 0.21**	**Mo**	**0.12 - 0.30**

E

SCIENTIFIC NAME			*Quercus shumardii*
COMMON NAME			**Shumard Oak**
COLLECTED FROM			Field production nursery & botanical garden/arboretum
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.69 - 1.71	Fe	40 - 61
P	**0.11 - 0.14**	**Mn**	**412 - 1037**
K	0.68 - 0.77	B	19 - 31
Ca	**0.71 - 0.73**	**Cu**	**4 - 6**
Mg	0.15 - 0.26	Zn	18 - 47
S	**0.12 - 0.19**	**Mo**	**0.12 - 0.30**

F

SCIENTIFIC NAME			*Quercus stellata*
COMMON NAME			**Post Oak**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.88 - 2.80	Fe	45 - 108
P	**0.14 - 0.26**	**Mn**	**40 - 255**
K	0.98 - 1.72	B	15 - 30
Ca	**0.55 - 0.94**	**Cu**	**5 - 12**
Mg	0.20 - 0.38	Zn	15 - 35
S	**0.12 - 0.21**	**Mo**	**0.05 - 0.5**

Landscape and Forest Trees

A

Scientific Name			*Quercus velutina*
Common Name			**Black Oak**
Collected From			Botanical garden/arboretum & field research plots
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.84 - 2.22	Fe	46 - 250
P	**0.14 - 0.20**	**Mn**	**513 - 1870**
K	0.77 - 1.00	B	19 - 61
Ca	**0.70 - 2.17**	**Cu**	**6 - 7**
Mg	0.18 - 0.42	Zn	32 - 66
S	**0.04 - 0.14**	**Mo**	**0.12 - 0.13**

B

Scientific Name			*Quercus virginiana*
Common Name			**Live Oak**
Collected From			Field production nursery & botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.87 - 2.18	Fe	28 - 37
P	**0.13 - 0.19**	**Mn**	**123 - 1148**
K	0.63 - 0.87	B	14 - 36
Ca	**0.54 - 0.63**	**Cu**	**3 - 9**
Mg	0.10 - 0.19	Zn	15 - 18
S	**0.13 - 0.15**	**Mo**	**0.12 - 0.30**

C

Scientific Name			*Rhamnus caroliniana*
Common Name			**Carolina Buckthorn or Indian Cherry**
Collected From			Botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.68 - 2.32	Fe	34 - 69
P	**0.12 - 0.26**	**Mn**	**55 - 469**
K	1.32 - 2.18	B	21 - 37
Ca	**1.12 - 1.66**	**Cu**	**4 - 14**
Mg	0.33 - 0.37	Zn	12 - 25
S	**0.15 - 0.23**	**Mo**	**0.1 - 0.32**

D

Scientific Name			*Robinia pseudoacacia*
Common Name			**Black Locust**
Collected From			Field research plots
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.98 - 3.12	Fe	46 - 330
P	**0.18 - 0.31**	**Mn**	**19 - 70**
K	0.98 - 1.21	B	32 - 41
Ca	**2.65 - 4.54**	**Cu**	**4 - 9**
Mg	0.3 - 0.41	Zn	32 - 50
S	**0.12 - 0.17**	**Mo**	**0.05 - 0.3**

E

Scientific Name			*Salix babylonica*
Common Name			**Weeping Willow**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.23 - 3.03	Fe	42 - 78
P	**0.18 - 0.27**	**Mn**	**43 - 134**
K	1.45 - 2.06	B	21 - 38
Ca	**0.96 - 1.27**	**Cu**	**5 - 12**
Mg	0.21 - 0.33	Zn	23 - 40
S	**0.23 - 0.60**	**Mo**	**0.08 - 0.21**

F

Scientific Name			*Salix caprea*
Common Name			**Goat or Pussy Willow**
Collected From			Botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.28	Fe	36 - 87
P	**0.09 - 0.16**	**Mn**	**45 - 290**
K	1.01 - 1.85	B	32 - 74
Ca	**1.33 - 2.52**	**Cu**	**5 - 16**
Mg	0.3 - 0.38	Zn	26 - 177
S	**0.22 - 0.34**	**Mo**	**0.1 - 0.32**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Salix chaenomeloides*
COMMON NAME	**Giant or Scarlet-bud Pussy Willow**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.71 - 2.32	Fe	31 - 85
P	**0.11 - 0.20**	**Mn**	**45 - 158**
K	1.63 - 2.14	B	24 - 52
Ca	**1.65 - 2.21**	**Cu**	**5 - 15**
Mg	0.15 - 0.36	Zn	24 - 233
S	**0.21 - 0.32**	**Mo**	**0.07 - 0.17**

B

SCIENTIFIC NAME	*Salix matsudana 'Tortuosa'*
COMMON NAME	**Cockscrew or Dragon's Claw Willow**
COLLECTED FROM	Field production nursery & botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Tortuosa'

Macronutrients %		Micronutrients ppm	
N	2.03 - 2.80	Fe	57 - 71
P	**0.12 - 0.27**	**Mn**	**134 - 179**
K	1.50 - 1.60	B	15 - 47
Ca	**1.43 - 2.41**	**Cu**	**4 - 16**
Mg	0.30 - 0.33	Zn	73 - 96
S	**0.40 - 0.44**	**Mo**	**0.06 - 0.12**

C

SCIENTIFIC NAME	*Salix nigra*
COMMON NAME	**Swamp or Black Willow**
COLLECTED FROM	Field research plots
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.03 - 2.19	Fe	42 - 132
P	**0.18 - 0.25**	**Mn**	**344 - 2278**
K	1.33 - 1.58	B	29 - 36
Ca	**0.9 - 1.33**	**Cu**	**5 - 12**
Mg	0.3 - 0.35	Zn	32 - 101
S	**0.21 - 0.32**	**Mo**	**0.15 - 0.20**

D

SCIENTIFIC NAME	*Salix x 'Scarlet Curls'*
COMMON NAME	**Red-stem Dragon's Claw Willow**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Scarlet Curls'

Macronutrients %		Micronutrients ppm	
N	2.15 - 3.68	Fe	33 - 55
P	**0.13 - 0.22**	**Mn**	**77 - 131**
K	1.48 - 1.72	B	16 - 27
Ca	**0.88 - 1.45**	**Cu**	**6 - 12**
Mg	0.26 - 0.33	Zn	21 - 47
S	**0.23 - 0.66**	**Mo**	**0.08 - 0.25**

E

SCIENTIFIC NAME	*Sapium sebiferum*
COMMON NAME	**Chinese Tallow or Popcorn Tree**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.11 - 2.86	Fe	35 - 44
P	**0.23 - 0.34**	**Mn**	**56 - 170**
K	1.51 - 2.17	B	18 - 26
Ca	**1.04 - 1.52**	**Cu**	**5 - 17**
Mg	0.15 - 0.36	Zn	13 - 21
S	**0.15 - 0.20**	**Mo**	**0.06 - 0.11**

F

SCIENTIFIC NAME	*Sophora japonica*
COMMON NAME	**Japanese Pagoda Tree or Chinese Scholar Tree**
COLLECTED FROM	Field production nursery & botanical garden/arboretum
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Princeton Upright'

Macronutrients %		Micronutrients ppm	
N	2.40 - 3.37	Fe	100 - 110
P	**0.18 - 0.30**	**Mn**	**43 - 201**
K	1.83 - 2.51	B	80 - 197
Ca	**1.51 - 1.94**	**Cu**	**6 - 9**
Mg	0.27 - 0.40	Zn	7 - 22
S	**0.26 - 0.28**	**Mo**	**0.12 - 0.41**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Sorbus aucuparia*
COMMON NAME	**European Mountain Ash or Rowan**
COLLECTED FROM	Field production nursery
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.21 - 3.04	Fe	42 - 245
P	**0.13 - 0.35**	**Mn**	**56 - 227**
K	1.56 - 1.99	B	17 - 28
Ca	**1.11 - 1.78**	**Cu**	**5 - 12**
Mg	0.36 - 0.44	Zn	12 - 21
S	**0.15 - 0.23**	**Mo**	**0.22 - 1.70**

B

SCIENTIFIC NAME	*Staphylea trifolia*
COMMON NAME	**American Bladdernut**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.05 - 2.65	Fe	36 - 121
P	**0.15 - 0.26**	**Mn**	**55 - 87**
K	2.36 - 3.99	B	22 - 38
Ca	**1.65 - 2.25**	**Cu**	**5 - 11**
Mg	0.38 - 0.84	Zn	8 - 23
S	**0.13 - 0.22**	**Mo**	**0.1 - 0.3**

C

SCIENTIFIC NAME	*Stewartia monadelpha*
COMMON NAME	**Tall Stewartia**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.68 - 2.32	Fe	38 - 95
P	**0.09 - 0.11**	**Mn**	**392 - 1264**
K	0.67 - 1.29	B	29 - 80
Ca	**1.57 - 1.76**	**Cu**	**3 - 5**
Mg	0.26 - 0.34	Zn	12 - 21
S	**0.22 - 0.40**	**Mo**	**0.12 - 0.30**

D

SCIENTIFIC NAME	*Stewartia pseudocamellia*
COMMON NAME	**Japanese Stewartia**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.65 - 2.21	Fe	48 - 87
P	**0.14 - 0.23**	**Mn**	**234 - 1223**
K	0.89 - 1.73	B	19 - 24
Ca	**1.13 - 1.47**	**Cu**	**2 - 12**
Mg	0.28 - 0.31	Zn	13 - 23
S	**0.19 - 0.28**	**Mo**	**0.17 - 0.52**

E

SCIENTIFIC NAME	*Styrax americana*
COMMON NAME	**American Snowbell**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.56 - 2.47	Fe	31 - 68
P	**0.11 - 0.26**	**Mn**	**55 - 244**
K	0.57 - 2.22	B	20 - 33
Ca	**1.03 - 1.8**	**Cu**	**5 - 14**
Mg	0.24 - 0.4	Zn	8 - 22
S	**0.16 - 0.24**	**Mo**	**0.1 - 0.4**

F

SCIENTIFIC NAME	*Styrax japonicus*
COMMON NAME	**Japanese Snowbell**
COLLECTED FROM	Field production nursery & botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Pink Chimes'

Macronutrients %		Micronutrients ppm	
N	2.79 - 3.12	Fe	78 - 161
P	**0.14 - 0.27**	**Mn**	**246 - 685**
K	1.22 - 1.55	B	17 - 64
Ca	**0.75 - 1.48**	**Cu**	**4 - 11**
Mg	0.08 - 0.17	Zn	12 - 20
S	**0.23 - 0.28**	**Mo**	**0.01 - 0.21**

Landscape and Forest Trees

A

Scientific Name			*Styrax obassia*
Common Name			**Fragrant Snowbell**
Collected From			Botanical garden/arboretum
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.81 - 2.26	Fe	35 - 104
P	**0.13 - 0.19**	**Mn**	**44 - 212**
K	2.11 - 2.41	B	28 - 49
Ca	**1.23 - 1.42**	**Cu**	**3 - 8**
Mg	0.19 - 0.29	Zn	10 - 23
S	**0.17 - 0.26**	**Mo**	**0.3 - 0.55**

B

Scientific Name			*Syzygium paniculatum*
Common Name			**Australian Brush Cherry**
Collected From			Container production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.50	Fe	50 - 200
P	**0.40 - 0.80**	**Mn**	**50 - 200**
K	1.50 - 3.00	B	25 - 75
Ca	**1.00 - 2.50**	**Cu**	**10 - 50**
Mg	0.20 - 0.80	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.1 - 0.4**

C

Scientific Name			*Tetradium daniellii*
Common Name			**Korean Evodia**
Collected From			Botanical garden/arboretum
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.77 - 2.42	Fe	41 - 107
P	**0.11 - 0.23**	**Mn**	**111 - 136**
K	1.16 - 1.97	B	25 - 76
Ca	**2.22 - 5.02**	**Cu**	**5 - 11**
Mg	0.33 - 0.46	Zn	11 - 23
S	**0.16 - 0.23**	**Mo**	**0.09 - 0.23**

D

Scientific Name			*Tilia americana*
Common Name			**American Linden or Basswood**
Collected From			Botanical garden/arboretum & field research plots
Plant Part			10 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.39 - 5.49	Fe	95 - 330
P	**0.11 - 0.75**	**Mn**	**124 - 350**
K	0.32 - 3.56	B	28 - 155
Ca	**1.10 - 6.43**	**Cu**	**8 - 13**
Mg	0.18 - 0.38	Zn	19 - 54
S	**0.09 - 0.24**	**Mo**	**0.12 - 7.9**

E

Scientific Name			*Tilia cordata*
Common Name			**Littleleaf Linden**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.98 - 2.76	Fe	41 - 90
P	**0.15 - 0.23**	**Mn**	**89 - 151**
K	1.65 - 2.16	B	32 - 126
Ca	**2.03 - 3.06**	**Cu**	**5 - 13**
Mg	0.29 - 0.37	Zn	17 - 22
S	**0.17 - 0.24**	**Mo**	**0.07 - 0.3**

F

Scientific Name			*Ulmus americana*
Common Name			**American Elm**
Collected From			Field research plots
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.16 - 2.13	Fe	123 - 680
P	**0.13 - 0.39**	**Mn**	**80 - 267**
K	0.59 - 1.69	B	45 - 98
Ca	**0.95 - 2.45**	**Cu**	**4 - 25**
Mg	0.26 - 0.58	Zn	20 - 50
S	**0.07 - 0.09**	**Mo**	**0.11 - 8.6**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Ulmus parvifolia*		
COMMON NAME	**Chinese or Lacebark Elm**		
COLLECTED FROM	Field production nursery & botanical garden/arboretum		
PLANT PART	35 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species, 'Emer I' ('Athena'), 'Emer II' ('Allee'), 'King's Choice'		
Macronutrients %		**Micronutrients ppm**	
N	2.17 - 4.64	Fe	38 - 75
P	**0.27 - 0.88**	**Mn**	**31 - 78**
K	1.06 - 1.76	B	15 - 62
Ca	**1.00 - 2.56**	**Cu**	**10 - 15**
Mg	0.28 - 0.50	Zn	25 - 45
S	**0.18 - 0.28**	**Mo**	**0.13 - 0.30**

B

SCIENTIFIC NAME	*Ulmus pumila*		
COMMON NAME	**Siberian Elm**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	35 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.14 - 2.73	Fe	46 - 76
P	**0.16 - 0.21**	**Mn**	**17 - 45**
K	1.25 - 1.56	B	18 - 95
Ca	**2.01 - 4.03**	**Cu**	**5 - 13**
Mg	0.28 - 0.48	Zn	11 - 21
S	**0.17 - 0.21**	**Mo**	**0.11 - 0.21**

C

SCIENTIFIC NAME	*Ulmus x 'Regal'*		
COMMON NAME	**Regal' Hybrid Elm**		
COLLECTED FROM	Field production nursery		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Regal'		
Macronutrients %		**Micronutrients ppm**	
N	1.97 - 2.76	Fe	35 - 62
P	**0.12 - 0.17**	**Mn**	**45 - 176**
K	1.16 - 1.89	B	28 - 48
Ca	**0.97 - 1.65**	**Cu**	**6 - 16**
Mg	0.25 - 0.36	Zn	19 - 29
S	**0.16 - 0.21**	**Mo**	**0.09 - 0.35**

D

SCIENTIFIC NAME	*Vitex agnus-castus*		
COMMON NAME	**Chastetree**		
COLLECTED FROM	Container & field production nurseries & botanical garden/arboretum		
PLANT PART	20 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species, 'Alba'		
Macronutrients %		**Micronutrients ppm**	
N	2.14 - 3.74	Fe	35 - 103
P	**0.23 - 0.46**	**Mn**	**74 - 173**
K	1.22 - 2.25	B	17 - 36
Ca	**0.80 - 1.59**	**Cu**	**6 - 10**
Mg	0.22 - 0.33	Zn	76 - 150
S	**0.14 - 0.28**	**Mo**	**0.12 - 0.30**

E

SCIENTIFIC NAME	*Vitex negundo var. heterophylla*		
COMMON NAME	**Cut-leaf or Fern-leaf Chastetree**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	var. heterophylla only		
Macronutrients %		**Micronutrients ppm**	
N	2.33 - 3.36	Fe	35 - 65
P	**0.18 - 0.23**	**Mn**	**54 - 74**
K	1.22 - 2.12	B	21 - 35
Ca	**1.21 - 1.31**	**Cu**	**5 - 12**
Mg	0.28 - 0.32	Zn	32 - 93
S	**0.18 - 0.21**	**Mo**	**0.1 - 0.32**

F

SCIENTIFIC NAME	*Zelkova serrata 'Green Vase'*		
COMMON NAME	**Green Vase' Japanese Zelkova**		
COLLECTED FROM	Field production nursery		
PLANT PART	30 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Green Vase'		
Macronutrients %		**Micronutrients ppm**	
N	2.24 - 2.33	Fe	58 - 90
P	**0.15 - 0.24**	**Mn**	**63 - 474**
K	0.70 - 1.88	B	31 - 44
Ca	**1.15 - 1.87**	**Cu**	**3 - 5**
Mg	0.13 - 0.14	Zn	10 - 17
S	**0.14 - 0.17**	**Mo**	**0.12 - 0.30**

Landscape and Forest Trees

A

SCIENTIFIC NAME	*Zelkova serrata 'Village Green'*
COMMON NAME	**Village Green' Japanese Zelkova**
COLLECTED FROM	Field production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Village Green'

Macronutrients %		Micronutrients ppm	
N	2.22 - 3.57	Fe	34 - 50
P	**0.17 - 0.24**	**Mn**	**55 - 324**
K	1.29 - 2.11	B	18 - 32
Ca	**0.75 - 1.45**	**Cu**	**5 - 17**
Mg	0.17 - 0.35	Zn	20 - 31
S	**0.19 - 0.23**	**Mo**	**0.08 - 0.43**

B

SCIENTIFIC NAME	*Zelkova serrata cultivars*
COMMON NAME	**Japanese Zelkova**
COLLECTED FROM	Field production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Autumn Glow', 'Halka'

Macronutrients %		Micronutrients ppm	
N	2.32 - 3.10	Fe	37–88
P	**0.16 - 0.26**	**Mn**	**122–590**
K	0.97 - 1.75	B	16–44
Ca	**0.88 - 1.37**	**Cu**	**4–7**
Mg	0.16 - 0.20	Zn	6–19
S	**0.15 - 0.18**	**Mo**	**0.12 - 0.30**

C

D

E

F

Ornamental Grasses, Sedges and Bamboos

A

Scientific Name	*Acorus gramineus*		
Common Name	**Japanese Sweet Flag**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 3.35	Fe	35 - 164
P	**0.25 - 0.44**	**Mn**	**22 - 43**
K	1.98 - 2.77	B	18 - 28
Ca	**.98 - 1.12**	**Cu**	**4 - 9**
Mg	.22 - .33	Zn	25 - 35
S	**0.21 - 0.28**	**Mo**	**0.13 - 0.18**

B

Scientific Name	*Acorus gramineus 'Ogon'*		
Common Name	**Gold-leaf Japanese Sweet Flag**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Ogon'		
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 3.25	Fe	35 - 57
P	**0.28 - 0.47**	**Mn**	**36 - 55**
K	1.98 - 2.98	B	18 - 26
Ca	**.94 - 1.33**	**Cu**	**5 - 10**
Mg	0.3 - 0.36	Zn	25 - 38
S	**0.25 - 0.35**	**Mo**	**0.2 - 0.37**

C

Scientific Name	*Acorus gramineus 'Variegatus'*		
Common Name	**Variegated Japanese Sweet Flag**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Variegatus'		
Macronutrients %		**Micronutrients ppm**	
N	2.1 - 3.35	Fe	29 - 56
P	**0.28 - 0.63**	**Mn**	**44 - 71**
K	2 - 3.22	B	.18 - .289
Ca	**.84 - 1.11**	**Cu**	**3 - 6**
Mg	.33 - 0.37	Zn	25 - 39
S	**0.19 - 0.32**	**Mo**	**0.16 - 0.24**

D

Scientific Name	*Arundo donax var. versicolor*		
Common Name	**Variegated Giant Reed Cane**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. versicolor only		
Macronutrients %		**Micronutrients ppm**	
N	1.88 - 2.93	Fe	25 - 43
P	**0.14 - 0.20**	**Mn**	**21 - 55**
K	1.50 - 3.33	B	3 - 15
Ca	**0.40 - 0.65**	**Cu**	**3 - 5**
Mg	0.16 - 0.25	Zn	22 - 36
S	**0.11 - 0.15**	**Mo**	**0.10 - 0.18**

E

Scientific Name	*Carex conica Snowline ('Variegata')*		
Common Name	**Variegated Japanese Wood Sedge**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Snowline'		
Macronutrients %		**Micronutrients ppm**	
N	1.92 - 2.26	Fe	39 - 69
P	**0.19 - 0.47**	**Mn**	**88 - 96**
K	1.88 - 2.15	B	4 - 19
Ca	**0.88 - 1.12**	**Cu**	**2 - 10**
Mg	0.2 - 0.25	Zn	16 - 26
S	**0.14 - 0.22**	**Mo**	**0.44 - 1.00**

F

Scientific Name	*Carex hachijoensis 'Evergold'*		
Common Name	**Old Gold Sedge**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Evergold'		
Macronutrients %		**Micronutrients ppm**	
N	1.18 - 2.24	Fe	40 - 83
P	**0.08 - 0.13**	**Mn**	**78 - 145**
K	1.45 - 1.80	B	14 - 26
Ca	**0.8 - 1.31**	**Cu**	**11 - 84**
Mg	0.15 - 0.29	Zn	18 - 28
S	**0.12 - 0.19**	**Mo**	**1.17 - 5.17**

Ornamental Grasses, Sedges and Bamboos

A

SCIENTIFIC NAME	*Carex morrowii 'Variegata'*
COMMON NAME	**Variegated Japanese Sedge Grass**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Variegata'

Macronutrients %		Micronutrients ppm	
N	1.81 - 2.3	Fe	40 - 92
P	**0.23 - 0.52**	**Mn**	**88 - 102**
K	2.26 - 2.71	B	4 - 19
Ca	**0.49 - 1**	**Cu**	**3 - 12**
Mg	0.14 - 0.24	Zn	11 - 21
S	**0.15 - 0.22**	**Mo**	**0.14 - 0.32**

B

SCIENTIFIC NAME	*Carex morrowii (green leaf form)*
COMMON NAME	**Japanese Sedge Grass**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.03 - 2.16	Fe	39 - 137
P	**0.56 - 1.07**	**Mn**	**61 - 243**
K	3.38 - 3.46	B	4 - 7
Ca	**0.60 - 0.65**	**Cu**	**4 - 8**
Mg	0.12 - 0.17	Zn	19 - 22
S	**0.14 - 0.16**	**Mo**	**0.14 - 0.21**

C

SCIENTIFIC NAME	*Carex plantaginea*
COMMON NAME	**Plantain Sedge**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.54 - 2.28	Fe	42 - 108
P	**0.12 - 0.18**	**Mn**	**178 - 312**
K	2.24 - 3.68	B	7 - 20
Ca	**0.9 - 1.36**	**Cu**	**5 - 10**
Mg	0.23 - 0.28	Zn	21 - 32
S	**0.13 - 0.23**	**Mo**	**0.08 - 0.33**

D

SCIENTIFIC NAME	*Cortaderia selloana*
COMMON NAME	**Pampas Grass**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.37 - 2.34	Fe	18 - 54
P	**0.08 - 0.15**	**Mn**	**22 - 67**
K	1.55 - 1.82	B	2 - 26
Ca	**0.36 - 1.15**	**Cu**	**4 - 14**
Mg	0.05 - 0.23	Zn	9 - 29
S	**0.21 - 0.30**	**Mo**	**0.1 - 0.21**

E

SCIENTIFIC NAME	*Cyperus alternifolius*
COMMON NAME	**Umbrella Plant or Umbrella Palm or Umbrella Sedge**
COLLECTED FROM	Container production nursery
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.45 - 2.60	Fe	38 - 50
P	**0.14 - 0.20**	**Mn**	**20 - 167**
K	2.13 - 3.64	B	5 - 20
Ca	**0.18 - 0.45**	**Cu**	**3 - 9**
Mg	0.22 - 0.27	Zn	24 - 51
S	**0.15 - 0.24**	**Mo**	**0.18 - 0.62**

F

SCIENTIFIC NAME	*Cyperus papyrus*
COMMON NAME	**Papyrus or Egyptian Paper Plant**
COLLECTED FROM	Container production nursery
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.97 - 2.35	Fe	35 - 65
P	**0.14 - 0.22**	**Mn**	**124 - 191**
K	1.55 - 1.98	B	6 - 18
Ca	**0.22 - 1.24**	**Cu**	**4 - 9**
Mg	0.18 - 0.21	Zn	32 - 74
S	**0.15 - 0.21**	**Mo**	**0.09 - 0.18**

Ornamental Grasses, Sedges and Bamboos

A

SCIENTIFIC NAME			*General Ornamental Grass*
COMMON NAME			**General average**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			10-15 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.61 - 2.97	Fe	39 - 137
P	**0.22 - 0.45**	**Mn**	**61 - 243**
K	1.75 - 2.80	B	4 - 15
Ca	**0.50 - 0.95**	**Cu**	**4 - 8**
Mg	0.19 - 0.40	Zn	20 - 42
S	**0.15 - 0.32**	**Mo**	**0.20 - 0.50**

B

SCIENTIFIC NAME			*Imperata cylindrica 'Rubra'*
COMMON NAME			**Japanese Blood Grass**
COLLECTED FROM			Container production nursery
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Rubra'
Macronutrients %		**Micronutrients ppm**	
N	0.81 - 1.89	Fe	43 - 72
P	**0.12 - 0.18**	**Mn**	**7 - 76**
K	1.64 - 2.11	B	14 - 24
Ca	**0.3 - 0.99**	**Cu**	**5 - 16**
Mg	0.09 - 0.19	Zn	9 - 25
S	**0.1 - 0.18**	**Mo**	**0.19 - 0.30**

C

SCIENTIFIC NAME			*Miscanthus sinensis 'Zebrinus'*
COMMON NAME			**Zebra Grass**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Zebrinus'
Macronutrients %		**Micronutrients ppm**	
N	1.40 - 2.20	Fe	20 - 170
P	**0.18 - 0.48**	**Mn**	**20 - 160**
K	0.60 - 2.11	B	5 - 19
Ca	**0.25 - 0.53**	**Cu**	**5 - 15**
Mg	0.16 - 0.30	Zn	15 - 50
S	**0.15 - 0.24**	**Mo**	**0.12 - 0.44**

D

SCIENTIFIC NAME			*Pennisetum alopecuroides 'Hameln'*
COMMON NAME			**Dwarf Fountain Grass or Chinese Pennisetum**
COLLECTED FROM			Container production nursery
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Hameln'
Macronutrients %		**Micronutrients ppm**	
N	1.59 - 2.27	Fe	42 - 108
P	**0.17 - 0.29**	**Mn**	**60 - 234**
K	1.98 - 2.35	B	9 - 25
Ca	**0.28 - 0.89**	**Cu**	**5 - 12**
Mg	0.19 - 0.27	Zn	23 - 37
S	**0.09 - 0.15**	**Mo**	**0.14 - 0.33**

E

SCIENTIFIC NAME			*Pennisetum setaceum 'Rubrum'*
COMMON NAME			**Purple Fountain Grass or Purple-leaf African Pennisetum**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			20 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Rubrum'
Macronutrients %		**Micronutrients ppm**	
N	2.0 - 3.5	Fe	20 - 150
P	**0.17 - 0.29**	**Mn**	**35 - 140**
K	1.85 - 3.05	B	10 - 25
Ca	**0.44 - 1.00**	**Cu**	**5 - 15**
Mg	0.20 - 0.50	Zn	10 - 30
S	**0.18 - 0.35**	**Mo**	**0.12 - 0.20**

F

SCIENTIFIC NAME			*Phalaris arundinacea var. picta*
COMMON NAME			**Ribbon Grass or Gardener's Garters**
COLLECTED FROM			Container production nursery & botanical garden/arboretum
PLANT PART			25 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			var. picta only
Macronutrients %		**Micronutrients ppm**	
N	2.2 - 3.8	Fe	41 - 104
P	**0.37 - 0.61**	**Mn**	**47 - 106**
K	2.1 - 3.4	B	5 - 15
Ca	**0.23 - 0.49**	**Cu**	**5 - 20**
Mg	0.19 - 0.62	Zn	26 - 45
S	**0.21 - 0.67**	**Mo**	**0.12 - 0.41**

Ornamental Grasses, Sedges and Bamboos

A

SCIENTIFIC NAME	*Phyllostachys nigra*
COMMON NAME	**Black Bamboo**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.12 - 2.61	Fe	28 - 68
P	**0.12 - 0.17**	**Mn**	**67 - 221**
K	0.81 - 2.14	B	5 - 17
Ca	**0.77 - 1.21**	**Cu**	**1 - 11**
Mg	0.14 - 0.24	Zn	7 - 18
S	**0.22 - 0.32**	**Mo**	**0.14 - 1**

B

SCIENTIFIC NAME	*Sasa palmata*
COMMON NAME	**Japanese Running Bamboo**
COLLECTED FROM	Container production nursery
PLANT PART	5 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.56 - 2.18	Fe	40 - 56
P	**0.16 - 0.23**	**Mn**	**91 - 116**
K	1.36 - 2.2	B	4 - 27
Ca	**0.63 - 1.15**	**Cu**	**2 - 9**
Mg	0.12 - 0.16	Zn	18 - 38
S	**0.17 - 0.21**	**Mo**	**0.11 - 0.33**

C

D

E

F

Ornamental Vines and Ground Covers

A

SCIENTIFIC NAME	*Ajuga pyramidalis*
COMMON NAME	**Upright Bugleweed**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Metallica Crispa'

Macronutrients %		Micronutrients ppm	
N	1.75 - 3.33	Fe	75 - 163
P	**0.33 - 0.45**	**Mn**	**37 - 88**
K	2.5 - 3.49	B	15 - 23
Ca	**.5 - 0.75**	**Cu**	**6 - 9**
Mg	.22 - 0.30	Zn	25 - 39
S	**0.15 - 0.27**	**Mo**	**0.25 - 0.5**

B

SCIENTIFIC NAME	*Ajuga reptans*
COMMON NAME	**Bugleweed**
COLLECTED FROM	Container production nursery& botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Bronze Beauty', 'Catlin's Giant', 'Rosea'

Macronutrients %		Micronutrients ppm	
N	2.04 - 3.81	Fe	46 - 194
P	**0.45 - 0.81**	**Mn**	**49 - 77**
K	2.92 - 4.30	B	22 - 29
Ca	**0.68 - 1.43**	**Cu**	**10 - 17**
Mg	0.23 - 0.42	Zn	23 - 66
S	**0.16 - 0.42**	**Mo**	**0.46 - 1.71**

C

SCIENTIFIC NAME	*Ajuga reptans cultivars*
COMMON NAME	**Variegated Bugleweed**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Burgundy Golw', 'Silver Beauty'

Macronutrients %		Micronutrients ppm	
N	2.1 - 3.71	Fe	77 - 156
P	**0.44 - 0.70**	**Mn**	**59 - 106**
K	2.68 - 4.16	B	22 - 29
Ca	**0.67 - 1.51**	**Cu**	**7 - 10**
Mg	0.34 - 0.53	Zn	36 - 53
S	**0.22 - 0.42**	**Mo**	**0.29 - 1.46**

D

SCIENTIFIC NAME	*Akebia quinata*
COMMON NAME	**Akebia, Five-leaf**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.88 - 2.33	Fe	33 - 51
P	**0.2 - 0.45**	**Mn**	**45 - 77**
K	1 - 1.76	B	20 - 67
Ca	**.75 - 2.34**	**Cu**	**5 - 9**
Mg	.13 - .35	Zn	17 - 37
S	**0.18 - 0.31**	**Mo**	**0.21 - 0.33**

E

SCIENTIFIC NAME	*Campsis radicans*
COMMON NAME	**Common Trumpetcreeper**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.01 - 2.39	Fe	38 - 62
P	**0.19 - 0.24**	**Mn**	**36 - 146**
K	1.54 - 2.18	B	21 - 35
Ca	**0.89 - 1.07**	**Cu**	**4 - 15**
Mg	0.14 - 0.24	Zn	18 - 28
S	**0.15 - 0.22**	**Mo**	**0.07 - 0.23**

F

SCIENTIFIC NAME	*Campsis tagliabuana 'Madame Galen'*
COMMON NAME	**Madame Galen 'Trumpetkeeper'**
COLLECTED FROM	Container production nursery
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Madame Galen'

Macronutrients %		Micronutrients ppm	
N	1.88 - 2.97	Fe	41 - 73
P	**0.15 - 0.20**	**Mn**	**24 - 94**
K	1.51 - 2.25	B	19 - 33
Ca	**0.67 - 1.1**	**Cu**	**6 - 26**
Mg	0.19 - 0.28	Zn	20 - 30
S	**0.15 - 0.20**	**Mo**	**0.23 - 1.10**

Ornamental Vines and Ground Covers

A

SCIENTIFIC NAME	*Clematis armandii*
COMMON NAME	**Armand's Clematis**
COLLECTED FROM	Container production nursery
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.0 - 2.9	Fe	40 - 150
P	**0.2 - 0.4**	**Mn**	**35 - 90**
K	2.06 - 2.75	B	25 - 40
Ca	**0.4 - 1.22**	**Cu**	**5 - 15**
Mg	0.20 - 0.35	Zn	20 - 40
S	**0.18 - 0.28**	**Mo**	**0.5 - 1.0**

B

SCIENTIFIC NAME	*Clematis terniflora*
COMMON NAME	**Sweetautumn Clematis**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.86 - 1.93	Fe	44 - 75
P	**0.13 - 0.21**	**Mn**	**115 - 128**
K	1.78 - 2.10	B	17 - 37
Ca	**1.11 - 1.75**	**Cu**	**6 - 12**
Mg	0.1 - 0.19	Zn	17 - 28
S	**0.19 - 0.31**	**Mo**	**0.21 - 0.72**

C

SCIENTIFIC NAME	*Euonymus fortunei (green leaf form)*
COMMON NAME	**Wintercreeper Euonymus**
COLLECTED FROM	Container production nursery
PLANT PART	30 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Acutus', 'Kewensis'

Macronutrients %		Micronutrients ppm	
N	1.00 - 2.56	Fe	52 - 196
P	**0.12 - 0.28**	**Mn**	**9 - 36**
K	0.88 - 1.42	B	21 - 29
Ca	**0.46 - 0.79**	**Cu**	**1 - 6**
Mg	0.16 - 0.47	Zn	11 - 34
S	**0.13 - 0.22**	**Mo**	**0.12 - 0.36**

D

SCIENTIFIC NAME	*Euonymus fortunei cultivars*
COMMON NAME	**Variegated Wintercreeper Euonymus**
COLLECTED FROM	Container production nursery
PLANT PART	30 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Coloratus', 'Emerald Gaiety', 'Ivory Jade'

Macronutrients %		Micronutrients ppm	
N	0.92 - 2.00	Fe	24 - 86
P	**0.13 - 0.41**	**Mn**	**10 - 90**
K	0.93 - 1.70	B	25 - 35
Ca	**0.70 - 2.32**	**Cu**	**1 - 6**
Mg	0.16 - 0.31	Zn	11 - 99
S	**0.19 - 0.36**	**Mo**	**0.15 - 1.13**

E

SCIENTIFIC NAME	*Ficus pumila*
COMMON NAME	**Climbing or Creeping Fig**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.61 - 2.44	Fe	41 - 76
P	**0.1 - 0.19**	**Mn**	**27 - 126**
K	1.57 - 2.25	B	25 - 52
Ca	**1.25 - 2.33**	**Cu**	**5 - 13**
Mg	0.2 - 0.23	Zn	21 - 29
S	**0.11 - 0.19**	**Mo**	**0.13 - 0.21**

F

SCIENTIFIC NAME	*Gelsemium sempervirens*
COMMON NAME	**Carolina or Yellow Jasmine or Jessamine**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.25 - 2.66	Fe	26 - 69
P	**0.10 - 0.22**	**Mn**	**522 - 926**
K	0.93 - 1.32	B	39 - 45
Ca	**0.40 - 0.54**	**Cu**	**1 - 6**
Mg	0.13 - 0.20	Zn	7 - 17
S	**0.11 - 0.26**	**Mo**	**0.05 - 0.12**

Ornamental Vines and Ground Covers

A

Scientific Name	*Hedera algeriensis*
Common Name	**Algerian Ivy**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.07 - 2.83	Fe	61 - 167
P	**0.29 - 0.47**	**Mn**	**152 - 192**
K	1.40 - 2.55	B	23 - 66
Ca	**0.78 - 3.24**	**Cu**	**8 - 17**
Mg	0.29 - 0.34	Zn	91 - 144
S	**0.24 - 0.30**	**Mo**	**0.12 - 0.64**

B

Scientific Name	*Hedera helix*
Common Name	**English Ivy**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	- Species, 'Arborescens', 'Hahn's', 'Manda's Crested', 'Needlepoint', 'Wilsonii'

Macronutrients %		Micronutrients ppm	
N	1.52 - 3.25	Fe	61 - 389
P	**0.16 - 0.65**	**Mn**	**59 - 853**
K	1.55 - 3.84	B	22 - 52
Ca	**0.44 - 3.13**	**Cu**	**3 - 26**
Mg	0.15 - 0.44	Zn	50 - 160
S	**0.13 - 0.30**	**Mo**	**0.06 - 0.9**

C

Scientific Name	*Hedera helix cultivars*
Common Name	**Variegated English Ivy**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Anne Marie', 'Glacier', 'Goldchild'

Macronutrients %		Micronutrients ppm	
N	1.36 - 3.45	Fe	78 - 246
P	**0.28 - 0.63**	**Mn**	**90 - 352**
K	2.47 - 3.57	B	26 - 39
Ca	**0.83 - 1.95**	**Cu**	**4 - 33**
Mg	0.28 - 0.52	Zn	94 - 168
S	**0.18 - 0.39**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Hydrangea anomala ssp. petiolaris*
Common Name	**Climbing Hydrangea**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	ssp. petiolaris only

Macronutrients %		Micronutrients ppm	
N	2.35 - 3.14	Fe	45 - 107
P	**0.23 - 0.76**	**Mn**	**55 - 73**
K	1.66 - 2.05	B	20 - 33
Ca	**0.88 - 1.68**	**Cu**	**1 - 9**
Mg	0.33 - 0.41	Zn	16 - 26
S	**0.21 - 0.30**	**Mo**	**0.14 - 0.3**

E

Scientific Name	*Liriope exiliflora 'Silvery Sunproof'*
Common Name	**Silvery Sunproof' Liriope**
Collected From	Container production nursery
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Silvery Sunproof'

Macronutrients %		Micronutrients ppm	
N	1.66 - 2.17	Fe	45 - 164
P	**0.12 - 0.18**	**Mn**	**57 - 155**
K	1.39 - 2.3	B	5 - 18
Ca	**0.47 - 1.25**	**Cu**	**5 - 10**
Mg	0.35 - 0.49	Zn	18 - 28
S	**0.17 - 0.21**	**Mo**	**0.11 - 0.21**

F

Scientific Name	*Liriope muscari cultivars*
Common Name	**Common or Clumping Liriope or Lily-turf**
Collected From	Container production nursery
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Big Blue', 'Evergreen Giant', 'Green Midget', 'Majestic', 'Monroe White', 'Royal Purple'

Macronutrients %		Micronutrients ppm	
N	1.32 - 1.95	Fe	65 - 125
P	**0.15 - 0.34**	**Mn**	**29 - 376**
K	1.04 - 2.31	B	14 - 31
Ca	**0.35 - 1.22**	**Cu**	**1 - 8**
Mg	0.18 - 0.33	Zn	27 - 93
S	**0.12 - 0.21**	**Mo**	**0.12 - 0.58**

Ornamental Vines and Ground Covers

A

Scientific Name	*Liriope muscari cultivars*
Common Name	**Variegated Liriope or Lily-turf**
Collected From	Container production nursery
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	var. variegata, 'John Burch', 'Silver Midget'

Macronutrients %		Micronutrients ppm	
N	1.25 - 2.57	Fe	56 - 164
P	**0.12 - 0.42**	**Mn**	**19 - 298**
K	1.07 - 2.42	B	5 - 36
Ca	**0.36 - 0.86**	**Cu**	**4 - 15**
Mg	0.10 - 0.49	Zn	25 - 78
S	**0.14 - 0.26**	**Mo**	**0.12 - 1.74**

B

Scientific Name	*Liriope spicata*
Common Name	**Creeping Liriope or Lily-turf**
Collected From	Container production nursery
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.80 - 2.47	Fe	119 - 154
P	**0.14 - 0.42**	**Mn**	**28 - 112**
K	1.06 - 2.11	B	15 - 26
Ca	**0.42 - 1.15**	**Cu**	**4 - 18**
Mg	0.19 - 0.45	Zn	26 - 49
S	**0.12 - 0.22**	**Mo**	**0.12 - 3.02**

C

Scientific Name	*Liriope spicata 'Silver Dragon'*
Common Name	**Variegated Creeping Liriope or Lily-turf**
Collected From	Container production nursery
Plant Part	40 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Silver Dragon'

Macronutrients %		Micronutrients ppm	
N	1.65 - 2.03	Fe	33 - 73
P	**0.21 - 0.53**	**Mn**	**26 - 134**
K	2.22 - 2.84	B	17 - 27
Ca	**0.95 - 1.25**	**Cu**	**3 - 14**
Mg	0.18 - 0.21	Zn	31 - 58
S	**0.19 - 0.24**	**Mo**	**0.09 - 0.38**

D

Scientific Name	*Lonicera japonica*
Common Name	**Japanese Honeysuckle**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Purpurea'

Macronutrients %		Micronutrients ppm	
N	1.80 - 1.87	Fe	88 - 109
P	**0.24 - 0.27**	**Mn**	**43 - 214**
K	2.23 - 2.56	B	29 - 75
Ca	**0.54 - 1.47**	**Cu**	**6 - 8**
Mg	0.43 - 0.48	Zn	44 - 57
S	**0.17 - 0.18**	**Mo**	**0.11 - 0.21**

E

Scientific Name	*Lonicera sempervirens*
Common Name	**Trumpet or Coral Honeysuckle**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.27 - 1.50	Fe	35 - 46
P	**0.24 - 0.26**	**Mn**	**115 - 197**
K	1.31 - 2.01	B	34 - 64
Ca	**0.71 - 2.90**	**Cu**	**3 - 7**
Mg	0.39 - 0.42	Zn	36 - 42
S	**0.10 - 0.15**	**Mo**	**0.13 - 1.14**

F

Scientific Name	*Ophiopogon japonicus*
Common Name	**Mondo or Monkey Grass**
Collected From	Container production nursery
Plant Part	75 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.44 - 2.65	Fe	97 - 490
P	**0.20 - 0.33**	**Mn**	**25 - 149**
K	1.26 - 1.90	B	21 - 34
Ca	**0.95 - 1.23**	**Cu**	**4 - 20**
Mg	0.21 - 0.67	Zn	44 - 110
S	**0.18 - 0.22**	**Mo**	**0.12 - 0.44**

Ornamental Vines and Ground Covers

A

Scientific Name	*Ophiopogon japonicus 'Kyoto Dwarf'*		
Common Name	**Dwarf Mondo Grass**		
Collected From	Container production nursery		
Plant Part	75 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Kyoto Dwarf'		
Macronutrients %		**Micronutrients ppm**	
N	1.92 - 2.39	Fe	43 - 77
P	**0.21 - 0.32**	**Mn**	**30 - 288**
K	1.5 - 2.25	B	14 - 26
Ca	**0.97 - 1.63**	**Cu**	**4 - 15**
Mg	0.28 - 0.32	Zn	28 - 79
S	**0.17 - 0.22**	**Mo**	**0.34 - 1.03**

B

Scientific Name	*Ophiopogon planiscapus 'Nigrescens'*		
Common Name	**Black Mondo**		
Collected From	Container production nursery		
Plant Part	40 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Nigrescens'		
Macronutrients %		**Micronutrients ppm**	
N	1.95 - 2.14	Fe	49 - 124
P	**0.29 - 0.34**	**Mn**	**147 - 753**
K	2.01 - 2.84	B	22 - 26
Ca	**0.56 - 1.09**	**Cu**	**1 - 6**
Mg	0.15 - 0.21	Zn	48 - 101
S	**0.20 - 0.24**	**Mo**	**0.10 - 0.12**

C

Scientific Name	*Pachysandra procumbens*		
Common Name	**Alleghany Spurge or Pachysandra**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 2.43	Fe	55 - 123
P	**0.15 - 0.28**	**Mn**	**231 - 366**
K	2.25 - 3.30	B	24 - 51
Ca	**1.02 - 1.68**	**Cu**	**6 - 10**
Mg	0.33 - 0.73	Zn	21 - 31
S	**0.21 - 0.30**	**Mo**	**0.11 - 0.41**

D

Scientific Name	*Pachysandra terminalis*		
Common Name	**Japanese Pachysandra or Spurge**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	40 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Green Sheen', 'Kingswood'		
Macronutrients %		**Micronutrients ppm**	
N	1.27 - 2.76	Fe	49 - 105
P	**0.13 - 0.34**	**Mn**	**28 - 111**
K	1.10 - 2.14	B	15 - 43
Ca	**0.31 - 1.19**	**Cu**	**2 - 13**
Mg	0.16 - 0.40	Zn	34 - 121
S	**0.12 - 0.27**	**Mo**	**0.10 - 0.17**

E

Scientific Name	*Pachysandra terminalis 'Variegata'*		
Common Name	**Variegated Japanese Pachysandra or Spurge**		
Collected From	Container production nursery		
Plant Part	40 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Variegata'		
Macronutrients %		**Micronutrients ppm**	
N	1.69 - 2.24	Fe	47 - 135
P	**0.17 - 0.25**	**Mn**	**30 - 89**
K	1.97 - 2.24	B	18 - 29
Ca	**0.93 - 1.23**	**Cu**	**3 - 16**
Mg	0.33 - 0.56	Zn	33 - 148
S	**0.18 - 0.24**	**Mo**	**0.01 - 0.02**

F

Scientific Name	*Parthenocissus quinquefolia*		
Common Name	**Virginia Creeper**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.17 - 3.10	Fe	90 - 105
P	**0.16 - 0.20**	**Mn**	**267 - 300**
K	1.30 - 1.45	B	25 - 33
Ca	**2.52 - 2.77**	**Cu**	**7 - 11**
Mg	0.14 - 0.33	Zn	13 - 37
S	**0.16 - 0.22**	**Mo**	**0.12 - 0.30**

Ornamental Vines and Ground Covers

A

Scientific Name	*Parthenocissus quinquefolia 'Variegata'*		
Common Name	**Variegated Virginia Creeper**		
Collected From	Container production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Variegata'		
Macronutrients %		**Micronutrients ppm**	
N	1.97 - 2.99	Fe	48 - 78
P	**0.18 - 0.27**	**Mn**	**65 - 93**
K	1.35 - 2.25	B	15 - 25
Ca	**1.14 - 1.41**	**Cu**	**5 - 15**
Mg	0.18 - 0.28	Zn	17 - 27
S	**0.19 - 0.26**	**Mo**	**0.11 - 0.38**

B

Scientific Name	*Parthenocissus tricuspidata*		
Common Name	**Boston Ivy or Japanese Creeper**		
Collected From	Container production nursery		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.09 - 3.23	Fe	45 - 126
P	**0.21 - 0.35**	**Mn**	**55 - 99**
K	1.65 - 1.94	B	14 - 28
Ca	**0.98 - 1.14**	**Cu**	**5 - 12**
Mg	0.26 - 0.32	Zn	18 - 27
S	**0.18 - 0.24**	**Mo**	**0.19 - 0.32**

C

Scientific Name	*Sutera spp.*		
Common Name	**Bacopa**		
Collected From	Home Landscape		
Plant Part	Mature leaves from recently mature growth		
Season	Bloom		
Data Type	Survey Range		
Cultivars Used	Bacopa is a genus of 70 - 100 aquatic plants		
Macronutrients %		**Micronutrients ppm**	
N	4.68 - 5.6	Fe	55.6 - 60.5
P	**0.49 - 0.61**	**Mn**	**95.8 - 115**
K	5.07 - 5.11	B	39 - 48
Ca	**1.35 - 1.66**	**Cu**	**6.8 - 7.8**
Mg	0.4 - 0.41	Zn	22 - 27
S	**0.34 - 0.45**	**Mo**	**0.07 - 0.34**

D

Scientific Name	*Sutera spp. (cutting)*		
Common Name	**Bacopa**		
Collected From	Greenhouse Production		
Plant Part	Mature leaves from recently mature growth		
Season	Bloom		
Data Type	Survey Range		
Cultivars Used	Bacopa is a genus of 70 - 100 aquatic plants		
Macronutrients %		**Micronutrients ppm**	
N	4 - 5.77	Fe	66.3 - 167
P	**0.38 - 0.8**	**Mn**	**55.4 - 194.6**
K	2.86 - 4.71	B	23 - 72
Ca	**0.56 - 1.35**	**Cu**	**4.9 - 36.3**
Mg	0.23 - 0.5	Zn	27 - 81
S	**0.25 - 0.70**	**Mo**	**0.09 - 0.28**

E

Scientific Name	*Trachelospermum asiaticum*		
Common Name	**Asiatic or Japanese Star Jasmine**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	30 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 2.08	Fe	49 - 102
P	**0.14 - 0.19**	**Mn**	**342 - 526**
K	1.37 - 1.50	B	14 - 20
Ca	**0.42 - 2.08**	**Cu**	**3 - 9**
Mg	0.18 - 0.21	Zn	35 - 45
S	**0.16 - 0.19**	**Mo**	**0.04 - 0.32**

F

Scientific Name	*Trachelospermum asiaticum 'Variegatum'*		
Common Name	**Variegated Asiatic or Japanese Star Jasmine**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	30 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Variegatum'		
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 1.85	Fe	42 - 123
P	**0.19 - 0.22**	**Mn**	**23 - 140**
K	1.54 - 1.75	B	29 - 30
Ca	**1.00 - 2.53**	**Cu**	**4 - 9**
Mg	0.21 - 0.28	Zn	27 - 65
S	**0.16 - 0.20**	**Mo**	**0.04 - 0.12**

Ornamental Vines and Ground Covers

A

Scientific Name	*Trachelospermum jasminoides*
Common Name	**Confederate or Star Jasmine**
Collected From	Container production nursery
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Madison'

Macronutrients %		Micronutrients ppm	
N	1.89 - 2.77	Fe	45 - 76
P	**0.13 - 0.19**	**Mn**	**111 - 209**
K	1.88 - 2.36	B	15 - 28
Ca	**0.78 - 1.19**	**Cu**	**2 - 12**
Mg	0.18 - 0.23	Zn	19 - 32
S	**0.15 - 0.23**	**Mo**	**0.09 - 0.26**

B

Scientific Name	*Vinca major*
Common Name	**Large Periwinkle**
Collected From	Container production nursery
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, spp. Hirsuta

Macronutrients %		Micronutrients ppm	
N	1.44 - 4.53	Fe	63 - 150
P	**0.13 - 0.50**	**Mn**	**23 - 421**
K	1.32 - 4.18	B	12 - 44
Ca	**0.40 - 0.72**	**Cu**	**2 - 15**
Mg	0.17 - 0.33	Zn	28 - 74
S	**0.12 - 0.41**	**Mo**	**0.12 - 0.46**

C

Scientific Name	*Vinca major 'Variegata'*
Common Name	**Variegated Large Periwinkle**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Variegata'

Macronutrients %		Micronutrients ppm	
N	1.80 - 4.56	Fe	58 - 712
P	**0.24 - 0.55**	**Mn**	**24 - 71**
K	3.24 - 5.62	B	25 - 79
Ca	**0.97 - 1.33**	**Cu**	**8 - 24**
Mg	0.19 - 0.47	Zn	11 - 125
S	**0.26 - 0.69**	**Mo**	**0.12 - 1.53**

D

Scientific Name	*Vinca minor*
Common Name	**Common Periwinkle**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	30 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Alba', 'La Grave'

Macronutrients %		Micronutrients ppm	
N	1.07 - 3.98	Fe	57 - 430
P	**0.13 - 0.39**	**Mn**	**67 - 240**
K	1.23 - 2.26	B	19 - 91
Ca	**0.46 - 1.20**	**Cu**	**4 - 23**
Mg	0.21 - 0.44	Zn	32 - 73
S	**0.13 - 0.31**	**Mo**	**0.02 - 0.27**

E

Scientific Name	*Vinca minor cultivars*
Common Name	**Variegated Common Periwinkle**
Collected From	Container production nursery
Plant Part	30 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Aureovariegata', 'Sterling Silver'

Macronutrients %		Micronutrients ppm	
N	3.32 - 4.21	Fe	176 - 186
P	**0.41 - 0.49**	**Mn**	**59 - 193**
K	2.65 - 2.87	B	42 - 47
Ca	**0.75 - 1.05**	**Cu**	**12 - 20**
Mg	0.28 - 0.38	Zn	74 - 124
S	**0.30 - 0.48**	**Mo**	**0.12 - 1.31**

F

Scientific Name	*Wisteria sinensis*
Common Name	**Chinese Wisteria**
Collected From	Botanical garden/arboretum
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.34 - 3.44	Fe	33 - 61
P	**0.11 - 0.17**	**Mn**	**87 - 335**
K	1.47 - 2.14	B	18 - 29
Ca	**0.66 - 1.56**	**Cu**	**5 - 14**
Mg	0.1 - 0.25	Zn	12 - 22
S	**0.18 - 0.24**	**Mo**	**0.24 - 0.68**

Ornamental Vines and Groundcovers

A

Scientific Name			*Ardisia japonica*
Common Name			**Japanese Ardisia or Marlberry**
Collected From			Container production nursery
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.24 - 1.80	Fe	25 - 35
P	**0.11 - 0.17**	**Mn**	**0.34 - 89**
K	1.00 - 1.99	B	14 - 21
Ca	**1.12 - 1.62**	**Cu**	**3 - 6**
Mg	0.13 - 0.23	Zn	24 - 31
S	**0.15 - 0.28**	**Mo**	**0.10 - 0.26**

B

Scientific Name			*Aspidistra elatior*
Common Name			**Cast-iron Plant or Aspidistra**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			5 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.53 - 3.90	Fe	33 - 249
P	**0.17 - 0.31**	**Mn**	**75 - 734**
K	1.95 - 3.48	B	10 - 44
Ca	**0.69 - 1.55**	**Cu**	**4 - 15**
Mg	0.12 - 0.33	Zn	16 - 44
S	**0.18 - 0.32**	**Mo**	**0.12 - 1.34**

C

Scientific Name			*Bignonia capreolata*
Common Name			**Crossvine**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.22 - 2.73	Fe	37 - 63
P	**0.12 - 0.20**	**Mn**	**288 - 1808**
K	1.17 - 2.18	B	18 - 28
Ca	**1.01 - 1.19**	**Cu**	**6 - 17**
Mg	0.2 - 0.31	Zn	23 - 72
S	**0.18 - 0.25**	**Mo**	**0.08 - 0.23**

D

E

F

Palms

A

Scientific Name			*Archontophoenix cunninghamiana*
Common Name			**Bangalow or Piccabeen Palm**
Collected From			Field production nursery
Plant Part			25 leaflets from mid section of young, fully-mature leaves
Season			Summer
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 1.94	Fe	29 - 45
P	**0.24 - 0.27**	**Mn**	**30 - 45**
K	1.28 - 1.62	B	13 - 16
Ca	**0.67 - 0.73**	**Cu**	**6 - 8**
Mg	0.25 - 0.28	Zn	10 - 15
S	**0.48 - 0.63**	**Mo**	**1.99 - 2.20**

B

Scientific Name			*Areca catechu*
Common Name			**Betel-nut Palm**
Collected From			Field production nursery
Plant Part			20 leaflets from mid section of young, fully-mature leaves
Season			Summer
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.66 - 2.23	Fe	16 - 30
P	**0.24 - 0.30**	**Mn**	**18 - 26**
K	0.79 - 1.05	B	16 - 20
Ca	**0.28 - 0.43**	**Cu**	**3 - 5**
Mg	0.18 - 0.25	Zn	20 - 24
S	**0.48 - 0.63**	**Mo**	**1.17 - 1.95**

C

Scientific Name			*Caryota mitis*
Common Name			**Clustered Fishtail Palm**
Collected From			Field production nursery
Plant Part			25 leaflets from mid-section of young, fully mature leaves
Season			Summer
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.73 - 2.49	Fe	26 - 36
P	**0.24 - 0.30**	**Mn**	**18 - 30**
K	2.32 - 2.45	B	13 - 23
Ca	**0.61 - 0.82**	**Cu**	**6 - 8**
Mg	0.32 - 0.37	Zn	10 - 13
S	**0.12 - 0.19**	**Mo**	**0.12 - 0.13**

D

Scientific Name			*Chamaedorea elegans*
Common Name			**Parlor or Good-luck Palm**
Collected From			Container production nursery
Plant Part			25 leaflets from mid-section of young, fully mature leaves
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.50	Fe	50 - 300
P	**0.15 - 0.35**	**Mn**	**50 - 250**
K	1.00 - 3.00	B	25 - 60
Ca	**0.30 - 2.50**	**Cu**	**6 - 50**
Mg	0.25 - 0.80	Zn	25 - 200
S	**0.21 - 0.40**	**Mo**	**0.23 - 0.34**

E

Scientific Name			*Chamaedorea erumpens*
Common Name			**Bamboo Palm**
Collected From			Container production nursery
Plant Part			25 leaflets from mid-section of young, fully mature leaves
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.50 - 3.50	Fe	50 - 300
P	**0.15 - 0.30**	**Mn**	**50 - 250**
K	1.60 - 2.80	B	25 - 60
Ca	**1.00 - 2.50**	**Cu**	**6 - 50**
Mg	0.25 - 0.80	Zn	25 - 200
S	**0.21 - 0.40**	**Mo**	**0.21 - 0.39**

F

Scientific Name			*Chrysalidocarpus lutescens*
Common Name			**Areca or Butterfly Palm**
Collected From			Container production nursery
Plant Part			25 leaflets from mid-section of young, fully mature leaves
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 3.50	Fe	18 - 250
P	**0.11 - 0.80**	**Mn**	**47 - 250**
K	0.70 - 4.00	B	15 - 60
Ca	**0.80 - 2.50**	**Cu**	**1 - 25**
Mg	0.20 - 0.80	Zn	13 - 200
S	**0.21 - 0.75**	**Mo**	**0.76 - 2.33**

Palms

A

Scientific Name		*Howea forsterana*	
Common Name		**Kentia or Sentry Palm**	
Collected From		Container production nursery & botanical garden/arboretum	
Plant Part		20 leaflets from mid-section of young, fully-mature leaves	
Season		Summer	
Data Type		Sufficiency Range	
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.10 - 2.80	Fe	56 - 300
P	**0.12 - 0.28**	**Mn**	**27 - 165**
K	1.30 - 2.50	B	19 - 54
Ca	**0.40 - 2.00**	**Cu**	**1 - 10**
Mg	0.18 - 0.30	Zn	20 - 200
S	**0.19 - 0.29**	**Mo**	**0.15 - 0.23**

B

Scientific Name		*Normanbya normanbyi*	
Common Name		**Black Palm**	
Collected From		Field production nursery	
Plant Part		25 leaflets from mid-section of young, fully-mature leaves	
Season		Summer	
Data Type		Survey Range	
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.12 - 1.70	Fe	19 - 21
P	**0.11 - 0.15**	**Mn**	**11 - 19**
K	0.79 - 0.99	B	10 - 14
Ca	**0.32 - 0.35**	**Cu**	**1 - 3**
Mg	0.24 - 0.30	Zn	10 - 14
S	**0.14 - 0.24**	**Mo**	**0.12 - 0.37**

C

Scientific Name		*Phoenix roebelenii*	
Common Name		**Pygmy Date Palm**	
Collected From		Container production nursery	
Plant Part		25 leaflets from mid-section of young, fully-mature leaves	
Season		Summer	
Data Type		Sufficiency Range	
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.80 - 2.80	Fe	15 - 200
P	**0.16 - 0.40**	**Mn**	**25 - 200**
K	1.20 - 2.50	B	10 - 30
Ca	**0.32 - 1.50**	**Cu**	**4 - 20**
Mg	0.18 - 0.30	Zn	15 - 125
S	**0.18 - 0.27**	**Mo**	**0.21 - 0.51**

D

Scientific Name		*Ravenea rivularis General*	
Common Name		**Majesty Palm**	
Collected From		Field production nursery	
Plant Part		20 leaflets from mid-section of young, fully-mature leaves	
Season		Summer	
Data Type		Sufficiency Range	
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.80 - 3.10	Fe	50 - 150
P	**0.16 - 0.40**	**Mn**	**48 - 125**
K	1.20 - 2.50	B	14 - 24
Ca	**0.85 - 1.5**	**Cu**	**5 - 20**
Mg	0.25 - 0.35	Zn	15 - 45
S	**0.18 - 0.28**	**Mo**	**0.21 - 0.50**

E

Scientific Name		*Rhapis excelsa*	
Common Name		**Lady Palm or Fern Rhapis**	
Collected From		Container production nursery	
Plant Part		25 leaflets from mid-section of young, fully-mature leaves	
Season		Summer	
Data Type		Sufficiency Range	
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.80 - 2.80	Fe	80 - 300
P	**0.15 - 0.80**	**Mn**	**50 - 250**
K	1.50 - 2.50	B	16 - 75
Ca	**0.41 - 1.00**	**Cu**	**7 - 25**
Mg	0.20 - 0.30	Zn	20 - 200
S	**0.15 - 0.75**	**Mo**	**0.08 - 0.45**

F

Scientific Name		*Veitchia joannis*	
Common Name		**Joannis or Fiji Island Christmas Palm**	
Collected From		Field production nursery	
Plant Part		25 leaflets from mid-section of young, fully-mature leaves	
Season		Summer	
Data Type		Survey Range	
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	1.79 - 2.18	Fe	30 - 60
P	**0.17 - 0.25**	**Mn**	**42 - 95**
K	0.98 - 2.17	B	14 - 29
Ca	**0.61 - 1.14**	**Cu**	**4 - 12**
Mg	0.28 - 0.37	Zn	11 - 21
S	**0.22 - 0.34**	**Mo**	**0.09 - 0.25**

Palms

A

SCIENTIFIC NAME	*Veitchia merrillii*
COMMON NAME	**Christmas or Manila or Adonidia Palm**
COLLECTED FROM	Field production nursery
PLANT PART	25 leaflets from mid-section of young, fully-mature leaves
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	1.73 - 1.95	Fe	26 - 66
P	**0.15 - 0.24**	**Mn**	**48 - 113**
K	0.81–2	B	15 - 26
Ca	**0.55 - 1.13**	**Cu**	**5 - 10**
Mg	0.27 - 0.34	Zn	8 - 20
S	**0.23 - 0.34**	**Mo**	**0.11 - 0.24**

B

C

D

E

F

Turfgrasses

A

SCIENTIFIC NAME	*Agrostis alba*
COMMON NAME	**Redtop**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	3.3 - 4.3	Fe	34 - 190
P	**0.28 - 0.38**	**Mn**	**33 - 128**
K	2 - 3.33	B	10 - 18
Ca	**.56 - 1.12**	**Cu**	**7 - 22**
Mg	.25 - 0.37	Zn	24 - 40
S	**0.19 - 0.26**	**Mo**	**0.13 - 0.30**

B

SCIENTIFIC NAME	*Agrostis palustris*
COMMON NAME	**Creeping Bentgrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	4.50 - 6.00	Fe	100 - 300
P	**0.30 - 0.60**	**Mn**	**50 - 100**
K	2.20 - 2.60	B	8 - 20
Ca	**0.50 - 0.75**	**Cu**	**8 - 30**
Mg	0.25 - 0.30	Zn	25 - 75
S	**0.22 - 0.40**	**Mo**	**0.4 - 1.01**

C

SCIENTIFIC NAME	*Agrostis palustris*
COMMON NAME	**Creeping Bentgrass**
COLLECTED FROM	Golfcourse greens
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	2.40 - 8.30	Fe	99 - 500
P	**0.20 - 0.55**	**Mn**	**30 - 160**
K	0.86 - 2.55	B	5 - 24
Ca	**0.21 - 0.50**	**Cu**	**9 - 40**
Mg	0.09 - 0.22	Zn	5 - 60
S	**0.23 - 0.39**	**Mo**	**0.50 - 1.00**

D

SCIENTIFIC NAME	*Agrostis palustris 'Penncross'*
COMMON NAME	**Penncross' Creeping Bentgrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Penncross'

Macronutrients %		Micronutrients ppm	
N	3.99 - 4.81	Fe	190 - 342
P	**0.50 - 0.63**	**Mn**	**67 - 77**
K	2.24 - 2.54	B	19 - 31
Ca	**0.98 - 1.08**	**Cu**	**4 - 6**
Mg	0.30 - 0.35	Zn	46 - 62
S	**0.34 - 0.43**	**Mo**	**0.37 - 1.06**

E

SCIENTIFIC NAME	*Agrostis tenuis*
COMMON NAME	**Colonial Bentgrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.24 - 3.90	Fe	80 - 179
P	**0.24 - 0.46**	**Mn**	**33 - 144**
K	1.25 - 3.02	B	6 - 26
Ca	**.36 - .78**	**Cu**	**7 - 19**
Mg	.25 - .3	Zn	25 - 50
S	**0.22 - 0.35**	**Mo**	**0.4 - 1.25**

F

SCIENTIFIC NAME	*Cynodon dactylon*
COMMON NAME	**Bermudagrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	1.74 - 3.01	Fe	117 - 256
P	**0.34 - 0.54**	**Mn**	**71 - 88**
K	1.16 - 2.44	B	7 - 10
Ca	**0.53 - 0.70**	**Cu**	**3 - 7**
Mg	0.13 - 0.20	Zn	32 - 65
S	**0.49 - 0.72**	**Mo**	**0.08 - 0.63**

Turfgrasses

A

Scientific Name			*Cynodon dactylon*
Common Name			**Bermudagrass**
Collected From			Golfcourse fairways and lawns
Plant Part			Clippings from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Not specified
Macronutrients %		**Micronutrients ppm**	
N	2.30 - 5.00	Fe	50 - 500
P	**0.15 - 0.50**	**Mn**	**25 - 300**
K	1.00 - 4.00	B	6 - 30
Ca	**0.35 - 1.00**	**Cu**	**5 - 50**
Mg	0.13 - 0.50	Zn	20 - 250
S	**0.15 - 0.50**	**Mo**	**0.10 - 1.20**

B

Scientific Name			*Cynodon dactylon*
Common Name			**Bermudagrass**
Collected From			Golfcourse greens and tees
Plant Part			Clippings from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Not specified
Macronutrients %		**Micronutrients ppm**	
N	4.00 - 6.00	Fe	50 - 500
P	**0.25 - 0.60**	**Mn**	**25 - 300**
K	1.50 - 4.00	B	6 - 30
Ca	**0.50 - 1.00**	**Cu**	**5 - 50**
Mg	0.13 - 0.40	Zn	20 - 250
S	**0.20 - 0.50**	**Mo**	**0.10 - 1.20**

C

Scientific Name			*Cynodon dactylon 'Cheyenne'*
Common Name			**Cheyenne' Bermudagrass**
Collected From			Field test plots
Plant Part			Clippings from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Cheyenne'
Macronutrients %		**Micronutrients ppm**	
N	1.35 - 2.67	Fe	129 - 320
P	**0.26 - 0.54**	**Mn**	**57 - 92**
K	1.07 - 2.12	B	6 - 9
Ca	**0.52 - 0.70**	**Cu**	**1 - 5**
Mg	0.10 - 0.20	Zn	28 - 56
S	**0.39 - 0.55**	**Mo**	**0.11 - 0.56**

D

Scientific Name			*Cynodon dactylon 'NuMex Sahara'*
Common Name			**NuMex Sahara' Bermudagrass**
Collected From			Field test plots
Plant Part			Clippings from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'NuMex Sahara'
Macronutrients %		**Micronutrients ppm**	
N	2.96 - 3.66	Fe	114 - 161
P	**0.25 - 0.29**	**Mn**	**51 - 65**
K	1.65 - 1.90	B	7 - 11
Ca	**0.68 - 0.82**	**Cu**	**3 - 9**
Mg	0.14 - 0.17	Zn	52 - 69
S	**0.46 - 0.50**	**Mo**	**0.12 - 0.20**

E

Scientific Name			*Cynodon dactylon 'Sahara'*
Common Name			**Sahara' Bermudagrass**
Collected From			Field test plots
Plant Part			Clippings from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Sahara'
Macronutrients %		**Micronutrients ppm**	
N	1.66 - 2.93	Fe	164 - 309
P	**0.34 - 0.42**	**Mn**	**53 - 68**
K	1.31 - 2.16	B	7 - 12
Ca	**0.44 - 0.60**	**Cu**	**4 - 8**
Mg	0.11 - 0.17	Zn	33 - 60
S	**0.47 - 0.67**	**Mo**	**0.21 - 0.40**

F

Scientific Name			*Cynodon dactylon 'Santa Ana'*
Common Name			**Santa Ana' Bermudagrass**
Collected From			Field test plots
Plant Part			Clippings from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Santa Ana'
Macronutrients %		**Micronutrients ppm**	
N	3.10 - 3.81	Fe	125 - 232
P	**0.27 - 0.39**	**Mn**	**50 - 65**
K	1.31 - 1.88	B	6 - 9
Ca	**0.74 - 0.80**	**Cu**	**3 - 6**
Mg	0.14 - 0.16	Zn	85 - 201
S	**0.34 - 0.38**	**Mo**	**0.30 - 0.80**

Turfgrasses

A

Scientific Name	*Cynodon dactylon 'Texturf 10'*		
Common Name	**Texturf 10' Bermudagrass**		
Collected From	Field test plots		
Plant Part	Clippings from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Texturf 10'		
Macronutrients %		**Micronutrients ppm**	
N	2.23 - 2.86	Fe	103 - 232
P	**0.18 - 0.26**	**Mn**	**50 - 80**
K	0.97 - 1.46	B	6 - 11
Ca	**0.68 - 0.87**	**Cu**	**1 - 3**
Mg	0.12 - 0.14	Zn	57 - 96
S	**0.30 - 0.40**	**Mo**	**0.12 - 0.30**

B

Scientific Name	*Cynodon dactylon x Cynodon transvaalensis 'Tifdwarf'*		
Common Name	**Tifdwarf' Hybrid Bermudagrass**		
Collected From	Field test plots		
Plant Part	Clippings from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Tifdwarf'		
Macronutrients %		**Micronutrients ppm**	
N	2.24 - 3.11	Fe	145 - 340
P	**0.27 - 0.37**	**Mn**	**54 - 79**
K	1.01 - 1.38	B	9 - 12
Ca	**0.56 - 0.89**	**Cu**	**3 - 9**
Mg	0.12 - 0.21	Zn	17 - 41
S	**0.45 - 0.56**	**Mo**	**0.31 - 0.65**

C

Scientific Name	*Cynodon dactylon x Cynodon transvaalensis 'Tifeagle' ('Tifeagle' Hybrid Bermuda)*		
Common Name	**Tifeagle' Hybrid Bermuda**		
Collected From	Field test plots		
Plant Part	Clippings from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Tifeagle		
Macronutrients %		**Micronutrients ppm**	
N	2.01 - 3.33	Fe	140 - 380
P	**0.25 - 0.40**	**Mn**	**55 - 80**
K	1.10 - 1.65	B	9 - 14
Ca	**0.56 - 0.71**	**Cu**	**4 - 9**
Mg	0.18 - 0.30	Zn	17 - 41
S	**0.35 - 0.46**	**Mo**	**0.31 - 0.65**

D

Scientific Name	*Cynodon dactylon x Cynodon transvaalensis 'Tifgreen'*		
Common Name	**Tifgreen' Hybrid Bermudagrass**		
Collected From	Field test plots		
Plant Part	Clippings from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Tifgreen'		
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 3.51	Fe	102 - 498
P	**0.27 - 0.51**	**Mn**	**38 - 80**
K	0.67 - 1.94	B	5 - 11
Ca	**0.53 - 1.14**	**Cu**	**2 - 8**
Mg	0.11 - 0.21	Zn	32 - 199
S	**0.33 - 0.49**	**Mo**	**0.25 - 1.04**

E

Scientific Name	*Cynodon dactylon x Cynodon transvaalensis 'Tifway II'*		
Common Name	**TifwayII' Hybrid Bermudagrass**		
Collected From	Field test plots		
Plant Part	Clippings from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Tifway II'		
Macronutrients %		**Micronutrients ppm**	
N	1.79 - 2.69	Fe	190 - 353
P	**0.30 - 0.48**	**Mn**	**67 - 84**
K	0.98 - 1.71	B	6 - 11
Ca	**0.53 - 0.68**	**Cu**	**2 - 8**
Mg	0.11 - 0.17	Zn	30 - 68
S	**0.40 - 0.53**	**Mo**	**0.63 - 1.20**

F

Scientific Name	*Cynodon dactylon x Cynodon transvaalensis 'Tifway'*		
Common Name	**Tifway' Hybrid Bermudagrass**		
Collected From	Field test plots		
Plant Part	Clippings from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Tifway'		
Macronutrients %		**Micronutrients ppm**	
N	2.49 - 4.56	Fe	104 - 316
P	**0.26 - 0.38**	**Mn**	**45 - 80**
K	0.95 - 1.97	B	6 - 12
Ca	**0.50 - 0.90**	**Cu**	**2 - 10**
Mg	0.13 - 0.16	Zn	46 - 122
S	**0.32 - 0.51**	**Mo**	**0.18 - 1.77**

Turfgrasses

A

SCIENTIFIC NAME	*Eremochloa Ophiuroides*		
COMMON NAME	**Centipede**		
COLLECTED FROM	Field test plots		
PLANT PART	Clippings from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	1.5 - 2.9	Fe	102 - 221
P	**0.18 - 0.26**	**Mn**	**35 - 75**
K	1.12 - 2.5	B	5 - 10
Ca	**0.50 - 1.15**	**Cu**	**2 - 7**
Mg	0.12 - 0.21	Zn	17 - 40
S	**0.20 - 0.38**	**Mo**	**0.14 - 0.30**

B

SCIENTIFIC NAME	*Eremochloa ophiuroides*		
COMMON NAME	**Centipede Grass**		
COLLECTED FROM	Field test plots		
PLANT PART	Clippings from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	1.79 - 2.70	Fe	83 - 167
P	**0.18 - 0.35**	**Mn**	**54 - 150**
K	1.25 - 2.05	B	6 - 11
Ca	**0.45 - 1.00**	**Cu**	**5 - 8**
Mg	0.20 - 0.34	Zn	17 - 41
S	**0.16 - 0.32**	**Mo**	**0.31 - 0.55**

C

SCIENTIFIC NAME	*Festuca arundinacea*		
COMMON NAME	**Tall Fescue**		
COLLECTED FROM	Field test plots		
PLANT PART	Clippings from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Not specified		
Macronutrients %		Micronutrients ppm	
N	3.40 - 4.65	Fe	83 - 167
P	**0.34 - 0.50**	**Mn**	**54 - 74**
K	3.00 - 4.00	B	15 - 20
Ca	**0.40 - 0.45**	**Cu**	**9 - 15**
Mg	0.24 - 0.29	Zn	28 - 64
S	**0.40 - 0.44**	**Mo**	**0.69 - 1.21**

D

SCIENTIFIC NAME	*Festuca arundinacea 'Kentucky-31'*		
COMMON NAME	**Kentucky-31' Tall Fescue**		
COLLECTED FROM	Field test plots		
PLANT PART	Clippings from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Kentucky-31'		
Macronutrients %		Micronutrients ppm	
N	2.99 - 5.40	Fe	66 - 354
P	**0.18 - 0.51**	**Mn**	**28 - 71**
K	2.25 - 3.70	B	9 - 19
Ca	**0.49 - 1.01**	**Cu**	**6 - 34**
Mg	0.28 - 0.35	Zn	18 - 47
S	**0.16 - 0.32**	**Mo**	**0.19 - 1.05**

E

SCIENTIFIC NAME	*Festuca rubra*		
COMMON NAME	**Creeping Red Fescue**		
COLLECTED FROM	Field test plots		
PLANT PART	Clippings from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		Micronutrients ppm	
N	2.22 - 3.70	Fe	57 - 266
P	**0.18 - 0.34**	**Mn**	**33 - 54**
K	1.66 - 2.62	B	6 - 16
Ca	**0.39 - 0.87**	**Cu**	**5 - 20**
Mg	0.21 - 0.24	Zn	18 - 30
S	**0.18 - 0.30**	**Mo**	**0.2 - 1.72**

F

SCIENTIFIC NAME	*Lolium perenne*		
COMMON NAME	**Perennial Ryegrass**		
COLLECTED FROM	Field test plots		
PLANT PART	Clippings from new growth		
SEASON	Summer		
DATA TYPE	Sufficiency Range		
CULTIVARS USED	Not specified		
Macronutrients %		Micronutrients ppm	
N	3.34 - 5.10	Fe	97 - 934
P	**0.35 - 0.55**	**Mn**	**30 - 73**
K	2.00 - 3.42	B	5 - 17
Ca	**0.25 - 0.51**	**Cu**	**6 - 38**
Mg	0.16 - 0.32	Zn	14 - 64
S	**0.27 - 0.56**	**Mo**	**0.50 - 1.00**

Turfgrasses

A

SCIENTIFIC NAME	*Lolium perenne 'Medalist X' blend*
COMMON NAME	**Medalist X' Perennial Ryegrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	'Medalist X'

Macronutrients %		Micronutrients ppm	
N	3.48 - 4.02	Fe	123 - 156
P	**0.48 - 0.55**	**Mn**	**34 - 64**
K	3.14 - 3.57	B	5 - 9
Ca	**0.70 - 0.79**	**Cu**	**3 - 5**
Mg	0.23 - 0.25	Zn	45 - 56
S	**0.39 - 0.45**	**Mo**	**0.72 - 1.53**

B

SCIENTIFIC NAME	*Poa pratensis*
COMMON NAME	**Kentucky Bluegrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	2.51 - 5.10	Fe	102 - 182
P	**0.27 - 0.40**	**Mn**	**18 - 37**
K	1.73 - 3.00	B	6 - 8
Ca	**0.27 - 0.58**	**Cu**	**8 - 33**
Mg	0.13 - 0.16	Zn	19 - 88
S	**0.18 - 0.24**	**Mo**	**0.82 - 1.77**

C

SCIENTIFIC NAME	*Poa pratensis 'Merion'*
COMMON NAME	**Merion' Kentucky Bluegrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Merion'

Macronutrients %		Micronutrients ppm	
N	2.87 - 5.40	Fe	56 - 189
P	**0.22 - 0.49**	**Mn**	**33 - 48**
K	2.33 - 3.08	B	9 - 21
Ca	**0.36 - 0.89**	**Cu**	**5 - 25**
Mg	0.22 - 0.45	Zn	18 - 45
S	**0.16 - 0.28**	**Mo**	**0.2 - 1.35**

D

SCIENTIFIC NAME	*Poa trivialis 'Colt'*
COMMON NAME	**Colt' Rough Bluegrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Colt'

Macronutrients %		Micronutrients ppm	
N	2.36 - 3.22	Fe	148 - 324
P	**0.35 - 0.46**	**Mn**	**101 - 133**
K	2.25 - 3.08	B	10 - 14
Ca	**0.66 - 0.83**	**Cu**	**2 - 6**
Mg	0.27 - 0.30	Zn	33 - 41
S	**0.46 - 0.51**	**Mo**	**0.57 - 1.33**

E

SCIENTIFIC NAME	*Poa trivialis 'Danish Common'*
COMMON NAME	**Danish Common' Rough Bluegrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Danish Common'

Macronutrients %		Micronutrients ppm	
N	2.41 - 2.79	Fe	129 - 291
P	**0.38 - 0.43**	**Mn**	**95 - 127**
K	2.91 - 3.14	B	10 - 14
Ca	**0.62 - 0.80**	**Cu**	**4 - 12**
Mg	0.30 - 0.37	Zn	31 - 37
S	**0.38 - 0.48**	**Mo**	**0.51 - 0.90**

F

SCIENTIFIC NAME	*Poa trivialis 'Darkhorse'*
COMMON NAME	**Darkhorse' Rough Bluegrass**
COLLECTED FROM	Field test plots
PLANT PART	Clippings from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Darkhorse'

Macronutrients %		Micronutrients ppm	
N	2.55 - 3.03	Fe	102 - 271
P	**0.36 - 0.40**	**Mn**	**89 - 99**
K	2.58 - 3.17	B	9 - 11
Ca	**0.55 - 0.70**	**Cu**	**3 - 7**
Mg	0.23 - 0.26	Zn	37 - 42
S	**0.45 - 0.50**	**Mo**	**0.24 - 1.56**

Turfgrasses

A

SCIENTIFIC NAME			*Poa trivialis 'Laser'*
COMMON NAME			**Laser' Rough Bluegrass**
COLLECTED FROM			Field test plots
PLANT PART			Clippings from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Laser'
Macronutrients %		**Micronutrients ppm**	
N	2.67 - 3.00	Fe	127 - 241
P	**0.35 - 0.40**	**Mn**	**91 - 98**
K	2.48 - 2.77	B	10 - 12
Ca	**0.66 - 0.72**	**Cu**	**3 - 5**
Mg	0.25 - 0.28	Zn	38 - 43
S	**0.22 - 0.48**	**Mo**	**0.02 - 1.16**

B

SCIENTIFIC NAME			*Poa trivialis 'Pro Am'*
COMMON NAME			**Pro Am' Rough Bluegrass**
COLLECTED FROM			Field test plots
PLANT PART			Clippings from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Pro Am'
Macronutrients %		**Micronutrients ppm**	
N	2.97 - 3.24	Fe	206 - 308
P	**0.35 - 0.40**	**Mn**	**76 - 88**
K	2.89 - 3.24	B	8 - 14
Ca	**0.61 - 0.75**	**Cu**	**6 - 8**
Mg	0.23 - 0.26	Zn	43 - 47
S	**0.47 - 0.53**	**Mo**	**0.54 - 1.88**

C

SCIENTIFIC NAME			*Poa trivialis 'Sabre'*
COMMON NAME			**Sabre' Rough Bluegrass**
COLLECTED FROM			Field test plots
PLANT PART			Clippings from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Sabre'
Macronutrients %		**Micronutrients ppm**	
N	2.69 - 3.49	Fe	129 - 249
P	**0.36 - 0.40**	**Mn**	**79 - 104**
K	2.93 - 3.15	B	8 - 10
Ca	**0.60 - 0.72**	**Cu**	**3 - 6**
Mg	0.24 - 0.27	Zn	35 - 42
S	**0.44 - 0.55**	**Mo**	**0.29 - 0.99**

D

SCIENTIFIC NAME			*Poa trivialis 'Winterplay'*
COMMON NAME			**Winterplay' Rough Bluegrass**
COLLECTED FROM			Field test plots
PLANT PART			Clippings from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Winterplay'
Macronutrients %		**Micronutrients ppm**	
N	3.04 - 3.41	Fe	126 - 391
P	**0.37 - 0.40**	**Mn**	**95 - 104**
K	2.82 - 2.96	B	10 - 13
Ca	**0.60 - 0.77**	**Cu**	**6 - 8**
Mg	0.24 - 0.29	Zn	40 - 45
S	**0.49 - 0.59**	**Mo**	**0.42 - 0.70**

E

SCIENTIFIC NAME			*Stenotaphrum secundatum*
COMMON NAME			**St. Augustinegrass**
COLLECTED FROM			Field test plots
PLANT PART			Clippings from new growth
SEASON			Summer
DATA TYPE			Sufficiency Range
CULTIVARS USED			Not specified
Macronutrients %		**Micronutrients ppm**	
N	1.90 - 3.00	Fe	50 - 300
P	**0.20 - 0.50**	**Mn**	**40 - 250**
K	2.50 - 4.00	B	5 - 10
Ca	**0.30 - 0.50**	**Cu**	**10 - 20**
Mg	0.15 - 0.25	Zn	20 - 100
S	**0.18 - 0.33**	**Mo**	**0.15 - 0.5**

F

SCIENTIFIC NAME			*Stenotaphrum secundatum 'Seville'*
COMMON NAME			**Seville' St. Augustinegrass**
COLLECTED FROM			Field test plots
PLANT PART			Clippings from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Seville'
Macronutrients %		**Micronutrients ppm**	
N	2.75 - 3.10	Fe	208 - 356
P	**0.28 - 0.33**	**Mn**	**49 - 68**
K	2.02 - 2.36	B	7 - 12
Ca	**0.59 - 0.76**	**Cu**	**5 - 6**
Mg	0.20 - 0.23	Zn	57 - 68
S	**0.34 - 0.40**	**Mo**	**0.12 - 0.30**

Turfgrasses

A

Scientific Name	*Zoysia japonica 'El Toro'*
Common Name	**El Toro' Zoysiagrass**
Collected From	Field test plots
Plant Part	Clippings from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'El Toro'

Macronutrients %		Micronutrients ppm	
N	1.89 - 2.17	Fe	161 - 273
P	**0.18 - 0.26**	**Mn**	**26 - 31**
K	1.12 - 1.46	B	6 - 12
Ca	**0.42 - 0.52**	**Cu**	**1 - 3**
Mg	0.13 - 0.15	Zn	37 - 55
S	**0.29 - 0.32**	**Mo**	**0.12 - 0.30**

B

Scientific Name	*Zoysia japonica 'Meyer'*
Common Name	**Meyer' Zoysiagrass**
Collected From	Field test plots
Plant Part	Clippings from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Meyer'

Macronutrients %		Micronutrients ppm	
N	1.91 - 2.40	Fe	58 - 203
P	**0.2 - 0.29**	**Mn**	**34 - 89**
K	1.45 - 2.19	B	6 - 18
Ca	**0.29 - 0.92**	**Cu**	**5 - 17**
Mg	0.13 - 4	Zn	21 - 35
S	**0.22 - 0.33**	**Mo**	**0.2 - 1.77**

C

Scientific Name	*Zoysia japonica x Zoysia tenuifolia 'Emerald'*
Common Name	**Emerald' Hybrid Zoysiagrass**
Collected From	Field test plots
Plant Part	Clippings from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Emerald'

Macronutrients %		Micronutrients ppm	
N	2.04 - 2.36	Fe	188 - 318
P	**0.19 - 0.22**	**Mn**	**25 - 34**
K	1.05 - 1.27	B	6 - 11
Ca	**0.44 - 0.56**	**Cu**	**2 - 4**
Mg	0.13 - 0.15	Zn	36 - 55
S	**0.32 - 0.37**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Zoysia matrella*
Common Name	**Manilagrass**
Collected From	Field test plots
Plant Part	Clippings from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	2.23 - 3.35	Fe	43 - 79
P	**0.11 - 0.39**	**Mn**	**37 - 55**
K	0.38 - 1.51	B	13 - 25
Ca	**0.31 - 0.54**	**Cu**	**5 - 13**
Mg	0.11 - 0.25	Zn	20 - 45
S	**0.2 - 0.33**	**Mo**	**0.09 - 0.45**

E

F

Vegetables

A

Scientific Name	*Abelmoschus esculentus [L.] Moench*
Common Name	**Okra**
Collected From	Production fields
Plant Part	Most recentley matured leaf and petiole
Season	30 days after seeding
Data Type	Survey Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.5 - 5	Fe	50 - 100
P	**0.3 - 0.6**	**Mn**	**30 - 100**
K	2 - 3	B	25 - 50
Ca	**0.5 - 0.8**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	30 - 50
S	**0.23 - 0.29**	**Mo**	**0.23 - 0.44**

B

Scientific Name	*Abelmoschus esculentus [L.] Moench*
Common Name	**Okra**
Collected From	Production fields
Plant Part	10-15 mature leaves from new growth
Season	15 weeks
Data Type	Survey Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.7 - 4.5	Fe	73 - 200
P	**0.3 - 0.42**	**Mn**	**75 - 291**
K	1.7 - 2.7	B	20 - 40
Ca	**2.5 - 3.5**	**Cu**	**5 - 12**
Mg	0.4 - 0.7	Zn	20 - 75
S	**0.27 - 0.35**	**Mo**	**0.2 - 1.25**

C

Scientific Name	*Abelmoschus esculentus [L.] Moench*
Common Name	**Okra**
Collected From	Production fields
Plant Part	Most recentley matured leaf and petiole
Season	Prior to harvest
Data Type	Survey Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	2.5 - 3	Fe	50 - 100
P	**0.3 - 0.6**	**Mn**	**30 - 100**
K	2 - 3	B	25 - 50
Ca	**1 - 1.5**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	30 - 50
S	**0.21 - 0.29**	**Mo**	**0.24 - 1.14**

D

Scientific Name	*Allium cepa (Cepa group)*
Common Name	**Onion, maturing bulb**
Collected From	Production fields
Plant Part	12-15 whole tops (green portion only), 1/2-full maturity
Season	1/2 grown to maturity
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.50 - 5.50	Fe	60 - 300
P	**0.31 - 0.45**	**Mn**	**50 - 250**
K	3.50 - 5.00	B	25 - 75
Ca	**1.50 - 2.20**	**Cu**	**15 - 35**
Mg	0.25 - 0.40	Zn	25 - 100
S	**0.50 - 1.00**	**Mo**	**0.14 - 0.21**

E

Scientific Name	*Allium cepa (Cepa group)*
Common Name	**Onion, Vidalia, Sweet Georgia**
Collected From	Production fields
Plant Part	12-15 whole tops (green portion only), 1/2-full maturity
Season	1/3 maturity
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3 - 4	Fe	87 - 166
P	**0.35 - 0.5**	**Mn**	**50 - 250**
K	2.5 - 3.45	B	18 - 35
Ca	**1.04 - 1.75**	**Cu**	**15 - 35**
Mg	.2 - .33	Zn	32 - 55
S	**0.36 - 0.55**	**Mo**	**0.5 - 2.27**

F

Scientific Name	*Allium cepa (Cepa group)*
Common Name	**Onion, young bulb**
Collected From	Production fields
Plant Part	12-15 whole tops (green portion only), 1/3-1/2 maturity
Season	1/3 to 1/2 maturity
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	5.00 - 6.0	Fe	60 - 300
P	**0.35 - 0.5**	**Mn**	**50 - 250**
K	4.00 - 5.5	B	22 - 60
Ca	**1.00 - 3.5**	**Cu**	**15 - 35**
Mg	0.30 - 0.5	Zn	25 - 80
S	**0.50 - 1.0**	**Mo**	**1 - 5**

Vegetables

A

Scientific Name	*Allium sativum*
Common Name	**Garlic**
Collected From	Production fields
Plant Part	12-15 most recent fully-developed (green portion only)
Season	Bulbing
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.40 - 4.5	Fe	60 - 138
P	**0.28 - 0.5**	**Mn**	**45 - 60**
K	3.00 - 4.5	B	18 - 55
Ca	**1.00 - 1.8**	**Cu**	**15 - 25**
Mg	0.23 - 0.3	Zn	33 - 67
S	**0.22 - 0.43**	**Mo**	**0.33 - 0.45**

B

Scientific Name	*Allium sativum*
Common Name	**Garlic**
Collected From	Production fields
Plant Part	12-15 most recent fully-developed (green portion only)
Season	Post bulbing
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	2.90 - 3.5	Fe	55 - 167
P	**0.26 - 0.4**	**Mn**	**44 - 167**
K	1.80 - 2.8	B	21 - 33
Ca	**1.50 - 2.5**	**Cu**	**12 - 18**
Mg	0.25 - 0.35	Zn	32 - 66
S	**0.21 - 0.34**	**Mo**	**0.23 - 0.5**

C

Scientific Name	*Allium sativum*
Common Name	**Garlic**
Collected From	Production fields
Plant Part	12-15 most recent fully-developed (green portion only)
Season	Pre bulbing stage
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.04 - 5.00	Fe	50 - 156
P	**0.30 - 0.60**	**Mn**	**33 - 56**
K	3.33 - 4.80	B	18 - 28
Ca	**0.80 - 1.50**	**Cu**	**5 - 15**
Mg	0.15 - 0.25	Zn	35 - 65
S	**0.25 - 0.33**	**Mo**	**0.15 - 0.4**

D

Scientific Name	*Amaranthus dubious*
Common Name	**Callaloo-field production**
Collected From	Production Fields
Plant Part	10-15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.0 - 5.8	Fe	50 - 300
P	**0.45 - 0.68**	**Mn**	**40 - 280**
K	3.88 - 5.50	B	25 - 75
Ca	**1.75 - 2.80**	**Cu**	**8 - 15**
Mg	0.40 - 1.10	Zn	25 - 65
S	**0.32 - 0.65**	**Mo**	**0.13 - 0.55**

E

Scientific Name	*Amaranthus gangeticus*
Common Name	**Hinn Choy or Chinese Spinach**
Collected From	Research test plots
Plant Part	40 blades from fully expanded leaves
Season	Summer
Data Type	Survey Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.5 - 5.60	Fe	59 - 380
P	**0.28 - 0.49**	**Mn**	**40 - 235**
K	3.57 - 5.01	B	27 - 63
Ca	**1.65 - 2.50**	**Cu**	**6 - 16**
Mg	.6 - 1.10	Zn	31 - 101
S	**0.21 - 0.34**	**Mo**	**0.16 - 0.5**

F

Scientific Name	*Amaranthus tricolor*
Common Name	**Tampala**
Collected From	Research test plots
Plant Part	40 blades from fully expanded leaves
Season	Summer
Data Type	Survey Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	2.11 - 4.29	Fe	45 - 376
P	**0.38 - 0.69**	**Mn**	**43 - 79**
K	2.22 - 5.58	B	22 - 47
Ca	**1.24 - 3.25**	**Cu**	**5 - 9**
Mg	.45 - 1.39	Zn	28 - 35
S	**0.28 - 0.45**	**Mo**	**0.19 - 0.24**

Vegetables

A

SCIENTIFIC NAME	*Apium graveolens var. dulce*
COMMON NAME	**Celery**
COLLECTED FROM	Production fields
PLANT PART	12-15 petioles from most recent fully-developed leaves
SEASON	6 week old plants
DATA TYPE	Sufficiency Range
CULTIVARS USED	var. dulce

Macronutrients %		Micronutrients ppm	
N	1.60 - 2.00	Fe	30 - 100
P	**0.30 - 0.60**	**Mn**	**10 - 100**
K	8.60 - 10.0	B	25 - 50
Ca	**2.20 - 3.50**	**Cu**	**5 - 15**
Mg	0.25 - 0.50	Zn	25 - 100
S	**0.09 - 0.20**	**Mo**	**0.01 - 0.5**

B

SCIENTIFIC NAME	*Apium graveolens var. dulce*
COMMON NAME	**Celery**
COLLECTED FROM	Production fields
PLANT PART	12-15 mature leaves from new growth
SEASON	Mature plant, non flowering
DATA TYPE	Sufficiency Range
CULTIVARS USED	var. dulce

Macronutrients %		Micronutrients ppm	
N	2.50 - 3.50	Fe	30 - 70
P	**0.30 - 0.50**	**Mn**	**100 - 300**
K	4.00 - 7.00	B	30 - 60
Ca	**0.60 - 3.00**	**Cu**	**5 - 8**
Mg	0.20 - 0.50	Zn	20 - 70
S	**0.09 - 0.20**	**Mo**	**0.01 - 0.5**

C

SCIENTIFIC NAME	*Apium graveolens var. dulce*
COMMON NAME	**Celery**
COLLECTED FROM	Production greenhouse
PLANT PART	12-15 mature leaves from new growth
SEASON	6 weeks after transplanting
DATA TYPE	Survey Range
CULTIVARS USED	var. dulce

Macronutrients %		Micronutrients ppm	
N	1.52 - 1.73	Fe	15 - 30
P	**0.33 - 0.62**	**Mn**	**5 - 10**
K	6.0 - 7.82	B	12 - 25
Ca	**0.56 - 1.3**	**Cu**	**3 - 5**
Mg	0.3 - 0.6	Zn	20 - 40
S	**0.15 - 0.22**	**Mo**	**0.1 - 0.5**

D

SCIENTIFIC NAME	*Armoracia rusticana*
COMMON NAME	**Horseradish**
COLLECTED FROM	Production fields
PLANT PART	12-15 leaf blades with midribs from most recently developed leaves
SEASON	Middle of growing season
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.00 - 3.5	Fe	50 - 200
P	**0.20 - 0.5**	**Mn**	**0.3 - 0.5**
K	2.50 - 4.5	B	25 - 60
Ca	**2.30 - 3.0**	**Cu**	**8 - 25**
Mg	0.25 - 3.0	Zn	25 - 200
S	**0.15 - 0.28**	**Mo**	**0.01 - 0.31**

E

SCIENTIFIC NAME	*Asparagus officinalis*
COMMON NAME	**Asparagus**
COLLECTED FROM	Production fields
PLANT PART	10-12 top 15 cm fronds
SEASON	Mid-summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	4.50 - 5.5	Fe	55 - 233
P	**0.35 - 0.5**	**Mn**	**21 - 240**
K	3.50 - 4.5	B	18 - 43
Ca	**0.67 - 1.5**	**Cu**	**5 - 18**
Mg	0.21 - 0.38	Zn	24 - 100
S	**0.19 - 0.33**	**Mo**	**0.2 - 0.8**

F

SCIENTIFIC NAME	*Asparagus officinalis*
COMMON NAME	**Asparagus**
COLLECTED FROM	Production Fields
PLANT PART	10-15 top 50 cm fronds
SEASON	Late summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.40 - 4.0	Fe	40 - 250
P	**0.20 - 0.5**	**Mn**	**10 - 200**
K	1.50 - 2.8	B	25 - 100
Ca	**0.40 - 1.0**	**Cu**	**5 - 25**
Mg	0.15 - 0.30	Zn	20 - 100
S	**0.18 - 0.25**	**Mo**	**0.2 - 0.8**

Vegetables

A

SCIENTIFIC NAME	*Beta vulgaris (Crassa group)*
COMMON NAME	**Table Beet**
COLLECTED FROM	Production fields
PLANT PART	20-25 mature leaves from new growth
SEASON	8-10 weeks after seeding
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.69 - 4.58	Fe	40 - 100
P	**0.22 - 0.33**	**Mn**	**20 - 65**
K	2.45 - 3.88	B	25 - 55
Ca	**1.33 - 2**	**Cu**	**3.6 - 10**
Mg	0.31 - 0.44	Zn	0.14 - 0.55
S	**0.2 - 0.29**	**Mo**	**0.2 - 0.34**

B

SCIENTIFIC NAME	*Beta vulgaris (Crassa group)*
COMMON NAME	**Table Beet**
COLLECTED FROM	Production fields
PLANT PART	20-25 mature leaves from new growth
SEASON	4-6 weeks after seeding
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.50 - 5.5	Fe	50 - 200
P	**0.25 - 0.5**	**Mn**	**50 - 250**
K	3.00 - 4.5	B	30 - 85
Ca	**2.50 - 3.5**	**Cu**	**5 - 15**
Mg	0.30 - 1.0	Zn	15 - 200
S	**0.19 - 0.29**	**Mo**	**0.15 - 0.42**

C

SCIENTIFIC NAME	*Brassica juncea*
COMMON NAME	**Akajuki Miiki Mustard**
COLLECTED FROM	Research test plots
PLANT PART	20 blades from fully-expanded leaves
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	"Akajuki Miiki" type

Macronutrients %		Micronutrients ppm	
N	2.4 - 5.02	Fe	30 - 347
P	**0.28 - 0.58**	**Mn**	**22 - 37**
K	2 - 5.27	B	14 - 25
Ca	**0.88 - 1.84**	**Cu**	**7 - 15**
Mg	0.23 - 0.4	Zn	22 - 43
S	**0.23 - 0.68**	**Mo**	**0.2 - 3.1**

D

SCIENTIFIC NAME	*Brassica juncea*
COMMON NAME	**Chinese Broadleaf Mustard**
COLLECTED FROM	Research test plots
PLANT PART	20 blades from fully-expanded leaves
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.67 - 4.79	Fe	45 - 251
P	**0.18 - 0.45**	**Mn**	**38 - 205**
K	2.56 - 4.86	B	14 - 26
Ca	**1.12 - 2.27**	**Cu**	**5 - 11**
Mg	0.19 - 0.24	Zn	15 - 29
S	**0.22 - 0.85**	**Mo**	**0.22 - 2**

E

SCIENTIFIC NAME	*Brassica juncea*
COMMON NAME	**Hakata Shiro Mustard**
COLLECTED FROM	Research test plots
PLANT PART	20 blades from fully-expanded leaves
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	"Hakata Shiro" type

Macronutrients %		Micronutrients ppm	
N	2.21 - 3.14	Fe	56 - 220
P	**0.22 - 0.59**	**Mn**	**33 - 87**
K	2.65 - 5.60	B	22 - 34
Ca	**1.45 - 2.66**	**Cu**	**5 - 16**
Mg	0.21 - 0.3	Zn	20 - 35
S	**0.16 - 0.48**	**Mo**	**1.14 - 3.9**

F

SCIENTIFIC NAME	*Brassica juncea*
COMMON NAME	**Hsuen Li Hung Mustard**
COLLECTED FROM	Research test plots
PLANT PART	20 blades from fully-expanded leaves
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	"Hsuen Li Hung" type

Macronutrients %		Micronutrients ppm	
N	2.35 - 4.95	Fe	56 - 277
P	**0.32 - 0.63**	**Mn**	**37 - 145**
K	2.8 - 5.56	B	18 - 28
Ca	**1.53 - 2.15**	**Cu**	**5 - 15**
Mg	0.19 - 0.24	Zn	33 - 55
S	**0.22 - 0.51**	**Mo**	**0.09 - 3.3**

Vegetables

A

SCIENTIFIC NAME			*Brassica juncea*
COMMON NAME			**Indian Mustard or Bayam**
COLLECTED FROM			Research test plots
PLANT PART			20 blades from fully-expanded leaves
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	2.39 - 3.77	Fe	47 - 563
P	**0.25 - 0.35**	**Mn**	**87 - 119**
K	2.45 - 5.52	B	21 - 30
Ca	**1.78 - 3.01**	**Cu**	**2 - 14**
Mg	0.32 - 1.08	Zn	21 - 32
S	**0.21 - 0.31**	**Mo**	**0.11 - 0.3**

B

SCIENTIFIC NAME			*Brassica juncea*
COMMON NAME			**Katsuo Na Mustard**
COLLECTED FROM			Research test plots
PLANT PART			20 blades from fully-expanded leaves
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			"Katsuo Na" type
Macronutrients %		**Micronutrients ppm**	
N	2.35 - 4.81	Fe	52 - 333
P	**0.31 - 0.60**	**Mn**	**32 - 44**
K	2.41 - 4.56	B	18 - 29
Ca	**1.35 - 2.11**	**Cu**	**5 - 15**
Mg	0.18 - 0.24	Zn	22 - 43
S	**0.22 - 0.71**	**Mo**	**0.17 - 2.5**

C

SCIENTIFIC NAME			*Brassica juncea*
COMMON NAME			**Ooba Takana Mustard**
COLLECTED FROM			Research test plots
PLANT PART			20 blades from fully-expanded leaves
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			"Ooba Takana" type
Macronutrients %		**Micronutrients ppm**	
N	2.78 - 3.73	Fe	46 - 169
P	**0.33 - 0.45**	**Mn**	**25 - 232**
K	2.58 - 4.23	B	17 - 28
Ca	**1.21 - 1.68**	**Cu**	**5 - 14**
Mg	0.2 - 0.28	Zn	23 - 31
S	**0.28 - 0.79**	**Mo**	**1.56 - 2.7**

D

SCIENTIFIC NAME			*Brassica juncea*
COMMON NAME			**Pot-herb Mustard**
COLLECTED FROM			Research test plots
PLANT PART			20 blades from fully-expanded leaves
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			
Macronutrients %		**Micronutrients ppm**	
N	2.31 - 2.63	Fe	44 - 105
P	**0.25 - 0.35**	**Mn**	**31 - 244**
K	2.33 - 3.55	B	20 - 31
Ca	**1.36 - 2.09**	**Cu**	**4 - 11**
Mg	0.2 - 0.3	Zn	18 - 28
S	**0.25 - 0.63**	**Mo**	**0.9 - 1.6**

E

SCIENTIFIC NAME			*Brassica juncea*
COMMON NAME			**Sendai Basyouna Mustard**
COLLECTED FROM			Research test plots
PLANT PART			20 blades from fully-expanded leaves
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			"Sendai Basyouna" type
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 2.99	Fe	45 - 129
P	**0.32 - 0.45**	**Mn**	**33 - 129**
K	2.56 - 3.75	B	18 - 27
Ca	**1.45 - 1.76**	**Cu**	**4 - 11**
Mg	0.17 - 0.26	Zn	18 - 27
S	**0.28 - 0.68**	**Mo**	**1.8 - 2.9**

F

SCIENTIFIC NAME			*Brassica juncea*
COMMON NAME			**Sensuji Kyouna Mustard**
COLLECTED FROM			Research test plots
PLANT PART			20 blades from fully-expanded leaves
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			"Sensuji Kyouna" type
Macronutrients %		**Micronutrients ppm**	
N	1.76 - 2.49	Fe	55 - 225
P	**0.23 - 0.28**	**Mn**	**36 - 133**
K	2.54 - 3.46	B	15 - 25
Ca	**1.63 - 2.07**	**Cu**	**5 - 10**
Mg	0.23 - 0.34	Zn	18 - 31
S	**0.29 - 0.83**	**Mo**	**0.8 - 1.1**

Vegetables

A

Scientific Name	*Brassica juncea*		
Common Name	**Wase Mibuna Mustard**		
Collected From	Research test plots		
Plant Part	20 blades from fully-expanded leaves		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	"Wase Mibuna" type		
Macronutrients %		**Micronutrients ppm**	
N	2.01 - 2.25	Fe	44 - 157
P	**0.22 - 0.37**	**Mn**	**41 - 178**
K	2.65 - 3.57	B	15 - 29
Ca	**1.65 - 2.26**	**Cu**	**5 - 15**
Mg	0.19 - 0.24	Zn	20 - 25
S	**0.31 - 0.54**	**Mo**	**0.18 - 2.9**

B

Scientific Name	*Brassica juncea var. multisecta*		
Common Name	**Cut-leaf Mustard**		
Collected From	Research test plots		
Plant Part	20 blades from fully-expanded leaves		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. multisecta		
Macronutrients %		**Micronutrients ppm**	
N	2.17 - 3.16	Fe	55 - 339
P	**0.19 - 0.3**	**Mn**	**51 - 167**
K	2.23 - 3.45	B	14 - 25
Ca	**1.21 - 2.11**	**Cu**	**5 - 15**
Mg	0.26 - 0.34	Zn	21 - 39
S	**0.43 - 0.52**	**Mo**	**0.16 - 2.4**

C

Scientific Name	*Brassica juncea var. rugosa*		
Common Name	**Mustard Greens**		
Collected From	Research test plots		
Plant Part	20 blades from fully-expanded leaves		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. rugosa		
Macronutrients %		**Micronutrients ppm**	
N	2.97 - 3.85	Fe	76 - 209
P	**0.41 - 0.64**	**Mn**	**40 - 52**
K	3.18 - 4.39	B	20 - 35
Ca	**1.52 - 2.51**	**Cu**	**3 - 5**
Mg	0.21 - 0.36	Zn	20 - 36
S	**0.61 - 0.67**	**Mo**	**1.37 - 5.00**

D

Scientific Name	*Brassica oleracea var. acephala*		
Common Name	**Collards**		
Collected From	Production fields		
Plant Part	Most recently matured leaf and petiole		
Season	Young Plants		
Data Type	Sufficiency Range		
Cultivars Used	var. acephala		
Macronutrients %		**Micronutrients ppm**	
N	4 - 5	Fe	40 - 100
P	**0.3 - 0.6**	**Mn**	**40 - 100**
K	3 - 5	B	25 - 50
Ca	**1 - 2**	**Cu**	**5 - 10**
Mg	0.4 - 1	Zn	25 - 50
S	**0.28 - 0.60**	**Mo**	**0.26 - 1.46**

E

Scientific Name	*Brassica oleracea var. acephala*		
Common Name	**Collards**		
Collected From	Production fields		
Plant Part	12-15 mature leaves from new growth		
Season	Middle of growing season		
Data Type	Sufficiency Range		
Cultivars Used	var. acephala		
Macronutrients %		**Micronutrients ppm**	
N	4.00 - 5.0	Fe	50 - 150
P	**0.30 - 0.7**	**Mn**	**30 - 250**
K	3.00 - 4.5	B	30 - 100
Ca	**3.00 - 4.0**	**Cu**	**4 - 20**
Mg	0.25 - 0.75	Zn	20 - 100
S	**0.23 - 0.55**	**Mo**	**0.34 - 1.23**

F

Scientific Name	*Brassica oleracea var. acephala*		
Common Name	**Collards**		
Collected From	Production fields		
Plant Part	Most recently matured leaf and petiole		
Season	Harvest		
Data Type	Sufficiency Range		
Cultivars Used	var. acephala		
Macronutrients %		**Micronutrients ppm**	
N	3 - 5	Fe	40 - 100
P	**0.3 - 0.5**	**Mn**	**40 - 100**
K	2.5 - 4	B	25 - 50
Ca	**1 - 2**	**Cu**	**5 - 10**
Mg	0.35 - 1	Zn	20 - 40
S	**0.2 - 0.49**	**Mo**	**0.35 - 1.11**

Vegetables

A

Scientific Name	*Brassica oleracea var. acephala*		
Common Name	**Kale**		
Collected From	Production fields		
Plant Part	12-15 mature leaves from new growth		
Season	Middle of growing season		
Data Type	Survey Range		
Cultivars Used	var. acephala		
Macronutrients %		**Micronutrients ppm**	
N	3.10 - 5.50	Fe	60 - 300
P	**0.30 - 0.70**	**Mn**	**30 - 250**
K	2.00 - 4.00	B	30 - 100
Ca	**1.30 - 2.50**	**Cu**	**4 - 25**
Mg	0.25 - 0.70	Zn	30 - 250
S	**0.22 - 0.29**	**Mo**	**0.10 - 0.15**

B

Scientific Name	*Brassica oleracea var. alboglabra*		
Common Name	**Chinese Kale**		
Collected From	Production fields		
Plant Part	12-15 mature leaves from new growth		
Season	8-leaf stage		
Data Type	Sufficiency Range		
Cultivars Used	var. alboglabra		
Macronutrients %		**Micronutrients ppm**	
N	4.50 - 5.5	Fe	31 - 200
P	**0.50 - 0.6**	**Mn**	**25 - 200**
K	7.50 - 9.0	B	23 - 75
Ca	**3.00 - 5.5**	**Cu**	**5 - 25**
Mg	0.35 - 0.5	Zn	30 - 200
S	**0.18 - 0.45**	**Mo**	**0.15 - 1.3**

C

Scientific Name	*Brassica oleracea var. alboglabra*		
Common Name	**Chinese Kale**		
Collected From	Production fields		
Plant Part	12 blades from fully expanded leaves		
Season	Mature plants		
Data Type	Survey Range		
Cultivars Used	Green Lance', white-flowered form, yellow-flowered form		
Macronutrients %		**Micronutrients ppm**	
N	2.96 - 5.14	Fe	48 - 89
P	**0.31 - 0.68**	**Mn**	**40 - 57**
K	2.55 - 4.04	B	12 - 17
Ca	**2.10 - 3.20**	**Cu**	**2 - 5**
Mg	0.31 - 0.52	Zn	21 - 35
S	**0.22 - 0.42**	**Mo**	**1.0 - 2.3**

D

Scientific Name	*Brassica oleracea var. botrytis*		
Common Name	**Cauliflower**		
Collected From	Production fields		
Plant Part	Most recently matured leaf and petiole		
Season	Buttoning		
Data Type	Sufficiency Range		
Cultivars Used	var. botrytis		
Macronutrients %		**Micronutrients ppm**	
N	3 - 5	Fe	30 - 60
P	**0.4 - 0.7**	**Mn**	**30 - 80**
K	2 - 4	B	30 - 50
Ca	**0.8 - 2**	**Cu**	**5 - 10**
Mg	0.25 - 0.6	Zn	30 - 50
S	**0.22 - 0.56**	**Mo**	**0.32 - 0.56**

E

Scientific Name	*Brassica oleracea var. botrytis*		
Common Name	**Cauliflower**		
Collected From	Production fields		
Plant Part	12-15 mature leaves from new growth		
Season	At heading		
Data Type	Sufficiency Range		
Cultivars Used	var. botrytis		
Macronutrients %		**Micronutrients ppm**	
N	3.30 - 4.5	Fe	30 - 200
P	**0.33 - 0.8**	**Mn**	**25 - 250**
K	2.60 - 4.2	B	30 - 100
Ca	**2.00 - 3.5**	**Cu**	**4 - 15**
Mg	0.24 - 0.5	Zn	20 - 250
S	**0.22 - 0.48**	**Mo**	**0.5 - 0.8**

F

Scientific Name	*Brassica oleracea var. capitata*		
Common Name	**Common Cabbage**		
Collected From	Production fields		
Plant Part	15-20 whole tops		
Season	2-6 weeks old		
Data Type	Sufficiency Range		
Cultivars Used	var. capitata		
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 5.0	Fe	30 - 200
P	**0.35 - 0.75**	**Mn**	**50 - 200**
K	3.50 - 6.0	B	25 - 75
Ca	**3.00 - 4.5**	**Cu**	**5 - 15**
Mg	0.50 - 2.0	Zn	25 - 200
S	**0.23 - 0.38**	**Mo**	**0.09 - 0.89**

Vegetables

A

Scientific Name	*Brassica oleracea var. capitata*		
Common Name	**Common Cabbage**		
Collected From	Production fields		
Plant Part	12-15 wrapper leaves		
Season	2-3 months old		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.60 - 5.00	Fe	30 - 200
P	**0.33 - 0.75**	**Mn**	**25 - 200**
K	3.00 - 5.00	B	25 - 75
Ca	**1.10 - 3.00**	**Cu**	**5 - 15**
Mg	0.40 - 0.75	Zn	20 - 200
S	**0.30 - 0.75**	**Mo**	**0.4 - 0.7**

B

Scientific Name	*Brassica oleracea var. capitata*		
Common Name	**Common Cabbage**		
Collected From	Production fields		
Plant Part	12-15 wrapper leaves		
Season	Head 3/4 mature		
Data Type	Sufficiency Range		
Cultivars Used	var. capitata		
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 4.80	Fe	30 - 200
P	**0.30 - 0.65**	**Mn**	**25 - 200**
K	2.00 - 4.00	B	30 - 100
Ca	**1.30 - 3.50**	**Cu**	**5 - 15**
Mg	0.25 - 0.80	Zn	20 - 200
S	**0.30 - 0.75**	**Mo**	**0.3 - 1.0**

C

Scientific Name	*Brassica oleracea var. capitata*		
Common Name	**Common Cabbage**		
Collected From	Production fields		
Plant Part	15-20 midribs from wrapper leaves		
Season	Mature plants		
Data Type	Sufficiency Range		
Cultivars Used	var. capitata		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 4.5	Fe	40 - 200
P	**0.25 - 1.0**	**Mn**	**40 - 200**
K	3.00 - 5.5	B	25 - 75
Ca	**1.00 - 2.0**	**Cu**	**6 - 15**
Mg	0.26 - 1.0	Zn	20 - 200
S	**0.25 - 1.0**	**Mo**	**0.14 - 0.78**

D

Scientific Name	*Brassica oleracea var. gemmifera*		
Common Name	**Brussels Sprouts**		
Collected From	Production fields		
Plant Part	Most recently matured leaf and petiole		
Season	At early sprouts		
Data Type	Sufficiency Range		
Cultivars Used	var. gemmifera		
Macronutrients %		**Micronutrients ppm**	
N	3 - 5	Fe	50 - 150
P	**0.3 - 0.6**	**Mn**	**20 - 200**
K	1.1 - 3.5	B	30 - 70
Ca	**0.8 - 2**	**Cu**	**5 - 10**
Mg	0.23 - 0.4	Zn	20 - 80
S	**0.28 - 0.80**	**Mo**	**0.2 - 0.31**

E

Scientific Name	*Brassica oleracea var. gemmifera*		
Common Name	**Brussels Sprouts**		
Collected From	Production fields		
Plant Part	12-15 mature leaves from new growth		
Season	Maturity		
Data Type	Sufficiency Range		
Cultivars Used	var. gemmifera		
Macronutrients %		**Micronutrients ppm**	
N	3.10 - 5.50	Fe	60 - 300
P	**0.30 - 0.75**	**Mn**	**25 - 200**
K	2.00 - 4.00	B	30 - 100
Ca	**1.00 - 2.50**	**Cu**	**5 - 15**
Mg	0.25 - 0.75	Zn	25 - 200
S	**0.30 - 0.75**	**Mo**	**0.25 - 1.0**

F

Scientific Name	*Brassica oleracea var. gongylodes*		
Common Name	**Kohlrabi**		
Collected From	Production & research test fields		
Plant Part	12-15 mature leaves from new growth		
Season	Middle of growing season		
Data Type	Sufficiency Range		
Cultivars Used	Purple Vienna'		
Macronutrients %		**Micronutrients ppm**	
N	2.90 - 5.0	Fe	50 - 300
P	**0.30 - 0.7**	**Mn**	**32 - 250**
K	2.49 - 4.5	B	16 - 75
Ca	**1.85 - 3.5**	**Cu**	**3 - 30**
Mg	0.26 - 0.5	Zn	23 - 250
S	**0.34 - 0.8**	**Mo**	**0.13 - 2.3**

Vegetables

A

Scientific Name	*Brassica oleracea var. gongylodes*		
Common Name	**Kohlrabi**		
Collected From	Production greenhouse		
Plant Part	12-15 mature leaves from new growth		
Season	Mature plants, non-flowering		
Data Type	Survey Range		
Cultivars Used	var. gemmifera		
Macronutrients %		**Micronutrients ppm**	
N	2.15 - 4.76	Fe	43 - 67
P	**0.33 - 0.4**	**Mn**	**16 - 27**
K	2.23 - 3.33	B	43 - 54
Ca	**2.81 - 3.61**	**Cu**	**5 - 15**
Mg	0.29 - 0.70	Zn	31 - 39
S	**0.23 - 1.28**	**Mo**	**0.11 - 0.36**

B

Scientific Name	*Brassica oleracea var. italica*		
Common Name	**Brocoli**		
Collected From	Production fields		
Plant Part	12-15 mature leaves from new growth		
Season	Heading		
Data Type	Sufficiency Range		
Cultivars Used	var. italica		
Macronutrients %		**Micronutrients ppm**	
N	3.20 - 5.50	Fe	70 - 300
P	**0.30 - 0.75**	**Mn**	**25 - 200**
K	2.00 - 4.00	B	30 - 100
Ca	**1.00 - 2.50**	**Cu**	**4 - 15**
Mg	0.23 - 0.75	Zn	20 - 200
S	**0.30 - 0.75**	**Mo**	**0.30 - 0.50**

C

Scientific Name	*Brassica perviridis*		
Common Name	**Tendergreen or Spinach Mustard or Mizuna**		
Collected From	Research test plots		
Plant Part	15 blades from fully expanded leaves		
Season	Summer		
Data Type	Survey Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.64 - 4.19	Fe	74 - 231
P	**0.30 - 0.53**	**Mn**	**28 - 49**
K	3.08 - 4.44	B	20 - 31
Ca	**1.43 - 3.03**	**Cu**	**4 - 6**
Mg	0.17 - 0.32	Zn	23 - 31
S	**0.53 - 0.87**	**Mo**	**1.0 - 3.2**

D

Scientific Name	*Brassica rapa var. chinensis*		
Common Name	**Pak-choi or Chinese or Celery Mustard**		
Collected From	Research test plots		
Plant Part	15 blades from fully expanded leaves		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. chinensis		
Macronutrients %		**Micronutrients ppm**	
N	2.39 - 5.51	Fe	85 - 363
P	**0.36 - 0.80**	**Mn**	**35 - 52**
K	2.86 - 5.74	B	19 - 39
Ca	**1.29 - 3.21**	**Cu**	**3 - 7**
Mg	0.19 - 0.35	Zn	14 - 38
S	**0.41 - 0.77**	**Mo**	**1.5 - 6.4**

E

Scientific Name	*Brassica rapa var. pekinensis*		
Common Name	**Chinese or Celery Cabbage or PeTsai Mustard**		
Collected From	Production fields		
Plant Part	10-12 oldest outter/undamaged leaves		
Season	8-leaf stage		
Data Type	Sufficiency Range		
Cultivars Used	var. pekinensis		
Macronutrients %		**Micronutrients ppm**	
N	4.5 - 5	Fe	45 - 88
P	**0.5 - 0.6**	**Mn**	**14 - 20**
K	7.5 - 8.5	B	15 - 25
Ca	**4.5 - 5**	**Cu**	**5 - 10**
Mg	0.35 - 0.45	Zn	30 - 50
S	**0.22 - 0.45**	**Mo**	**0.28 - 0.68**

F

Scientific Name	*Brassica rapa var. pekinensis*		
Common Name	**Chinese or Celery Cabbage or PeTsai Mustard**		
Collected From	Production & research test fields		
Plant Part	12-15 mature leaves from new growth		
Season	Mature Plants		
Data Type	Sufficiency Range		
Cultivars Used	var. pekinensis		
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 4.0	Fe	40 - 300
P	**0.40 - 0.7**	**Mn**	**25 - 200**
K	4.50 - 7.5	B	26 - 100
Ca	**1.90 - 6.0**	**Cu**	**5 - 25**
Mg	0.20 - 0.7	Zn	19 - 200
S	**0.40 - 0.80**	**Mo**	**2.8 - 5.6**

Vegetables

A

Scientific Name	*Brassica rapa var. rapa*
Common Name	**Turnip**
Collected From	Production & research test fields
Plant Part	12-15 most recent fully developed leaves
Season	Middle of growing season
Data Type	Sufficiency Range
Cultivars Used	var. rapa

Macronutrients %		**Micronutrients ppm**	
N	3.50 - 5.00	Fe	40 - 300
P	**0.33 - 0.60**	**Mn**	**40 - 250**
K	3.50 - 5.00	B	40 - 100
Ca	**1.50 - 4.00**	**Cu**	**6 - 25**
Mg	0.30 - 1.00	Zn	20 - 250
S	**0.32 - 0.54**	**Mo**	**0.2 - 2.48**

B

Scientific Name	*Brassica rapa var. rapa*
Common Name	**Turnip Greens**
Collected From	Production fields
Plant Part	Most recently matured leaf and petiole
Season	Midseason - before root enlargement
Data Type	Sufficiency Range
Cultivars Used	var. rapa

Macronutrients %		**Micronutrients ppm**	
N	3 - 5	Fe	30 - 100
P	**0.3 - 0.8**	**Mn**	**30 - 100**
K	2.5 - 4	B	20 - 40
Ca	**0.8 - 1.5**	**Cu**	**5 - 10**
Mg	0.25 - 0.6	Zn	20 - 40
S	**0.2 - 0.60**	**Mo**	**0.19 - 0.34**

C

Scientific Name	*Capsicum annuum*
Common Name	**Pepper**
Collected From	Production fields
Plant Part	Most recently matured leaf and petiole
Season	Prior to blossoming
Data Type	Survey Range
Cultivars Used	

Macronutrients %		**Micronutrients ppm**	
N	4 - 5	Fe	30 - 150
P	**0.3 - 0.5**	**Mn**	**30 - 100**
K	5 - 6	B	20 - 50
Ca	**0.9 - 1.5**	**Cu**	**5 - 10**
Mg	0.35 - 0.6	Zn	25 - 80
S	**0.3 - 0.60**	**Mo**	**0.14 - 2.13**

D

Scientific Name	*Capsicum annuum*
Common Name	**Pepper**
Collected From	Production fields
Plant Part	Most recently matured leaf and petiole
Season	First blossoms open
Data Type	Survey Range
Cultivars Used	

Macronutrients %		**Micronutrients ppm**	
N	3 - 5	Fe	30 - 150
P	**0.3 - 0.5**	**Mn**	**30 - 100**
K	2.5 - 5	B	20 - 50
Ca	**0.9 - 1.5**	**Cu**	**5 - 10**
Mg	0.3 - 0.5	Zn	25 - 80
S	**0.3 - 0.60**	**Mo**	**0.09 - 1.19**

E

Scientific Name	*Capsicum annuum*
Common Name	**Pepper**
Collected From	Production fields
Plant Part	Most recently matured leaf and petiole
Season	Early fruit set
Data Type	Survey Range
Cultivars Used	

Macronutrients %		**Micronutrients ppm**	
N	2.9 - 4	Fe	30 - 150
P	**0.3 - 0.4**	**Mn**	**30 - 100**
K	2.5 - 4	B	20 - 50
Ca	**1 - 1.5**	**Cu**	**5 - 10**
Mg	0.3 - 0.4	Zn	25 - 80
S	**0.3 - 0.40**	**Mo**	**0.17 - 2.3**

F

Scientific Name	*Capsicum annuum*
Common Name	**Pepper**
Collected From	Production fields
Plant Part	Most recently matured leaf and petiole
Season	Early harvest
Data Type	Survey Range
Cultivars Used	

Macronutrients %		**Micronutrients ppm**	
N	2.5 - 3	Fe	30 - 150
P	**0.2 - 0.4**	**Mn**	**30 - 100**
K	2 - 3	B	20 - 50
Ca	**1 - 1.5**	**Cu**	**5 - 10**
Mg	0.3 - 0.4	Zn	25 - 80
S	**0.3 - 0.40**	**Mo**	**0.1 - 0.2**

Vegetables

A

Scientific Name	*Capsicum annuum (Grossum group)*
Common Name	**Bell or Sweet or Green Pepper**
Collected From	Production fields
Plant Part	25-30 mature leaves from new growth
Season	1/2 Mature fruit
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.00 - 6.0	Fe	60 - 300
P	**0.35 - 1.0**	**Mn**	**50 - 250**
K	4.00 - 6.0	B	25 - 75
Ca	**1.00 - 2.5**	**Cu**	**6 - 25**
Mg	0.30 - 1.0	Zn	20 - 200
S	**0.28 - 0.45**	**Mo**	**0.5 - 1.0**

B

Scientific Name	*Capsicum annuum (Grossum group)*
Common Name	**Bell or Sweet or Green Pepper**
Collected From	Production fields
Plant Part	25-30 mature leaves from new growth
Season	Mature plants, full harvest
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.50 - 5.0	Fe	60 - 300
P	**0.22 - 0.7**	**Mn**	**50 - 250**
K	3.50 - 4.5	B	25 - 75
Ca	**1.30 - 2.8**	**Cu**	**6 - 25**
Mg	0.30 - 2.8	Zn	20 - 200
S	**0.28 - 0.45**	**Mo**	**0.5 - 1.0**

C

Scientific Name	*Capsicum Chinense*
Common Name	**Scotch Bonnet-field production**
Collected From	Research test plots
Plant Part	25 mature leaves from new growth
Season	Small fruit to harvest
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.0 - 6.0	Fe	60 - 450
P	**0.35 - 1.1**	**Mn**	**50 - 250**
K	4.0 - 6.0	B	30 - 75
Ca	**1.5 - 2.5**	**Cu**	**10 - 25**
Mg	0.35 - 1.2	Zn	25 - 45
S	**0.32 - 0.65**	**Mo**	**0.18 - 0.5**

D

Scientific Name	*Cichorium endiva*
Common Name	**Endive or Escarole**
Collected From	Production fields
Plant Part	10-12 leaves, oldest leaf
Season	8-leaf stage
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.30 - 5.0	Fe	40 - 150
P	**0.40 - 0.7**	**Mn**	**15 - 250**
K	5.00 - 6.0	B	25 - 75
Ca	**1.50 - 2.5**	**Cu**	**5 - 25**
Mg	1.50 - 2.5	Zn	30 - 250
S	**0.25 - 0.5**	**Mo**	**0.06 - 0.43**

E

Scientific Name	*Cichorium endiva*
Common Name	**Endive or Escarole**
Collected From	Production greenhouse
Plant Part	10-12 leaves, oldest leaf
Season	Mature plant, non-flowering
Data Type	Survey Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	2.22 - 4.20	Fe	45 - 89
P	**0.22 - 0.29**	**Mn**	**33 - 167**
K	2.55 - 7.82	B	18 - 31
Ca	**1.15 - 1.55**	**Cu**	**5 - 14**
Mg	0.28 - 0.36	Zn	33 - 55
S	**0.15 - 0.45**	**Mo**	**0.11 - 0.34**

F

Scientific Name	*Citrullus lanatus*
Common Name	**Watermelon**
Collected From	Production fields
Plant Part	10-12 unfurled leaves
Season	Flower start to small fruit
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.0 - 5.5	Fe	50 - 300
P	**0.3 - 0.8**	**Mn**	**50 - 250**
K	4.0 - 5.0	B	25 - 60
Ca	**1.7 - 3.0**	**Cu**	**6 - 20**
Mg	0.5 - 0.8	Zn	20 - 50
S	**0.31 - 0.45**	**Mo**	**0.14 - 0.23**

Vegetables

A

Scientific Name	*Citrullus lanatus*		
Common Name	**Watermelon**		
Collected From	Production fields		
Plant Part	12-15 mature leaves from new growth		
Season	Mature plants, small fruit stage		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.0 - 3.0	Fe	100 - 300
P	**0.2 - 0.3**	**Mn**	**60 - 240**
K	2.5 - 3.5	B	30 - 80
Ca	**2.5 - 3.5**	**Cu**	**4 - 8**
Mg	0.6 - 3.5	Zn	20 - 60
S	**0.33 - 0.47**	**Mo**	**0.05 - 1.14**

B

Scientific Name	*Citrullus lanatus*		
Common Name	**Watermelon**		
Collected From	Production fields		
Plant Part	12-15 unfurled leaves (5th leaf from tip)		
Season	Older fruit to harvest		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4.00 - 5.00	Fe	50 - 300
P	**0.25 - 0.70**	**Mn**	**40 - 250**
K	3.50 - 4.50	B	25 - 60
Ca	**2.00 - 3.20**	**Cu**	**5 - 20**
Mg	0.30 - 0.80	Zn	20 - 250
S	**0.33 - 0.55**	**Mo**	**0.9 - 1.98**

C

Scientific Name	*Cucumis melo (Cantaloupensis group and Reticulatus group)*		
Common Name	**Cantaloupe or Muskmelon or Persian Melon**		
Collected From	Production fields		
Plant Part	12-15 unfurled leaves (5th leaf from tip)		
Season	Flower start to small fruit		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4.50 - 5.50	Fe	50 - 300
P	**0.30 - 0.80**	**Mn**	**50 - 250**
K	4.00 - 5.00	B	25 - 60
Ca	**2.30 - 3.00**	**Cu**	**7 - 30**
Mg	0.35 - 0.80	Zn	20 - 200
S	**0.25 - 1.40**	**Mo**	**0.18 - 0.34**

D

Scientific Name	*Cucumis melo (Cantaloupensis group and Reticulatus group)*		
Common Name	**Cantaloupe or Muskmelon or Persian Melon**		
Collected From	Production fields		
Plant Part	12-15 unfurled leaves (5th leaf from tip)		
Season	Small fruit to harvest		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4.09 - 5.0	Fe	50 - 300
P	**0.25 - 0.8**	**Mn**	**50 - 250**
K	3.59 - 5.0	B	25 - 60
Ca	**2.30 - 3.2**	**Cu**	**7 - 30**
Mg	0.35 - 0.8	Zn	20 - 200
S	**0.23 - 1.4**	**Mo**	**0.19 - 0.5**

E

Scientific Name	*Cucumis melo (Cantaloupensis group and Reticulatus group)*		
Common Name	**Cantaloupe or Muskmelon or Persian Melon**		
Collected From	Production fields		
Plant Part	12-15 most recently matured leaf and petiole		
Season	12 inch vines		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4 - 5	Fe	40 - 100
P	**0.4 - 0.7**	**Mn**	**20 - 100**
K	5 - 7	B	20 - 80
Ca	**3 - 5**	**Cu**	**5 - 10**
Mg	0.35 - 0.45	Zn	20 - 60
S	**0.2 - 0.33**	**Mo**	**0.6 - 1**

F

Scientific Name	*Cucumis melo (Inodorus group)*		
Common Name	**Honeydew or Casaba Melon**		
Collected From	Production fields		
Plant Part	12-15 unfurled leaves (5th leaf from tip)		
Season	Flower start to small fruit		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4.50 - 5.5	Fe	50 - 300
P	**0.30 - 0.8**	**Mn**	**50 - 250**
K	4.00 - 5.0	B	25 - 60
Ca	**2.30 - 3.0**	**Cu**	**7 - 30**
Mg	0.35 - 0.8	Zn	20 - 200
S	**0.25 - 1.4**	**Mo**	**0.17 - 0.35**

Vegetables

A

Scientific Name	*Cucumis melo (Inodorus group)*
Common Name	**Honeydew or Casaba Melon**
Collected From	Production fields
Plant Part	12-15 unfurled leaves (5th leaf from tip)
Season	Small fruit to harvest
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.09 - 5.0	Fe	50 - 300
P	**0.25 - 0.6**	**Mn**	**50 - 250**
K	3.59 - 4.5	B	25 - 60
Ca	**2.59 - 3.2**	**Cu**	**7 - 30**
Mg	0.35 - 0.8	Zn	20 - 200
S	**0.23 - 1.2**	**Mo**	**0.09 - 0.18**

B

Scientific Name	*Cucumis sativus*
Common Name	**Cucumber**
Collected From	Production fields
Plant Part	Most recently matured leaf and petiole
Season	Before bloom
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.5 - 6	Fe	40 - 100
P	**0.3 - 0.6**	**Mn**	**30 - 100**
K	1.6 - 3	B	20 - 60
Ca	**2 - 4**	**Cu**	**5 - 20**
Mg	0.58 - 0.7	Zn	20 - 50
S	**0.3 - 0.80**	**Mo**	**0.3 - 1**

C

Scientific Name	*Cucumis sativus*
Common Name	**Cucumber, field-grown cultivar**
Collected From	Production fields
Plant Part	12 leaf blades (5th leaf from tip)
Season	Flower start to small fruit
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.50 - 6.00	Fe	50 - 300
P	**0.34 - 1.25**	**Mn**	**50 - 300**
K	3.90 - 5.00	B	25 - 60
Ca	**1.40 - 3.50**	**Cu**	**7 - 20**
Mg	0.30 - 1.00	Zn	25 - 100
S	**0.40 - 0.70**	**Mo**	**0.8 - 3.3**

D

Scientific Name	*Cucumis sativus*
Common Name	**Cucumber, field-grown cultivar**
Collected From	Production fields
Plant Part	12 leaf blades (5th leaf from tip)
Season	Small fruit to harvest
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.50 - 6.00	Fe	50 - 300
P	**0.25 - 1.25**	**Mn**	**50 - 400**
K	3.50 - 5.50	B	25 - 100
Ca	**1.50 - 5.50**	**Cu**	**5 - 20**
Mg	1.50 - 4.00	Zn	25 - 300
S	**0.30 - 1.00**	**Mo**	**0.8 - 4.0**

E

Scientific Name	*Cucumis sativus*
Common Name	**Greenhouse Cucumber**
Collected From	Greenhouse production
Plant Part	3rd-5th leaf from top
Season	Flowering to harvest
Data Type	Sufficiency Range
Cultivars Used	General All Varieties

Macronutrients %		Micronutrients ppm	
N	4.2 - 5.8	Fe	75 - 300
P	**0.58 - 1**	**Mn**	**55 - 300**
K	3.33 - 4.56	B	50 - 60
Ca	**2 - 2.5**	**Cu**	**5 - 17**
Mg	0.4 - 0.71	Zn	52 - 140
S	**0.32 - 0.63**	**Mo**	**1 - 2**

F

Scientific Name	*Cucumis sativus*
Common Name	**Hydroponic cucumber**
Collected From	Greenhouse production
Plant Part	10-15 mature leaves from new growth
Season	Mid Production of Fruit
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.50 - 6.00	Fe	50 - 300
P	**0.34 - 1.25**	**Mn**	**50 - 300**
K	3.90 - 5.00	B	25 - 60
Ca	**1.40 - 3.50**	**Cu**	**7 - 20**
Mg	0.30 - 1.00	Zn	25 - 100
S	**0.40 - 0.70**	**Mo**	**0.8 - 3.3**

Vegetables

A

SCIENTIFIC NAME	*Cucumis sativus cultivars*
COMMON NAME	**Seedless or European Cucumber**
COLLECTED FROM	Production fields and greenhouses
PLANT PART	15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	4.30 - 6.0	Fe	50 - 300
P	**0.30 - 1.0**	**Mn**	**50 - 300**
K	3.10 - 5.5	B	30 - 100
Ca	**2.40 - 4.0**	**Cu**	**8 - 10**
Mg	0.35 - 1.0	Zn	25 - 200
S	**0.32 - 0.7**	**Mo**	**0.8 - 5.0**

B

SCIENTIFIC NAME	*Cucurbita moschata*
COMMON NAME	**Butternut Squash**
COLLECTED FROM	Production Fields
PLANT PART	12-15 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.6 - 5.8	Fe	50 - 200
P	**0.48 - 0.70**	**Mn**	**40 - 75**
K	3.00 - 5.00	B	20 - 50
Ca	**1.25 - 2.50**	**Cu**	**8 - 20**
Mg	0.35 - 2.00	Zn	20 - 75
S	**0.28 - 0.50**	**Mo**	**0.15 - 0.80**

C

SCIENTIFIC NAME	*Cucurbita pepo var. melopepo*
COMMON NAME	**Summer Squash**
COLLECTED FROM	Production fields
PLANT PART	Most recently matured leaf and petiole
SEASON	Early fruit
DATA TYPE	Sufficiency Range
CULTIVARS USED	var. melopepo

Macronutrients %		Micronutrients ppm	
N	3 - 5	Fe	40 - 100
P	**0.3 - 0.5**	**Mn**	**40 - 100**
K	2 - 3	B	25 - 40
Ca	**1 - 2**	**Cu**	**5 - 20**
Mg	0.3 - 0.5	Zn	20 - 50
S	**0.2 - 0.50**	**Mo**	**0.3 - 0.5**

D

SCIENTIFIC NAME	*Cucurbita pepo var. melopepo*
COMMON NAME	**Summer Squash**
COLLECTED FROM	Production fields
PLANT PART	12 leaf blades from most recent fully-developed leaves
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	var. melopepo

Macronutrients %		Micronutrients ppm	
N	4.0 - 6.0	Fe	50 - 200
P	**0.3 - 0.5**	**Mn**	**50 - 250**
K	3.0 - 5.0	B	25 - 75
Ca	**1.2 - 2.5**	**Cu**	**10 - 25**
Mg	0.3 - 1.0	Zn	20 - 200
S	**0.18 - 0.29**	**Mo**	**0.23 - 0.49**

E

SCIENTIFIC NAME	*Cucurbita pepo var. melopepo*
COMMON NAME	**Zucchini or Courgette**
COLLECTED FROM	Production greenhouse
PLANT PART	12-15 mature leaves from new growth
SEASON	Mature plants, non-fruiting
DATA TYPE	Survey Range
CULTIVARS USED	var. melopepo

Macronutrients %		Micronutrients ppm	
N	3.0 - 5.0	Fe	50 - 200
P	**0.3 - 0.5**	**Mn**	**50 - 250**
K	3.0 - 5.0	B	25 - 75
Ca	**1.2 - 2.5**	**Cu**	**10 - 25**
Mg	0.3 - 1.3	Zn	20 - 150
S	**0.2 - 0.45**	**Mo**	**0.2 - 0.75**

F

SCIENTIFIC NAME	*Cucurbita pepo var. pepo*
COMMON NAME	**Pumpkin**
COLLECTED FROM	Production fields
PLANT PART	Most recently matured leaf and petiole
SEASON	5 weeks from seeding
DATA TYPE	Sufficiency Range
CULTIVARS USED	var. pepo

Macronutrients %		Micronutrients ppm	
N	3 - 6	Fe	40 - 100
P	**0.3 - 0.5**	**Mn**	**40 - 100**
K	2.3 - 4	B	25 - 40
Ca	**0.9 - 1.5**	**Cu**	**5 - 10**
Mg	0.35 - 0.6	Zn	20 - 50
S	**0.2 - 0.40**	**Mo**	**0.3 - 0.5**

Vegetables

A

Scientific Name			*Cucurbita pepo var. pepo*
Common Name			**Pumpkin**
Collected From			Production fields
Plant Part			Most recently matured leaf and petiole
Season			8 weeks from seeding
Data Type			Sufficiency Range
Cultivars Used			var. pepo
Macronutrients %		**Micronutrients ppm**	
N	3 - 4	Fe	40 - 100
P	**0.3 - 0.4**	**Mn**	**40 - 100**
K	2 - 3	B	20 - 40
Ca	**0.9 - 1.5**	**Cu**	**5 - 10**
Mg	0.3 - 0.5	Zn	20 - 50
S	**0.2 - 0.40**	**Mo**	**0.3 - 0.5**

B

Scientific Name			*Cucurbita pepo var. pepo*
Common Name			**Pumpkin**
Collected From			Production fields
Plant Part			15-20 mature leaves from new growth
Season			Middle of growing season
Data Type			Sufficiency Range
Cultivars Used			var. pepo
Macronutrients %		**Micronutrients ppm**	
N	4.00 - 6.00	Fe	50 - 200
P	**0.6 - 0.7**	**Mn**	**50 - 250**
K	3.00 - 5.00	B	25 - 75
Ca	**1.20 - 2.50**	**Cu**	**7 - 25**
Mg	0.30 - 2.50	Zn	20 - 200
S	**0.21 - 0.29**	**Mo**	**0.11 - 0.5**

C

Scientific Name			*Daucus carota ssp. sativus*
Common Name			**Carrot**
Collected From			Production fields
Plant Part			15-20 mature leaves from new growth
Season			Middle of the growing season
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.10 - 3.5	Fe	50 - 350
P	**0.20 - 0.5**	**Mn**	**60 - 300**
K	2.50 - 4.3	B	30 - 100
Ca	**1.40 - 3.0**	**Cu**	**5 - 15**
Mg	0.30 - 3.0	Zn	25 - 250
S	**0.16 - 0.28**	**Mo**	**0.5 - 1.5**

D

Scientific Name			*Daucus carota ssp. sativus*
Common Name			**Carrot**
Collected From			Production fields
Plant Part			15-20 leaves (oldest leaves)
Season			Mature plants
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.00 - 3.5	Fe	50 - 300
P	**0.20 - 0.4**	**Mn**	**50 - 200**
K	2.90 - 3.5	B	30 - 75
Ca	**1.00 - 2.0**	**Cu**	**5 - 15**
Mg	0.25 - 0.6	Zn	20 - 250
S	**0.16 - 0.28**	**Mo**	**0.5 - 1.4**

E

Scientific Name			*Eruca sativa*
Common Name			**Argula or Roquette Salad or Rocket Cress**
Collected From			Research test plots
Plant Part			40-50 leaves, fully expanded
Season			Summer
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.86 - 3.97	Fe	187 - 215
P	**0.61 - 0.72**	**Mn**	**38 - 44**
K	4.80 - 5.16	B	20 - 25
Ca	**2.40 - 2.46**	**Cu**	**3 - 5**
Mg	0.28 - 0.29	Zn	40 - 45
S	**0.52 - 0.55**	**Mo**	**5.7 - 5.9**

F

Scientific Name			*General Vegetables*
Common Name			**General**
Collected From			Production fields
Plant Part			Top fully developed leaves
Season			Small fruit to harvest
Data Type			Survey Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 4	Fe	50 - 250
P	**0.25 - 0.8**	**Mn**	**30 - 200**
K	2 - 9	B	30 - 60
Ca	**0.35 - 2**	**Cu**	**8 - 20**
Mg	0.25 - 1	Zn	30 - 100
S	**0.16 - 0.50**	**Mo**	**0.5 - 5**

Vegetables

A

SCIENTIFIC NAME	*Ipomoea batatas*
COMMON NAME	**Sweetpotato**
COLLECTED FROM	Production fields
PLANT PART	Most recently matured leaf and petiole
SEASON	Early vining
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	4 - 5	Fe	40 - 100
P	**0.3 - 0.5**	**Mn**	**40 - 100**
K	2.5 - 4	B	20 - 50
Ca	**0.8 - 1.6**	**Cu**	**5 - 10**
Mg	0.4 - 0.8	Zn	20 - 40
S	**0.2 - 0.60**	**Mo**	**0.19 - 0.22**

B

SCIENTIFIC NAME	*Ipomoea batatas*
COMMON NAME	**Sweetpotato**
COLLECTED FROM	Production fields
PLANT PART	Most recently matured leaf and petiole
SEASON	Midseason - before root enlargement
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3 - 4	Fe	40 - 100
P	**0.2 - 0.3**	**Mn**	**40 - 100**
K	2 - 4	B	25 - 40
Ca	**0.8 - 1.8**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	20 - 40
S	**0.2 - 0.40**	**Mo**	**0.09 - 0.27**

C

SCIENTIFIC NAME	*Ipomoea batatas*
COMMON NAME	**Sweetpotato**
COLLECTED FROM	Production fields
PLANT PART	Most recently matured leaf and petiole
SEASON	Root enlargement
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3 - 4	Fe	40 - 100
P	**0.2 - 0.3**	**Mn**	**40 - 100**
K	2 - 4	B	20 - 50
Ca	**0.8 - 1.6**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	25 - 50
S	**0.2 - 0.60**	**Mo**	**0.18 - 0.35**

D

SCIENTIFIC NAME	*Ipomoea batatas*
COMMON NAME	**Sweetpotato**
COLLECTED FROM	Production fields
PLANT PART	15-20 most recently matured leaves
SEASON	1st half of growing season
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.30 - 4.5	Fe	40 - 100
P	**0.23 - 0.5**	**Mn**	**40 - 250**
K	3.10 - 4.5	B	25 - 75
Ca	**0.70 - 1.2**	**Cu**	**4 - 10**
Mg	0.35 - 1.0	Zn	20 - 50
S	**0.19 - 0.26**	**Mo**	**0.17 - 0.41**

E

SCIENTIFIC NAME	*Ipomoea batatas*
COMMON NAME	**Sweetpotato**
COLLECTED FROM	Production fields
PLANT PART	15-20 most recently matured leaf and petiole
SEASON	Just before harvest
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.8 - 3.5	Fe	40 - 100
P	**0.2 - 0.3**	**Mn**	**40 - 100**
K	2 - 4	B	20 - 50
Ca	**0.8 - 1.6**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	25 - 40
S	**0.2 - 0.60**	**Mo**	**0.11 - 0.33**

F

SCIENTIFIC NAME	*Lactuca sativa*
COMMON NAME	**General Hydroponic Leaf Lettuce**
COLLECTED FROM	Production Fields
PLANT PART	12-15 leaves from new growth
SEASON	Mid Growth
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.75 - 5.60	Fe	50 - 150
P	**0.45 - 0.77**	**Mn**	**55 - 110**
K	3.00 - 6.50	B	15 - 45
Ca	**1.25 - 2.50**	**Cu**	**6 - 16**
Mg	0.45 - 0.78	Zn	25 - 60
S	**0.25 - 0.35**	**Mo**	**0.33 - 0.58**

Vegetables

A

SCIENTIFIC NAME			*Lactuca sativa*
COMMON NAME			**Bibb Lettuce**
COLLECTED FROM			Production Fields
PLANT PART			12-15 leaves from new growth
SEASON			Mid Growth
DATA TYPE			Sufficiency Range
CULTIVARS USED			
Macronutrients %		Micronutrients ppm	
N	4.50 - 5.60	Fe	50 - 150
P	**0.45 - 0.77**	**Mn**	**55 - 110**
K	3.00 - 8.50	B	15 - 45
Ca	**0.80 - 1.30**	**Cu**	**6 - 16**
Mg	0.30 - 0.70	Zn	25 - 60
S	**0.25 - 0.35**	**Mo**	**0.33 - 0.58**

B

SCIENTIFIC NAME			*Lactuca sativa var. capitata*
COMMON NAME			**Boston or Butterhead Lettuce**
COLLECTED FROM			Production fields
PLANT PART			12-15 leaves (oldest leaf)
SEASON			8-leaf stage
DATA TYPE			Sufficiency Range
CULTIVARS USED			var. capitata
Macronutrients %		Micronutrients ppm	
N	4.7 - 5.5	Fe	50 - 100
P	**0.5 - 1.0**	**Mn**	**15 - 250**
K	7.5 - 9.0	B	23 - 50
Ca	**2.0 - 3.0**	**Cu**	**8 - 25**
Mg	0.5 - 0.8	Zn	25 - 250
S	**0.18 - 0.28**	**Mo**	**0.13 - 0.33**

C

SCIENTIFIC NAME			*Lactuca sativa var. capitata*
COMMON NAME			**Boston or Butterhead Lettuce**
COLLECTED FROM			Production fields
PLANT PART			12-15 fully expanded leaves
SEASON			Mature plants
DATA TYPE			Sufficiency Range
CULTIVARS USED			var. capitata
Macronutrients %		Micronutrients ppm	
N	4.0 - 5.0	Fe	50 - 100
P	**0.4 - 0.6**	**Mn**	**15 - 250**
K	6.0 - 7.0	B	25 - 60
Ca	**2.3 - 3.5**	**Cu**	**8 - 25**
Mg	0.5 - 3.5	Zn	25 - 250
S	**0.18 - 0.28**	**Mo**	**0.15 - 0.35**

D

SCIENTIFIC NAME			*Lactuca sativa var. capitata*
COMMON NAME			**Boston or Butterhead Lettuce (greenhouse grown)**
COLLECTED FROM			Production greenhouse
PLANT PART			12-15 mature leaves from new growth
SEASON			Mature plants, prior to heading
DATA TYPE			Survey Range
CULTIVARS USED			var. capitata
Macronutrients %		Micronutrients ppm	
N	4.20 - 5.60	Fe	168 - 223
P	**0.62 - 0.77**	**Mn**	**55 - 110**
K	7.82 - 13.68	B	32 - 43
Ca	**0.80 - 1.20**	**Cu**	**6 - 16**
Mg	0.24 - 0.73	Zn	33 - 196
S	**0.26 - 0.32**	**Mo**	**0.29 - 0.58**

E

SCIENTIFIC NAME			*Lactuca sativa var. capitata*
COMMON NAME			**Head or Iceberg Lettuce**
COLLECTED FROM			Production fields
PLANT PART			12-15 wrapper leaves
SEASON			Mature plants
DATA TYPE			Sufficiency Range
CULTIVARS USED			var. capitata
Macronutrients %		Micronutrients ppm	
N	3.80 - 5.00	Fe	50 - 100
P	**0.45 - 0.60**	**Mn**	**25 - 250**
K	6.60 - 9.00	B	23 - 50
Ca	**1.50 - 2.25**	**Cu**	**7 - 25**
Mg	0.15 - 0.25	Zn	25 - 250
S	**0.19 - 0.29**	**Mo**	**0.19 - 0.51**

F

SCIENTIFIC NAME			*Lactuca sativa var. capitata*
COMMON NAME			**Head or Iceberg Lettuce**
COLLECTED FROM			Production fields
PLANT PART			12-15 leaves from mature heads
SEASON			Heading
DATA TYPE			Sufficiency Range
CULTIVARS USED			var. capitata
Macronutrients %		Micronutrients ppm	
N	2.5 - 4.0	Fe	50 - 500
P	**0.4 - 0.6**	**Mn**	**30 - 90**
K	6.0 - 8.0	B	30 - 100
Ca	**1.4 - 2.0**	**Cu**	**7 - 10**
Mg	0.5 - 0.7	Zn	25 - 100
S	**0.2 - 0.4**	**Mo**	**0.1 - 0.4**

Vegetables

A

Scientific Name			*Lactuca sativa var. longifolia*
Common Name			**Cos or Romaine Lettuce**
Collected From			Production fields
Plant Part			12-15 undamaged outer/wrapper leaves
Season			8-leaf stage
Data Type			Sufficiency Range
Cultivars Used			var. longifolia
Macronutrients %		**Micronutrients ppm**	
N	5 - 6	Fe	45 - 98
P	**0.4 - 0.8**	**Mn**	**15 - 25**
K	5 - 6	B	30 - 45
Ca	**2 - 3**	**Cu**	**5 - 10**
Mg	0.25 - 0.35	Zn	20 - 50
S	**0.18 - 0.29**	**Mo**	**0.11 - 0.45**

B

Scientific Name			*Lactuca sativa var. longifolia*
Common Name			**Cos or Romaine Lettuce**
Collected From			Production fields
Plant Part			12-15 undamaged outer/wrapper leaves
Season			Mature plants
Data Type			Sufficiency Range
Cultivars Used			var. longifolia
Macronutrients %		**Micronutrients ppm**	
N	3.50 - 4.5	Fe	40 - 100
P	**0.45 - 0.8**	**Mn**	**11 - 250**
K	5.50 - 6.2	B	25 - 60
Ca	**2.00 - 2.8**	**Cu**	**5 - 20**
Mg	0.60 - 0.8	Zn	20 - 250
S	**0.2 - 0.28**	**Mo**	**0.15 - 0.65**

C

Scientific Name			*Lycopersicon lycopersicum*
Common Name			**Tomato "indeterminate" tomatoes**
Collected From			Production fields
Plant Part			Most recently matured leaf and petiole
Season			5-leaf stage
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3 - 5	Fe	40 - 100
P	**0.3 - 0.6**	**Mn**	**30 - 100**
K	3 - 5	B	20 - 40
Ca	**1 - 2**	**Cu**	**5 - 15**
Mg	0.3 - 0.5	Zn	25 - 40
S	**0.3 - 0.80**	**Mo**	**0.2 - 0.6**

D

Scientific Name			*Lycopersicon lycopersicum*
Common Name			**Tomato "indeterminate" tomatoes**
Collected From			Production fields
Plant Part			Most recently matured leaf and petiole
Season			First flower
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.8 - 4	Fe	40 - 100
P	**0.2 - 0.4**	**Mn**	**30 - 100**
K	2.5 - 4	B	20 - 40
Ca	**1 - 2**	**Cu**	**5 - 15**
Mg	0.3 - 0.5	Zn	25 - 40
S	**0.3 - 0.80**	**Mo**	**0.2 - 0.6**

E

Scientific Name			*Lycopersicon lycopersicum*
Common Name			**Tomato "indeterminate" tomatoes**
Collected From			Production fields
Plant Part			Most recently matured leaf and petiole
Season			First ripe fruit
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2 - 3.5	Fe	40 - 100
P	**0.2 - 0.4**	**Mn**	**30 - 100**
K	2 - 4	B	20 - 40
Ca	**1 - 2**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	20 - 40
S	**0.3 - 0.60**	**Mo**	**0.2 - 0.6**

F

Scientific Name			*Lycopersicon lycopersicum*
Common Name			**Tomato "indeterminate" tomatoes**
Collected From			Production fields
Plant Part			Most recently matured leaf and petiole
Season			During harvest period
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2 - 3	Fe	40 - 100
P	**0.2 - 0.4**	**Mn**	**30 - 100**
K	1.5 - 2.5	B	20 - 40
Ca	**1 - 2**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	20 - 40
S	**0.3 - 0.60**	**Mo**	**0.2 - 0.6**

Vegetables

A

SCIENTIFIC NAME	*Lycopersicon lycopersicum*
COMMON NAME	**Tomato "indeterminate" tomatoes**
COLLECTED FROM	Production fields
PLANT PART	Most recently matured leaf and petiole
SEASON	Early fruit set
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.5 - 4	Fe	40 - 100
P	**0.2 - 0.4**	**Mn**	**30 - 100**
K	2.5 - 4	B	20 - 40
Ca	**1 - 2**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	20 - 40
S	**0.3 - 0.60**	**Mo**	**0.2 - 0.6**

B

SCIENTIFIC NAME	*Lycopersicon lycopersicum*
COMMON NAME	**Tomato (field type)**
COLLECTED FROM	Production fields
PLANT PART	15-20 compound leaves adjacent top inflorescences
SEASON	Mid-bloom
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	4.00 - 6.00	Fe	40 - 80
P	**0.25 - 0.80**	**Mn**	**40 - 100**
K	2.50 - 5.00	B	25 - 50
Ca	**1.00 - 3.00**	**Cu**	**5 - 20**
Mg	0.40 - 0.90	Zn	20 - 50
S	**0.30 - 1.20**	**Mo**	**0.18 - 0.60**

C

SCIENTIFIC NAME	*Lycopersicon lycopersicum*
COMMON NAME	**Tomato (greenhouse grown)**
COLLECTED FROM	Production greenhouse
PLANT PART	25-30 compound leaves from new growth
SEASON	Mature plants, non-fruiting
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.80 - 4.20	Fe	84 - 112
P	**0.31 - 0.46**	**Mn**	**55 - 165**
K	3.52 - 5.08	B	45 - 76
Ca	**1.60 - 3.21**	**Cu**	**5 - 10**
Mg	0.36 - 0.49	Zn	25 - 39
S	**0.25 - 1.28**	**Mo**	**2.9 - 5.8**

D

SCIENTIFIC NAME	*Lycopersicon lycopersicum*
COMMON NAME	**Tomato (trellis type)**
COLLECTED FROM	Production fields
PLANT PART	12-15 leaf petioles opposite or below top flower cluster
SEASON	Mid-bloom 1st cluster
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.5 - 5.0	Fe	60 - 300
P	**0.7 - 1.3**	**Mn**	**50 - 250**
K	1 - 6	B	25 - 75
Ca	**1.4 - 2.2**	**Cu**	**5 - 50**
Mg	0.3 - 0.7	Zn	20 - 250
S	**0.25 - 0.55**	**Mo**	**0.11 - 0.26**

E

SCIENTIFIC NAME	*Lycopersicon lycopersicum*
COMMON NAME	**Tomato (trellis type)**
COLLECTED FROM	Production fields
PLANT PART	12-15 leaf petioles opposite or below top flower cluster
SEASON	Mid-bloom 3rd cluster
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.0 - 4.0	Fe	60 - 300
P	**0.4 - 1.0**	**Mn**	**50 - 250**
K	5.0 - 9.0	B	25 - 75
Ca	**1.5 - 2.4**	**Cu**	**5 - 50**
Mg	0.3 - 0.8	Zn	20 - 250
S	**0.26 - 0.45**	**Mo**	**0.07 - 0.39**

F

SCIENTIFIC NAME	*Lycopersicon lycopersicum*
COMMON NAME	**Tomato (trellis type)**
COLLECTED FROM	Production fields
PLANT PART	12-15 leaf petioles opposite or below top flower cluster
SEASON	Mid-bloom 4th cluster
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.50 - 3.50	Fe	60 - 300
P	**0.35 - 0.55**	**Mn**	**50 - 250**
K	3.50 - 5.00	B	25 - 75
Ca	**1.50 - 2.50**	**Cu**	**5 - 50**
Mg	0.32 - 2.50	Zn	20 - 250
S	**0.26 - 0.55**	**Mo**	**0.13 - 0.45**

Vegetables

A

Scientific Name			*Lycopersicon lycopersicum*
Common Name			**Tomato (trellis type)**
Collected From			Production fields
Plant Part			12-15 leaf petioles opposite or below top flower cluster
Season			Mid-bloom 5th cluster
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.5 - 3.0	Fe	60 - 300
P	**0.3 - 0.5**	**Mn**	**50 - 250**
K	3.0 - 4.5	B	25 - 75
Ca	**1.5 - 2.5**	**Cu**	**5 - 50**
Mg	0.3 - 0.9	Zn	20 - 250
S	**0.26 - 0.45**	**Mo**	**0.08 - 0.28**

B

Scientific Name			*Lycopersicon lycopersicum*
Common Name			**Tomato (trellis type)**
Collected From			Production fields
Plant Part			12-15 leaf petioles opposite or below top flower cluster
Season			Mid-bloom 6th cluster
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.5	Fe	60 - 300
P	**0.30 - 0.50**	**Mn**	**50 - 250**
K	0.30 - 0.50	B	25 - 75
Ca	**3.50 - 4.50**	**Cu**	**5 - 50**
Mg	1.50 - 2.50	Zn	20 - 250
S	**0.33 - 0.90**	**Mo**	**0.07 - 1.01**

C

Scientific Name			*Lycopersicon lycopersicum*
Common Name			**Tomato (trellis type)**
Collected From			Production fields
Plant Part			12-15 leaf petioles opposite or below top flower cluster
Season			Mid-bloom 2nd cluster
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.2 - 4.5	Fe	60 - 300
P	**0.5 - 1.2**	**Mn**	**50 - 250**
K	5.0 - 10	B	25 - 75
Ca	**1.5 - 2.4**	**Cu**	**5 - 50**
Mg	0.3 - 0.8	Zn	20 - 250
S	**0.25 - 0.67**	**Mo**	**0.14 - 0.29**

D

Scientific Name			*Lycopersicon lycopersicum*
Common Name			**Tomato-Trust Variety**
Collected From			Production fields
Plant Part			25-30 mature leaves from new growth
Season			Mid Production of Fruit
Data Type			Sufficiency Range
Cultivars Used			Trust Variety
Macronutrients %		**Micronutrients ppm**	
N	4.5 - 5.5	Fe	80 - 125
P	**0.6 - 0.9**	**Mn**	**80 - 125**
K	4.0 - 5.5	B	40 - 60
Ca	**2.2 - 3.0**	**Cu**	**15 - 25**
Mg	.5 - .8	Zn	20 - 40
S	**0.23 - 0.31**	**Mo**	**1.0 - 3.0**

E

Scientific Name			*Nasturtium officinale*
Common Name			**Watercress**
Collected From			Production fields
Plant Part			25-30 mature leaves from new growth
Season			Middle of growing season
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4.2 - 6.0	Fe	50 - 100
P	**0.7 - 1.3**	**Mn**	**50 - 150**
K	4.0 - 8.0	B	25 - 50
Ca	**1.0 - 2.0**	**Cu**	**6 - 15**
Mg	1.0 - 2.0	Zn	20 - 40
S	**0.31 - 0.44**	**Mo**	**0.11 - 0.35**

F

Scientific Name			*Phaseolus vulgaris*
Common Name			**Navy Bean - pod fill**
Collected From			Production greenhouse
Plant Part			10-15 uppermost recent fully-developed trifoliate leaves
Season			Pod fillings
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3 - 6	Fe	50 - 200
P	**0.30 - 0.75**	**Mn**	**35 - 100**
K	1.80 - 4.00	B	20 - 45
Ca	**0.80 - 2.80**	**Cu**	**5 - 30**
Mg	0.25 - 1.00	Zn	20 - 50
S	**0.25 - 0.35**	**Mo**	**0.20 - 0.50**

Vegetables

A

SCIENTIFIC NAME	*Phaseolus vulgaris*
COMMON NAME	**Snap or Green or String or Kidney or French Bean**
COLLECTED FROM	Production & research test fields
PLANT PART	10-15 uppermost recent fully-developed trifoliate leaves
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.00 - 6.00	Fe	50 - 400
P	**0.25 - 0.75**	**Mn**	**30 - 300**
K	1.80 - 4.00	B	20 - 75
Ca	**0.80 - 3.00**	**Cu**	**5 - 30**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.19 - 0.23**	**Mo**	**0.11 - 0.32**

B

SCIENTIFIC NAME	*Phaseolus vulgaris*
COMMON NAME	**Snapbean**
COLLECTED FROM	Production fields
PLANT PART	Most recently matured leaf and petiole
SEASON	Before bloom
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3 - 4	Fe	25 - 200
P	**0.3 - 0.5**	**Mn**	**20 - 100**
K	2 - 3	B	15 - 40
Ca	**0.8 - 1.5**	**Cu**	**5 - 10**
Mg	0.26 - 0.45	Zn	20 - 40
S	**0.2 - 0.40**	**Mo**	**0.11 - 0.33**

C

SCIENTIFIC NAME	*Phaseolus vulgaris*
COMMON NAME	**Snapbean**
COLLECTED FROM	Production fields
PLANT PART	Most recently matured leaf and petiole
SEASON	First bloom
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3 - 4	Fe	25 - 200
P	**0.3 - 0.5**	**Mn**	**20 - 100**
K	2 - 3	B	15 - 40
Ca	**0.8 - 1.5**	**Cu**	**5 - 10**
Mg	0.26 - 0.45	Zn	20 - 40
S	**0.2 - 0.40**	**Mo**	**0.14 - 0.4**

D

SCIENTIFIC NAME	*Phaseolus vulgaris*
COMMON NAME	**Snapbean**
COLLECTED FROM	Production fields
PLANT PART	Most recently matured leaf and petiole
SEASON	Full bloom
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.5 - 4	Fe	25 - 200
P	**0.2 - 0.4**	**Mn**	**20 - 100**
K	1.6 - 2.5	B	15 - 40
Ca	**0.8 - 1.5**	**Cu**	**5 - 10**
Mg	0.25 - 0.45	Zn	20 - 40
S	**0.2 - 0.40**	**Mo**	**0.13 - 0.4**

E

SCIENTIFIC NAME	*Pisum sativum ssp. sativum*
COMMON NAME	**Garden or English Pea**
COLLECTED FROM	Production fields
PLANT PART	50-60 most recent fully-developed leaflets
SEASON	First bloom
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	4.00 - 5.00	Fe	50 - 300
P	**0.28 - 0.38**	**Mn**	**25 - 400**
K	2.00 - 3.50	B	5 - 60
Ca	**1.20 - 2.00**	**Cu**	**7 - 10**
Mg	0.30 - 0.70	Zn	25 - 400
S	**0.08 - 0.16**	**Mo**	**0.6 - 1.13**

F

SCIENTIFIC NAME	*Pisum sativum ssp. sativum f. macrocarpon*
COMMON NAME	**Sugar or Snow or Edible-podded Pea or Chinese Pea**
COLLECTED FROM	Research test plots
PLANT PART	50 blades from fully expanded leaves
SEASON	First bloom
DATA TYPE	Survey Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.15 - 4.75	Fe	26 - 78
P	**0.24 - 0.26**	**Mn**	**45 - 1000**
K	2.55 - 4.40	B	10 - 29
Ca	**1.34 - 1.78**	**Cu**	**5 - 13**
Mg	0.24 - 0.27	Zn	21 - 28
S	**0.23 - 0.32**	**Mo**	**0.11 - 0.28**

Vegetables

A

Scientific Name	*Raphanus raphanastrum*		
Common Name	**Wild Radish**		
Collected From	Research test plots		
Plant Part	40 blades from fully expanded leaves		
Season	Summer		
Data Type	Survey Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.12 - 5.47	Fe	43 - 142
P	**0.34 - 0.80**	**Mn**	**69 - 243**
K	2.55 - 6.10	B	19 - 28
Ca	**1.88 - 3.12**	**Cu**	**4 - 9**
Mg	0.36 - 0.49	Zn	23 - 53
S	**0.32 - 0.56**	**Mo**	**1.26 - 2**

B

Scientific Name	*Raphanus sativus Radicula group*		
Common Name	**Radish**		
Collected From	Production fields & greenhouse		
Plant Part	30-35 most recent fully developed leaves		
Season	Middle of growing season		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.0 - 5.0	Fe	50 - 200
P	**0.3 - 0.7**	**Mn**	**50 - 250**
K	4.0 - 7.5	B	25 - 125
Ca	**3.0 - 4.5**	**Cu**	**5 - 25**
Mg	0.5 - 4.5	Zn	25 - 100
S	**0.22 - 0.28**	**Mo**	**0.23 - 0.9**

C

Scientific Name	*Raphanus sativus Radicula group*		
Common Name	**Radish**		
Collected From	Production fields		
Plant Part	Most recently matured leaf and petiole		
Season	At harvest		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3 - 4.5	Fe	30 - 50
P	**0.3 - 0.4**	**Mn**	**20 - 40**
K	1.5 - 3	B	15 - 30
Ca	**1 - 2**	**Cu**	**3 - 10**
Mg	0.3 - 0.5	Zn	30 - 50
S	**0.23 - 0.29**	**Mo**	**0.1 - 2**

D

Scientific Name	*Rheum rhabarbarum*		
Common Name	**Rhubarb**		
Collected From	Research test plots		
Plant Part	20 blades from fully expanded leaves		
Season	Summer		
Data Type	Survey Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	3.01 - 4.60	Fe	47 - 261
P	**0.33 - 0.45**	**Mn**	**45 - 67**
K	2.31 - 5.78	B	19 - 33
Ca	**1.35 - 1.68**	**Cu**	**5 - 12**
Mg	0.34 - 0.71	Zn	31 - 52
S	**0.22 - 0.31**	**Mo**	**0.11 - 0.34**

E

Scientific Name	*Rumex acetosa*		
Common Name	**Garden Sorrel**		
Collected From	Research test plots		
Plant Part	30 blades from fully expanded leaves		
Season	Summer		
Data Type	Survey Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	2.54 - 4.67	Fe	57 - 264
P	**0.28 - 0.44**	**Mn**	**119 - 217**
K	2.56 - 6.40	B	17 - 27
Ca	**1.18 - 1.73**	**Cu**	**4 - 17**
Mg	0.25 - 0.53	Zn	22 - 47
S	**0.17 - 0.35**	**Mo**	**0.23 - 0.63**

F

Scientific Name	*Solanum melongena*		
Common Name	**Eggplant or Aubergine**		
Collected From	Production fields & greenhouse		
Plant Part	12-15 blades from most recently fully-developed leaves		
Season	Flower start to small fruit		
Data Type	Sufficiency Range		
Cultivars Used			
Macronutrients %		**Micronutrients ppm**	
N	4.0 - 5.0	Fe	50 - 300
P	**0.13 - 0.23**	**Mn**	**40 - 250**
K	3.5 - 5.0	B	25 - 75
Ca	**1.0 - 2.5**	**Cu**	**5 - 10**
Mg	0.3 - 1.0	Zn	20 - 250
S	**0.29 - 0.60**	**Mo**	**0.11 - 0.56**

Vegetables

A

Scientific Name	*Solanum tuberosum*
Common Name	**Potato**
Collected From	Production fields
Plant Part	25 most recent fully-developed leaves
Season	Plants 30 cm tall
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.00 - 6.00	Fe	50 - 150
P	**0.2 - 0.5**	**Mn**	**30 - 450**
K	4.0 - 11.5	B	25 - 50
Ca	**0.60 - 1.00**	**Cu**	**7 - 20**
Mg	0.50 - 1.50	Zn	20 - 250
S	**0.19 - 0.36**	**Mo**	**0.09 - 0.34**

B

Scientific Name	*Solanum tuberosum*
Common Name	**Potato**
Collected From	Production fields
Plant Part	Most recently matured leaf and petiole
Season	First blossom
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3 - 4	Fe	40 - 150
P	**0.2 - 0.5**	**Mn**	**30 - 100**
K	3 - 5	B	20 - 30
Ca	**0.6 - 2**	**Cu**	**5 - 10**
Mg	0.25 - 0.6	Zn	30 - 60
S	**0.2 - 0.50**	**Mo**	**0.1 - 0.2**

C

Scientific Name	*Solanum tuberosum*
Common Name	**Potato**
Collected From	Production fields
Plant Part	25-30 most recent fully-developed leaves
Season	Tubers 1/2 grown
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3 - 4	Fe	40 - 100
P	**0.25 - 0.4**	**Mn**	**30 - 250**
K	6 - 8	B	40 - 70
Ca	**1.5 - 2.5**	**Cu**	**7 - 20**
Mg	0.7 - 1	Zn	30 - 200
S	**0.2 - 0.50**	**Mo**	**0.07 - 2.43**

D

Scientific Name	*Solanum tuberosum*
Common Name	**Potato**
Collected From	Production fields
Plant Part	Most recently matured leaf and petiole
Season	Maturity
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	2 - 3	Fe	40 - 150
P	**0.2 - 0.4**	**Mn**	**20 - 100**
K	1.5 - 3	B	20 - 30
Ca	**0.6 - 2**	**Cu**	**5 - 10**
Mg	0.2 - 0.5	Zn	30 - 60
S	**0.2 - 0.50**	**Mo**	**0.1 - 0.2**

E

Scientific Name	*Spinacia oleracea*
Common Name	**Hydroponic Spinach**
Collected From	Greenhouse production
Plant Part	15-20 most recent fully-developed leaves
Season	25-30 days old
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	3.75 - 5.60	Fe	45 - 135
P	**0.45 - 0.77**	**Mn**	**44 - 88**
K	3.50 - 6.50	B	15 - 45
Ca	**1.25 - 2.50**	**Cu**	**5 - 12**
Mg	0.50 - 0.75	Zn	30 - 50
S	**0.18 - 0.35**	**Mo**	**0.33 - 0.50**

F

Scientific Name	*Spinacia oleracea*
Common Name	**Field grown Spinach**
Collected From	Production fields
Plant Part	15-20 most recent fully-developed leaves
Season	25-30 days old
Data Type	Sufficiency Range
Cultivars Used	

Macronutrients %		Micronutrients ppm	
N	4.0 - 6.0	Fe	60 - 200
P	**0.3 - 0.6**	**Mn**	**30 - 250**
K	5.0 - 8.0	B	25 - 60
Ca	**0.7 - 1.2**	**Cu**	**5 - 25**
Mg	0.6 - 1.0	Zn	25 - 100
S	**0.2 - 0.28**	**Mo**	**0.22 - 0.55**

Vegetables

A

Scientific Name			*Spinacia oleracea*
Common Name			**Field grown Spinach**
Collected From			Production greenhouse
Plant Part			15-20 mature leaves from new growth
Season			1/2 Mature, non-flowering
Data Type			Survey Range
Cultivars Used			
Macronutrients %		Micronutrients ppm	
N	2.56 - 5.60	Fe	44 - 79
P	**0.33 - 0.93**	**Mn**	**35 - 90**
K	2.66 - 9.77	B	20 - 41
Ca	**0.8 - 1.23**	**Cu**	**7 - 14**
Mg	0.36 - 0.97	Zn	24 - 34
S	**0.19 - 0.32**	**Mo**	**0.18 - 0.37**

B

Scientific Name			*Spinacia oleracea*
Common Name			**Spinach field grown**
Collected From			Production fields
Plant Part			15-20 most recent fully-developed leaves
Season			Mature plants
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		Micronutrients ppm	
N	3.50 - 5.50	Fe	60 - 245
P	**0.25 - 0.58**	**Mn**	**30 - 250**
K	4.00 - 5.50	B	25 - 63
Ca	**0.60 - 1.50**	**Cu**	**5 - 25**
Mg	0.70 - 1.80	Zn	25 - 100
S	**0.21 - 0.32**	**Mo**	**0.23 - 0.65**

C

Scientific Name			*Trigonella foenum-graecum*
Common Name			**Fenugreek**
Collected From			Research test plots
Plant Part			30 fully expanded leaves
Season			Summer
Data Type			Survey Range
Cultivars Used			
Macronutrients %		Micronutrients ppm	
N	2.35 - 4.32	Fe	55 - 241
P	**0.18 - 0.27**	**Mn**	**35 - 159**
K	2.23 - 3.00	B	15 - 26
Ca	**1.02 - 1.80**	**Cu**	**4 - 16**
Mg	0.27 - 0.34	Zn	0.3 - 18
S	**0.18 - 0.29**	**Mo**	**0.11 - 0.45**

D

Scientific Name			*Vigna unguiculata ssp. unguiculata*
Common Name			**Southern Pea**
Collected From			Research test plots
Plant Part			Most recently matured leaf and petiole
Season			Before bloom
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		Micronutrients ppm	
N	3.5 - 5	Fe	30 - 100
P	**0.3 - 0.8**	**Mn**	**30 - 100**
K	2 - 4	B	15 - 25
Ca	**1 - 1.5**	**Cu**	**5 - 10**
Mg	0.3 - 0.5	Zn	20 - 40
S	**0.19 - 0.24**	**Mo**	**0.11 - 0.45**

E

Scientific Name			*Vigna unguiculata ssp. unguiculata*
Common Name			**Southern Pea**
Collected From			Production fields
Plant Part			Most recently matured leaf and petiole
Season			First bloom
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		Micronutrients ppm	
N	2.5 - 4	Fe	30 - 100
P	**0.2 - 0.4**	**Mn**	**30 - 100**
K	2 - 4	B	15 - 25
Ca	**1 - 1.5**	**Cu**	**5 - 10**
Mg	0.3 - 0.5	Zn	20 - 40
S	**0.18 - 0.25**	**Mo**	**4 - 6**

F

Scientific Name			*Vigna unguiculata ssp. unguiculata*
Common Name			**Southernpea or Black-eyed Pea or Cowpea**
Collected From			Production fields
Plant Part			12 most recent fully-developed trifoliate leaves
Season			Early bloom
Data Type			Sufficiency Range
Cultivars Used			
Macronutrients %		Micronutrients ppm	
N	4.0 - 5.0	Fe	50 - 100
P	**0.3 - 0.6**	**Mn**	**50 - 300**
K	2.2 - 3.0	B	25 - 80
Ca	**2.0 - 3.0**	**Cu**	**6 - 25**
Mg	0.3 - 0.5	Zn	20 - 100
S	**0.16 - 0.25**	**Mo**	**0.33 - 0.56**

Vegetables

A

SCIENTIFIC NAME	*Zea mays ssp. mays*
COMMON NAME	**Sweet Corn**
COLLECTED FROM	Production fields
PLANT PART	Whole tops
SEASON	3-leaf stage
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3 - 4	Fe	50 - 100
P	**0.4 - 0.5**	**Mn**	**40 - 100**
K	2.5 - 4	B	10 - 30
Ca	**0.6 - 0.8**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	30 - 40
S	**0.4 - 0.60**	**Mo**	**0.1 - 0.2**

B

SCIENTIFIC NAME	*Zea mays ssp. mays*
COMMON NAME	**Sweet Corn**
COLLECTED FROM	Production fields
PLANT PART	Whole tops
SEASON	6-leaf stage
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3 - 4	Fe	50 - 100
P	**0.3 - 0.5**	**Mn**	**40 - 100**
K	2.5 - 4	B	10 - 30
Ca	**0.5 - 0.8**	**Cu**	**5 - 10**
Mg	0.25 - 0.5	Zn	30 - 40
S	**0.4 - 0.60**	**Mo**	**0.1 - 0.2**

C

SCIENTIFIC NAME	*Zea mays ssp. mays*
COMMON NAME	**Sweet Corn**
COLLECTED FROM	Production fields
PLANT PART	8-12 unfurled leaves (5th leaf from tip)
SEASON	30-50 cm tall plants
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	4.00 - 4.5	Fe	50 - 350
P	**0.60 - 1.0**	**Mn**	**31 - 300**
K	3.50 - 4.5	B	8 - 25
Ca	**0.50 - 0.8**	**Cu**	**5 - 25**
Mg	0.20 - 0.5	Zn	20 - 150
S	**0.21 - 0.7**	**Mo**	**0.9 - 10**

D

SCIENTIFIC NAME	*Zea mays ssp. mays*
COMMON NAME	**Sweet Corn**
COLLECTED FROM	Production fields
PLANT PART	8-12 unfurled leaves (5th leaf from tip)
SEASON	5-6 weeks old, plants 50-70 cm tall
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	3.50 - 4.5	Fe	50 - 350
P	**0.30 - 0.5**	**Mn**	**31 - 300**
K	2.80 - 3.8	B	8 - 25
Ca	**0.50 - 0.9**	**Cu**	**5 - 25**
Mg	0.20 - 0.5	Zn	20 - 150
S	**0.21 - 0.7**	**Mo**	**0.9 - 10**

E

SCIENTIFIC NAME	*Zea mays ssp. mays*
COMMON NAME	**Sweet Corn**
COLLECTED FROM	Production fields
PLANT PART	8-12 unfurled leaves (5th leaf from tip)
SEASON	7-8 week-old plants; tassel start
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.70 - 3.5	Fe	50 - 350
P	**0.30 - 0.5**	**Mn**	**31 - 300**
K	2.50 - 3.5	B	8 - 25
Ca	**0.70 - 1.0**	**Cu**	**5 - 25**
Mg	0.20 - 0.5	Zn	20 - 150
S	**0.21 - 0.7**	**Mo**	**0.9 - 10**

F

SCIENTIFIC NAME	*Zea mays ssp. mays*
COMMON NAME	**Sweet Corn**
COLLECTED FROM	Production fields
PLANT PART	8-12 unfurled leaves (5th leaf from tip)
SEASON	End of silk (silk browning)
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.20 - 2.7	Fe	50 - 350
P	**0.25 - 0.4**	**Mn**	**31 - 300**
K	1.40 - 2.5	B	8 - 25
Ca	**0.60 - 1.1**	**Cu**	**5 - 25**
Mg	0.20 - 0.5	Zn	20 - 150
S	**0.21 - 0.7**	**Mo**	**0.9 - 10**

Vegetables

A

SCIENTIFIC NAME	*Zea mays ssp. mays*
COMMON NAME	**Sweet Corn**
COLLECTED FROM	Production fields
PLANT PART	8-12 unfurled leaves (5th leaf from tip)
SEASON	Full tassel to silk start
DATA TYPE	Sufficiency Range
CULTIVARS USED	

Macronutrients %		Micronutrients ppm	
N	2.50 - 3.5	Fe	50 - 350
P	**0.25 - 0.4**	**Mn**	**20 - 300**
K	1.50 - 2.8	B	8 - 70
Ca	**0.6 - 2.5**	**Cu**	**5 - 25**
Mg	0.20 - 0.8	Zn	20 - 150
S	**0.21 - 0.7**	**Mo**	**0.2–10**

B

SCIENTIFIC NAME	*Zingiber officinale*
COMMON NAME	**Ginger or ginger root**
COLLECTED FROM	Production fields
PLANT PART	15 leaves from 3rd leaf blade
SEASON	2-3 months of growth
DATA TYPE	Survey Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	3 - 3.5	Fe	110 - 160
P	**0.24 - 0.33**	**Mn**	**25 - 250**
K	3.9 - 5.7	B	80 - 112
Ca	**1.1 - 1.45**	**Cu**	**4 - 14**
Mg	0.5 - 0.8	Zn	22 - 40
S	**0.25 - 0.40**	**Mo**	**0.06 - 0.23**

C

D

E

F

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Abelia 'Edward Goucher'*		
COMMON NAME	**Abelia, 'Edward Goucher' Abelia**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	20 2-3" terminal summer cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Edward Goucher'		
Macronutrients %		**Micronutrients ppm**	
N	1.87 - 2.56	Fe	33 - 57
P	**0.18 - 0.34**	**Mn**	**15 - 67**
K	1.89 - 2.4	B	18 - 39
Ca	**1.05 - 1.65**	**Cu**	**6 - 12**
Mg	.25 - .46	Zn	.2 - .33
S	**0.14 - 0.27**	**Mo**	**0.18 - 0.5**

B

SCIENTIFIC NAME	*Abelia grandiflora*		
COMMON NAME	**Abelia, Glossy**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	20 2-3" terminal summer cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.15	Fe	33 - 76
P	**0.12 - 0.16**	**Mn**	**111 - 132**
K	1.40 - 1.99	B	59 - 91
Ca	**1.29 - 1.45**	**Cu**	**4 - 7**
Mg	0.30 - 0.36	Zn	25 - 30
S	**0.18 - 0.25**	**Mo**	**0.01 - 0.12**

C

SCIENTIFIC NAME	*Abelia grandiflora 'Prostrata'*		
COMMON NAME	**Abelia, Creeping or Prostrate Glossy**		
COLLECTED FROM	Container production nursery/botanical garden/arboretum		
PLANT PART	20 2-3" terminal summer cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Prostrata'		
Macronutrients %		**Micronutrients ppm**	
N	1.75 - 2.40	Fe	33 - 143
P	**0.19 - 0.26**	**Mn**	**45 - 243**
K	1.07 - 2.10	B	33 - 41
Ca	**0.53 - 0.69**	**Cu**	**4 - 7**
Mg	0.25 - 0.34	Zn	21 - 47
S	**0.16 - 0.21**	**Mo**	**0.14 - 0.38**

D

SCIENTIFIC NAME	*Abeliophyllum distichum*		
COMMON NAME	**Forsythia, White or Korean Abelialeaf**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	35 mature leaves from new summer growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.63 - 2.73	Fe	52 - 58
P	**0.13 - 0.18**	**Mn**	**478 - 599**
K	0.68 - 1.51	B	58 - 102
Ca	**1.17 - 1.62**	**Cu**	**6 - 8**
Mg	0.20 - 0.24	Zn	20 - 122
S	**0.14 - 0.19**	**Mo**	**0.12 - 0.30**

E

SCIENTIFIC NAME	*Adina rubella*		
COMMON NAME	**Glossy Buttonbush or Sputnik Plant**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	20 2-3" terminal cutting from summer growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.25 - 3.40	Fe	33 - 82
P	**0.22 - 0.33**	**Mn**	**.22 - 35**
K	1.65 - 2.45	B	28 - 55
Ca	**1.28 - 1.63**	**Cu**	**5 - 12**
Mg	.33 - 0.43	Zn	33 - 97
S	**0.21 - 0.27**	**Mo**	**0.13 - 0.17**

F

SCIENTIFIC NAME	*Aesculus parviflora*		
COMMON NAME	**Bottlebrush Buckeye**		
COLLECTED FROM	Container production nursery		
PLANT PART	10 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.24 - 3.67	Fe	33 - 60
P	**0.33 - 0.48**	**Mn**	**55 - 506**
K	1.89 - 2.33	B	28 - 60
Ca	**1.11 - 2.43**	**Cu**	**6 - 10**
Mg	.34 - 0.52	Zn	25 - 40
S	**0.15 - 0.26**	**Mo**	**0.14 - 0.22**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Aesculus splendens*
COMMON NAME	**Scarlet Buckeye**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.33 - 3.45	Fe	25 - 50
P	**0.26 - 0.45**	**Mn**	**44 - 142**
K	.89 - 2.22	B	22 - 34
Ca	**1.5 - 2**	**Cu**	**6 - 12**
Mg	.36 - 0.48	Zn	15 - 24
S	**0.19 - 0.27**	**Mo**	**0.03 - 0.22**

B

SCIENTIFIC NAME	*Aesculus sylvatica*
COMMON NAME	**Painted or Georgia Buckeye**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	10 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.85 - 2.29	Fe	53 - 166
P	**0.19 - 0.41**	**Mn**	**114 - 117**
K	1.02 - 1.19	B	12 - 23
Ca	**1.79 - 2.02**	**Cu**	**4 - 9**
Mg	0.26 - 0.31	Zn	10 - 13
S	**0.19 - 0.21**	**Mo**	**0.12 - 0.30**

C

SCIENTIFIC NAME	*Agarista populifolia*
COMMON NAME	**Florida Leucothoe or Doghobble**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.25 - 2.22	Fe	35 - 45
P	**0.18 - 0.26**	**Mn**	**34 - 335**
K	.98 - 1.6	B	28 - 38
Ca	**.95 - 1.33**	**Cu**	**4 - 8**
Mg	.2 - .289	Zn	24 - 50
S	**0.16 - 0.25**	**Mo**	**0.14 - 0.24**

D

SCIENTIFIC NAME	*Arbutus unedo 'Compacta'*
COMMON NAME	**Dwarf Strawberry Tree**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Compacta'

Macronutrients %		Micronutrients ppm	
N	1.11 - 1.75	Fe	25 - 45
P	**0.10 - 0.22**	**Mn**	**0.25 - 34**
K	0.88 - 1.65	B	21 - 33
Ca	**1.11 - 1.47**	**Cu**	**4 - 7**
Mg	0.22 - 0.30	Zn	31 - 68
S	**0.11 - 0.16**	**Mo**	**0.12 - 0.5**

E

SCIENTIFIC NAME	*Aucuba japonica 'Variegata'*
COMMON NAME	**Variegated Japanese Aucuba or Gold-dust Plant**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Variegata'

Macronutrients %		Micronutrients ppm	
N	1.43 - 2.23	Fe	33 - 55
P	**0.14 - 0.28**	**Mn**	**0.25 - 443**
K	1.12 - 1.75	B	21 - 27
Ca	**0.88 - 1.15**	**Cu**	**3 - 8**
Mg	0.18 - 0.30	Zn	21 - 35
S	**0.15 - 0.25**	**Mo**	**0.11 - 0.40**

F

SCIENTIFIC NAME	*Berberis julianae*
COMMON NAME	**Wintergreen Barberry**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	15 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.19 - 2.19	Fe	34 - 65
P	**0.13 - 0.20**	**Mn**	**65 - 85**
K	0.58 - 1.52	B	29 - 143
Ca	**1.66 - 2.05**	**Cu**	**4 - 11**
Mg	0.13 - 0.3	Zn	26 - 58
S	**0.1 - 0.17**	**Mo**	**0.15 - 0.23**

Woody Ornamental Shrubs

A

Scientific Name	*Berberis thunbergii 'Aurea'*		
Common Name	**Gold-leaf Japanese Barberry**		
Collected From	Container production nursery		
Plant Part	20 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Aurea'		
Macronutrients %		**Micronutrients ppm**	
N	2.33 - 2.66	Fe	55 - 110
P	**0.11 - 0.21**	**Mn**	**67 - 207**
K	1.04 - 2.03	B	28 - 52
Ca	**0.95 - 1.28**	**Cu**	**3 - 11**
Mg	0.21 - 0.26	Zn	29 - 42
S	**0.17 - 0.24**	**Mo**	**0.09 - 0.29**

B

Scientific Name	*Berberis thunbergii var. atropurpurea*		
Common Name	**Purple-leaf Japanese Barberry**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	20 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. atropurpurea, 'Crimson Pygmy', 'Rose Glow'		
Macronutrients %		**Micronutrients ppm**	
N	1.53 - 2.20	Fe	48 - 187
P	**0.13 - 0.21**	**Mn**	**46 - 291**
K	0.76 - 1.11	B	71 - 77
Ca	**0.84 - 1.25**	**Cu**	**2 - 6**
Mg	0.11 - 0.26	Zn	9 - 35
S	**0.16 - 0.22**	**Mo**	**0.03 - 0.16**

C

Scientific Name	*Buddleia 'Lochinch'*		
Common Name	**Lochinch' Butterfly Bush**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Lochinch'		
Macronutrients %		**Micronutrients ppm**	
N	1.81 - 3.64	Fe	80 - 256
P	**0.22 - 0.52**	**Mn**	**21 - 131**
K	1.12 - 2.88	B	25 - 39
Ca	**0.51 - 1.17**	**Cu**	**14 - 22**
Mg	0.22 - 0.43	Zn	20 - 69
S	**0.26 - 0.55**	**Mo**	**0.08 - 1.16**

D

Scientific Name	*Buddleia davidii 'Harlequin'*		
Common Name	**Variegated Butterfly Bush**		
Collected From	Container production nursery		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Harlequin'		
Macronutrients %		**Micronutrients ppm**	
N	2.19 - 2.91	Fe	45 - 94
P	**0.21 - 0.38**	**Mn**	**57 - 159**
K	1.78 - 2.09	B	20 - 31
Ca	**1.07 - 1.23**	**Cu**	**4 - 13**
Mg	0.2 - 0.3	Zn	31 - 45
S	**0.23 - 0.42**	**Mo**	**0.11 - 0.33**

E

Scientific Name	*Buddleia davidii cultivars*		
Common Name	**Butterfly Bush**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Black Knight', 'Dubonnet', 'Empire Blue', 'Pink Delight', 'White Profusion'		
Macronutrients %		**Micronutrients ppm**	
N	2.35 - 3.93	Fe	53 - 170
P	**0.16 - 0.55**	**Mn**	**44 - 123**
K	0.71 - 3.18	B	28 - 50
Ca	**0.75 - 2.04**	**Cu**	**4 - 20**
Mg	0.17 - 0.44	Zn	13 - 50
S	**0.23 - 0.50**	**Mo**	**0.09 - 0.39**

F

Scientific Name	*Buddleia davidii var. nanhoensis*		
Common Name	**Compact Butterfly Bush**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Nanho Purple', 'Mongo' ('Petite Indigo')		
Macronutrients %		**Micronutrients ppm**	
N	2.86 - 3.73	Fe	75 - 141
P	**0.23 - 0.65**	**Mn**	**23 - 191**
K	1.26 - 2.93	B	28 - 48
Ca	**0.72 - 1.27**	**Cu**	**11 - 22**
Mg	0.23 - 0.50	Zn	40 - 78
S	**0.23 - 0.49**	**Mo**	**0.12 - 0.61**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Buddleia weyeriana*
COMMON NAME	**Gold-flower Butterfly Bush**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Golden Glow'

Macronutrients %		Micronutrients ppm	
N	2.75 - 3.25	Fe	41 - 84
P	**0.16 - 0.25**	**Mn**	**46 - 169**
K	1.98 - 2.06	B	19 - 30
Ca	**0.87 - 1.24**	**Cu**	**5 - 13**
Mg	0.19 - 0.29	Zn	19 - 29
S	**0.16 - 0.25**	**Mo**	**0.33 - 0.95**

B

SCIENTIFIC NAME	*Buxus microphylla var. insularis*
COMMON NAME	**Korean Hybrid Boxwoods**
COLLECTED FROM	Container production nursery
PLANT PART	25 3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Green Mountian', 'Green Velvet'

Macronutrients %		Micronutrients ppm	
N	2.41 - 2.80	Fe	42 - 57
P	**0.14 - 0.22**	**Mn**	**66 - 102**
K	0.79 - 1.35	B	24 - 28
Ca	**0.86 - 0.98**	**Cu**	**4 - 6**
Mg	0.18 - 0.28	Zn	15 - 22
S	**0.19 - 0.27**	**Mo**	**0.11 - 2.15**

C

SCIENTIFIC NAME	*Buxus microphylla var. insularis 'Winter Gem'*
COMMON NAME	**Winter Gem' Boxwood**
COLLECTED FROM	Container production nursery
PLANT PART	25 3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Winter Gem'

Macronutrients %		Micronutrients ppm	
N	2.01 - 2.29	Fe	43 - 94
P	**0.11 - 0.21**	**Mn**	**54 - 85**
K	1.3 - 1.65	B	20 - 30
Ca	**1.23 - 1.40**	**Cu**	**5 - 14**
Mg	0.24 - 0.27	Zn	15 - 25
S	**0.17 - 0.24**	**Mo**	**0.34 - 1.12**

D

SCIENTIFIC NAME	*Buxus microphylla var. japonica*
COMMON NAME	**Japanese Boxwood**
COLLECTED FROM	Container production nursery
PLANT PART	25 3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	var. japonica only

Macronutrients %		Micronutrients ppm	
N	3.00 - 3.60	Fe	44 - 100
P	**0.20 - 0.40**	**Mn**	**68 - 131**
K	0.85 - 2.00	B	22 - 40
Ca	**1.00 - 2.00**	**Cu**	**5 - 12**
Mg	0.20 - 0.60	Zn	20 - 31
S	**0.15 - 0.23**	**Mo**	**0.08 - 0.48**

E

SCIENTIFIC NAME	*Buxus sempervirens*
COMMON NAME	**English or Common Boxwood**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Suffruticosa'

Macronutrients %		Micronutrients ppm	
N	3.0 - 3.26	Fe	31 - 46
P	**0.13 - 0.15**	**Mn**	**6 - 23**
K	0.87 - 0.97	B	36 - 46
Ca	**1.79 - 1.94**	**Cu**	**4 - 6**
Mg	0.21 - 0.36	Zn	12 - 21
S	**0.18 - 0.26**	**Mo**	**0.12 - 0.30**

F

SCIENTIFIC NAME	*Callicarpa americana*
COMMON NAME	**American Beautyberry or French Mulberry**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, var. lactea

Macronutrients %		Micronutrients ppm	
N	2.04 - 3.49	Fe	111 - 148
P	**0.30 - 0.38**	**Mn**	**157 - 648**
K	2.41 - 2.47	B	42 - 56
Ca	**1.29 - 1.76**	**Cu**	**13 - 18**
Mg	0.27 - 0.42	Zn	25 - 35
S	**0.13 - 0.23**	**Mo**	**0.12 - 0.30**

Woody Ornamental Shrubs

A

Scientific Name	*Callicarpa dichotoma*		
Common Name	**Purple Beautyberry**		
Collected From	Container production nursery		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.21 - 2.72	Fe	32 - 66
P	**0.18 - 0.32**	**Mn**	**231 - 441**
K	1.53 - 1.92	B	18 - 27
Ca	**1.01 - 1.28**	**Cu**	**5 - 11**
Mg	0.25 - 0.33	Zn	41 - 58
S	**0.15 - 0.22**	**Mo**	**0.05 - 0.35**

B

Scientific Name	*Calycanthus floridus*		
Common Name	**Sweetshrub or Carolina Allspice**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Athens'		
Macronutrients %		**Micronutrients ppm**	
N	1.70 - 2.20	Fe	30 - 58
P	**0.16 - 0.26**	**Mn**	**76 - 234**
K	0.43 - 0.66	B	14 - 41
Ca	**0.80 - 1.32**	**Cu**	**3 - 6**
Mg	0.12 - 0.17	Zn	20 - 29
S	**0.18 - 0.24**	**Mo**	**0.15 - 1.55**

C

Scientific Name	*Camellia hiemalis 'Shishi Gashira'*		
Common Name	**Shishi Gashira' Camellia**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Shishi Gashira'		
Macronutrients %		**Micronutrients ppm**	
N	1.6 - 2.6	Fe	43 - 67
P	**0.09 - 0.11**	**Mn**	**356 - 1500**
K	0.58 - 1.54	B	21 - 54
Ca	**1.07 - 1.27**	**Cu**	**3 - 9**
Mg	0.12 - 0.29	Zn	7 - 20
S	**0.16 - 0.22**	**Mo**	**0.11 - 0.17**

D

Scientific Name	*Camellia japonica cultivars*		
Common Name	**Japanese or Common Camellia**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Betty Sheffield', 'Dr. Tinsley', 'Lady Clare', 'Professor C.S. Sargent', 'R.L. Wheeler', 'Rose Dawn'		
Macronutrients %		**Micronutrients ppm**	
N	1.20 - 1.98	Fe	33–151
P	**0.09 - 0.17**	**Mn**	**300–1800**
K	0.85 - 1.70	B	32–49
Ca	**0.94 - 1.45**	**Cu**	**2–7**
Mg	0.20 - 0.33	Zn	6–15
S	**0.21 - 0.42**	**Mo**	**0.13 - 0.28**

E

Scientific Name	*Camellia sasanqua cultivars*		
Common Name	**Sasanqua Camellia**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Bonanza', 'Maiden's Blush', 'Showa-No-Sakae', 'Snow on the Mountain'		
Macronutrients %		**Micronutrients ppm**	
N	1.39 - 3.54	Fe	28 - 58
P	**0.08 - 0.11**	**Mn**	**750 - 1500**
K	0.68 - 1.11	B	28 - 46
Ca	**0.69 - 1.46**	**Cu**	**3 - 6**
Mg	0.14 - 0.28	Zn	7 - 17
S	**0.14 - 0.19**	**Mo**	**0.12 - 0.92**

F

Scientific Name	*Camellia sinensis*		
Common Name	**Tea**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.5	Fe	38–77
P	**0.1 - 0.17**	**Mn**	**287–1187**
K	1.11 - 1.84	B	21–34
Ca	**1.09 - 1.32**	**Cu**	**5–11**
Mg	0.26 - 0.3	Zn	13–26
S	**0.17 - 0.25**	**Mo**	**0.09 - 0.23**

Woody Ornamental Shrubs

A

Scientific Name	*Carissa macrocarpa*		
Common Name	**Natal Plum**		
Collected From	Container production nursery		
Plant Part	40 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.80 - 3.50	Fe	50 - 200
P	**0.18 - 0.60**	**Mn**	**50 - 250**
K	1.50 - 3.50	B	25 - 100
Ca	**1.00 - 3.00**	**Cu**	**6 - 25**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.09 - 0.43**

B

Scientific Name	*Caryopteris incana*		
Common Name	**Blue Spirea or Bluebeard**		
Collected From	Container production nursery		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.23 - 3.00	Fe	45 - 125
P	**0.12 - 0.21**	**Mn**	**80 - 176**
K	1.47 - 2.22	B	15 - 26
Ca	**1 - 1.35**	**Cu**	**4 - 11**
Mg	0.16 - 0.23	Zn	30 - 57
S	**0.19 - 0.26**	**Mo**	**0.11 - 0.45**

C

Scientific Name	*Caryopteris x clandonensis*		
Common Name	**Bluebeard**		
Collected From	Container production nursery		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Longwood Blue'		
Macronutrients %		**Micronutrients ppm**	
N	1.99 - 2.26	Fe	44 - 98
P	**0.21 - 0.34**	**Mn**	**22 - 221**
K	1.25 - 2.15	B	21 - 32
Ca	**0.98 - 1.35**	**Cu**	**5 - 14**
Mg	0.19 - 0.29	Zn	34 - 69
S	**0.17 - 0.24**	**Mo**	**0.16 - 0.32**

D

Scientific Name	*Ceanothus impressus*		
Common Name	**Santa Barbara Ceanothus**		
Collected From	Container production nursery		
Plant Part	20 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Victoria'		
Macronutrients %		**Micronutrients ppm**	
N	2.12 - 3.07	Fe	50 - 63
P	**0.13 - 0.24**	**Mn**	**232 - 261**
K	1.22 - 1.32	B	20 - 38
Ca	**0.90 - 0.97**	**Cu**	**5 - 9**
Mg	0.16 - 0.19	Zn	45 - 52
S	**0.15 - 0.22**	**Mo**	**0.11 - 2.0**

E

Scientific Name	*Chaenomeles speciosa*		
Common Name	**Flowering Quince**		
Collected From	Botanical garden/arboretum		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Nivalis', others not specified		
Macronutrients %		**Micronutrients ppm**	
N	1.65 - 1.97	Fe	42 - 47
P	**0.11 - 0.56**	**Mn**	**63 - 69**
K	1.64 - 1.98	B	66 - 72
Ca	**1.72 - 2.39**	**Cu**	**6 - 21**
Mg	0.20 - 0.30	Zn	7 - 21
S	**0.14 - 0.20**	**Mo**	**0.12 - 0.45**

F

Scientific Name	*Chimonanthus praecox*		
Common Name	**Fragrant Wintersweet**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.77 - 3.15	Fe	28 - 95
P	**0.20 - 0.30**	**Mn**	**85 - 192**
K	0.53 - 0.80	B	22 - 130
Ca	**0.73 - 2.76**	**Cu**	**1 - 6**
Mg	0.23 - 0.37	Zn	25 - 151
S	**0.15 - 0.29**	**Mo**	**0.19 - 0.53**

Woody Ornamental Shrubs

A

Scientific Name			*Clerodendrum trichotomum*
Common Name			**Harlequin Glorybower**
Collected From			Botanical garden/arboretum
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.37 - 3.46	Fe	31 - 54
P	**0.18 - 0.25**	**Mn**	**48 - 123**
K	1.22 - 1.78	B	34 - 115
Ca	**1.32 - 1.90**	**Cu**	**5 - 13**
Mg	0.18 - 0.29	Zn	9 - 33
S	**0.19 - 0.50**	**Mo**	**0.11 - 0.32**

B

Scientific Name			*Clethra alnifolia*
Common Name			**Summersweet Clethra**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species, 'Rosea'
Macronutrients %		**Micronutrients ppm**	
N	1.60 - 2.37	Fe	44 - 218
P	**0.18 - 0.27**	**Mn**	**469 - 1922**
K	1.08 - 1.91	B	70 - 104
Ca	**1.52 - 1.95**	**Cu**	**4 - 6**
Mg	0.59 - 0.93	Zn	86 - 608
S	**0.16 - 0.30**	**Mo**	**0.02 - 0.05**

C

Scientific Name			*Cornus alba*
Common Name			**Tatarian Dogwood**
Collected From			Container production nursery
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.97 - 2.6	Fe	36 - 75
P	**0.25 - 0.62**	**Mn**	**13 - 78**
K	1.1 - 1.62	B	20 - 34
Ca	**1.56 - 2.23**	**Cu**	**5 - 10**
Mg	0.28 - 0.36	Zn	21 - 33
S	**0.16 - 0.21**	**Mo**	**0.43 - 1.8**

D

Scientific Name			*Cornus racemosa*
Common Name			**Gray or Panicled Dogwood**
Collected From			Container production nursery
Plant Part			5 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.82 - 2.43	Fe	42 - 82
P	**0.21 - 0.31**	**Mn**	**10 - 100**
K	1.18 - 2.17	B	21 - 30
Ca	**1.69 - 2.95**	**Cu**	**5 - 9**
Mg	0.33 - 0.58	Zn	22 - 29
S	**0.15 - 0.23**	**Mo**	**0.23 - 0.88**

E

Scientific Name			*Cornus stolonifera 'Silver and Gold'*
Common Name			**Variegated Yellow-Stem Redosier Dogwood**
Collected From			Botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Silver and Gold'
Macronutrients %		**Micronutrients ppm**	
N	2.33 - 2.73	Fe	34 - 65
P	**0.18 - 0.35**	**Mn**	**43 - 145**
K	1.6 - 1.77	B	31 - 58
Ca	**1.28 - 2.91**	**Cu**	**5 - 13**
Mg	0.33 - 0.60	Zn	24 - 36
S	**0.22 - 0.51**	**Mo**	**0.09 - 0.28**

F

Scientific Name			*Corylopsis sinensis*
Common Name			**Chinese Winterhazel**
Collected From			Container production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.45 - 2.35	Fe	37 - 74
P	**0.14 - 0.25**	**Mn**	**78 - 189**
K	0.56 - 1.89	B	24 - 69
Ca	**1.42 - 2.11**	**Cu**	**3 - 11**
Mg	0.11 - 0.28	Zn	13 - 26
S	**0.14 - 0.19**	**Mo**	**0.07 - 0.25**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Corylopsis sinensis var. calvescens f. veitchiana*
COMMON NAME	**Veitch's Winterhazel**
COLLECTED FROM	Container production nursery & botanical garden /arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	f. veitchiana only

Macronutrients %		Micronutrients ppm	
N	1.69 - 1.79	Fe	27 - 36
P	**0.41 - 0.69**	**Mn**	**65 - 99**
K	1.21 - 1.33	B	22 - 35
Ca	**1.43 - 1.54**	**Cu**	**2 - 9**
Mg	0.18 - 0.21	Zn	10 - 16
S	**0.14 - 0.17**	**Mo**	**0.12 - 0.23**

B

SCIENTIFIC NAME	*Corylus avellana 'Contorta'*
COMMON NAME	**Harry Lauder's Walkingstick or Contorted European Filbert**
COLLECTED FROM	Container production nursery & botanical garden /arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Contorta'

Macronutrients %		Micronutrients ppm	
N	2.51 - 3.23	Fe	60 - 62
P	**0.17 - 0.47**	**Mn**	**135 - 1000**
K	1.18 - 1.33	B	48 - 78
Ca	**1.29 - 1.76**	**Cu**	**2 - 11**
Mg	0.22 - 0.29	Zn	26 - 41
S	**0.18 - 0.25**	**Mo**	**0.12 - 0.47**

C

SCIENTIFIC NAME	*Cotoneaster apiculatus*
COMMON NAME	**Cranberry Cotoneaster**
COLLECTED FROM	Container production nursery
PLANT PART	20 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.80 - 3.90	Fe	202 - 228
P	**0.34 - 0.36**	**Mn**	**137–218**
K	1.13 - 2.00	B	10–35
Ca	**1.10 - 1.38**	**Cu**	**3–14**
Mg	0.17 - 0.27	Zn	20–43
S	**0.15 - 0.22**	**Mo**	**0.12 - 0.65**

D

SCIENTIFIC NAME	*Cotoneaster dammeri*
COMMON NAME	**Bearberry Cotoneaster**
COLLECTED FROM	Container production nursery
PLANT PART	20 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Coral Beauty'

Macronutrients %		Micronutrients ppm	
N	1.86 - 3.40	Fe	54 - 167
P	**0.21 - 0.35**	**Mn**	**86 - 132**
K	1.21 - 1.92	B	35 - 77
Ca	**0.89 - 1.20**	**Cu**	**3 - 12**
Mg	0.22 - 0.45	Zn	30 - 49
S	**0.12 - 0.21**	**Mo**	**0.12 - 1.44**

E

SCIENTIFIC NAME	*Cotoneaster lacteus*
COMMON NAME	**Parney Cotoneaster**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients Ppm	
N	1.4 - 2.23	Fe	39–60
P	**0.11 - 0.20**	**Mn**	**63–137**
K	1.29 - 1.64	B	33–69
Ca	**2 - 3.15**	**Cu**	**5–11**
Mg	0.25 - 0.31	Zn	33–43
S	**0.12 - 0.23**	**Mo**	**0.1 - 0.21**

F

SCIENTIFIC NAME	*Cotoneaster salicifolius*
COMMON NAME	**Willowleaf Cotoneaster**
COLLECTED FROM	Container production nursery
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Emerald Carpet'

Macronutrients %		Micronutrients ppm	
N	1.92 - 2.03	Fe	40 - 85
P	**0.15 - 0.22**	**Mn**	**55 - 151**
K	1.17 - 1.63	B	27 - 54
Ca	**0.89 - 1.33**	**Cu**	**5 - 8**
Mg	0.25 - 0.31	Zn	19 - 36
S	**0.14 - 0.23**	**Mo**	**0.07 - 0.18**

Woody Ornamental Shrubs

A

Scientific Name			*Cuphea hyssopifolia*
Common Name			**Hawaiian Heather**
Collected From			Container production nursery
Plant Part			20 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Alba'
Macronutrients %		**Micronutrients Ppm**	
N	1.74 - 2.10	Fe	30–52
P	**0.25 - 0.31**	**Mn**	**30–143**
K	1.5 - 2	B	25–35
Ca	**1.15 - 1.39**	**Cu**	**5–12**
Mg	0.23 - 0.47	Zn	18–90
S	**0.16 - 0.23**	**Mo**	**0.43 - 1.86**

B

Scientific Name			*Cyrilla racemiflora*
Common Name			**Swamp Cyrilla or Leatherwood**
Collected From			Field production nursery
Plant Part			40 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.24	Fe	25 - 73
P	**0.14 - 0.17**	**Mn**	**75 - 169**
K	1.15 - 1.39	B	18 - 29
Ca	**0.58 - 0.97**	**Cu**	**5 - 12**
Mg	0.11 - 0.28	Zn	20 - 30
S	**0.14 - 0.20**	**Mo**	**0.11 - 0.3**

C

Scientific Name			*Danae racemosa*
Common Name			**Alexandrian Laurel**
Collected From			Botanical garden/arboretum
Plant Part			40 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients Ppm**	
N	1.87 - 2.18	Fe	44–78
P	**0.1 - 0.17**	**Mn**	**176–337**
K	1.74 - 2.66	B	25–42
Ca	**0.54 - 1.14**	**Cu**	**6–15**
Mg	0.22 - 0.27	Zn	29–126
S	**0.15 - 0.28**	**Mo**	**0.11 - 0.43**

D

Scientific Name			*Daphne odora*
Common Name			**Fragrant or Winter Daphne**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Alba', 'Aureomarginata'
Macronutrients %		**Micronutrients ppm**	
N	1.80 - 3.23	Fe	45 - 51
P	**0.29 - 0.40**	**Mn**	**62 - 250**
K	0.73 - 1.18	B	72 - 84
Ca	**1.02 - 1.20**	**Cu**	**4 - 6**
Mg	0.10 - 0.18	Zn	44 - 157
S	**0.15 - 0.21**	**Mo**	**0.12 - 0.15**

E

Scientific Name			*Daphniphyllum macropodum*
Common Name			**Blue Daphniphyllum**
Collected From			Botanical garden/arboretum
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients Ppm**	
N	1.59 - 2.19	Fe	26–66
P	**0.09 - 0.13**	**Mn**	**18–67**
K	0.7 - 1.79	B	15–25
Ca	**1.56 - 2.03**	**Cu**	**1–12**
Mg	0.24 - 0.34	Zn	18–29
S	**0.12 - 0.22**	**Mo**	**0.11 - 0.34**

F

Scientific Name			*Deutzia gracilis*
Common Name			**Slender Deutzia**
Collected From			Container production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.98 - 2.33	Fe	42 - 67
P	**0.14 - 0.22**	**Mn**	**62 - 109**
K	1.29 - 1.54	B	26 - 46
Ca	**1.87 - 3.07**	**Cu**	**5 - 11**
Mg	0.31 - 0.62	Zn	21 - 56
S	**0.22 - 0.30**	**Mo**	**0.32 - 0.90**

Woody Ornamental Shrubs

A

Scientific Name			*Diervilla sessilifolia*
Common Name			**Southern Bush-honeysuckle**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients Ppm**	
N	1.76 - 2.20	Fe	46–288
P	**0.23 - 0.35**	**Mn**	**32–93**
K	2.23 - 2.81	B	27–58
Ca	**1.14 - 1.62**	**Cu**	**5–11**
Mg	0.28 - 0.50	Zn	34–163
S	**0.13 - 0.21**	**Mo**	**0.11 - 0.29**

B

Scientific Name			*Dirca palustris*
Common Name			**Leatherwood**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.88 - 1.98	Fe	34 - 77
P	**0.17 - 0.21**	**Mn**	**136 - 640**
K	2.12 - 2.52	B	34 - 58
Ca	**1.41 - 2.99**	**Cu**	**5 - 11**
Mg	0.35 - 0.83	Zn	18 - 30
S	**0.19 - 0.51**	**Mo**	**0.09 - 0.22**

C

Scientific Name			*Elaeagnus pungens*
Common Name			**Silverberry or Thorny Eleagnus**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients Ppm**	
N	2.97 - 3.31	Fe	71–96
P	**0.12 - 0.13**	**Mn**	**806–1225**
K	1.66 - 1.88	B	43–66
Ca	**0.97 - 2.26**	**Cu**	**2–11**
Mg	0.17 - 0.22	Zn	18–30
S	**0.20 - 0.22**	**Mo**	**0.12 - 0.30**

D

Scientific Name			*Eleutherococcus sieboldianus*
Common Name			**Fiveleaf Aralia**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.39 - 2.99	Fe	41 - 76
P	**0.16 - 0.24**	**Mn**	**233 - 484**
K	1.65 - 1.88	B	26 - 55
Ca	**2.01 - 4.24**	**Cu**	**5 - 9**
Mg	0.21 - 0.29	Zn	41 - 140
S	**0.16 - 0.20**	**Mo**	**0.15 - 0.29**

E

Scientific Name			*Eleutherococcus sieboldianus 'Variegatus'*
Common Name			**Variegated Fiveleaf Aralia**
Collected From			Container production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Variegatus'
Macronutrients %		**Micronutrients Ppm**	
N	2.32 - 3.05	Fe	39–63
P	**0.33 - 0.51**	**Mn**	**337–731**
K	2.3 - 3.03	B	22–36
Ca	**0.95 - 1.49**	**Cu**	**4–11**
Mg	0.26 - 0.31	Zn	41–106
S	**0.13 - 0.21**	**Mo**	**0.06 - 0.23**

F

Scientific Name			*Erythrina crista-galli*
Common Name			**Coral Tree**
Collected From			Botanical garden/arboretum
Plant Part			15 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.89 - 4.55	Fe	48 - 84
P	**0.21 - 0.37**	**Mn**	**78 - 124**
K	2.11 - 2.73	B	19 - 35
Ca	**1.32 - 2.55**	**Cu**	**6 - 10**
Mg	0.21 - 0.29	Zn	21 - 49
S	**0.18 - 0.25**	**Mo**	**0.15 - 0.35**

Woody Ornamental Shrubs

A

Scientific Name	*Euonymus alatus*		
Common Name	**Winged Euonymus**		
Collected From	Container & field production nurseries & botanical garden/arboretum		
Plant Part	40 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients Ppm**	
N	2.37 - 2.62	Fe	100–304
P	**0.15 - 0.21**	**Mn**	**73–636**
K	1.18 - 1.46	B	28–40
Ca	**1.46 - 3.08**	**Cu**	**3–12**
Mg	0.10 - 0.23	Zn	12–34
S	**0.24 - 0.33**	**Mo**	**0.12 - 0.69**

B

Scientific Name	*Euonymus japonicus 'Silver King'*		
Common Name	**Variegated Japanese Euonymus**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Silver King'		
Macronutrients %		**Micronutrients ppm**	
N	1.05 - 2.32	Fe	32 - 69
P	**0.26 - 0.41**	**Mn**	**72 - 83**
K	1.08 - 1.97	B	38 - 45
Ca	**3.42 - 3.74**	**Cu**	**7 - 9**
Mg	0.20 - 0.32	Zn	30 - 52
S	**0.15 - 0.24**	**Mo**	**0.24 - 0.99**

C

Scientific Name	*Eurya japonica*		
Common Name	**Japanese Eurya**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients Ppm**	
N	1.43 - 2.12	Fe	33–69
P	**0.1 - 0.21**	**Mn**	**266–2600**
K	0.78 - 1.63	B	19–33
Ca	**0.75 - 1.36**	**Cu**	**2–12**
Mg	0.18 - 0.22	Zn	10–30
S	**0.18 - 0.25**	**Mo**	**0.11 - 0.55**

D

Scientific Name	*Exochorda racemosa*		
Common Name	**Common Pearlbush**		
Collected From	Botanical garden/arboretum		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.41	Fe	55 - 136
P	**0.11 - 0.15**	**Mn**	**45 - 256**
K	1.22 - 1.44	B	20 - 32
Ca	**1.33 - 1.87**	**Cu**	**4 - 14**
Mg	0.26 - 0.31	Zn	20 - 31
S	**0.16 - 0.23**	**Mo**	**0.09 - 0.32**

E

Scientific Name	*Fatshedera lizei*		
Common Name	**Fatshedera**		
Collected From	Botanical garden/arboretum		
Plant Part	10 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.27 - 2.82	Fe	38 - 95
P	**0.23 - 0.67**	**Mn**	**204 - 1067**
K	2.22 - 5.22	B	33 - 50
Ca	**0.99 - 1.20**	**Cu**	**6 - 11**
Mg	0.26 - 0.33	Zn	34 - 138
S	**0.19 - 0.32**	**Mo**	**0.13 - 0.17**

F

Scientific Name	*Fatsia japonica*		
Common Name	**Japanese Fatsia**		
Collected From	Botanical garden/arboretum		
Plant Part	5 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.51 - 2.41	Fe	34 - 94
P	**0.14 - 0.24**	**Mn**	**55 - 157**
K	1.22 - 1.42	B	27 - 48
Ca	**1.25 - 2.69**	**Cu**	**5 - 9**
Mg	0.2 - 0.28	Zn	32 - 171
S	**0.17 - 0.25**	**Mo**	**0.11 - 0.24**

Woody Ornamental Shrubs

A

Scientific Name	*Feijoa sellowiana*
Common Name	**Pineapple Guava**
Collected From	Botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Nazemetz'

Macronutrients %		Micronutrients ppm	
N	1.20 - 1.45	Fe	17 - 53
P	**0.12 - 0.37**	**Mn**	**34 - 206**
K	1.01 - 1.17	B	32 - 56
Ca	**0.86 - 1.80**	**Cu**	**2 - 4**
Mg	0.15 - 0.22	Zn	18 - 22
S	**0.13 - 0.18**	**Mo**	**0.19 - 0.38**

B

Scientific Name	*Forsythia 'Gold Leaf'*
Common Name	**Gold-leaf Forsythia**
Collected From	Container production nursery
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Gold Leaf'

Macronutrients %		Micronutrients ppm	
N	2.26 - 2.46	Fe	41 - 74
P	**0.17 - 0.29**	**Mn**	**45 - 105**
K	1.78 - 2.12	B	21 - 30
Ca	**0.64 - 1.56**	**Cu**	**6 - 16**
Mg	0.2 - 0.3	Zn	34 - 51
S	**0.14 - 0.19**	**Mo**	**0.26 - 0.48**

C

Scientific Name	*Forsythia intermedia*
Common Name	**Border Forsythia**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	0.98 - 2.58	Fe	80 - 102
P	**0.09 - 0.31**	**Mn**	**10 - 600**
K	1.00 - 1.40	B	14 - 59
Ca	**0.44 - 1.58**	**Cu**	**5 - 22**
Mg	0.12 - 0.26	Zn	10 - 38
S	**0.15 - 0.19**	**Mo**	**0.12 - 1.18**

D

Scientific Name	*Forsythia viridissima*
Common Name	**Greenstem Forsythia**
Collected From	Botanical garden/arboretum
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.75 - 2.37	Fe	40 - 73
P	**0.1 - 0.15**	**Mn**	**254 - 1173**
K	1.23 - 1.94	B	24 - 35
Ca	**0.81 - 1.34**	**Cu**	**3 - 9**
Mg	0.13 - 0.31	Zn	13 - 27
S	**0.14 - 0.19**	**Mo**	**0.11 - 0.29**

E

Scientific Name	*Fothergilla gardenii*
Common Name	**Dwarf Fothergilla or Witchalder**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.64 - 2.34	Fe	47 - 155
P	**0.11 - 0.21**	**Mn**	**85 - 93**
K	0.62 - 1.05	B	25 - 30
Ca	**0.96 - 1.87**	**Cu**	**3 - 8**
Mg	0.20 - 0.26	Zn	9 - 29
S	**0.13 - 0.19**	**Mo**	**0.12 - 0.30**

F

Scientific Name	*Fothergilla major*
Common Name	**Large Fothergilla or Witchalder**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Mt. Airy'

Macronutrients %		Micronutrients ppm	
N	1.90 - 2.44	Fe	100 - 122
P	**0.19 - 0.31**	**Mn**	**37 - 109**
K	0.79 - 1.03	B	33 - 36
Ca	**1.48 - 1.65**	**Cu**	**4 - 8**
Mg	0.23 - 0.42	Zn	9 - 83
S	**0.12 - 0.17**	**Mo**	**0.05 - 0.30**

Woody Ornamental Shrubs

A

Scientific Name	*Gardenia jasminoides*
Common Name	**Common Gardenia or Cape Jasmine**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Not specified

Macronutrients %		Micronutrients ppm	
N	1.6 - 1.77	Fe	40 - 71
P	**0.14 - 0.21**	**Mn**	**20 - 32**
K	1.17 - 1.44	B	33 - 38
Ca	**1.2 - 1.93**	**Cu**	**5 - 8**
Mg	0.3 - 0.41	Zn	15 - 21
S	**0.16 - 0.25**	**Mo**	**0.26 - 0.72**

B

Scientific Name	*Gardenia jasminoides 'Daisy'*
Common Name	**Daisy' Hardy Gardenia**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Daisy'

Macronutrients %		Micronutrients ppm	
N	2.00 - 3.00	Fe	35 - 70
P	**0.15 - 0.25**	**Mn**	**20 - 35**
K	1.25 - 1.75	B	12 - 25
Ca	**0.75 - 1.50**	**Cu**	**4 - 8**
Mg	0.30 - 0.45	Zn	15 - 30
S	**0.18 - 0.25**	**Mo**	**0.26 - 0.50**

C

Scientific Name	*Gardenia jasminoides 'Radicans'*
Common Name	**Dwarf or Creeping Gardenia**
Collected From	Botanical garden/arboretum
Plant Part	20 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Radicans'

Macronutrients %		Micronutrients ppm	
N	1.52 - 2.35	Fe	55 - 87
P	**0.14 - 0.17**	**Mn**	**25 - 88**
K	1.33 - 1.89	B	22 - 31
Ca	**1.04 - 1.32**	**Cu**	**7 - 11**
Mg	0.21 - 0.36	Zn	21 - 32
S	**0.11 - 0.18**	**Mo**	**0.09 - 0.19**

D

Scientific Name	*Hamamelis intermedia 'Arnold Promise'*
Common Name	**Arnold Promise' Witchhazel**
Collected From	Container & field production nurseries
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Arnold Promise'

Macronutrients %		Micronutrients ppm	
N	1.57 - 1.94	Fe	38 - 60
P	**0.16 - 0.51**	**Mn**	**419 - 895**
K	0.84 - 0.96	B	8 - 23
Ca	**0.55 - 0.77**	**Cu**	**5 - 15**
Mg	0.15 - 0.18	Zn	9 - 13
S	**0.15 - 0.16**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Hamamelis macrophylla*
Common Name	**Southern Witchhazel**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.65 - 1.92	Fe	33 - 69
P	**0.11 - 0.18**	**Mn**	**243 - 649**
K	0.28 - 1.91	B	24 - 44
Ca	**0.88 - 1.1**	**Cu**	**2 - 8**
Mg	0.17 - 0.27	Zn	13 - 26
S	**0.13 - 0.17**	**Mo**	**0.19 - 0.23**

F

Scientific Name	*Hamamelis mollis*
Common Name	**Chinese Witchhazel**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Pallida'

Macronutrients %		Micronutrients ppm	
N	1.28 - 1.87	Fe	70 - 117
P	**0.18 - 0.24**	**Mn**	**331 - 430**
K	0.86 - 1.28	B	23 - 96
Ca	**0.52 - 1.20**	**Cu**	**4 - 9**
Mg	0.16 - 0.18	Zn	10 - 13
S	**0.15 - 0.18**	**Mo**	**0.02 - 0.17**

Woody Ornamental Shrubs

A

Scientific Name	*Hamamelis vernalis*
Common Name	**Vernal Witchhazel**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.61 - 2.35	Fe	32 - 77
P	**0.15 - 0.25**	**Mn**	**169 - 268**
K	0.64 - 1.54	B	23 - 65
Ca	**1.12 - 1.60**	**Cu**	**3 - 11**
Mg	0.18 - 0.28	Zn	11 - 23
S	**0.14 - 0.22**	**Mo**	**0.11 - 0.21**

B

Scientific Name	*Heteropteris glabra*
Common Name	**Redwing**
Collected From	Botanical garden/arboretum
Plant Part	35 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	2.56 - 3.81	Fe	33 - 58
P	**0.15 - 0.24**	**Mn**	**76 - 96**
K	1.69 - 2.00	B	18 - 24
Ca	**0.75 - 1.15**	**Cu**	**5 - 11**
Mg	0.22 - 0.30	Zn	22 - 41
S	**0.16 - 0.23**	**Mo**	**0.08 - 0.26**

C

Scientific Name	*Hibiscus syriacus*
Common Name	**Shrub Althea or Rose-of-Sharon**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Aphrodite', 'Blue Bird', 'Blushing Bride', 'Collie Mullens', 'Diana', 'Helene', 'Red Heart'

Macronutrients %		Micronutrients ppm	
N	2.61 - 4.56	Fe	56 - 100
P	**0.20 - 0.41**	**Mn**	**108 - 289**
K	1.21 - 3.35	B	51 - 114
Ca	**2.31 - 5.18**	**Cu**	**8 - 28**
Mg	0.36 - 1.12	Zn	35 - 97
S	**0.24 - 0.33**	**Mo**	**0.12 - 1.8**

D

Scientific Name	*Hydrangea arborescens 'Annabelle'*
Common Name	**Annabelle' Smooth Hydrangea**
Collected From	Container production nursery
Plant Part	20 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Annabelle'

Macronutrients %		Micronutrients ppm	
N	2.14 - 2.52	Fe	43 - 88
P	**0.19 - 0.33**	**Mn**	**78 - 153**
K	1.52 - 1.95	B	15 - 26
Ca	**2.23 - 2.69**	**Cu**	**2 - 12**
Mg	0.29 - 0.34	Zn	32 - 50
S	**0.18 - 0.23**	**Mo**	**0.13 - 0.34**

E

Scientific Name	*Hydrangea macrophylla*
Common Name	**French Hydrangea or Hortensia**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Unspecified clone, 'Pink Beauty'

Macronutrients %		Micronutrients ppm	
N	2.66 - 3.07	Fe	40 - 80
P	**0.23 - 0.67**	**Mn**	**128 - 256**
K	2.79 - 3.43	B	24 - 69
Ca	**1.55 - 2.81**	**Cu**	**2 - 8**
Mg	0.29 - 0.48	Zn	52 - 59
S	**0.20 - 0.25**	**Mo**	**0.01 - 0.12**

F

Scientific Name	*Hydrangea macrophylla 'Maculata'*
Common Name	**Variegated Lacecap French Hydrangea**
Collected From	Botanical garden/arboretum
Plant Part	15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Maculata'

Macronutrients %		Micronutrients ppm	
N	1.89 - 2.17	Fe	38 - 54
P	**0.22 - 0.35**	**Mn**	**45 - 100**
K	2.21 - 4.00	B	20 - 28
Ca	**1.01 - 1.15**	**Cu**	**5 - 11**
Mg	0.3 - 0.40	Zn	20 - 38
S	**0.16 - 0.26**	**Mo**	**0.07 - 0.19**

Woody Ornamental Shrubs

A

Scientific Name	*Hydrangea paniculata*		
Common Name	**Panicled Hydrangea**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Grandiflora', 'Tardiva'		
Macronutrients %		**Micronutrients ppm**	
N	1.08 - 2.44	Fe	56 - 191
P	**0.23 - 0.59**	**Mn**	**87 - 340**
K	2.15 - 2.41	B	32 - 73
Ca	**1.91 - 2.72**	**Cu**	**2 - 8**
Mg	0.30 - 0.56	Zn	34 - 164
S	**0.14 - 0.37**	**Mo**	**0.09 - 0.15**

B

Scientific Name	*Hydrangea quercifolia*		
Common Name	**Oakleaf Hydrangea**		
Collected From	Botanical garden/arboretum		
Plant Part	10 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Snow Queen'		
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 2.34	Fe	41 - 79
P	**0.13 - 0.23**	**Mn**	**57 - 122**
K	1.38 - 1.93	B	25 - 58
Ca	**1.45 - 2.78**	**Cu**	**5 - 13**
Mg	0.31 - 0.39	Zn	24 - 31
S	**0.13 - 0.18**	**Mo**	**0.08 - 0.18**

C

Scientific Name	*Hypericum calycinum*		
Common Name	**Aaronsbeard St. Johnswort**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.33 - 2.14	Fe	29 - 84
P	**0.18 - 0.28**	**Mn**	**33 - 97**
K	1.28 - 1.72	B	21 - 145
Ca	**0.35 - 1.26**	**Cu**	**3 - 8**
Mg	0.24 - 0.35	Zn	20 - 44
S	**0.14 - 0.23**	**Mo**	**0.12 - 0.80**

D

Scientific Name	*Hypericum densiflorum*		
Common Name	**Shrubby Hypericum**		
Collected From	Botanical garden/arboretum		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.79 - 2.67	Fe	33 - 46
P	**0.12 - 0.18**	**Mn**	**96 - 242**
K	0.49 - 1.48	B	32 - 86
Ca	**0.97 - 1.2**	**Cu**	**4 - 15**
Mg	0.14 - 0.27	Zn	22 - 35
S	**0.16 - 0.23**	**Mo**	**0.11 - 0.17**

E

Scientific Name	*Hypericum frondosum*		
Common Name	**Golden St. Johnswort**		
Collected From	Container production nursery		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Sunburst'		
Macronutrients %		**Micronutrients ppm**	
N	1.7 - 2.18	Fe	17 - 71
P	**0.14 - 0.23**	**Mn**	**56 - 114**
K	0.67 - 2.01	B	22 - 48
Ca	**0.49 - 1.15**	**Cu**	**7 - 40**
Mg	0.18 - 0.33	Zn	22 - 42
S	**0.13 - 0.23**	**Mo**	**0.19 - 0.32**

F

Scientific Name	*Hypericum moserianum 'Tricolor'*		
Common Name	**Variegated Moser's St. Johnswort**		
Collected From	Container production nursery		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Tricolor'		
Macronutrients %		**Micronutrients ppm**	
N	1.79 - 2.15	Fe	59 - 86
P	**0.19 - 0.25**	**Mn**	**27 - 334**
K	1.30 - 1.37	B	59 - 83
Ca	**0.78 - 1.30**	**Cu**	**3 - 18**
Mg	0.23 - 0.24	Zn	31 - 41
S	**0.16 - 0.20**	**Mo**	**0.3 - 0.8**

Woody Ornamental Shrubs

A

Scientific Name	*Ilex 'Emily Bruner'*		
Common Name	**Emily Bruner' Holly**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Emily Bruner'		
Macronutrients %		**Micronutrients ppm**	
N	0.80 - 1.69	Fe	17 - 40
P	**0.05 - 0.13**	**Mn**	**262 - 1763**
K	0.80 - 1.59	B	13 - 66
Ca	**0.72 - 1.62**	**Cu**	**2 - 8**
Mg	0.40 - 0.44	Zn	10 - 91
S	**0.12 - 0.17**	**Mo**	**0.12 - 0.30**

B

Scientific Name	*Ilex 'Herbert Kahrs'*		
Common Name	**Herbert Kahrs' Holly**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Herbert Kahrs'		
Macronutrients %		**Micronutrients ppm**	
N	1.12 - 1.87	Fe	33 - 64
P	**0.07 - 0.19**	**Mn**	**288 - 3812**
K	0.46 - 1.65	B	33 - 79
Ca	**1.33 - 2.04**	**Cu**	**3 - 11**
Mg	0.33 - 0.43	Zn	34 - 168
S	**0.15 - 0.19**	**Mo**	**0.11 - 0.34**

C

Scientific Name	*Ilex 'Nellie R. Stevens'*		
Common Name	**Nellie R. Stevens' Holly**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Nellie R. Stevens'		
Macronutrients %		**Micronutrients ppm**	
N	1.80 - 2.00	Fe	79 - 102
P	**0.13 - 0.14**	**Mn**	**1131 - 1442**
K	1.32 - 2.02	B	59 - 74
Ca	**0.93 - 1.51**	**Cu**	**4 - 13**
Mg	0.33 - 0.36	Zn	257 - 384
S	**0.16 - 0.23**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Ilex 'Sparkleberry'*		
Common Name	**Sparkleberry' Deciduous Holly**		
Collected From	Container & field production nurseries & botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Sparkleberry'		
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.54	Fe	30 - 65
P	**0.12 - 0.24**	**Mn**	**425 - 2133**
K	0.95 - 2.08	B	19 - 33
Ca	**0.39 - 0.82**	**Cu**	**3 - 9**
Mg	0.35 - 0.67	Zn	55 - 421
S	**0.19 - 0.29**	**Mo**	**0.12 - 1.74**

E

Scientific Name	*Ilex (deciduous cultivars)*		
Common Name	**Deciduous Hollies**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Autumn Glow', 'Bonfire', 'Harvest Red'		
Macronutrients %		**Micronutrients ppm**	
N	1.91 - 2.22	Fe	55 - 90
P	**0.11 - 0.17**	**Mn**	**1241 - 3175**
K	0.52 - 1.98	B	32 - 58
Ca	**0.77 - 1.36**	**Cu**	**5 - 8**
Mg	0.40 - 0.97	Zn	106 - 263
S	**0.18 - 0.27**	**Mo**	**0.02 - 0.08**

F

Scientific Name	*Ilex ambigua*		
Common Name	**Carolina Holly**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Specias only		
Macronutrients %		**Micronutrients ppm**	
N	2.01 - 3.11	Fe	56 - 132
P	**0.12 - 0.21**	**Mn**	**267 - 1749**
K	2.22 - 3.20	B	24 - 58
Ca	**0.86 - 0.94**	**Cu**	**5 - 10**
Mg	0.4 - 0.65	Zn	21 - 40
S	**0.16 - 0.21**	**Mo**	**0.08 - 0.22**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME			*Ilex aquifolium cultivars*
COMMON NAME			**Variegated English Holly**
COLLECTED FROM			Container production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Argentea Marginata', 'Monvila' ('Gold Coast')
Macronutrients %		Micronutrients ppm	
N	1.39 - 1.57	Fe	20 - 70
P	**0.11 - 0.14**	**Mn**	**387 - 889**
K	1.33 - 1.72	B	25 - 29
Ca	**0.73 - 0.82**	**Cu**	**11 - 83**
Mg	0.32 - 0.35	Zn	183 - 363
S	**0.19 - 0.26**	**Mo**	**0.12 - 2.10**

B

SCIENTIFIC NAME			*Ilex aquipernyi 'Dragon Lady'*
COMMON NAME			**Dragon Lady' Holly**
COLLECTED FROM			Field production nursery
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Dragon Lady'
Macronutrients %		Micronutrients ppm	
N	1.65 - 2.22	Fe	25 - 40
P	**0.08 - 0.19**	**Mn**	**778 - 1789**
K	0.69 - 1.44	B	13 - 32
Ca	**0.55 - 0.66**	**Cu**	**3 - 6**
Mg	0.16 - 0.33	Zn	17 - 49
S	**0.12 - 0.19**	**Mo**	**0.12 - 0.30**

C

SCIENTIFIC NAME			*Ilex attenuata 'East Palatka'*
COMMON NAME			**East Palatka' Holly**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'East Palatka'
Macronutrients %		Micronutrients ppm	
N	1.27 - 2.14	Fe	35 - 89
P	**0.07 - 0.14**	**Mn**	**248 - 1092**
K	0.94 - 1.76	B	19 - 33
Ca	**0.93 - 1.33**	**Cu**	**1 - 11**
Mg	0.31 - 0.41	Zn	33 - 239
S	**0.11 - 0.16**	**Mo**	**0.11 - 0.2**

D

SCIENTIFIC NAME			*Ilex attenuata 'Foster #2'*
COMMON NAME			**Foster Holly**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			35 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Foster #2'
Macronutrients %		Micronutrients ppm	
N	1.46 - 2.34	Fe	34 - 89
P	**0.07 - 0.19**	**Mn**	**32 - 834**
K	0.7 - 1.77	B	18 - 29
Ca	**0.59 - 1.25**	**Cu**	**3 - 11**
Mg	0.22 - 0.33	Zn	34 - 183
S	**0.17 - 0.24**	**Mo**	**0.11 - 0.23**

E

SCIENTIFIC NAME			*Ilex attenuata 'Savannah'*
COMMON NAME			**Savannah' Holly**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			'Savannah'
Macronutrients %		Micronutrients ppm	
N	1.55 - 2.29	Fe	32 - 69
P	**0.06 - 0.13**	**Mn**	**266 - 1067**
K	0.58 - 1.87	B	22 - 37
Ca	**0.94 - 1.21**	**Cu**	**1 - 8**
Mg	0.33 - 0.43	Zn	45 - 301
S	**0.15 - 0.20**	**Mo**	**0.1 - 0.32**

F

SCIENTIFIC NAME			*Ilex attenuata cultivars*
COMMON NAME			**Topal Holly selections**
COLLECTED FROM			Botanical garden/arboretum
PLANT PART			30 mature leaves from new growth
SEASON			Summer
DATA TYPE			Survey Range
CULTIVARS USED			Hume #2', 'Nasa', 'Sundrops'
Macronutrients %		Micronutrients ppm	
N	1.46 - 1.51	Fe	40 - 66
P	**0.07 - 0.10**	**Mn**	**223 - 647**
K	0.69 - 0.90	B	26 - 30
Ca	**0.63 - 0.86**	**Cu**	**2 - 6**
Mg	0.28 - 0.39	Zn	71 - 227
S	**0.14 - 0.24**	**Mo**	**0.09 - 0.12**

Woody Ornamental Shrubs

A

Scientific Name	*Ilex cassine*
Common Name	**Dahoon Holly**
Collected From	Botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Lowei'

Macronutrients %		Micronutrients ppm	
N	0.90 - 1.53	Fe	37 - 50
P	**0.05 - 0.11**	**Mn**	**536 - 2122**
K	0.55 - 1.15	B	34 - 46
Ca	**0.71 - 1.29**	**Cu**	**2 - 8**
Mg	0.41 - 0.56	Zn	117 - 157
S	**0.13 - 0.17**	**Mo**	**0.12 - 0.30**

B

Scientific Name	*Ilex cornuta 'Burfordii'*
Common Name	**Burford Holly**
Collected From	Botanical garden/arboretum
Plant Part	15 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Burfordii'

Macronutrients %		Micronutrients ppm	
N	1.22 - 2.18	Fe	45 - 86
P	**0.1 - 0.17**	**Mn**	**276 - 944**
K	0.87 - 2.18	B	29 - 99
Ca	**1.28 - 1.54**	**Cu**	**3 - 14**
Mg	0.25 - 0.3	Zn	34 - 510
S	**0.18 - 0.23**	**Mo**	**0.09 - 0.15**

C

Scientific Name	*Ilex cornuta 'Carissa'*
Common Name	**Carissa' Chinese Holly**
Collected From	Botanical garden/arboretum
Plant Part	15 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Carissa'

Macronutrients %		Micronutrients ppm	
N	1.48 - 2.9	Fe	44 - 75
P	**0.15 - 0.22**	**Mn**	**121 - 236**
K	1.45 - 1.84	B	21 - 42
Ca	**0.97 - 1.16**	**Cu**	**5 - 11**
Mg	0.33 - 0.41	Zn	44 - 197
S	**0.15 - 0.22**	**Mo**	**0.08 - 0.17**

D

Scientific Name	*Ilex cornuta 'Dwarf Burford'*
Common Name	**Dwarf Burford' Chinese Holly**
Collected From	Botanical garden/arboretum
Plant Part	15 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Dwarf Burford'

Macronutrients %		Micronutrients ppm	
N	1.86 - 1.90	Fe	53 - 59
P	**0.12 - 0.15**	**Mn**	**478 - 1031**
K	1.33 - 1.42	B	87 - 93
Ca	**1.77 - 2.13**	**Cu**	**5 - 7**
Mg	0.30 - 0.33	Zn	96 - 200
S	**0.15 - 0.20**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Ilex cornuta 'Rotunda'*
Common Name	**Dwarf Chinese Holly**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	15 2-3" terminal cuttings
Season	Summer
Data Type	Sufficiency Range
Cultivars Used	'Rotunda'

Macronutrients %		Micronutrients ppm	
N	1.35 - 2.40	Fe	35 - 200
P	**0.12 - 0.30**	**Mn**	**75 - 1150**
K	0.80 - 2.20	B	30 - 50
Ca	**0.70 - 1.50**	**Cu**	**10 - 20**
Mg	0.30 - 1.00	Zn	34 - 235
S	**0.14 - 0.25**	**Mo**	**0.19 - 0.61**

F

Scientific Name	*Ilex cornuta cultivars*
Common Name	**Chinese Holly**
Collected From	Field production nursery & botanical garden/arboretum
Plant Part	15 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Anicet Delcambre' ('Needlepoint'), 'Fine Line', 'Willowleaf'

Macronutrients %		Micronutrients ppm	
N	1.43 - 1.92	Fe	37 - 45
P	**0.12 - 0.13**	**Mn**	**1550 - 2081**
K	0.80 - 1.87	B	34 - 72
Ca	**0.72 - 1.57**	**Cu**	**2 - 7**
Mg	0.19 - 0.45	Zn	26 - 139
S	**0.12 - 0.17**	**Mo**	**0.11 - 0.30**

Woody Ornamental Shrubs

A

Scientific Name			*Ilex crenata 'Compacta'*
Common Name			**Dwarf Japanese Holly**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Compacta'
Macronutrients %		**Micronutrients ppm**	
N	2.18 - 2.36	Fe	52 - 173
P	**0.12 - 0.13**	**Mn**	**289 - 1566**
K	0.72 - 1.00	B	49 - 53
Ca	**1.21 - 1.59**	**Cu**	**5 - 9**
Mg	0.39 - 0.43	Zn	568 - 588
S	**0.23 - 0.29**	**Mo**	**0.12 - 0.34**

B

Scientific Name			*Ilex crenata 'Convexa'*
Common Name			**Convexa' Japanese Holly**
Collected From			Botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			'Convexa'
Macronutrients %		**Micronutrients ppm**	
N	1.85 - 2.26	Fe	56 - 102
P	**0.17 - 0.18**	**Mn**	**235 - 2430**
K	0.77 - 1.56	B	29 - 65
Ca	**0.84 - 1.46**	**Cu**	**6 - 9**
Mg	0.33 - 0.47	Zn	33 - 252
S	**0.17 - 0.23**	**Mo**	**0.11 - 0.24**

C

Scientific Name			*Ilex crenata 'Helleri'*
Common Name			**Helleri' Japanese Holly**
Collected From			Botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			'Helleri'
Macronutrients %		**Micronutrients ppm**	
N	1.30 - 2.25	Fe	39 - 112
P	**0.08 - 0.11**	**Mn**	**72 - 1962**
K	0.52 - 0.93	B	21 - 39
Ca	**0.76 - 1.34**	**Cu**	**4 - 11**
Mg	0.29 - 0.44	Zn	54 - 357
S	**0.17 - 0.21**	**Mo**	**0.03 - 0.56**

D

Scientific Name			*Ilex crenata 'Hetzii'*
Common Name			**Hetzii' Japanese Holly**
Collected From			Container production nursery
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			'Hetzii'
Macronutrients %		**Micronutrients ppm**	
N	2.29 - 2.94	Fe	38 - 94
P	**0.13 - 0.19**	**Mn**	**344 - 2524**
K	1.11 - 1.45	B	30 - 74
Ca	**1.04 - 1.45**	**Cu**	**5 - 9**
Mg	0.24 - 0.32	Zn	45 - 393
S	**0.13 - 0.20**	**Mo**	**0.09 - 0.24**

E

Scientific Name			*Ilex crenata cultivars*
Common Name			**Japanese Holly**
Collected From			Container & field production nurseries & botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Cherokee', 'Kingesville Green Cushion', 'Rotundifolia'
Macronutrients %		**Micronutrients ppm**	
N	1.88 - 2.74	Fe	43 - 170
P	**0.12 - 0.27**	**Mn**	**248 - 2103**
K	0.71 - 1.68	B	14 - 137
Ca	**0.67 - 2.12**	**Cu**	**1 - 13**
Mg	0.33 - 0.64	Zn	63 - 949
S	**0.21 - 0.32**	**Mo**	**0.12 - 0.26**

F

Scientific Name			*Ilex decidua*
Common Name			**Possumhaw or Deciduous Holly**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Specias, 'Warnren's Red'
Macronutrients %		**Micronutrients ppm**	
N	2.06 - 2.30	Fe	59 - 103
P	**0.13 - 0.20**	**Mn**	**982 - 1855**
K	0.94 - 1.40	B	37 - 48
Ca	**1.08 - 1.45**	**Cu**	**4 - 7**
Mg	0.53 - 0.89	Zn	38 - 264
S	**0.50 - 0.55**	**Mo**	**0.12 - 0.30**

Woody Ornamental Shrubs

A

Scientific Name			*Ilex glabra cultivars*
Common Name			**Dwarf Inkberry Holly**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Compacta', 'Shamrock'
Macronutrients %		**Micronutrients ppm**	
N	1.41 - 1.63	Fe	26 - 41
P	**0.06 - 0.10**	**Mn**	**50 - 770**
K	0.51 - 0.55	B	29 - 53
Ca	**0.45 - 0.60**	**Cu**	**2 - 5**
Mg	0.09 - 0.19	Zn	80 - 209
S	**0.14 - 0.21**	**Mo**	**0.12 - 1.16**

B

Scientific Name			*Ilex integra*
Common Name			**Nepal Holly**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.53 - 2.31	Fe	44 - 85
P	**0.11 - 0.21**	**Mn**	**154 - 1868**
K	1.22 - 1.96	B	28 - 55
Ca	**0.99 - 1.28**	**Cu**	**5 - 11**
Mg	0.26 - 0.39	Zn	55 - 256
S	**0.15 - 0.23**	**Mo**	**0.12 - 0.12**

C

Scientific Name			*Ilex koehneana 'Wirt L. Winn'*
Common Name			**Wirt L. Winn' Koehne Holly**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Wirt L. Winn'
Macronutrients %		**Micronutrients ppm**	
N	1.41 - 2.29	Fe	33 - 67
P	**0.08 - 0.11**	**Mn**	**324 - 1384**
K	1.09 - 1.69	B	26 - 60
Ca	**1.11 - 1.32**	**Cu**	**5 - 11**
Mg	0.29 - 0.38	Zn	27 - 98
S	**0.13 - 0.18**	**Mo**	**0.11 - 0.29**

D

Scientific Name			*Ilex laevigata*
Common Name			**Smooth Winterberry**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.08 - 2.97	Fe	34 - 88
P	**0.11 - 0.18**	**Mn**	**126 - 542**
K	2.25 - 2.77	B	24 - 67
Ca	**0.69 - 1.18**	**Cu**	**5 - 13**
Mg	0.33 - 0.75	Zn	31 - 117
S	**0.15 - 0.22**	**Mo**	**0.1 - 0.26**

E

Scientific Name			*Ilex latifolia*
Common Name			**Lusterleaf Holly**
Collected From			Field production nursery & botanical garden/arboretum
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.10 - 1.42	Fe	25 - 50
P	**0.08 - 0.12**	**Mn**	**613 - 918**
K	0.99 - 1.38	B	19 - 50
Ca	**1.64 - 1.91**	**Cu**	**3 - 8**
Mg	0.25 - 0.47	Zn	6 - 21
S	**0.09 - 0.11**	**Mo**	**0.09 - 0.30**

F

Scientific Name			*Ilex myrtifolia*
Common Name			**Myrtle-leaf Holly**
Collected From			Botanical garden/arboretum
Plant Part			20 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.05	Fe	42 - 75
P	**0.09 - 0.12**	**Mn**	**348 - 1559**
K	0.6 - 1.57	B	26 - 40
Ca	**0.71 - 1.27**	**Cu**	**5 - 11**
Mg	0.28 - 0.35	Zn	40 - 286
S	**0.13 - 0.17**	**Mo**	**0.02 - 0.15**

Woody Ornamental Shrubs

A

Scientific Name	*Ilex opaca*
Common Name	**American Holly**
Collected From	Container & field production nurseries & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Greenleaf', 'Howard', 'Pomona'

Macronutrients %		Micronutrients ppm	
N	1.59 - 2.94	Fe	19 - 199
P	**0.08 - 0.23**	**Mn**	**97 - 1281**
K	0.65 - 1.23	B	13 - 76
Ca	**0.33 - 0.80**	**Cu**	**3 - 10**
Mg	0.20 - 0.36	Zn	21 - 634
S	**0.13 - 0.22**	**Mo**	**0.11 - 0.30**

B

Scientific Name	*Ilex opaca*
Common Name	**American Holly**
Collected From	Field research plots
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.08 - 2.13	Fe	46 - 270
P	**0.07 - 0.16**	**Mn**	**288 - 540**
K	0.74 - 1.88	B	19 - 30
Ca	**0.97 - 1.38**	**Cu**	**6 - 17**
Mg	0.31 - 0.51	Zn	27 - 240
S	**0.17 - 0.33**	**Mo**	**0.11 - 0.34**

C

Scientific Name	*Ilex opaca (dwarf) cultivars*
Common Name	**Dwarf or Spreading American Holly**
Collected From	Botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Clarendon Spreading', 'Maryland Dwarf'

Macronutrients %		Micronutrients ppm	
N	1.68 - 1.81	Fe	30 - 39
P	**0.09 - 0.13**	**Mn**	**1077 - 1590**
K	0.61 - 0.81	B	38 - 58
Ca	**0.65 - 0.82**	**Cu**	**4 - 6**
Mg	0.37 - 0.49	Zn	142 - 151
S	**0.17 - 0.20**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Ilex pernyi*
Common Name	**Perny Holly**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	20 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.54 - 1.91	Fe	59 - 162
P	**0.13 - 0.15**	**Mn**	**1397 - 1804**
K	0.86 - 1.35	B	62 - 148
Ca	**1.15 - 1.48**	**Cu**	**1 - 4**
Mg	0.30 - 0.65	Zn	20 - 285
S	**0.15 - 0.17**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Ilex verticillata 'Winter Red'*
Common Name	**Winter Red' Winterberry**
Collected From	Field production nursery & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Winter Red'

Macronutrients %		Micronutrients ppm	
N	2.14 - 2.33	Fe	30 - 75
P	**0.12 - 0.20**	**Mn**	**589 - 3067**
K	0.56 - 1.48	B	10 - 33
Ca	**0.28 - 0.67**	**Cu**	**4 - 10**
Mg	0.24 - 0.49	Zn	44 - 326
S	**0.21 - 0.24**	**Mo**	**0.12 - 0.30**

F

Scientific Name	*Ilex verticillata cultivars*
Common Name	**Winterberry**
Collected From	Botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Afterglow', 'Aureantiaca', 'Cacapon', 'Chrysocarpa', 'Sunset', 'Winter Gold'

Macronutrients %		Micronutrients ppm	
N	1.90 - 2.58	Fe	28 - 132
P	**0.11 - 0.19**	**Mn**	**1652 - 5545**
K	0.50 - 2.59	B	18 - 73
Ca	**0.42 - 1.21**	**Cu**	**4 - 17**
Mg	0.12 - 0.82	Zn	133 - 563
S	**0.20 - 0.26**	**Mo**	**0.05 - 0.12**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Ilex vomitoria*
COMMON NAME	**Yaupon**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Shadow's Female', 'Virginia Dare',

Macronutrients %		Micronutrients ppm	
N	1.74 - 2.56	Fe	25 - 63
P	**0.10 - 0.15**	**Mn**	**701 - 3190**
K	0.67 - 1.04	B	15 - 98
Ca	**0.23 - 0.60**	**Cu**	**4 - 8**
Mg	0.32 - 0.56	Zn	19 - 80
S	**0.12 - 0.18**	**Mo**	**0.12 - 0.30**

B

SCIENTIFIC NAME	*Ilex vomitoria 'Pendula'*
COMMON NAME	**Weeping Yaupon**
COLLECTED FROM	Field production nursery
PLANT PART	20 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Pendula'

Macronutrients %		Micronutrients ppm	
N	1.89 - 2.08	Fe	41 - 60
P	**0.15 - 0.28**	**Mn**	**56 - 192**
K	1.17 - 1.63	B	29 - 90
Ca	**0.52 - 0.87**	**Cu**	**5 - 10**
Mg	0.33 - 0.47	Zn	47 - 100
S	**0.15 - 0.20**	**Mo**	**0.11 - 0.32**

C

SCIENTIFIC NAME	*Ilex vomitoria cultivars*
COMMON NAME	**Dwarf Yaupon**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Nana', 'Schilling's Dwarf' ('Stokes Dwarf')

Macronutrients %		Micronutrients ppm	
N	2.02 - 2.55	Fe	42 - 57
P	**0.10 - 0.13**	**Mn**	**215 - 1415**
K	0.78 - 1.11	B	57 - 82
Ca	**0.43 - 0.48**	**Cu**	**2 - 11**
Mg	0.45 - 0.53	Zn	48 - 209
S	**0.11 - 0.15**	**Mo**	**0.01 - 0.12**

D

SCIENTIFIC NAME	*Ilex x Meserve-type hybrids*
COMMON NAME	**China Boy' and 'China Girl' Hollies**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Mesdob' ('China Boy'), 'Mesog' ('China Girl')

Macronutrients %		Micronutrients ppm	
N	1.97 - 2.16	Fe	43 - 104
P	**0.14 - 0.18**	**Mn**	**891 - 2466**
K	1.05 - 1.42	B	55 - 70
Ca	**0.88 - 1.15**	**Cu**	**4 - 10**
Mg	0.27 - 0.32	Zn	155 - 203
S	**0.14 - 0.18**	**Mo**	**0.12 - 2.55**

E

SCIENTIFIC NAME	*Ilex x meserveae cultivars*
COMMON NAME	**Blue Meserve Hollies**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Blue Boy', 'Blue Girl'

Macronutrients %		Micronutrients ppm	
N	1.91 - 3.80	Fe	103 - 194
P	**0.11 - 0.14**	**Mn**	**538 - 1633**
K	1.01 - 1.64	B	40 - 72
Ca	**0.66 - 1.36**	**Cu**	**2 - 21**
Mg	0.21 - 0.51	Zn	123 - 389
S	**0.18 - 0.27**	**Mo**	**0.12 - 0.56**

F

SCIENTIFIC NAME	*Illicium anisatum*
COMMON NAME	**Japanese Star Anise or Anise-tree**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.67 - 2.35	Fe	29 - 67
P	**0.13 - 0.19**	**Mn**	**78 - 844**
K	0.6 - 2	B	16 - 29
Ca	**0.53 - 1.22**	**Cu**	**2 - 11**
Mg	0.17 - 0.36	Zn	15 - 26
S	**0.13 - 0.20**	**Mo**	**0.05 - 0.21**

Woody Ornamental Shrubs

A

Scientific Name	*Illicium floridanum*		
Common Name	**Florida Anise-tree**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Alba'		
Macronutrients %		**Micronutrients ppm**	
N	1.24 - 2.07	Fe	23 - 87
P	**0.17 - 0.29**	**Mn**	**54 - 527**
K	0.57 - 0.78	B	8 - 10
Ca	**0.44 - 0.61**	**Cu**	**3 - 5**
Mg	0.23 - 0.32	Zn	7 - 12
S	**0.12 - 0.15**	**Mo**	**0.12 - 0.28**

B

Scientific Name	*Illicium parviflorum*		
Common Name	**Small or Ocala or Yellow Anise-tree**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Spacies only		
Macronutrients %		**Micronutrients ppm**	
N	0.99 - 2.08	Fe	19 - 25
P	**0.12 - 0.18**	**Mn**	**337 - 523**
K	0.67 - 0.95	B	8 - 11
Ca	**0.20 - 0.28**	**Cu**	**2 - 8**
Mg	0.11 - 23	Zn	6 - 11
S	**0.10 - 0.16**	**Mo**	**0.01 - 0.27**

C

Scientific Name	*Itea virginica*		
Common Name	**Virginia Sweetspire or Virginia Willow**		
Collected From	Container production nursery &botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Henery's Garnet'		
Macronutrients %		**Micronutrients ppm**	
N	1.64 - 4.50	Fe	48 - 85
P	**0.10 - 0.24**	**Mn**	**65 - 706**
K	0.36 - 0.80	B	12 - 17
Ca	**0.38 - 1.09**	**Cu**	**2 - 6**
Mg	0.13 - 0.20	Zn	65 - 264
S	**0.14 - 0.19**	**Mo**	**0.12 - 0.23**

D

Scientific Name	*Jasminum floridum*		
Common Name	**Showy Jasmine**		
Collected From	Botanical garden/arboretum		
Plant Part	30 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.9 - 2.8	Fe	45 - 80
P	**0.22 - 0.28**	**Mn**	**75 - 125**
K	1.67 - 1.89	B	18 - 28
Ca	**1.13 - 1.38**	**Cu**	**5 - 12**
Mg	0.27 - 0.33	Zn	18 - 27
S	**0.18 - 0.32**	**Mo**	**0.11 - 0.21**

E

Scientific Name	*Jasminum mesnyi*		
Common Name	**Primrose Jasmine**		
Collected From	Botanical garden/arboretum		
Plant Part	30 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.17 - 2.43	Fe	34 - 64
P	**0.2 - 0.33**	**Mn**	**44 - 135**
K	1.48 - 1.93	B	19 - 26
Ca	**1.25 - 1.80**	**Cu**	**5 - 15**
Mg	0.23 - 0.29	Zn	18 - 26
S	**0.16 - 0.24**	**Mo**	**0.14 - 0.28**

F

Scientific Name	*Jasminum nudiflorum*		
Common Name	**Winter Jasmine**		
Collected From	Botanical garden/arboretum		
Plant Part	30 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.73 - 2.31	Fe	46 - 67
P	**0.22 - 0.28**	**Mn**	**53 - 99**
K	1.50 - 1.77	B	20 - 26
Ca	**1.74 - 2.35**	**Cu**	**7 - 10**
Mg	0.35 - 0.48	Zn	6 - 9
S	**0.21 - 0.29**	**Mo**	**0.12 - 0.82**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Kalmia angustifolia*		
COMMON NAME	**Lambkill Kalmia or Sheep Laurel**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	35 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.62 - 2.22	Fe	35 - 70
P	**0.11 - 0.2**	**Mn**	**88 - 422**
K	0.63 - 1.71	B	21 - 34
Ca	**0.85 - 1.21**	**Cu**	**3 - 11**
Mg	0.11 - 0.31	Zn	21 - 32
S	**0.11 - 0.18**	**Mo**	**0.07 - 0.19**

B

SCIENTIFIC NAME	*Kalmia latifolia*		
COMMON NAME	**Mountain Laurel**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	25 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species, 'Nipmunk', 'Quinnipiac', 'Silver Doller'		
Macronutrients %		**Micronutrients ppm**	
N	1.12 - 1.35	Fe	24 - 42
P	**0.07 - 0.1**	**Mn**	**274 - 972**
K	0.51 - 0.67	B	28 - 42
Ca	**0.96 - 1.58**	**Cu**	**2 - 4**
Mg	0.22 - 0.98	Zn	25 - 39
S	**0.09 - 0.10**	**Mo**	**0.12 - 0.30**

C

SCIENTIFIC NAME	*Kerria japonica 'Picta'*		
COMMON NAME	**Variegated Japanese Kerria**		
COLLECTED FROM	Container production nursery		
PLANT PART	35 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Picta'		
Macronutrients %		**Micronutrients ppm**	
N	2.01 - 2.64	Fe	60 - 68
P	**0.31 - 0.37**	**Mn**	**150 - 432**
K	2.54 - 3.13	B	38 - 62
Ca	**1.21 - 1.30**	**Cu**	**3 - 9**
Mg	0.35 - 0.41	Zn	50 - 59
S	**0.11 - 0.13**	**Mo**	**0.05 - 0.66**

D

SCIENTIFIC NAME	*Kerria japonica 'Pleniflora'*		
COMMON NAME	**Double-flowering Japanese Kerria**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	35 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Pleniflora'		
Macronutrients %		**Micronutrients ppm**	
N	2.34 - 3.14	Fe	56 - 134
P	**0.17 - 0.32**	**Mn**	**60 - 119**
K	2.11 - 2.87	B	30 - 75
Ca	**1.43 - 2.75**	**Cu**	**5 - 10**
Mg	0.21 - 0.35	Zn	18 - 24
S	**0.15 - 0.23**	**Mo**	**0.11 - 0.39**

E

SCIENTIFIC NAME	*Leucophyllum frutescens*		
COMMON NAME	**Texas Sage or Silverleaf**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	20 2-3" terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Green Cloud'		
Macronutrients %		**Micronutrients ppm**	
N	2.35 - 2.80	Fe	31 - 72
P	**0.11 - 0.18**	**Mn**	**20 - 78**
K	2.01 - 2.28	B	20 - 33
Ca	**0.72 - 1.14**	**Cu**	**5 - 9**
Mg	0.18 - 0.26	Zn	20 - 31
S	**0.16 - 0.24**	**Mo**	**0.11 - 0.18**

F

SCIENTIFIC NAME	*Leucothoe axillaris*		
COMMON NAME	**Coast Leucothoe or Fetterbush**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	30 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.16 - 2.24	Fe	38 - 82
P	**0.09 - 0.15**	**Mn**	**243 - 660**
K	0.43 - 1.65	B	21 - 38
Ca	**1.19 - 1.55**	**Cu**	**4 - 11**
Mg	0.28 - 0.32	Zn	21 - 47
S	**0.11 - 0.18**	**Mo**	**0.11 - 0.18**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Leucothoe fontanesiana 'Girard's Rainbow'*
COMMON NAME	**Variegated Drooping Leucothoe or Fetterbush**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Girard's Rainbow'

Macronutrients %		Micronutrients ppm	
N	1.54 - 2.22	Fe	31 - 73
P	**0.15 - 0.21**	**Mn**	**222 - 471**
K	1.15 - 1.75	B	20 - 33
Ca	**0.92 - 1.19**	**Cu**	**2 - 5**
Mg	0.23 - 0.29	Zn	37 - 68
S	**0.14 - 0.19**	**Mo**	**0.07 - 0.18**

B

SCIENTIFIC NAME	*Ligustrum 'Vicaryi'*
COMMON NAME	**Golden Vicary Privet**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	35 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Vicaryi'

Macronutrients %		Micronutrients ppm	
N	2.16 - 2.38	Fe	54 - 142
P	**0.18 - 0.28**	**Mn**	**76 - 681**
K	1.56 - 1.89	B	23 - 35
Ca	**0.65 - 1.13**	**Cu**	**2 - 12**
Mg	0.25 - 0.32	Zn	34 - 115
S	**0.21 - 0.53**	**Mo**	**0.11 - 0.33**

C

SCIENTIFIC NAME	*Ligustrum japonicum*
COMMON NAME	**Japanese Privet or Waxleaf Ligustrum**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species, 'Recurvifolium'

Macronutrients %		Micronutrients ppm	
N	1.26 - 3.43	Fe	52 - 81
P	**0.09 - 0.24**	**Mn**	**87 - 657**
K	1.15 - 3.41	B	20 - 37
Ca	**0.67 - 1.76**	**Cu**	**3 - 10**
Mg	0.13 - 0.32	Zn	22 - 135
S	**0.14 - 0.33**	**Mo**	**0.08 - 0.30**

D

SCIENTIFIC NAME	*Ligustrum lucidum*
COMMON NAME	**Glossy Privet**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.44 - 2.34	Fe	44 - 94
P	**0.16 - 0.19**	**Mn**	**47 - 105**
K	1.77 - 2.09	B	20 - 37
Ca	**1.21 - 2.22**	**Cu**	**4 - 16**
Mg	0.28 - 0.32	Zn	33 - 67
S	**0.16 - 0.27**	**Mo**	**0.09 - 1.27**

E

SCIENTIFIC NAME	*Ligustrum sinense*
COMMON NAME	**Chinese Privet**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.3 - 3.29	Fe	41 - 92
P	**0.14 - 0.27**	**Mn**	**144 - 208**
K	1.65 - 2.23	B	25 - 44
Ca	**1.02 - 1.24**	**Cu**	**5 - 13**
Mg	0.25 - 0.34	Zn	22 - 87
S	**0.17 - 0.27**	**Mo**	**0.03 - 0.09**

F

SCIENTIFIC NAME	*Ligustrum sinense 'Variegatum'*
COMMON NAME	**Variegated Chinese Privet**
COLLECTED FROM	Container production nursery
PLANT PART	20 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Variegatum'

Macronutrients %		Micronutrients ppm	
N	1.67 - 2.03	Fe	46 - 83
P	**0.21 - 0.35**	**Mn**	**219 - 484**
K	1.35 - 1.62	B	23 - 35
Ca	**0.49 - 1.23**	**Cu**	**6 - 9**
Mg	0.22 - 0.28	Zn	36 - 88
S	**0.15 - 0.23**	**Mo**	**0.15 - 0.25**

Woody Ornamental Shrubs

A

Scientific Name			*Lindera benzoin*
Common Name			**Spicebush**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		Micronutrients ppm	
N	2.22 - 2.79	Fe	41 - 87
P	**0.19 - 0.29**	**Mn**	**188 - 385**
K	2.17 - 3.27	B	21 - 36
Ca	**0.89 - 1.17**	**Cu**	**5 - 13**
Mg	0.3 - 0.49	Zn	32 - 93
S	**0.17 - 0.22**	**Mo**	**0.11 - 0.27**

B

Scientific Name			*Lindera subcoriacea*
Common Name			**Bog Spicebush**
Collected From			Field production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		Micronutrients ppm	
N	2.25 - 3.02	Fe	45 - 76
P	**0.21 - 0.34**	**Mn**	**87 - 122**
K	1.44 - 1.93	B	18 - 29
Ca	**0.73 - 1.31**	**Cu**	**5 - 8**
Mg	0.16 - 0.26	Zn	31 - 60
S	**0.17 - 0.25**	**Mo**	**0.02 - 0.24**

C

Scientific Name			*Lonicera fragrantissima*
Common Name			**Winter Honeysuckle or Sweet Breath of Spring**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		Micronutrients ppm	
N	1.85 - 2.31	Fe	41 - 98
P	**0.16 - 0.24**	**Mn**	**45 - 62**
K	1.48 - 1.80	B	30 - 68
Ca	**1.25 - 1.81**	**Cu**	**5 - 8**
Mg	0.2 - 0.28	Zn	12 - 44
S	**0.13 - 0.19**	**Mo**	**0.22 - 0.46**

D

Scientific Name			*Lonicera maackii*
Common Name			**Amur Honeysuckle**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		Micronutrients ppm	
N	2.01 - 3.03	Fe	38 - 85
P	**0.14 - 0.21**	**Mn**	**86 - 167**
K	1.44 - 1.56	B	24 - 81
Ca	**2.01 - 3.05**	**Cu**	**7 - 17**
Mg	0.28 - 0.34	Zn	22 - 35
S	**0.17 - 0.24**	**Mo**	**0.09 - 0.22**

E

Scientific Name			*Lonicera nitida*
Common Name			**Boxleaf Honeysuckle**
Collected From			Botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		Micronutrients ppm	
N	1.78 - 2.29	Fe	66 - 140
P	**0.1 - 0.15**	**Mn**	**55 - 170**
K	1.55 - 2.35	B	31 - 107
Ca	**1.18 - 1.45**	**Cu**	**7 - 14**
Mg	0.31 - 0.46	Zn	15 - 28
S	**0.18 - 0.24**	**Mo**	**0.11 - 0.32**

F

Scientific Name			*Loropetalum chinense*
Common Name			**Chinese Loropetalum or Fringeflower**
Collected From			Field production nursery & botanical garden/arboretum
Plant Part			20 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		Micronutrients ppm	
N	1.43 - 1.90	Fe	58 - 69
P	**0.10 - 0.13**	**Mn**	**15 - 35**
K	0.40 - 0.52	B	55 - 126
Ca	**2.0 - 2.90**	**Cu**	**4 - 6**
Mg	0.13 - 0.15	Zn	7 - 21
S	**0.12 - 0.19**	**Mo**	**0.12 - 0.30**

Woody Ornamental Shrubs

A

Scientific Name	*Loropetalum chinense var. rubrum*		
Common Name	**Purple-leaf Chinese Loropetalum or Pink Fringeflower**		
Collected From	Container production nursery		
Plant Part	20 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Burgundy'		
Macronutrients %		**Micronutrients ppm**	
N	1.68 - 2.24	Fe	37 - 62
P	**0.13 - 0.19**	**Mn**	**37 - 93**
K	1.07 - 1.71	B	22 - 46
Ca	**1.21 - 1.51**	**Cu**	**5 - 12**
Mg	0.2 - 0.28	Zn	20 - 32
S	**0.13 - 0.19**	**Mo**	**0.23 - 0.59**

B

Scientific Name	*Mahonia 'King's Ransom'*		
Common Name	**King's Ransom' Grape Holly or Mahonia**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'King's Ransom'		
Macronutrients %		**Micronutrients ppm**	
N	2.03 - 2.29	Fe	44 - 66
P	**0.23 - 0.37**	**Mn**	**204 - 469**
K	0.99 - 1.72	B	40 - 100
Ca	**0.66 - 1.11**	**Cu**	**5 - 9**
Mg	0.19 - 0.25	Zn	27 - 47
S	**0.14 - 0.20**	**Mo**	**0.11 - 0.28**

C

Scientific Name	*Mahonia aquifolium*		
Common Name	**Oregon Grape Holly**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.13	Fe	11 - 33
P	**0.14 - 0.20**	**Mn**	**143 - 185**
K	0.61 - 0.97	B	59 - 64
Ca	**0.46 - 0.54**	**Cu**	**6 - 33**
Mg	0.13 - 0.24	Zn	21 - 49
S	**0.15 - 0.16**	**Mo**	**0.12 - 2.07**

D

Scientific Name	*Mahonia bealei*		
Common Name	**Leatherleaf Mahonia**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	10 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.99 - 2.10	Fe	27 - 47
P	**0.19 - 0.24**	**Mn**	**37 - 137**
K	1.17 - 1.40	B	22 - 54
Ca	**0.70 - 1.16**	**Cu**	**6 - 10**
Mg	0.18 - 0.22	Zn	17 - 43
S	**0.13 - 0.20**	**Mo**	**0.03 - 0.20**

E

Scientific Name	*Mahonia fortunei*		
Common Name	**Chinese Mahonia or Fortune's Grape Holly**		
Collected From	Botanical garden/arboretum		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.26	Fe	42 - 72
P	**0.17 - 0.32**	**Mn**	**40 - 155**
K	1.13 - 1.88	B	24 - 49
Ca	**0.56 - 1.13**	**Cu**	**5 - 11**
Mg	0.11 - 0.21	Zn	18 - 27
S	**0.17 - 0.22**	**Mo**	**0.3 - 1.74**

F

Scientific Name	*Mahonia repens*		
Common Name	**Creeping Mahonia**		
Collected From	Container production nursery		
Plant Part	15 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.96 - 2.15	Fe	27 - 75
P	**0.15 - 0.25**	**Mn**	**132 - 174**
K	1.39 - 1.88	B	25 - 37
Ca	**0.41 - 0.98**	**Cu**	**5 - 8**
Mg	0.11 - 0.23	Zn	24 - 49
S	**0.14 - 0.19**	**Mo**	**0.5 - 2.62**

Woody Ornamental Shrubs

A

Scientific Name	*Malpighia glabra*		
Common Name	**Barbados Cherry**		
Collected From	Container production nursery		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Sufficiency Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 3.50	Fe	50 - 200
P	**0.15 - 0.50**	**Mn**	**25 - 200**
K	1.50 - 3.00	B	25 - 75
Ca	**1.00 - 3.50**	**Cu**	**6 - 20**
Mg	0.25 - 0.80	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.14 - 0.27**

B

Scientific Name	*Michelia figo*		
Common Name	**Banana Magnolia or Banana Shrub**		
Collected From	Botanical garden/arboretum		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.54 - 2.21	Fe	27 - 72
P	**0.11 - 0.18**	**Mn**	**77 - 745**
K	0.68 - 2.201	B	23 - 53
Ca	**0.78 - 1.13**	**Cu**	**5 - 11**
Mg	0.26 - 0.30	Zn	13 - 26
S	**0.16 - 0.28**	**Mo**	**0.1 - 0.23**

C

Scientific Name	*Myrica cerifera*		
Common Name	**Southern Wax Myrtle**		
Collected From	Field production nursery & botanical garden/arboretum		
Plant Part	20 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Compacta', 'Emperor', 'King's Dwarf', 'Oklahoma', var. pumila 'Fairfax'		
Macronutrients %		**Micronutrients ppm**	
N	1.83 - 2.32	Fe	21 - 60
P	**0.05 - 0.14**	**Mn**	**151 - 942**
K	0.58 - 1.24	B	18 - 46
Ca	**0.61 - 1.32**	**Cu**	**2 - 5**
Mg	0.11 - 0.35	Zn	17 - 99
S	**0.16 - 0.23**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Myrica heterophylla*		
Common Name	**Southern Bayberry**		
Collected From	Botanical garden/arboretum		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.53 - 2.25	Fe	33 - 73
P	**0.05 - 0.11**	**Mn**	**319 - 1224**
K	0.82 - 1.81	B	21 - 30
Ca	**0.76 - 1.23**	**Cu**	**2 - 8**
Mg	0.13 - 0.27	Zn	15 - 25
S	**0.13 - 0.24**	**Mo**	**0.1 - 0.21**

E

Scientific Name	*Myrica pensylvanica*		
Common Name	**Northern Bayberry or Candleberry**		
Collected From	Container production nursery		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.85 - 2.43	Fe	26 - 58
P	**0.07 - 0.14**	**Mn**	**245 - 799**
K	0.91 - 0.98	B	31 - 37
Ca	**0.89 - 0.94**	**Cu**	**6 - 8**
Mg	0.21 - 0.24	Zn	25 - 43
S	**0.14 - 0.23**	**Mo**	**0.12 - 0.35**

F

Scientific Name	*Nandina domestica*		
Common Name	**Nandina or Heavenly Bamboo**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species, 'Alba', 'Aurea', 'Orihime' ('San Gabriel')		
Macronutrients %		**Micronutrients ppm**	
N	1.64 - 2.20	Fe	5 - 92
P	**0.11 - 0.21**	**Mn**	**5 - 166**
K	0.39 - 0.68	B	27 - 101
Ca	**0.41 - 1.26**	**Cu**	**4 - 11**
Mg	0.13 - 0.24	Zn	15 - 42
S	**0.14 - 0.16**	**Mo**	**0.12 - 0.43**

Woody Ornamental Shrubs

A

Scientific Name	*Nandina domestica 'Gulf Stream'*		
Common Name	**Gulf Stream' Nandina**		
Collected From	Botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Gulf Stream'		
Macronutrients %		**Micronutrients ppm**	
N	1.79 - 2.89	Fe	33 - 77
P	**0.11 - 0.19**	**Mn**	**52 - 102**
K	0.42 - 1.56	B	33 - 57
Ca	**0.88 - 1.75**	**Cu**	**2 - 12**
Mg	0.11 - 0.31	Zn	14 - 28
S	**0.14 - 0.20**	**Mo**	**0.13 - 0.24**

B

Scientific Name	*Nandina domestica 'Harbour Dwarf'*		
Common Name	**Harbour Dwarf' Nandina**		
Collected From	Botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Harbour Dwarf'		
Macronutrients %		**Micronutrients ppm**	
N	1.86 - 2.09	Fe	28 - 66
P	**0.15 - 0.23**	**Mn**	**43 - 69**
K	0.5 - 1.62	B	31 - 122
Ca	**1 - 1.34**	**Cu**	**5 - 11**
Mg	0.14 - 0.24	Zn	21 - 32
S	**0.15 - 0.22**	**Mo**	**0.11 - 0.27**

C

Scientific Name	*Nandina domestica 'Nana Purpurea'*		
Common Name	**Dwarf Nandina or Nana Purpurea Nandina**		
Collected From	Container production nursery		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Nana Purpurea'		
Macronutrients %		**Micronutrients ppm**	
N	2.23 - 2.40	Fe	33 - 104
P	**0.22 - 0.37**	**Mn**	**65 - 121**
K	1.36 - 1.69	B	20 - 33
Ca	**0.25 - 1.12**	**Cu**	**3 - 15**
Mg	0.13 - 0.31	Zn	22 - 41
S	**0.14 - 0.18**	**Mo**	**0.1 - 0.21**

D

Scientific Name	*Osmanthus americanus*		
Common Name	**Devilwood**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	0.88 - 1.89	Fe	20 - 80
P	**0.09 - 0.21**	**Mn**	**44 - 65**
K	0.63 - 1.76	B	9 - 23
Ca	**0.62 - 1.25**	**Cu**	**3 - 13**
Mg	0.11 - 0.31	Zn	17 - 29
S	**0.09 - 0.19**	**Mo**	**0.01 - 0.18**

E

Scientific Name	*Osmanthus fortunei*		
Common Name	**Fortune's Osmanthus or Tea Olive**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.63 - 1.87	Fe	41 - 51
P	**0.13 - 0.25**	**Mn**	**88 - 269**
K	1.02 - 1.29	B	19 - 26
Ca	**0.83 - 0.97**	**Cu**	**7 - 11**
Mg	0.17 - 0.21	Zn	82 - 225
S	**0.17 - 0.31**	**Mo**	**0.21 - 0.30**

F

Scientific Name	*Osmanthus fragrans*		
Common Name	**Sweet Olive or Fragrant Tea Olive**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	0.99 - 1.90	Fe	24 - 50
P	**0.10 - 0.15**	**Mn**	**141 - 155**
K	0.78 - 0.99	B	13 - 20
Ca	**1.08 - 1.60**	**Cu**	**4 - 11**
Mg	0.12 - 0.23	Zn	32 - 80
S	**0.14 - 0.19**	**Mo**	**0.11 - 0.30**

Woody Ornamental Shrubs

A

Scientific Name	*Osmanthus heterophyllus*
Common Name	**Holly Osmanthus or Holly Tea Olive or False-holly**
Collected From	Botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Gulftide', 'Rotundifolius'

Macronutrients %		Micronutrients ppm	
N	1.13 - 1.25	Fe	30 - 38
P	**0.11 - 0.13**	**Mn**	**167 - 381**
K	1.08 - 1.34	B	21 - 30
Ca	**0.69 - 1.08**	**Cu**	**4 - 10**
Mg	0.08 - 0.11	Zn	52 - 74
S	**0.15 - 0.18**	**Mo**	**0.02 - 0.12**

B

Scientific Name	*Philadelphus 'Natchez'*
Common Name	**Natchez' Mockorange**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Natchez'

Macronutrients %		Micronutrients ppm	
N	2.35 - 4.07	Fe	41 - 105
P	**0.17 - 0.32**	**Mn**	**55 - 96**
K	2.24 - 3.44	B	22 - 43
Ca	**1.21 - 1.86**	**Cu**	**5 - 15**
Mg	0.35 - 0.43	Zn	18 - 24
S	**0.15 - 0.21**	**Mo**	**0.14 - 0.33**

C

Scientific Name	*Phillyrea latifolia*
Common Name	**Box Olive**
Collected From	Botanical garden/arboretum
Plant Part	20 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.65 - 1.88	Fe	45 - 69
P	**0.09 - 0.18**	**Mn**	**38 - 192**
K	0.97 - 1.98	B	18 - 25
Ca	**1.45 - 1.99**	**Cu**	**5 - 11**
Mg	0.22 - 0.29	Zn	15 - 59
S	**0.18 - 0.24**	**Mo**	**0.12 - 0.38**

D

Scientific Name	*Phormium tenax 'Purpureum'*
Common Name	**Purple-leaf New Zealand Flax**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Purpureum'

Macronutrients %		Micronutrients ppm	
N	1.71 - 2.45	Fe	27 - 67
P	**0.11 - 0.16**	**Mn**	**65 - 135**
K	1.44 - 1.66	B	30 - 71
Ca	**0.52 - 1.19**	**Cu**	**4 - 9**
Mg	0.16 - 0.26	Zn	18 - 60
S	**0.14 - 0.21**	**Mo**	**1.35 - 2.85**

E

Scientific Name	*Photinia fraseri 'Birmingham'*
Common Name	**Fraser or Red Top Photinia**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Birmingham'

Macronutrients %		Micronutrients ppm	
N	0.95 - 1.75	Fe	9 - 47
P	**0.17 - 0.35**	**Mn**	**15 - 60**
K	1.31 - 1.40	B	42 - 49
Ca	**0.25 - 1.29**	**Cu**	**5 - 8**
Mg	0.17 - 0.30	Zn	18 - 51
S	**0.06 - 0.15**	**Mo**	**0.12 - 1.00**

F

Scientific Name	*Photinia glabra*
Common Name	**Japanese Photinia**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.44 - 2.37	Fe	36 - 86
P	**0.09 - 0.21**	**Mn**	**15 - 75**
K	0.77 - 1.69	B	25 - 38
Ca	**1.15 - 1.45**	**Cu**	**4 - 14**
Mg	0.22 - 0.32	Zn	28 - 91
S	**0.09 - 0.15**	**Mo**	**0.11 - 0.38**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Photinia serratifolia*		
COMMON NAME	**Chinese Photinia**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	20 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.15 - 2.22	Fe	45 - 78
P	**0.08 - 0.26**	**Mn**	**50 - 203**
K	1.17 - 2.02	B	20 - 27
Ca	**1.36 - 2.01**	**Cu**	**4 - 12**
Mg	0.19 - 0.3	Zn	17 - 31
S	**0.08 - 0.16**	**Mo**	**0.08 - 0.19**

B

SCIENTIFIC NAME	*Pieris japonica*		
COMMON NAME	**Japanese Pieris or Andromeda**		
COLLECTED FROM	Container production nursery & botanical garden/arboretum		
PLANT PART	20 2-3" terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Species, 'Dorothy Wyckoff', 'Mountain Fire', 'Scarlett O'Hara', 'Valley Rose'		
Macronutrients %		**Micronutrients ppm**	
N	1.39 - 1.91	Fe	33 - 96
P	**0.08 - 0.20**	**Mn**	**237 - 2322**
K	0.66 - 1.76	B	29 - 99
Ca	**0.55 - 1.58**	**Cu**	**1 - 5**
Mg	0.14 - 0.23	Zn	24 - 37
S	**0.15 - 0.18**	**Mo**	**0.12 - 0.46**

C

SCIENTIFIC NAME	*Pieris japonica 'Variegata'*		
COMMON NAME	**Variegated Japanese Pieris**		
COLLECTED FROM	Botanical garden/arboretum		
PLANT PART	20 2-3" terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Variegata'		
Macronutrients %		**Micronutrients ppm**	
N	1.08 - 2.21	Fe	34 - 48
P	**0.09 - 0.13**	**Mn**	**259 - 1367**
K	0.83 - 1.67	B	24 - 36
Ca	**0.94 - 1.18**	**Cu**	**2 - 9**
Mg	0.18 - 0.28	Zn	29 - 54
S	**0.12 - 0.16**	**Mo**	**0.05 - 0.14**

D

SCIENTIFIC NAME	*Pieris japonica (Taiwanensis group)*		
COMMON NAME	**Formosan Pieris**		
COLLECTED FROM	Container production nursery		
PLANT PART	20 2-3" terminal cuttings		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	Taiwanensis group only		
Macronutrients %		**Micronutrients ppm**	
N	1.78 - 1.92	Fe	51 - 141
P	**0.12 - 0.18**	**Mn**	**324 - 1013**
K	1.11 - 1.94	B	21 - 38
Ca	**0.95 - 1.24**	**Cu**	**3 - 11**
Mg	0.21 - 0.31	Zn	22 - 91
S	**0.16 - 0.21**	**Mo**	**0.11 - 0.41**

E

SCIENTIFIC NAME	*Pittosporum tobira*		
COMMON NAME	**Japanese Pittosporum or Australian Laurel**		
COLLECTED FROM	Container production nursery		
PLANT PART	40 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Sufficiency Range		
CULTIVARS USED	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.30 - 3.00	Fe	20 - 200
P	**0.25 - 0.50**	**Mn**	**75 - 1500**
K	1.40 - 4.25	B	20 - 110
Ca	**0.75 - 2.50**	**Cu**	**5 - 20**
Mg	0.18 - 0.75	Zn	30 - 200
S	**0.20 - 0.40**	**Mo**	**0.11 - 0.30**

F

SCIENTIFIC NAME	*Pittosporum tobira 'Variegatum'*		
COMMON NAME	**Variegated Japanese Pittosporum or Australian Laurel**		
COLLECTED FROM	Container production nursery		
PLANT PART	40 mature leaves from new growth		
SEASON	Summer		
DATA TYPE	Survey Range		
CULTIVARS USED	'Variegatum'		
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 3.50	Fe	32 - 106
P	**0.22 - 0.52**	**Mn**	**51 - 478**
K	1.92 - 3.25	B	26 - 100
Ca	**0.74 - 1.63**	**Cu**	**4 - 17**
Mg	0.19 - 0.32	Zn	60 - 272
S	**0.14 - 0.19**	**Mo**	**0.12 - 0.16**

Woody Ornamental Shrubs

A

Scientific Name	*Prunus laurocerasus 'Otto Luyken'*		
Common Name	**Otto Luyken' Cherrylaurel or English Laurel**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Otto Luyken'		
Macronutrients %		Micronutrients ppm	
N	1.69 - 2.24	Fe	42 - 77
P	**0.12 - 0.20**	**Mn**	**135 - 466**
K	1.47 - 2	B	22 - 35
Ca	**1.36 - 2.39**	**Cu**	**5 - 14**
Mg	0.33 - 0.49	Zn	23 - 34
S	**0.24 - 0.95**	**Mo**	**0.11 - 0.32**

B

Scientific Name	*Prunus laurocerasus cultivars*		
Common Name	**Dwarf Common Cherrylaurel or English Laurel**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Mount Vernon', 'Schipkaensis', 'Zabeliana'		
Macronutrients %		Micronutrients ppm	
N	1.53 - 2.59	Fe	31 - 97
P	**0.20 - 0.22**	**Mn**	**409 - 643**
K	0.93 - 1.35	B	26 - 34
Ca	**1.18 - 2.24**	**Cu**	**6 - 11**
Mg	0.40 - 0.61	Zn	22 - 35
S	**0.09 - 0.21**	**Mo**	**0.12 - 1.35**

C

Scientific Name	*Prunus lusitanica*		
Common Name	**Portuguese Cherrylaurel**		
Collected From	Botanical garden/arboretum		
Plant Part	25 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		Micronutrients ppm	
N	1.31 - 2.24	Fe	25 - 59
P	**0.11 - 0.19**	**Mn**	**19 - 88**
K	1.01 - 1.79	B	19 - 29
Ca	**0.79 - 1.28**	**Cu**	**5 - 9**
Mg	0.22 - 0.3	Zn	12 - 32
S	**0.09 - 0.16**	**Mo**	**0.11 - 0.28**

D

Scientific Name	*Punica granatum 'Nana'*		
Common Name	**Dwarf Pomegranate**		
Collected From	Botanical garden/arboretum		
Plant Part	20 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Nana'		
Macronutrients %		Micronutrients ppm	
N	1.3 - 2.25	Fe	58 - 103
P	**0.13 - 0.17**	**Mn**	**55 - 73**
K	0.9 - 1.87	B	21 - 33
Ca	**1.98 - 4.29**	**Cu**	**5 - 14**
Mg	0.35 - 0.45	Zn	16 - 26
S	**0.13 - 0.21**	**Mo**	**0.07 - 0.23**

E

Scientific Name	*Pyracantha 'Mohave'*		
Common Name	**Mohave' Firethorn**		
Collected From	Container production nursery		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Mohave'		
Macronutrients %		Micronutrients ppm	
N	2.17 - 2.27	Fe	42 - 131
P	**0.14 - 0.20**	**Mn**	**234 - 400**
K	1.11 - 1.81	B	21 - 37
Ca	**0.83 - 1.3**	**Cu**	**3 - 9**
Mg	0.22 - 0.31	Zn	34 - 86
S	**0.13 - 0.18**	**Mo**	**0.11 - 0.22**

F

Scientific Name	*Pyracantha koidzumii*		
Common Name	**Formosan Firethorn**		
Collected From	Botanical garden/arboretum		
Plant Part	35 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		Micronutrients ppm	
N	1.68 - 2.87	Fe	42 - 88
P	**0.13 - 0.2**	**Mn**	**154 - 254**
K	0.98 - 1.49	B	25 - 35
Ca	**1.61 - 2.60**	**Cu**	**5 - 12**
Mg	0.23 - 0.33	Zn	22 - 47
S	**0.14 - 0.22**	**Mo**	**0.11 - 0.32**

Woody Ornamental Shrubs

A

Scientific Name	*Rhaphiolepis indica*
Common Name	**Indian Hawthorn**
Collected From	Botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Hines Darkleaf' ('Bay Breeze')

Macronutrients %		Micronutrients ppm	
N	1.45 - 2.22	Fe	36 - 55
P	**0.15 - 0.25**	**Mn**	**36 - 75**
K	1.25 - 1.75	B	30 - 45
Ca	**1.50 - 2.50**	**Cu**	**6 - 15**
Mg	0.35 - 0.60	Zn	64 - 75
S	**0.15 - 0.28**	**Mo**	**0.01 - 0.65**

B

Scientific Name	*Rhaphiolepis umbellata 'Minor' ('Gulf Green')*
Common Name	**Gulf Green' Yeddo Hawthorn**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	30 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Minor' ('Gulf Green')

Macronutrients %		Micronutrients ppm	
N	1.61 - 2.22	Fe	3 - 16
P	**0.12 - 0.13**	**Mn**	**36 - 122**
K	1.44 - 1.53	B	31 - 37
Ca	**2.29 - 2.49**	**Cu**	**5 - 10**
Mg	0.30 - 0.33	Zn	64 - 112
S	**0.07 - 0.09**	**Mo**	**0.12 - 1.32**

C

Scientific Name	*Rhododendron 'Fashion' (Glenn Dale Hybrid)*
Common Name	**Fashion' Glenn Dale Hybrid Azalea**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	25 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Fashion'

Macronutrients %		Micronutrients ppm	
N	1.37 - 1.81	Fe	28 - 105
P	**0.12 - 0.14**	**Mn**	**112 - 293**
K	0.68 - 1.23	B	35 - 50
Ca	**1.05 - 1.31**	**Cu**	**1 - 6**
Mg	0.33 - 0.41	Zn	20 - 34
S	**0.19 - 0.21**	**Mo**	**0.12 - 0.30**

D

Scientific Name	*Rhododendron 'Herbert' (Gable Hybrid)*
Common Name	**Herbert' Gable Hybrid Azalea**
Collected From	Container production nursery
Plant Part	25 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	Herbert'

Macronutrients %		Micronutrients ppm	
N	1.71 - 2.59	Fe	38 - 110
P	**0.14 - 0.22**	**Mn**	**159 - 246**
K	0.88 - 1.78	B	21 - 64
Ca	**1.11 - 1.41**	**Cu**	**3 - 11**
Mg	0.23 - 0.44	Zn	33 - 86
S	**0.16 - 0.20**	**Mo**	**0.13 - 0.25**

E

Scientific Name	*Rhododendron 'Hino Crimson' (Kurume Hybrid)*
Common Name	**Hino Crimson' Kurume Hybrid Azalea**
Collected From	Container production nursery & botanical garden/arboretum
Plant Part	25 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Hino Crimson'

Macronutrients %		Micronutrients ppm	
N	1.76 - 2.39	Fe	9 - 58
P	**0.10 - 0.21**	**Mn**	**140 - 256**
K	1.19 - 1.41	B	42 - 57
Ca	**0.81 - 1.23**	**Cu**	**5 - 7**
Mg	0.17 - 0.29	Zn	23 - 36
S	**0.20 - 0.26**	**Mo**	**0.05 - 0.18**

F

Scientific Name	*Rhododendron 'Meiko' (Satsuki Hybrid)*
Common Name	**Meiko' Satsuki Hybrid Azalea**
Collected From	Botanical garden/arboretum
Plant Part	25 2-3" terminal cuttings
Season	Summer
Data Type	Survey Range
Cultivars Used	'Meiko'

Macronutrients %		Micronutrients ppm	
N	1.58 - 2.33	Fe	33 - 63
P	**0.12 - 0.18**	**Mn**	**36 - 137**
K	1.24 - 1.88	B	23 - 54
Ca	**1.1 - 1.23**	**Cu**	**3 - 9**
Mg	0.3 - 0.39	Zn	23 - 27
S	**0.16 - 0.20**	**Mo**	**0.09 - 0.32**

Woody Ornamental Shrubs

A

Scientific Name			*Rhododendron 'P.J.M.'*
Common Name			**P.J.M.' Rhododendron**
Collected From			Container production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'P.J.M.'
Macronutrients %		**Micronutrients ppm**	
N	1.88 - 2.26	Fe	92 - 144
P	**0.12 - 0.19**	**Mn**	**606 - 704**
K	0.91 - 1.20	B	44 - 51
Ca	**0.74 - 1.26**	**Cu**	**3 - 5**
Mg	0.20 - 0.31	Zn	41 - 69
S	**0.15 - 0.17**	**Mo**	**0.12 - 3.03**

B

Scientific Name			*Rhododendron 'Scintillation' (Dexter Hybrid)*
Common Name			**Scintillation' Dexter Hybrid Rhododendron**
Collected From			Container production nursery
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Scintillation'
Macronutrients %		**Micronutrients ppm**	
N	2.09 - 2.12	Fe	53 - 62
P	**0.16 - 0.27**	**Mn**	**815 - 1581**
K	1.35 - 1.84	B	56 - 71
Ca	**0.83 - 1.42**	**Cu**	**4 - 6**
Mg	0.19 - 0.38	Zn	48 - 70
S	**0.15 - 0.23**	**Mo**	**0.12 - 0.44**

C

Scientific Name			*Rhododendron (Glenn Dale Hybrids) cultivars*
Common Name			**White-flowering Glenn Dale Hybrid Azaleas**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Delaware Valley White', 'Glacier', 'H. H. Hume'
Macronutrients %		**Micronutrients ppm**	
N	1.32 - 2.23	Fe	29 - 209
P	**0.16 - 0.19**	**Mn**	**233 - 633**
K	0.54 - 1.44	B	38 - 58
Ca	**0.85 - 1.20**	**Cu**	**2 - 13**
Mg	0.29 - 0.39	Zn	31 - 35
S	**0.17 - 0.24**	**Mo**	**0.12 - 0.30**

D

Scientific Name			*Rhododendron (Knap Hill Hybrids) cultivars*
Common Name			**Knap Hill Hybrid Azaleas**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Gilbraltar', 'Klondyke'
Macronutrients %		**Micronutrients ppm**	
N	1.66 - 1.97	Fe	50 - 60
P	**0.10 - 0.18**	**Mn**	**573 - 588**
K	0.52 - 0.82	B	37 - 71
Ca	**0.95 - 1.17**	**Cu**	**5 - 7**
Mg	0.40 - 0.50	Zn	21 - 26
S	**0.13 - 0.17**	**Mo**	**0.12 - 0.30**

E

Scientific Name			*Rhododendron (Kurume Hybrids) cultivars*
Common Name			**Kurume Hybrid Azaleas**
Collected From			Container production nursery
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Coral Bells', 'Hershey's Red', 'Hinodegiri', Massasoit', 'Snow'
Macronutrients %		**Micronutrients ppm**	
N	1.79 - 2.08	Fe	56 - 185
P	**0.16 - 0.25**	**Mn**	**65 - 408**
K	1.08 - 1.65	B	33 - 76
Ca	**0.54 - 1.19**	**Cu**	**1 - 3**
Mg	0.22 - 0.40	Zn	26 - 62
S	**0.17 - 0.23**	**Mo**	**0.01 - 0.25**

F

Scientific Name			*Rhododendron (Robin Hill Hybrids) cultivars*
Common Name			**Robin Hill Hybrid Azaleas**
Collected From			Container production nursery
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Hilda Niblett', 'Nancy of Robin Hill'
Macronutrients %		**Micronutrients ppm**	
N	1.68 - 2.05	Fe	91 - 114
P	**0.17 - 0.19**	**Mn**	**156 - 541**
K	1.19 - 1.28	B	35 - 47
Ca	**0.58 - 1.21**	**Cu**	**1 - 2**
Mg	0.27 - 0.40	Zn	28 - 37
S	**0.18 - 0.23**	**Mo**	**0.09 - 0.30**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Rhododendron alabamense*
COMMON NAME	**Alabama Azalea**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.61 - 2.22	Fe	43 - 98
P	**0.11 - 0.17**	**Mn**	**345 - 1083**
K	1.71 - 2.71	B	26 - 45
Ca	**0.88 - 1.06**	**Cu**	**5 - 12**
Mg	0.38 - 0.71	Zn	17 - 27
S	**0.13 - 0.23**	**Mo**	**0.11 - 0.34**

B

SCIENTIFIC NAME	*Rhododendron arborescens*
COMMON NAME	**Sweet Azalea**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.61 - 2.21	Fe	38 - 62
P	**0.13 - 0.22**	**Mn**	**250 - 649**
K	1.89 - 2.46	B	23 - 45
Ca	**0.95 - 1.18**	**Cu**	**5 - 9**
Mg	0.33 - 0.70	Zn	21 - 28
S	**0.11 - 0.21**	**Mo**	**0.11 - 0.32**

C

SCIENTIFIC NAME	*Rhododendron austrinum*
COMMON NAME	**Florida Flame Azalea**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.58 - 2.27	Fe	40 - 114
P	**0.09 - 0.14**	**Mn**	**327 - 688**
K	0.9 - 1.78	B	32 - 48
Ca	**1.01 - 1.43**	**Cu**	**4 - 8**
Mg	0.35 - 0.63	Zn	18 - 28
S	**0.12 - 0.21**	**Mo**	**0.11 - 0.34**

D

SCIENTIFIC NAME	*Rhododendron canescens*
COMMON NAME	**Piedmont Azalea or Florida Pinxter**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.65 - 1.72	Fe	46 - 91
P	**0.09 - 0.17**	**Mn**	**261 - 670**
K	0.44 - 1.67	B	21 - 34
Ca	**1.09 - 1.38**	**Cu**	**3 - 11**
Mg	0.312 - 0.52	Zn	17 - 29
S	**0.12 - 0.18**	**Mo**	**0.09 - 0.17**

E

SCIENTIFIC NAME	*Rhododendron catawbiense hybrids or cultivars*
COMMON NAME	**Catawba-type Rhododendrons**
COLLECTED FROM	Container production nursery
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Album', 'Boursault', 'Chionoides', 'English Roseum', 'Lord Roberts', 'Nova Zembla', 'Roseum Elegans', 'Scarlet Wonder'

Macronutrients %		Micronutrients ppm	
N	1.42 - 1.82	Fe	42 - 113
P	**0.12 - 0.20**	**Mn**	**348 - 1193**
K	0.77 - 1.11	B	22 - 63
Ca	**0.52 - 2.19**	**Cu**	**2 - 6**
Mg	0.14 - 0.47	Zn	31 - 59
S	**0.10 - 0.17**	**Mo**	**0.04 - 0.55**

F

SCIENTIFIC NAME	*Rhododendron chapmanii*
COMMON NAME	**Chapman Rhododendron**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.33 - 2.32	Fe	43 - 88
P	**0.13 - 0.16**	**Mn**	**76 - 143**
K	1.46 - 2.12	B	25 - 59
Ca	**0.86 - 1.01**	**Cu**	**5 - 8**
Mg	0.33 - 0.41	Zn	23 - 39
S	**0.12 - 0.20**	**Mo**	**0.11 - 0.24**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Rhododendron cultivars*
COMMON NAME	**Hybrid Rhododendrons**
COLLECTED FROM	Container production nursery
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Rocket' (Shammarello Hybrid), 'Casablanca', 'Casablanca Improved'

Macronutrients %		Micronutrients ppm	
N	1.46 - 2.48	Fe	30 - 138
P	**0.09 - 0.19**	**Mn**	**425 - 516**
K	1.30 - 1.79	B	36 - 76
Ca	**0.55 - 1.10**	**Cu**	**4 - 19**
Mg	0.19 - 0.30	Zn	30 - 63
S	**0.13 - 0.31**	**Mo**	**0.08 - 0.53**

B

SCIENTIFIC NAME	*Rhododendron eriocarpum 'Gumpo Pink' & 'Gumpo White'*
COMMON NAME	**Gumpo Azaleas**
COLLECTED FROM	Container production nursery
PLANT PART	30 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Gumpo Pink', 'Gumpo White'

Macronutrients %		Micronutrients ppm	
N	1.82 - 2.02	Fe	85 - 94
P	**0.19 - 0.23**	**Mn**	**250 - 483**
K	1.21 - 1.30	B	33 - 53
Ca	**0.85 - 1.52**	**Cu**	**2 - 5**
Mg	0.25 - 0.36	Zn	30 - 35
S	**0.17 - 0.19**	**Mo**	**0.12 - 0.30**

C

SCIENTIFIC NAME	*Rhododendron indicum (Southern Indica Hybrids)*
COMMON NAME	**Southern Indica Azaleas**
COLLECTED FROM	Container production nursery
PLANT PART	40 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Not specified

Macronutrients %		Micronutrients ppm	
N	1.50 - 2.50	Fe	50 - 250
P	**0.20 - 0.50**	**Mn**	**40 - 200**
K	0.50 - 1.50	B	25 - 75
Ca	**0.50 - 1.50**	**Cu**	**6 - 25**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.20 - 0.50**	**Mo**	**0.32 - 1.32**

D

SCIENTIFIC NAME	*Rhododendron kaempferi*
COMMON NAME	**Torch Azalea**
COLLECTED FROM	Container production nursery
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Blue Danube'

Macronutrients %		Micronutrients ppm	
N	1.91 - 2.27	Fe	38 - 52
P	**0.11 - 0.17**	**Mn**	**191 - 243**
K	0.88 - 1.05	B	53 - 68
Ca	**1.00 - 1.05**	**Cu**	**6 - 13**
Mg	0.23 - 0.25	Zn	51 - 56
S	**0.20 - 0.25**	**Mo**	**0.32 - 2.41**

E

SCIENTIFIC NAME	*Rhododendron minus*
COMMON NAME	**Piedmont Rhododendron**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	20 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.14 - 2.21	Fe	46 - 75
P	**0.09 - 0.15**	**Mn**	**267 - 758**
K	0.59 - 1.61	B	21 - 50
Ca	**0.97 - 1.10**	**Cu**	**2 - 8**
Mg	0.31 - 0.37	Zn	20 - 31
S	**0.11 - 0.21**	**Mo**	**0.12 - 0.33**

F

SCIENTIFIC NAME	*Rhodotypos scandens*
COMMON NAME	**Black Jetbead**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	30 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	2.11 - 2.38	Fe	41 - 92
P	**0.22 - 0.45**	**Mn**	**79 - 210**
K	2.22 - 2.59	B	26 - 52
Ca	**1.64 - 1.96**	**Cu**	**5 - 16**
Mg	0.28 - 0.33	Zn	15 - 31
S	**0.15 - 0.23**	**Mo**	**0.11 - 0.31**

Woody Ornamental Shrubs

A

Scientific Name	*Rhus aromatica 'Gro-low'*		
Common Name	**Dwarf Fragrant Sumac**		
Collected From	Botanical garden/arboretum		
Plant Part	20 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Gro-low'		
Macronutrients %		**Micronutrients ppm**	
N	1.64 - 2.45	Fe	33 - 83
P	**0.11 - 0.16**	**Mn**	**151 - 224**
K	1.11 - 1.93	B	18 - 27
Ca	**0.96 - 1.55**	**Cu**	**4 - 10**
Mg	0.22 - 0.27	Zn	19 - 29
S	**0.14 - 0.21**	**Mo**	**0.11 - 0.21**

B

Scientific Name	*Rhus copallina*		
Common Name	**Shining or Flameleaf or Winged Sumac**		
Collected From	Botanical garden/arboretum		
Plant Part	10 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.91 - 1.91	Fe	45 - 66
P	**0.15 - 0.22**	**Mn**	**24 - 137**
K	1.17 - 1.87	B	20 - 28
Ca	**0.97 - 1.23**	**Cu**	**5 - 10**
Mg	0.18 - 28	Zn	19 - 28
S	**0.15 - 0.23**	**Mo**	**0.01 - 0.19**

C

Scientific Name	*Rhus typhina 'Laciniata'*		
Common Name	**Cut-leaf Staghorn Sumac**		
Collected From	Botanical garden/arboretum		
Plant Part	5 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Laciniata'		
Macronutrients %		**Micronutrients ppm**	
N	1.6 - 2.26	Fe	44 - 83
P	**0.2 - 0.30**	**Mn**	**20 - 154**
K	1.54 - 1.86	B	30 - 42
Ca	**1.24 - 1.80**	**Cu**	**5 - 12**
Mg	0.17 - 0.21	Zn	10 - 27
S	**0.16 - 0.22**	**Mo**	**0.15 - 0.48**

D

Scientific Name	*Ruscus aculeatus*		
Common Name	**Butcher's Broom**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	20 mature 'leaves' (cladodes) from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.64 - 1.96	Fe	41 - 109
P	**0.19 - 0.29**	**Mn**	**19 - 92**
K	1.84 - 2.08	B	21 - 27
Ca	**0.43 - 0.55**	**Cu**	**3 - 6**
Mg	0.16 - 0.17	Zn	30 - 36
S	**0.16 - 0.18**	**Mo**	**0.33 - 0.89**

E

Scientific Name	*Sarcococca confusa*		
Common Name	**Chinese Sweetbox or Christmas Box**		
Collected From	Container production nursery		
Plant Part	30 mature leaves from new growth		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.66 - 2.78	Fe	35 - 78
P	**0.13 - 0.21**	**Mn**	**110 - 138**
K	0.97 - 1.78	B	18 - 28
Ca	**1.22 - 1.34**	**Cu**	**3 - 9**
Mg	0.31 - 0.55	Zn	33 - 122
S	**0.12 - 0.19**	**Mo**	**0.17 - 0.39**

F

Scientific Name	*Sarcococca hookeriana var. humilis*		
Common Name	**Dwarf Himalayan Sweetbox**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	var. humilis only		
Macronutrients %		**Micronutrients ppm**	
N	2.00 - 2.50	Fe	41 - 45
P	**0.22 - 0.26**	**Mn**	**92 - 101**
K	1.13 - 1.30	B	41 - 64
Ca	**0.95 - 1.63**	**Cu**	**2 - 6**
Mg	0.24 - 0.26	Zn	57 - 79
S	**0.19 - 0.22**	**Mo**	**0.11 - 0.39**

Woody Ornamental Shrubs

A

Scientific Name			*Sarcococca ruscifolia*
Common Name			**Fragrant Sarcococca or Christmas Box**
Collected From			Container production nursery
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.96 - 2.28	Fe	46 - 109
P	**0.15 - 0.23**	**Mn**	**34 - 99**
K	1.04 - 1.85	B	20 - 31
Ca	**1.01 - 1.35**	**Cu**	**4 - 10**
Mg	0.3 - 0.47	Zn	31 - 72
S	**0.17 - 0.23**	**Mo**	**0.21 - 0.64**

B

Scientific Name			*Serissa foetida*
Common Name			**Yellowrim or Japanese Serissa**
Collected From			Botanical garden/arboretum
Plant Part			30 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.38 - 2.35	Fe	34 - 65
P	**0.13 - 0.23**	**Mn**	**55 - 179**
K	1.23 - 1.63	B	18 - 40
Ca	**1.18 - 1.67**	**Cu**	**5 - 9**
Mg	0.19 - 0.26	Zn	33 - 87
S	**0.15 - 0.19**	**Mo**	**0.18 - 0.37**

C

Scientific Name			*Spiraea canescens*
Common Name			**Himalayan Bridalwreath**
Collected From			Botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.31 - 2.59	Fe	33 - 83
P	**0.14 - 0.20**	**Mn**	**75 - 179**
K	1.22 - 1.57	B	18 - 28
Ca	**0.73 - 1.31**	**Cu**	**4 - 11**
Mg	0.21 - 0.26	Zn	18 - 28
S	**0.13 - 0.20**	**Mo**	**0.11 - 0.28**

D

Scientific Name			*Spiraea cantoniensis 'Lanceata'*
Common Name			**Reeves' Double Spirea or Bridalwreath**
Collected From			Botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			'Lanceata'
Macronutrients %		**Micronutrients ppm**	
N	2.12 - 2.47	Fe	45 - 75
P	**0.24 - 0.34**	**Mn**	**118 - 299**
K	1.58 - 1.96	B	22 - 50
Ca	**0.86 - 1.22**	**Cu**	**5 - 10**
Mg	0.18 - 0.24	Zn	16 - 29
S	**0.16 - 0.22**	**Mo**	**0.19 - 0.43**

E

Scientific Name			*Spiraea japonica 'Anthony Waterer'*
Common Name			**Anthony Waterer' Pink Spirea**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			'Anthony Waterer'
Macronutrients %		**Micronutrients ppm**	
N	1.50 - 2.16	Fe	75 - 84
P	**0.16 - 0.31**	**Mn**	**103 - 189**
K	1.45 - 1.60	B	36 - 44
Ca	**0.69 - 1.18**	**Cu**	**3 - 6**
Mg	0.20 - 0.29	Zn	18 - 32
S	**0.12 - 0.16**	**Mo**	**1.26 - 1.32**

F

Scientific Name			*Spiraea japonica 'Nana' ('Alpina')*
Common Name			**Dwarf Japanese Spirea or Daphne Spirea**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			25 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Nana' ('Alpina')
Macronutrients %		**Micronutrients ppm**	
N	2.06 - 2.24	Fe	36 - 461
P	**0.26 - 0.29**	**Mn**	**312 - 864**
K	1.35 - 1.55	B	31 - 35
Ca	**0.42 - 0.92**	**Cu**	**3 - 21**
Mg	0.17 - 0.33	Zn	22 - 61
S	**0.15 - 0.18**	**Mo**	**0.12 - 3.7**

Woody Ornamental Shrubs

A

Scientific Name	*Spiraea japonica cultivars*		
Common Name	**Gold-leaf Japanese Spireas**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Goldflame', 'Gold-mound', 'Monhub' ('Limemound')		
Macronutrients %		**Micronutrients ppm**	
N	1.91 - 3.08	Fe	33 - 241
P	**0.19 - 0.46**	**Mn**	**140 - 957**
K	1.04 - 2.78	B	22 - 53
Ca	**0.58 - 1.01**	**Cu**	**2 - 8**
Mg	0.19 - 0.37	Zn	19 - 49
S	**0.15 - 0.20**	**Mo**	**0.33 - 5.0**

B

Scientific Name	*Spiraea japonica cultivars*		
Common Name	**Japanese Spirea**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Coccinea', 'Froebelii', 'Gumball', 'Little Princess', 'Shirobana'		
Macronutrients %		**Micronutrients ppm**	
N	1.63 - 2.71	Fe	35 - 91
P	**0.14 - 0.43**	**Mn**	**114 - 943**
K	1.03 - 2.39	B	23 - 39
Ca	**0.49 - 1.20**	**Cu**	**2 - 7**
Mg	0.16 - 0.38	Zn	22 - 75
S	**0.12 - 0.16**	**Mo**	**0.06 - 4.59**

C

Scientific Name	*Spiraea nipponica 'Snowmound'*		
Common Name	**Snowmound' Spirea**		
Collected From	Container production nursery & botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Snowmound'		
Macronutrients %		**Micronutrients ppm**	
N	1.87 - 2.42	Fe	36 - 102
P	**0.14 - 0.34**	**Mn**	**36 - 43**
K	0.91 - 1.10	B	19 - 25
Ca	**0.52 - 0.99**	**Cu**	**3 - 13**
Mg	0.15 - 0.36	Zn	12 - 27
S	**0.14 - 0.19**	**Mo**	**0.12 - 2.1**

D

Scientific Name	*Spiraea prunifolia 'Plena'*		
Common Name	**Old-fashioned Bridalwreath**		
Collected From	Botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	'Plena'		
Macronutrients %		**Micronutrients ppm**	
N	2.01 - 2.11	Fe	39 - 75
P	**0.23 - 0.33**	**Mn**	**338 - 966**
K	1.11 - 1.95	B	20 - 31
Ca	**0.9 - 1.24**	**Cu**	**5 - 12**
Mg	0.11 - 0.3	Zn	20 - 32
S	**0.12 - 0.16**	**Mo**	**0.1 - 0.28**

E

Scientific Name	*Spiraea thunbergii*		
Common Name	**Thunberg Spirea**		
Collected From	Botanical garden/arboretum		
Plant Part	35 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.83 - 2.87	Fe	42 - 107
P	**0.15 - 0.20**	**Mn**	**206 - 410**
K	0.6 - 1.45	B	24 - 30
Ca	**0.86 - 1.12**	**Cu**	**4 - 11**
Mg	0.21 - 0.30	Zn	29 - 68
S	**0.14 - 0.23**	**Mo**	**0.06 - 0.21**

F

Scientific Name	*Spiraea vanhouttei*		
Common Name	**Vanhoutte Spirea**		
Collected From	Botanical garden/arboretum		
Plant Part	25 2-3" terminal cuttings		
Season	Summer		
Data Type	Survey Range		
Cultivars Used	Species only		
Macronutrients %		**Micronutrients ppm**	
N	1.89 - 2.05	Fe	40 - 80
P	**0.26 - 0.42**	**Mn**	**43 - 185**
K	1.23 - 1.83	B	31 - 37
Ca	**0.78 - 1.14**	**Cu**	**5 - 10**
Mg	0.25 - 0.35	Zn	21 - 32
S	**0.17 - 0.24**	**Mo**	**0.23 - 0.73**

Woody Ornamental Shrubs

A

Scientific Name			*Syringa laciniata*
Common Name			**Cut-leaf Lilac**
Collected From			Botanical garden/arboretum
Plant Part			30 2-3" terminal cuttings
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		Micronutrients ppm	
N	1.96 - 2.32	Fe	46 - 76
P	**0.32 - 0.54**	**Mn**	**79 - 146**
K	1.25 - 2.12	B	20 - 31
Ca	**1.78 - 3.37**	**Cu**	**5 - 10**
Mg	0.18 - 0.24	Zn	45 - 258
S	**0.17 - 0.26**	**Mo**	**0.19 - 0.25**

B

Scientific Name			*Syringa vulgaris*
Common Name			**Common Lilac**
Collected From			Container production nursery
Plant Part			20 mature leaves from new growth
Season			Summer
Data Type			Sufficiency Range
Cultivars Used			Not specified
Macronutrients %		Micronutrients ppm	
N	1.60 - 2.50	Fe	75 - 300
P	**0.25 - 0.40**	**Mn**	**30 - 300**
K	1.00 - 1.80	B	18 - 40
Ca	**0.60 - 1.20**	**Cu**	**8 - 25**
Mg	0.20 - 0.40	Zn	25 - 75
S	**0.16 - 0.21**	**Mo**	**0.12 - 4.0**

C

Scientific Name			*Ternstroemia gymnanthera*
Common Name			**False Cleyera or Japanese Ternstroemia**
Collected From			Botanical garden/arboretum
Plant Part			30 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		Micronutrients ppm	
N	1.37 - 1.50	Fe	40 - 46
P	**0.06 - 0.09**	**Mn**	**11 - 16**
K	0.94 - 1.03	B	38 - 49
Ca	**0.87 - 1.95**	**Cu**	**5 - 7**
Mg	0.29 - 0.33	Zn	8 - 11
S	**0.2 - 0.25**	**Mo**	**0.12 - 0.30**

D

Scientific Name			*Vaccinium arboreum*
Common Name			**Sparkleberry**
Collected From			Botanical garden/arboretum
Plant Part			35 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		Micronutrients ppm	
N	1.45 - 2.31	Fe	39 - 67
P	**0.06 - 0.12**	**Mn**	**287 - 500**
K	0.35 - 1.48	B	31 - 93
Ca	**0.96 - 1.14**	**Cu**	**4 - 11**
Mg	0.25 - 0.33	Zn	32 - 60
S	**0.21 - 0.35**	**Mo**	**0.09 - 0.31**

E

Scientific Name			*Viburnum 'Cayuga'*
Common Name			**Koreanspice Hybrid Viburnum**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Cayuga'
Macronutrients %		Micronutrients ppm	
N	1.52 - 2.32	Fe	76 - 222
P	**0.20 - 0.73**	**Mn**	**148 - 357**
K	1.09 - 1.53	B	47 - 79
Ca	**1.54 - 2.16**	**Cu**	**6 - 9**
Mg	0.40 - 0.43	Zn	40 - 228
S	**0.15 - 0.21**	**Mo**	**0.09 - 0.30**

F

Scientific Name			*Viburnum 'Eskimo'*
Common Name			**Utile Hybrid Viburnum**
Collected From			Botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Eskimo'
Macronutrients %		Micronutrients ppm	
N	1.59 - 2.11	Fe	90 - 107
P	**0.23 - 0.29**	**Mn**	**115 - 234**
K	1.26 - 1.49	B	39 - 86
Ca	**1.81 - 2.08**	**Cu**	**8 - 11**
Mg	0.16 - 0.34	Zn	51 - 54
S	**0.16 - 0.18**	**Mo**	**0.12 - 0.30**

Woody Ornamental Shrubs

A

Scientific Name			*Viburnum 'Mohawk'*
Common Name			**Burkwood Hybrid Viburnum**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Mohawk'
Macronutrients %		**Micronutrients ppm**	
N	1.21 - 2.32	Fe	75 - 191
P	**0.16 - 0.22**	**Mn**	**90 - 384**
K	1.16 - 1.35	B	58 - 80
Ca	**1.41 - 2.77**	**Cu**	**4 - 7**
Mg	0.22 - 0.25	Zn	17 - 183
S	**0.18 - 0.20**	**Mo**	**0.18 - 0.30**

B

Scientific Name			*Viburnum 'Pragense'*
Common Name			**Prague Viburnum**
Collected From			Field production nursery & botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			'Pragense'
Macronutrients %		**Micronutrients ppm**	
N	1.61 - 1.90	Fe	80 - 134
P	**0.16 - 0.17**	**Mn**	**178 - 246**
K	1.24 - 1.35	B	22 - 60
Ca	**1.96 - 2.13**	**Cu**	**3 - 9**
Mg	0.27 - 0.29	Zn	17 - 55
S	**0.15 - 0.19**	**Mo**	**0.12 - 0.30**

C

Scientific Name			*Viburnum awabuki*
Common Name			**Awabuki Viburnum**
Collected From			Botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.54 - 2.31	Fe	44 - 76
P	**0.25 - 0.63**	**Mn**	**83 - 216**
K	1.77 - 2.87	B	21 - 46
Ca	**1.21 - 1.54**	**Cu**	**3 - 9**
Mg	0.22 - 0.32	Zn	33 - 131
S	**0.21 - 0.34**	**Mo**	**0.11 - 0.27**

D

Scientific Name			*Viburnum bodnantense*
Common Name			**Bodnant or Pink Viburnum**
Collected From			Container production nursery
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Dawn'
Macronutrients %		**Micronutrients ppm**	
N	1.88 - 1.93	Fe	49 - 79
P	**0.16 - 0.28**	**Mn**	**97 - 200**
K	1.68 - 2.55	B	26 - 53
Ca	**1.18 - 1.75**	**Cu**	**2 - 9**
Mg	0.24 - 0.29	Zn	30 - 61
S	**0.18 - 0.25**	**Mo**	**0.02 - 0.15**

E

Scientific Name			*Viburnum bracteatum*
Common Name			**Bracted or Georgia Viburnum**
Collected From			Botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	2.15 - 2.26	Fe	38 - 70
P	**0.19 - 0.28**	**Mn**	**208 - 391**
K	1.4 - 2.22	B	28 - 43
Ca	**1.19 - 1.38**	**Cu**	**7 - 15**
Mg	0.23 - 0.36	Zn	31 - 58
S	**0.18 - 0.26**	**Mo**	**0.11 - 0.29**

F

Scientific Name			*Viburnum burkwoodii*
Common Name			**Burkwood Viburnum**
Collected From			Container production nursery & botanical garden/arboretum
Plant Part			25 mature leaves from new growth
Season			Summer
Data Type			Survey Range
Cultivars Used			Species only
Macronutrients %		**Micronutrients ppm**	
N	1.39 - 1.63	Fe	105 - 278
P	**0.10 - 0.17**	**Mn**	**149 - 251**
K	1.25 - 1.41	B	45 - 52
Ca	**2.13 - 2.84**	**Cu**	**7 - 11**
Mg	0.26 - 0.29	Zn	19 - 134
S	**0.13 - 0.19**	**Mo**	**0.12 - 1.29**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Viburnum cassinoides*
COMMON NAME	**Withe-rod Viburnum or Swamp Haw or Wild Raisin or Appalachian Tea**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.88 - 2.19	Fe	34 - 55
P	**0.15 - 0.25**	**Mn**	**243 - 406**
K	0.84 - 1.54	B	24 - 48
Ca	**1.01 - 1.22**	**Cu**	**4 - 8**
Mg	0.23 - 0.29	Zn	24 - 54
S	**0.15 - 0.25**	**Mo**	**0.06 - 0.09**

B

SCIENTIFIC NAME	*Viburnum dilatatum cultivars*
COMMON NAME	**Linden Viburnum**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.83 - 2.01	Fe	76 - 97
P	**0.09 - 0.12**	**Mn**	**280 - 376**
K	1.18 - 1.48	B	44 - 77
Ca	**1.91 - 2.88**	**Cu**	**3 - 9**
Mg	0.23 - 0.42	Zn	38 - 156
S	**0.16 - 0.20**	**Mo**	**0.05 - 0.30**

C

SCIENTIFIC NAME	*Viburnum juddii*
COMMON NAME	**Judd Viburnum**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.84 - 2.35	Fe	43 - 115
P	**0.12 - 0.19**	**Mn**	**124 - 336**
K	0.98 - 1.47	B	35 - 64
Ca	**1.38 - 2.35**	**Cu**	**4 - 8**
Mg	0.33 - 0.44	Zn	27 - 31
S	**0.14 - 0.19**	**Mo**	**0.11 - 0.34**

D

SCIENTIFIC NAME	*Viburnum macrocephalum 'Sterile'*
COMMON NAME	**Chinese Snowball Viburnum**
COLLECTED FROM	Field production nursery & botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Sterile'

Macronutrients %		Micronutrients ppm	
N	1.79 - 1.93	Fe	71 - 104
P	**0.17 - 0.21**	**Mn**	**113 - 384**
K	1.08 - 1.12	B	76 - 114
Ca	**1.33 - 1.52**	**Cu**	**6 - 8**
Mg	0.20 - 0.26	Zn	24 - 27
S	**0.13 - 0.22**	**Mo**	**0.12 - 0.30**

E

SCIENTIFIC NAME	*Viburnum obovatum*
COMMON NAME	**Small or Walter Viburnum**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 2-3" terminal cuttings
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.19 - 2.26	Fe	25 - 67
P	**0.13 - 0.18**	**Mn**	**55 - 75**
K	0.86 - 1.58	B	20 - 29
Ca	**0.78 - 0.97**	**Cu**	**4 - 12**
Mg	0.15 - 25	Zn	15 - 27
S	**0.11 - 0.19**	**Mo**	**0.11 - 0.32**

F

SCIENTIFIC NAME	*Viburnum odoratissimum*
COMMON NAME	**Sweet Viburnum**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.53 - 2.24	Fe	29 - 63
P	**0.11 - 0.17**	**Mn**	**38 - 134**
K	1.41 - 1.73	B	24 - 45
Ca	**1.15 - 1.47**	**Cu**	**5 - 10**
Mg	0.16 - 0.29	Zn	31 - 63
S	**0.14 - 0.19**	**Mo**	**0.08 - 0.17**

Woody Ornamental Shrubs

A

SCIENTIFIC NAME	*Viburnum opulus 'Roseum'*
COMMON NAME	**European Snowball or Guelder Rose**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Roseum'

Macronutrients %		Micronutrients ppm	
N	2.19 - 2.46	Fe	37 - 83
P	**0.13 - 0.21**	**Mn**	**52 - 134**
K	1.55 - 1.83	B	31 - 110
Ca	**1.37 - 1.72**	**Cu**	**5 - 7**
Mg	0.2 - 0.29	Zn	18 - 29
S	**0.18 - 0.27**	**Mo**	**0.09 - 0.18**

B

SCIENTIFIC NAME	*Viburnum plicatum 'Sterile'*
COMMON NAME	**Japanese Snowball Viburnum**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	'Sterile'

Macronutrients %		Micronutrients ppm	
N	1.74 - 2.33	Fe	55 - 115
P	**0.14 - 0.22**	**Mn**	**66 - 134**
K	1.56 - 2.05	B	31 - 81
Ca	**0.97 - 2.75**	**Cu**	**4 - 7**
Mg	0.23 - 0.33	Zn	26 - 40
S	**0.16 - 0.25**	**Mo**	**0.07 - 0.09**

C

SCIENTIFIC NAME	*Viburnum plicatum var. tomentosum*
COMMON NAME	**Doublefile Viburnum**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Mariesii', 'Shasta', 'Summer Snowflake'

Macronutrients %		Micronutrients ppm	
N	0.97 - 2.38	Fe	40 - 133
P	**0.09 - 0.23**	**Mn**	**58 - 568**
K	0.77 - 1.69	B	35 - 77
Ca	**0.97 - 1.81**	**Cu**	**1 - 7**
Mg	0.13 - 0.34	Zn	18 - 150
S	**0.13 - 0.24**	**Mo**	**0.02 - 0.52**

D

SCIENTIFIC NAME	*Viburnum rhytidophylloides*
COMMON NAME	**Lantanaphyllum Viburnum**
COLLECTED FROM	Container production nursery & botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Allegheny', 'Dart's Duke', 'Willowwood'

Macronutrients %		Micronutrients ppm	
N	1.79 - 2.06	Fe	41 - 314
P	**0.16 - 0.54**	**Mn**	**115 - 170**
K	1.43 - 2.28	B	27 - 45
Ca	**0.81 - 1.82**	**Cu**	**7 - 12**
Mg	0.21 - 0.36	Zn	34 - 68
S	**0.15 - 0.17**	**Mo**	**0.07 - 2.37**

E

SCIENTIFIC NAME	*Viburnum rufidulum*
COMMON NAME	**Rusty or Southern Blackhaw**
COLLECTED FROM	Botanical garden/arboretum
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Survey Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.2 - 1.98	Fe	40 - 79
P	**0.14 - 0.14**	**Mn**	**104 - 153**
K	1.21 - 1.75	B	25 - 77
Ca	**0.87 - 1.98**	**Cu**	**2 - 8**
Mg	0.17 - 0.25	Zn	12 - 25
S	**0.12 - 0.17**	**Mo**	**0.11 - 0.3**

F

SCIENTIFIC NAME	*Viburnum suspensum*
COMMON NAME	**Sandankwa Viburnum**
COLLECTED FROM	Container production nursery
PLANT PART	25 mature leaves from new growth
SEASON	Summer
DATA TYPE	Sufficiency Range
CULTIVARS USED	Species only

Macronutrients %		Micronutrients ppm	
N	1.50 - 2.50	Fe	30 - 200
P	**0.15 - 0.23**	**Mn**	**30 - 200**
K	0.90 - 2.00	B	20 - 75
Ca	**0.60 - 1.50**	**Cu**	**7 - 25**
Mg	0.25 - 1.00	Zn	20 - 200
S	**0.20 - 0.40**	**Mo**	**0.09 - 3.0**

Woody Ornamental Shrubs

A

Scientific Name	*Viburnum tinus*
Common Name	**Laurustinus or Laurel Viburnum**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients Ppm	
N	1.47 - 1.47	Fe	41 - 64
P	**0.1 - 0.24**	**Mn**	**68 - 317**
K	1.31 - 1.51	B	35 - 70
Ca	**0.84 - 1.24**	**Cu**	**5 - 9**
Mg	0.21 - 0.3	Zn	16 - 68
S	**0.15 - 0.22**	**Mo**	**0.05 - 0.35**

B

Scientific Name	*Xanthorhiza simplicissima*
Common Name	**Yellowroot**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species only

Macronutrients %		Micronutrients ppm	
N	1.59 - 2.11	Fe	90 - 107
P	**0.22 - 0.30**	**Mn**	**78 - 116**
K	1.64 - 2.00	B	22 - 36
Ca	**1.54 - 2.20**	**Cu**	**5 - 12**
Mg	0.19 - 0.26	Zn	22 - 85
S	**0.24 - 0.59**	**Mo**	**0.11 - 0.19**

C

Scientific Name	*Yucca flaccida 'Golden Sword'*
Common Name	**Variegated Weak-leaf Yucca**
Collected From	Container production nursery
Plant Part	5 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	'Golden Sword'

Macronutrients %		Micronutrients Ppm	
N	1.77 - 2.14	Fe	39 - 57
P	**0.23 - 0.42**	**Mn**	**58 - 116**
K	1.78 - 2.25	B	12 - 25
Ca	**0.56 - 0.89**	**Cu**	**2 - 12**
Mg	0.22 - 0.28	Zn	29 - 67
S	**0.13 - 0.22**	**Mo**	**0.11 - 0.17**

D

Scientific Name	*Aucuba japonica*
Common Name	**Japanese Aucuba**
Collected From	Botanical garden/arboretum
Plant Part	25 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	Species, 'Fructo Alba'

Macronutrients %		Micronutrients ppm	
N	1.35 - 1.94	Fe	37 - 60
P	**0.13 - 0.19**	**Mn**	**191 - 325**
K	0.64 - 1.00	B	23 - 29
Ca	**0.94 - 1.19**	**Cu**	**3 - 6**
Mg	0.13 - 0.26	Zn	24 - 87
S	**0.20 - 0.24**	**Mo**	**0.12 - 0.30**

E

Scientific Name	*Woody Ornamentals*
Common Name	**General**
Collected From	Averaged over garden and field grown arboretum
Plant Part	10-15 mature leaves from new growth
Season	Summer
Data Type	Survey Range
Cultivars Used	

Macronutrients %		Micronutrients Ppm	
N	2 - 5	Fe	75–350
P	**0.2 - 0.5**	**Mn**	**50 - 200**
K	1.5 - 3.5	B	15 - 50
Ca	**1.2 - 2.0**	**Cu**	**6 - 18**
Mg	.25 - .50	Zn	25 - 120
S	**0.19 - 0.27**	**Mo**	**0.6 - 2.4**

F

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Glossary of Terms

ABSORPTION - The process through which one substance is taken into and incorporated into another substance, e.g., intake of water by soil, or intake of gases, water, nutrients or other substances by plants.

ACID - A class of substances in chemistry will form hydrogen ions (H^+) in aqueous solutions, resulting in a pH less than 7. In a chemical reaction, these substances can act as a proton donor or as the recipient of a pair of electrons in the formation of a covalent bond.

ACID (FORMING) FERTILIZER - A nutritional amendment that will cause a decrease in pH when applied to the soil/growing media. Commonly used acid fertilizers: ammonium, ammonia, and urea.

ACID SOIL/MEDIA - Where a greater concentration of hydrogen ions (H^+) versus hydroxyl ions (OH^-) are present in the soil/media solution, indicated by a pH value below 7.0.

ACIDIFICATION - The process of lowering the pH of a solution. This process is used in the management of irrigation water to either reduce alkalinity or to maintain the acidity of the solution between pH 5.8 to 6.2. This is commonly done through the addition of sulfuric, phosphoric, or nitric acid.

ACTIVATED ALUMNIA - An artificially manufactured, very porous, form of aluminum oxide (Al_2O_3), which is commonly used in water treatment to filter out fluoride, arsenic, and selenium.

ACTIVATED CARBON - A form of carbon which has been processed, either through chemical activation or physical reactivation, to have an increased amount of surface area for adsorption or chemical reactions through the development of small low-volume pores. It is commonly used to remove impurities and pollutants from both water and air.

ADJUSTED SODIUM ADSORPTION RATIO (Adj. R_{Na}) - A calculation used to measure the potential sodium hazard of irrigation water, accounting for the salinity, calcium, magnesium, and bicarbonate content in relation to the sodium content. Similar measurements that are used to evaluate sodium hazard are: sodium absorption ratio (SAR), adjusted sodium absorption ratio (SAR_{adj}), exchangeable sodium percentage (ESP), sodium percentage, and residual sodium carbonate.

ADSORPTION - The process through which one substance is adhered to the surface of another substance through the principal of surface energy. This includes the adhesion of exchangeable cations and anions on soil particles.

AERATION (SOIL) - The exchange between air in a soil with atmospheric air above. The air in a well-aerated soil is similar in composition to that of the atmosphere above, while the air in a poorly aerated soil will have a higher concentration of carbon dioxide and a lower concentration of oxygen.

AGGREGATE - A grouping of soil particulates that are bound together, such that in regards to soil mechanics, behaves as a single unit.

AIR POROSITY or AIR SPACE - The portion of a soil, measured as a percent by volume, of a soil or media that is filled with air when the substrate is irrigated to capacity. This air is primarily held in the larger macropores of the substrate.

ALKALI SOIL/MEDIA - See SODIC SOIL/MEDIUM.

ALKALINE - Having a pH value greater then 7.0, indicating a relatively low concentration of hydrogen ions. Also referred to as "basic".

ALKALINE SOIL/MEDIA - A soil/medium which has a greater concentration of hydroxyl ions (OH^-) versus hydrogen ions (H^+), indicated by a pH value greater than 7.0.

ALKALINE SOLTION - An aqueous solution of a base, indicating a pH value greater than 7.0.

ALKALINITY - A descriptor for water's ability to neutralize acids. True alkalinity is calculated as is the sum of the dissolved bicarbonates, carbonates, hydroxides, ammonia, borates, organic bases, phosphates, and silicates in the water, but in practice is often given as the sum of the bicarbonates and carbonates (total carbonates) expressed as me/1 or ppm.

ALUM - Refers either to the specific chemical compound, hydrated potassium aluminum sulfate [$KAl(SO_4)_2 \cdot (12H_2O$]] or, more widely, to the double sulfate salts class chemical compounds, both of which are use in the treatment of irrigation and recycled water to flocculate and remove colloidal clay. Aluminum sulfate is more commonly used due to its lower costs and availability in both liquid and dry forms.

AMENDMENT - Any material that increases the productivity of the soil or growing medium it is worked into. Strictly, a fertilizer is an amendment, but the term is more commonly used for added materials other than fertilizer such as lime, gypsum, sawdust or synthetic conditioners.

AMINO ACIDS - A class of organic compounds comprised of an amine group ($-NH_2$), a carboxyl (-COOH) group, and a side chain that is specific to each amino acid. Protein molecules are formed from one or more folded chains of these compounds.

AMMONIA - A weakly basic, inorganic form of nitrogen (NH_3) that is commonly used in fertilizers and as a precursor to other nitrogenous compounds. It can be toxic in concentrations as low as 2.5 ppm (0.15 mM).
AMMONICAL - To consist of, contain or produce ammonia. In regards to fertilizers, it indicates that it contains ammonia or ammonium.

AMMONIATED SUPERPHOSPHATE - A multinutrient fertilizer containing nitrogen and phosphorus, formed by reacting ammonia (anhydrous, aqua or a solution containing ammonia and other forms of nitrogen) with superphosphate (a process which is called ammoniation of superphosphate).

AMMONIFICATION - The formation of ammonium or ammonium compounds from organic nitrogen sources through bacterial decomposition.

AMMONIUM - The cation NH_4^+ produced through the protonation of ammonia (NH_3), which is used as an inorganic nitrogen fertilizer. Ammonium will always contain a small amount of ammonia in equilibrium.

AMMONIUM CITRATE [$(NH_4)_3C_6H_5O_7$] - A salt formed from ammonia and citric acid which is used as an analytical reagent used to determine the available phosphoric acid in fertilizers. The sample is first washed with water to remove the water-soluble phosphorus oxide (P_2O_5), and then the residue is treated with a neutral ammonium citrate solution.

ANALYSIS - Generally speaking, it is the identification of a compound and determination of its composition through the separation of its parts. In regards to commercially available products, the analysis refers to the percentage composition of a compound that is reported in terms as the law requires and permits. In this regard, the term “analysis” is sometimes used synonymously with the term “grade”, even though it refers to the actual percentage composition while “grade” only provides a guaranteed minimum requirement (See also GRADE).

ANGLE OF REPOSE - The angle between the horizontal plane and the slope of a conical pile of loose material at equilibrium, with a range of 0^o-90^o.

ANION - A negatively charged ion. Some common soil anions are nitrate (NO^{3-}) and hydrogen phosphate (HPO_2^{4-}).

ANION EXCHANGE RESIN - An insoluble matrix, typically in the form of small (0.5-1.0 mm diameter) beads of an organic polymer bound to an innocuous anion. The resin is used in the separation, purification, and decontamination of waters from anionic contaminates by the replacement of the innocuous anion with the contaminates through preferential migration and binding.

ANNUAL - A plant that completes its entire life cycle in a single growing season.

ANTAGONISM - The suppressive action of one nutrient, present at a high concentration, on the activity of another nutrient causing an induced nutrient deficiency.
AOAC - Association of Official Analytical Chemists (of North America).

APATITE (rock phosphate) - A group of phosphate minerals, having the type formula $Ca_{10}(X_2)(PO_4)_6$ where X is usually fluorine, chlorine or the hydroxyl group, either singly or together. Fluorapatite, where X is fluorine, is an important fertilizer material. It is distributed either as amorphous phosphate rock or as crystalline florapatite, which contains 38-41% phosphorus oxide (P_2O_5) and from 3.2-4.3% fluorine. Calcium hydroxyapatite or calcium hydroxy-phosphate, $Ca_{10}(OH)_2(PO_4)_6$, may be formed to a small extent in the production of ammoniated superphosphate.

ARBORICULTURE - The cultivation of woody plants, those used for decoration and shade in particular.

ARTIFICIAL MEDIA - A manufactured substrate for growing plants in containers or beds, which can contain a variety of both organic and inorganic materials, but by definition excludes the use of soil. Also referred to as soilless media.

ATOM - The smallest division of an element that can be produced through chemical means. Atoms consist of a nucleus of protons and neutrons surrounded by a cloud of electrons. Elements are differentiated by the number of protons in the nucleus. The number of protons is known as the atom‘s atomic number.

ATOMIC WEIGHTMASS - The relative average mass of an atom, calculated as the average mass of its naturally occurring isotopes, to 1/12 of the mass of carbon-12.

AVAILABLE NUTRIENT IN SOIL/MEDIA - In regard to plant nutrition, the form of a nutrient capable of being assimilated by a growing plant at rates and amounts significant to plant growth. The available forms for some of the important macronutrients are:

- Available nitrogen - Water-soluble nitrogen plus that which can be made soluble or converted into free ammonia.
- Available phosphoric acid - Water-soluble phosphoric acid plus that which is soluble in ammonium citrate.
- Available potash - Water-soluble potash plus that which is soluble in a solution of ammonium oxalate.

AVAILABLE WATER CAPACITY (AWC) - The percent by volume of a soil or growing medium that is comprised of water that is available to a plant, calculated by subtracting the unavailable water (see PERMANENT WILTING PERCENTAGE - PWP) from the container capacity.

BAGASSE - A organic material, that can be used as a component of growing media or as a biofuel, that is produced from the fibrous material that remains from the processing of juice from sugarcane or sorghum.

BARK - An organic material from the bark of hardwood or softwood trees that can be used as a component of growing media that has typically been hammer milled, screened to size, and composted prior to use.

BASE - A class of substances in chemistry will form hydroxide ions (OH^-) in aqueous solutions, resulting in pH >7. In chemical reactions, these substances can act as proton acceptors and will dissociate (break apart) ionic bonds.

BASE EXCHANGE - The replacement of the cations held in the soil complex by other cations. (Also see CATION EXCHANGE CAPACITY)

BASIC - Having a pH >7.0, sometimes also called alkaline.

BASIC (FORMING) FERTILIZERS - A nutritional amendment that will cause an increase in pH when applied to the soil/growing media. A fertilizer is basic primarily due to its nitrate content, a common basic forming fertilizer is ammonia (NH_3).

BASIC SLAG - A by-product from the manufacturing of steel that contains lime and phosphate. Basic slags may contain from 10-17% phosphorus oxide (P_2O_5), 35-50% calcium oxide (CaO) and 2-10% magnesium oxide (MgO). Most American slag has an available phosphate content in the range of 8-10%. Slag may also contain small amounts of plant nutritional elements such as sulfur, manganese, and iron.

BASIC SOIL/MEDIA - See ALKALINE SOIL/MEDIA.

BEST MANAGEMENT PRACTICES (BMP) – Practical growing practices that work to minimize environmental contamination of agricultural inputs such as fertilizers and pesticides.

BICARBONATE - An intermediate form in the deprotonation of carbonic acid, with the chemical formula HCO_3^-, that plays an important role in the pH buffering system. Water with a pH between 7.4 and 9.3 will have bicarbonate as the main form of carbonic acid present.

BONEMEAL - A plant and animal nutritional supplement produced by grinding cooked animal bones. Raw bone meal contains the gelatin and glue portions, while cooked bone meal has been steamed under pressure to dissolve out part of the gelatin.

BOOM SYSTEM - An irrigation system where the watering nozzles are mounted on an overhead framework that moves over the plants to irrigate the plants from above.

BRAND - The word, name, or symbol that has been assigned by a manufacturer to a particular fertilizer product, particularly one that has been legally registered as a trademark.

BRIMSTONE - Another term for sulfur.

BRINE WATER - Water that is very high in solutes, and may also refer to the byproduct or wastewater from a purification system.

BUFFER CAPACITY OF SOIL - The measured amount of a soil's ability to resist a change in pH (hydrogen ion concentration) when an acid forming or a base forming material is added.

BUILDER'S LIME - See HYDRATED LIME.

BULK BLENDING - The practice of mixing dry individual granular fertilizer materials to make a fertilizer product mixture of granular materials rather than a singular granulated product. Bulk blending allows for custom rates of individual nutrients to be applied in a single application of dry fertilizer to a field or crop.

BULK DENSITY - The ratio of the mass of dry soil to its bulk volume, expressed as grams per cubic centimeter (g/cm^3) or pounds per cubic foot (lb/ft^3), also sometimes referred to as apparent density. The bulk density is numerically equal to apparent specific gravity or volume weight.

CALCAREOUS SOIL - A soil that contains large amounts of free calcium carbonate, enough calcium carbonate to effervesce (fizz) when treated with dilute hydrochloric acid. Such soils usually having a pH of 7.6-8.3, and are commonly found in the southwestern portion of the United States and other areas of low rainfall.

CALCINED CLAY - Clay that has been hardened through firing (calcined), crushed, and screened to size for use as an inorganic growing media component.

CALCITIC LIME - Also called calcitic limestone, it is a liming material derived from calcite that is composed of calcium carbonate ($CaCO_3$), and in its pure form will contain 40% Ca.

CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT - The amount of calcium carbonate needed to neutralize the acidity, or the amount required to produce the same amount of alkalinity, as produced by a given quantity of fertilizer product.

CAPILLARY ACTION - The method for the movement of a liquid through very narrow spaces, such as capillary pores, without the assistance of and very often in opposition to external forces, including gravity. This type of movement depends instead on intermolecular forces; the adhesive force between the liquid and the solid surface and the cohesion forces within the liquid it's self. In the case of very small tubes, or capillary pores, the diameter of the space is small enough that these intermolecular forces will draw, or wick, the liquid lifting it against gravitational forces. Some subirragation and drip systems utilize this force to wet growing media.

CAPILLARY MAT IRRAGATION SYSTEM - A method of subirrigation where containerized plants are grown on top of and in direct contact to a mat of adsorbant material that allows the movement of irrigation water into the container through capillary action.
CARBOHYDRATE - An organic compound constructed only of carbon, hydrogen and oxygen, usually the ratio of hydrogen and oxygen per compound occurs at a ratio of 2 to 1, such as in glucose ($C_6H_{12}O_6$).

CARBON:NITROGEN RATIO - The ratio of the percent organic carbon to nitrogen.

CARBONATE - A salt of carbonic acid, CO_3^{-2}, formed when carbonic acid is completely dissociated. In a solution with a pH of 10.3 or greater carbonate is present in a greater concentration then carbonic acid.

CARBONIC ACID - A solution of dissolved carbon dioxide in water, with the formula H_2CO_3. This week acid dissociates into carbonates and bicarbonates. At pH of 6.4 or below carbonic acid present at a greater concentration then carbonate.

CATION - An ion with a net positive charge. Some common soil cations; calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+}), potassium (K^{+}) and hydrogen (H^{+}).

CATION EXCHANGE CAPACITY(CEC) - The maximum amount of cations that a soil can absorb by through the process of cation exchange. The measured values of cation exchange capacity depend somewhat on the method used for the determination but are usually expressed as milliequivalents per 100 grams. In plant nutrition the cation exchange capacity is used as a measure of the nutrient holding capacity of a soil/media for cationic nutrients such as potassium (K^{+}), ammonium (NH_4^{+}), and calcium (Ca^{+2}).

CATION EXCHANGE RESIN- An ion exchange resin that has been charged with cations. In the process of water softening, a cation exchange resin charged with sodium (Na^{+}) is used to remove magnesium (Mg^{+2}) and calcium (Ca^{+2}). In the process of water purification, resins charged with sodium or potassium are used to remove poisonous cations, e.g. copper ($Cu^{+}/^{+2}$), and heavy metals, e.g. (lead (Pb^{+2}) and cadmium (Cd^{+2}).

CELLULOSE ACETATE MEMBRANES- A semipermeable membrane built from the synthetic polymer cellulose acetate. These membranes are used in reverse osmosis water purification systems. They are sensitive to pH but are resistant to chlorine.

CHELATE- The product of binding between a molecule or an ion and a metal ion through the process of chelation. They are formed from the metal ion and an organic compound, known as a chelating agent, which have an affinity for metal ions. These molecules have a ringed structure consisting of two nonmetal ions attached by coordinate bonds to the metal ion. The micronutrients iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), calcium (Ca), and magnesium (Mg) are can be held in one of these structures. Chelates are used with alkaline soil/media/water to keep Fe, Zn, Mn, and Cu soluble.

CHELATING AGENT- An organic molecule that is able to form two or more coordinate (dipolar) bonds with a metal ion, creating a molecule with a ringed structure. Some common chelating agents in fertilizers are; ethylenediaminetetraacetic acid (EDTA), hydroxyethylenediaminetriacetic acid (HEDTA), and diethylenetriaminepentaacetic acid (DTPA), and citric acid.

CHLORINATION - The process of adding chlorine to water as a method of water purification.

CHLOROSIS - A yellowing of the green portions of a plant, the leaves in particular, which is a common symptom of many nutrient deficiencies.

CITRATE - A salt or ester derived from citric acid. It can be used as a week chelating agent for the micronutrients iron, zinc, copper and magnesium.

CITRATE-SOLUBLE PHOSPHORIC ACID - The fraction of the phosphoric acid which insoluble in water but is soluble in neutral ammonium citrate. Since the fraction that is soluble in water is also soluble in ammonium citrate, "citrate-soluble" may be used to indicate the sum of water-soluble plus citrate-soluble phosphoric acid.

CLARIFIED WATER - Partially purified water, where only heavy sediments and floating debris have been removed.

CLARIFIER - Used in the process of water purification, it is a large tank, pit, or basin where the colloidal material is removed. In these containers, the water velocity is kept low to allow the floc to settle to the bottom of the tank so the clear water can be drawn off the top.

COAGULANT - A substance that causes or aids in the process of coagulation, which is the transformation of a liquid or gel into a solid state. In the process of water purification, coagulants such as aluminum sulfate are used to remove colloidal clay.

COATED FERTILIZERS - Fertilizer materials, commonly urea, which are coated so as to slow the release of the fertilizer. The most commonly used coating material is sulfur, but resins and thermoplastics are also used.

COEFFICIENT OF UNIFORMITY (CU) - A rating system for the uniformity of water delivery in. an irrigation system. The result are given as a percent uniformity, where a rating of 100% means the system would provide a uniform coverage of irrigation water for the given area and is considered to be highly effective, but a rating of 80% or above is still considered acceptable.

COIR FIBER - A natural fiber produced from coconut husks which is used as an organic component in growing media.

COLLOID - A substance that is dispersed throughout another substance on a microscopic level. In regards to soils, it refers to a soil particle having a diameter ranging from 0.20 to 0.005 micron. They may be inorganic or organic, and are characterized by a high base exchange.

COLLOIDAL SOLUTION - A solution where one substance is suspended in another substance on a microscopic level.
COMPLETE FERTILIZER - A fertilizer containing, in sufficient amounts to be of value as nutrients, all three of the primary fertilizer nutrients; nitrogen, phosphate and potash.

COMPOST - A mixture that consists largely of decayed organic matter, which is used to fertilize and condition soils.

COMPOSTING - A process for partially decomposing organic matter into humus.

COMPOUND - A substance consisting of two or more different elements.

CONCENTRATION - The volume of a constituent of a mixture divided by the total volume of the mixture, stated in o/o, o/oo, or ppm.

CONDITIONER (of fertilizer) - A substance which is added to fertilizers in order to prevent caking and which keeps it free-flowing.

CONDUCTIVITY METER - An instrument which is used to measure the electrical conductivity of a solution. It is also sometimes referred to as a solu-bridge or salts meter.

CONDUCTIVITY, ELECTRICAL - A measurement of the readiness with which a medium transmits electricity. This measurement is commonly used as an expression of the salinity of irrigation waters and soil extracts, as it can be directly related to salt concentration. It can be expressed as decisiemens per meter (dS/ m), millisiemens per centimeter (mS/ cm), or millimhos per centimeter (mmhos/ cm), at 25°C.

CONTAINER CAPACITY - The maximum amount of water a soil/media can hold, which is expressed as a percent by volume (volume/volume). The soil/media must be completely saturated and then drained of excess water, so only the water held by the substrate is measured. It is also referred to as the water holding capacity, and when referring to field soils it is referred to as field capacity.

CONTAINER STOCK - Nursery plants which are grown entirely in containers, as opposed to being transplanted from the field.

CONTROLLED-RELEASE FERTILIZER (CRF) - A fertilizer designed to release nutrients over a period of time. The rate of release, which can take weeks to months, is based either on low solubility, biological breakdown, or the presence of a semipermeable coating.

CRITICAL DEFICIENCY LIMIT - The lowest level of nutritional content required for tissue growth that will allow for growth without deficiencies.

CRITICAL TOXICITY LIMIT - The highest level of nutrient content required for tissue growth that will not result in toxicity.

CURING - The process of storing superphosphate or mixed fertilizers until the chemical reactions have run, or almost run, to completion.

CYTOPLASM - The portion of the protoplasm of a cell found outside the nucleus.

DAMPING-OFF - The sudden wilting and death of plant seedlings, as the result of an attack by microorganisms.

DECISIEMEN PER METER (dS/m) - A unit for the expression of electrical conductivity, where:
dS/m = one mS/cm = one mmhos/cm = (p.m./700).

DEFICIENCY - When the concentration of a nutrient is low enough to cause decreased growth or damage to the plant. There are often visual symptoms that will indicate a nutritional deficiency.

DEIONIZATION - Generally speaking, the removal of ions, but typically used in respect to the removal of ion from water. This method of water purification is typically achieved through the use of ion exchange resins or columns, which substitute the cations, present with H^+ and the anions for OH^-.

DENITRIFICATION - The reduction of the oxidized forms of nitrogen, such as nitrates or nitrites, in a soil or organic deposit by bacterial agents to lower oxides of nitrogen. This process ultimately results in the formation of dinitrogen (N_2) gas, which is released into the atmosphere.

DIFFUSION -A passive method of incorporation of a substance, liquid or gas, into another. This is due to the principal of a concentration gradient, as molecules will naturally move from regions of higher to lower concentrations.

DISTILLATION - A method of physical separation of a mixture, based on the differing volatilities of its components. This method is used as a water purification process, where the water is heated until it vaporizes, leaving the impurities, which would have a higher vaporization point, and then condensed to produce purified water.

DOLOMITE - A light or white colored carbonate mineral composed of calcium magnesium carbonate [$CaMg(CO_3)_2$]. It is used as a lime in situations where magnesium and calcium are also needed, as pure dolomite is 13.1% Mg. The term is sometimes used incorrectly for dolomitic lime, which is limestone containing some amount of dolomite.

DOLOMITIC LIME - A liming material containing both calcite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$]. While any lime that contains Mg from dolomite is a dolomitic lime, the concentration of Mg can vary from 1.3-11.7%.

DRIP IRRIGATION - A type of irrigation system where the water is applied to the surface of the soil/growing media by small nozzles, emitters, or tubes placed below the plant canopy. See LOW-VOLUME IRRIGATION.
DTPA - Diethylene triamine pentaacetic acid, also known as pentetic acid, is a polyamino carboxylic acid which can be considered an expanded version of EDTA. It has a high affinity for metal cations so it is used in many chelated liquid fertilizer as a chelating agent for ferric iron (Fe^{+3}) in acid to slightly alkaline soils.

EBB-AND-FLOW FLOODED FLOOR SYSTEM - An ebb-and-flow subirrigation system in which the flood containers are specialized molded concrete floors.

EBB-AND-FLOW SUBIRRAGATION SYSTEM - A type of subirragation system for containerized plants where they are grown in watertight areas, called the flood container, which can be alternately be flooded or drained of nutrient solution when necessary. This irrigation system may be referred to as ebb & flow, ebb-and-flood, flood irrigation, and pulsed sub irrigation.

EBB-AND-FLOW TRAY SYSTEM - A type of subirrigation system in which the flood containers are water tight trays, usually placed on benches.

EC_e - The electrical conductivity of a saturated soil extract.

EC_w - The electrical conductivity of water.

ECOLOGY - A branch of biology that deals with the mutual relations among organisms and between organisms and their environment.

DIFFUSION -A passive method of incorporation of a substance, liquid or gas, into another. This is due to the principal of a concentration gradient, as molecules will naturally move from regions of higher to lower concentrations.

EDDHA - (Ethylenediaminetetraacetic-o-hydroxyphenylacetic acid) A chelating agent with an affinity for ferric iron (Fe^{+3}) which can be used on highly alkaline soils/media but is very expensive.

EDTA - (Ethylenediaminetetraacetic acid) A chelating agent used improve the solubility of ferric iron (Fe^{+3}) in slightly acid soils/media and in many chelated liquid fertilizer formulations and hydroponic nutrient solutions.

ELECTRICAL CONDUCTIVITY (EC) - The measurement of a materials ability to conduct an electrical current. In respect to plant nutrition, EC is used to determine the conductivity of a solution, either a fertilizer, water, or soil extract. The EC of a liquid is dependent on the concentration of dissolved or suspended ionic solutes, so where salt water would be an effective conductor with a high EC deionizer water would act as an insulator and have an EC of 0. Each dissolved salt has its own unique conductivity, making EC an approximation of the actual salt content of a solution [ppm = (ds/m)(700)].

The preferred units for expressing EC are deciSiemen/meter (ds/m), they may also be expressed as milliSiemen/centimeter (mS/cm), millimhos/centimeter (mmhos/cm), EC × 10^{-3}, or micromhos/centimeter (μmhos/cm).
ELECTRODIALYSIS - A system for removing salt ions from one solution and moving them to another through an electrically charged ion-exchange membrane which is used as a water purification process.

ELECTROLYTES - A compound which ionizes when dissolved in a solvent, like water. This process forms a solution capable of conducting of electricity due to the charged ions in solution.

ELEMENT (CHEMICAL) - A chemical substance consisting of one type of atom. There are currently 118 identified chemical elements, which are listed as a periodic table of elements. They are divided into three groups, metals, metalloids, and non-metals.

ELEMENTAL GUARANTEES - See GUARANTEES.

ELEMENTAL SULFUR - A relatively pure form of sulfur, which forms a bright yellow crystalline structure. While elemental sulfur was once extracted from salt domes, where it can be found naturally in an almost pure form, it is currently produced as a byproduct of natural gas and petroleum processing. In regards to plant nutrition, it is used to as a source of the plant nutrient sulfur and to decrease the pH of an alkaline soil/media.

EMULSION - A heterogeneous mixture of two or more liquids.

ENVIRONMENT - The external conditions, which act upon an organism or soil to influence its development. This includes sunlight, temperature, moisture, as well as other organisms.

ENZYMES - Protein substances produced by living cells which can change the rate of chemical reactions; an organic catalyst.

EPSOM SALT - The naturally occurring inorganic salt magnesium sulfate ($MgSO_4 \bullet 7H_2O$), which can be used in regards to plant nutrition as a source of magnesium and sulfur which will not alter the pH of the soil/media.

Equilibrium reaction (pH_c) - A mathematical measure similar to pH, but it also takes into account the alkalinity, calcium, magnesium, carbonate, and bicarbonate content of water.

EQUIVALENT (eq, Eq,)- A unit describing the amount of a substance needed to react with or supply one mole of hydrogen in an acid-base reaction or which will react or supply one mole or electrons in a redox reaction. This means that one mole of a monovalent cation would contain one equivalent of positive charges, whereas one mole of a divalent cation would contain two equivalents of positive charges, for example:

- H^{+}+Cl^{-}→HCl
  Where the ratio of hydrogen:chlorine is 1:1, making 1eq. chlorine = 1 mole
  (continued on next page)
- Ca^{+2} +2(Cl^{-})→$CaCl_2$
  Where the ratio of calcium:chlorine is 1:2, making 1 eq of calcium = 0.5 mole

Equivalents can also be calculated as measure of weight, where the weight of one equivalent is equal to the weight of the atomic weight (in grams divided by the valence.

40 g/mol= 20 g/eq. . . . . 2 eq/mol

EQUIVALENT WEIGHT - The weight of one equivalent of an element or molecule, which is calculated by dividing the atomic or formula weight by the valence.
Univalent cation: KCl 1 eq.= 74.6 g
Bivalent cation: $MgSO_4$: 1 eq.= 60 g
Oxygen 1eq.=7.9 g

EROSION - The wearing, detachment, and transport of soil and rock materials away from the land surface through moving water, wind or other geological agents.

ESSENTIAL ELEMENT - One of the 17 elements that is necessary for a plant to produce normal growth, to develop completely, and to complete its lifecycle. The essential elements are: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl), and nickel (Ni).

EVAPOTRANSPIRATION (ET) - The loss of water from a soil by the mechanisms of evaporation and transpiration.

EXCHANGEABLE IONS - Ions that are held on the soil complex which may be replaced by other ions of like charge. Those ions that are bound too tightly to be exchanged are called *nonexchangeable*.

EXCHANGEABLE SODIUM PERCENTAGE - The degree of which the soil exchange complex is saturated with sodium, as calculated by the formula:
ESP =100Cation exchange capacity (me/100 g soil)
Exchangeable sodium (me/100 g soil)

EXPRESSED SAP TISSUE TESTING - The nutritional analysis of a plant's sap, which is typically performed in the field or greenhouse using a testing kit. This method is most useful for monitoring nitrogen, phosphorous, and potassium levels, but may not be particularly accurate in regards to some of the micronutrients.

FALLOW - Soil left idle in an effort to restore productivity, mainly through accumulation of water and/or nutrients. Bush or forest fallow is a period of rest under woody vegetation between crops. Summer fallow is a common stage before cereal grain in regions of limited rainfall. The soil is tilled for at least one growing season to control weeds, to aid decomposition of plant residues and to encourage the storage of moisture for the succeeding grain crop.

FERRIC - The form trivalent form of iron (Fe^{+3}), and is the most common form of iron. Ferric iron is insoluble in an aerobic environment unless it forms a chelate complex.

FERROUS - The divalent form of iron (Fe^{+2}), which is the primary form of iron that plants absorb. It is only present in significant concentrations in acidic or waterlogged soil/media conditions.

FERTIGATION - The application of soluble fertilizers and other amendments through irrigation water, a process that can also be referred to as liquid feed.

FERTILIZER - A natural or manufactured material that is added to a soil to supply one or more plant nutrients. This term is generally applied to largely inorganic materials, other than lime or gypsum.

FERTILIZER ANALYSIS - The sequence of three numbers present on all fertilizer labels which indicates the percent composition by weight of $N\text{-}P_2O_5\text{-}K_2O$ in the fertilizer.

FERTILIZER FORMULA - The quantity and grade of the materials used to make a fertilizer mixture.

FERTILIZER GRADE - An expression of the percentage (%) of plant nutritional compounds in a fertilizer, by weight. Thus, a 10-20-10 grade contains 10% nitrogen (N), 20% phosphorus oxide (P_2O_5) and 10 percent potash (K_2O).

FERTILIZER INJECTOR - A device which injects a small amount of concentrated fertilizer into the water stream of an irrigation line which produces a predetermined concentration of plant nutrients in the irrigation water. This system typically operates based on a ratio or proportions varying from 1:15 to 1:400 of fertilizer concentrate to irrigation water.

FERTILIZER RATIO - The relative proportion of primary plant nutrients, as $N\text{-}P_2O_5\text{-}K_2O$, in a fertilizer grade, reduced to the least common denominator; e.g., grades 10-6-4 and 20-12-8 have the ratio 5-3-2.

FIELD MOISTURE CAPACITY - The moisture content of soil in the field two or three days after a thorough wetting of the soil profile by rain or irrigation water which is expressed as moisture percentage on a dry-weight basis.

FIFTEEN-ATMOSPHERE PERCENTAGE - The moisture percentage, on a dry-weight basis, of a soil sample, which has been wetted and brought to equilibrium in a pressure-membrane apparatus at a pressure of 221 psi. This characteristic moisture value approximates the lower limit of water available for plant growth in a soil. (See also PERMANENT WILTING PERCENTAGE.)

FIXATION - The process by which previously available plant nutrients are rendered unavailable or "fixed" in the soil. Generally, potassium, phosphorus, and ammonium are rendered unavailable in the soil through this process. It can also be defined as the process by which free nitrogen is either naturally or synthetically chemically combined. (See also REVERSION and NITROGEN FIXATION.)

FLOODED FLOOR - See ebb-and-flow flooded floor system.

FLORICULTURE- The production of foliage or flowering ornamental plants materials, in field or greenhouse setting, for commercial sale.

FOG SYSTEM - An irrigation system that disperses water as fine droplets, which are small enough to stay suspended in the air for a period of time. These systems are used to deliver water in propagation setting, where the plant material would be easily disturbed, but they are used more. for humidity and temperature control in a greenhouse setting.

FORAGE - Plant material, which is used to feed domesticated animals. This term generally refers to unharvested plant material, which is consumed directly by the livestock, but can also refer to plant material which has been harvested, like hay or silage, which is fed directly to the livestock.

FRIT - A ceramic compound that has been heated in a specialized fusing oven, quenched in water to form a glass, then ground. In reference to plant nutrition, frit refers to a type of slow release fertilizer in which the nutritional elements, typically potassium or iron, have been impregnated into the powered glass.

GRADE - A guaranteed analysis of a fertilizer containing one or more of the primary plant nutritional elements. Grades are stated in terms of the guaranteed percentages by weight of nitrogen (N), phosphorus oxide (P_2O_5) and potassium oxide (K_2O), and always in that order. For example, a 20-10-5 grade would contain 20% N, 10% P_2O_5, and 5% K_2O. (See also ANALYSIS).

GRAY WATER - See RECYCLED WATER.

GROUND COVER - Plants which are grown specifically for their low, spreading habit, in an effort to protect soils, prevent the growth of weeds, and/or for aesthetic purposes.

GROWING MEDIA - The substrate used to support the root growth of a containerized plant. The composition of the growing media varies widely, but it is typically highly amended and often a completely soilless mixture. It is sometimes also referred to as potting soil, soilless media, mix, or substrate. Some important characteristics of a growing media are that it has sufficient airspace, the ability to hold water, and the ability to hold plant nutrients.

GUANO - The decomposed and dried excrement of birds and bats, which is used as a fertilizer. The most commonly know guano comes from the islands off the coast of Peru, and is derived from the excrement of seafowl. It is high in nitrogen and phosphate and was a major fertilizer at one time in the United States.

GUARANTEES - The AAPFCO official regulation is as follows: "The statement of guarantees of mixed fertilizer shall be given in whole numbers. All fertilizer components with the exception of potash (K_2O) and phosphorus oxide (P_2O_5), if guaranteed, shall be stated in terms of the elements."

GYPSUM ($CaSO_4$•$2H_2O$) - The common name for calcium sulfate, which is a mineral used by the fertilizer industry as a source of calcium and sulfur. When pure, it contains approximately 18.6% sulfur. While gypsum cannot be used as a liming material, it may reduce the alkalinity of sodic soils by replacing sodium with calcium, so it has been used widely in the western United States to help reclaim sodic soils. Another common name is landplaster.

HALF-LIFE - The amount of time required for half of an initial amount of a substance to be used or decay.

HARDPAN - A hardened or cemented soil horizon or layer. The soil material may be sandy or clayey, and it may be cemented by iron oxide, silica, calcium carbonate or other substances.

HARD WATER - A water that is has a high mineral content, particularly multivalent cations and most commonly calcium (Ca^{+2}) and/or magnesium (Mg^{+2}).

HEDTA - (N-(hydroxyethyl)-ethylenediaminetriacetic acid) A chelating agent with an affinity for ferric iron (Fe^{+3}) used under moderately alkaline soil conditions. It is also abbreviated as HEEDTA.

HOAGLAND SOLUTION - A nutrient solution containing all essential plant nutrients, which used for hydroponically grown plant, originally developed by Professor Hoagland at the University of California.

HOLLOW FIBER MEMBRANES - A type of membrane used in water purification, which consists of a mass of hollow microtubes with porous walls which allows for the quick filtration of large particulates, macromolecules, and bacteria.

HORIZON SOIL - A layer of soil, approximately parallel to the soil surface, that has distinct characteristics produced by the soil-forming processes.

HORTICULTURE - The science of the production and utilization of ornamental plants, fruits and vegetables.

HUMUS - The well-decomposed, and more or less stable, portion of the organic matter in mineral soils.
HYDRATED LIME - A type of liming material consisting of calcium hydroxide [$Ca(OH)_2$], which reacts quickly to raise the pH of the substrate.

HYDROGEN ION CONCENTRATION - (See pH).

HYDROLYSIS - A chemical reaction where the presence of water causes the separation of chemical bonds. For example, the degradation of calcium carbonate to calcium hydroxide. and carbonic acid:
$CaCO_3 + 2(H^+) + (OH^-) \rightarrow Ca(OH)_2 + H_2CO_3$

HYDROPONICS - The production of plants in a liquid solution or gravel medium which is supplemented with all of the required nutrients for proper growth and development.

HYDROXIDE - A diatomic anion formed from a covalently bonded oxygen and hydrogen (OH^-).

HYDROSCOPIC - Has the capacity to take-up moisture from the air.

IMMOBILE - A term used to describe a nutrient's ability to be translocated with in a plant. A nutrient that is immobile cannot be translocated from old tissue to new growth, so deficiencies in these types of nutrients present in the new growth first.

INORGANIC - Substances that occur as minerals in nature or are obtainable from them through chemical means. Referring to all matter except the compounds of carbon, but including carbonates. When referring to the components of a growing media it is used to describe mineral, synthetic, or other non- biological materials, such as perlite, vermiculite, and sand.

INSOLUBLE - Not soluble. In regards to phosphoric acid in fertilizer: that which is soluble neither in water nor in neutral ammonium citrate. In regards to potash and nitrogen: not soluble in water.

INTEGRATED PEST MANAGEMENT (IPM) - An approach to pest management which combines multiple practices and methods of pest damage control, including variety selection, economic considerations, cultural control, sanitation, timing of planting, biological control, pesticides, etc. The emphasis of this practice is to grow a healthy crop while creating the least amount of damage or disruption to the surrounding ecosystems by focusing on the control, and not eradication of pests, through preventative measures, monitoring, the use of mechanical and biological controls, and the responsible use of pesticides.

INTERVEINAL -The area of plant tissue between the veins of a leaf.

ION - A particle, either an element or combination of elements, where the number or electrons is greater or less then the number of protons giving it a positive or negative electrical charge respectively. Ions with a positive charge are called cations, and those with a negative charge are called anions. As used in regards to soils, this typically refers to the products of the break-down of an electrolyte in solution. As most soil solutions are very dilute, many salts are present as ions. For example: all or part of the potassium chloride (muriate of potash) content of most soils exists as potassium and chloride ions.

ION EXCHANGE RESIN - An organic insoluble polymer matrix, typically in the form of a small (0.5-1.0 mm) porous bead that has active binding sites that have been "charged" with a solution of ions, either cations or anions. These resins are commonly used in the process of water softening and purification where they are able to remove the undesirable ions by substituting them for benign ones through the process of preferential migration.

KELP - Any of several species of seaweed, which are sometimes harvested for, use as a fertilizer. Dried kelp typically contains 1.6-3.3% N, 1-2% P_2O_5, and 15-20% K_2O.

LEACHING - The removal of water-soluble nutrients, salts, pesticides, and other compounds by water, through rain or irrigation. It can occur from media and soils through rain and irrigation, or through the plant tissue when under mist as cuttings.

LEACHING POTENTIAL - Theprobability that a pesticide will leach through a soil and contaminate surrounding water sources. This is dependent on properties of both the pesticide and the soil/media it is being applied to, for example a water-soluble fertilizer has a higher leaching potential as will a pesticide applied to a sandy soil.

LEACHING REQUIREMENT (LR) - The percent of the irrigation water applied that. required to flush out of the root zone to reduce the buildup of excess salts that would be detrimental to crop production. The target range is dependent on the salinity tolerance of the plant and is calculated based on the EC of the soil/media and that of the irrigation water. The formula for a leaching requirement is:

$LR = Ecw/[5/(ECe-ECw)]$

Where ECw is the EC of the irrigation water, ECe is the EC of the soil extract, which accounts for the salinity in the soil as well as the salinity present in the irrigation water.

LIGNOSULFONATE - Water soluble anionic polymers which are the byproducts of the sulfite pulping process for producing wood pulp. In regards to plant nutrition, they are used as chelating agents for iron, manganese, copper, and zinc.

LIME - In strict terminology, lime refers to calcium oxide (CaO), but is also used to describe all limestone-derived materials which are applied to neutralize acid soils. Generally the term *lime*, or *agricultural lime*, refers to ground limestone (calcium carbonate), hydrated lime (calcium hydroxide) or burned lime (calcium oxide) with or without mixtures or magnesium carbonate, magnesium hydroxide or magnesium oxide. It also applies to materials such as basic slag which are used a amendments to reduce the acidity of acid soils. Commonly used liming materials include calcitic lime, dolomitic lime, dolomite, and hydrated lime. It can also be referred to as limestone.

LIME REQUIREMENT - The amount of standard ground limestone required to bring a 6.6-inch layer of an acre (about 2 million pounds in mineral soils) of acid soil to a specified lesser degree of acidity, typically slightly or very slightly acid. In common practice, lime requirements are given in tons per acre of nearly pure limestone, ground finely enough so that all of it passes a 10-mesh screen and at least half of it passes a 100-mesh screen.

LIMESTONE - See lime.

LIQUID FERTILIZER - A fluid in which the plant nutrients are in a true solution.

LOAM - The textural class of soil that has a moderate amount of sand, silt and clay. Loam soils contain 7-27% clay, 28-50% silt, and <52% sand. In the old literature (particularly English literature) the term loam applied to mellow soils rich in organic matter, regardless of the texture. As used in the United States, the term refers only to the relative amounts of sand, silt and clay; loam soils may or may not be mellow.

LOW-VOLUME IRRIGATION - Irrigation systems that are designed to apply water in or near the rooting zone in relatively precise amounts with respect to the plants needs. This category includes drip, micro sprinklers, misters and fogger systems.

LUXURY CONSUMPTION - The uptake of an essential nutrient by a plant in amounts that exceed what is needs. For example, if potassium is abundant in the soil, alfalfa may take in more than is required.

MACRONUTRIENTS - Nutrients that plants require in relatively large amounts. The macronutrients in plant nutrition are: nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur.

MAJOR ELEMENT - See macronutrient.

MANURE - As a general term, the refuse from stables and barnyards including animal excreta, straw or other litter. In some other countries, the term manure is used more broadly and includes both farmyard or animal manure and “chemical manures,” for which the term fertilizer is typically used in the United States.

MARL - An earthy deposit, which consists mainly of calcium carbonate, and is commonly mixed with clay or other impurities. It is formed chiefly at the margins of freshwater lakes, and is commonly used for liming acid soils.

MATRIC POTENTIAL -The negative pressure, or tension, that occurs in a soil/media due to the adhesive intermolecular forces that develop between the moisture and the surface of the soil/media particles and within the capillary pores of the soil/media. It can be related to water content by a moisture retention curve. This force is measured in

Pascals (preferred method), bars, or atmospheres of pressure. It can also be referred to a moisture tension, matric tension, and matrix potential/tension.

MICRONUTRIENT MIX - A commercial fertilizer formulated to provide two or more of micronutrients.

MICRONUTRIENT - Nutrients that plants need in only small or trace amounts. The essential micronutrients are: boron, chlorine, copper, iron, manganese, molybdenum nickel, and zinc.

MILLIEQUIVALENT or MILLIGRAM EQUIVALENT (me) - A one-thousandth of an equivalent. This term is used to express the concentrations of nutrients and salts in growing media, soil, and in plant analyses. In the case of sodium chloride, 1 me would be 0.023 gram of sodium and 0.0355 gram of chloride in 1 liter of water.

MILLIGRAM PER LITER (mg/L) - A common expression for the concentration of a liquid solution as well as the metric equivalent of parts per million (ppm).

MILLIMHOS PER CENTIMETER (mmhos/cm) - A unit of measurement which used to be the unit to express electrical conductivity, but has fallen out of use and has been replaced with deciSiemen/meter (dS/m) which is numerically equal to mmhos/cm. The term represents one-thousandth of a mhos per centimeter.

MINERALS - A naturally occurring inorganic solid that can be represented by a chemical formula and has an ordered atomic structure.

MOBILE - A term used to describe a nutrient's ability to be translocated with in a plant. A nutrient that is mobile is readily translocated from old tissue to the new growth of a plant. Deficiencies of nutrients that are mobile always occur in the old tissue first.

MOBILITY- An elements ability to move from one location to another. If a nutrient is mobile it will retranslocate (move) from old tissue to new growth while a nutrient that is immobile will not.

MODEL-BASED IRRAGATION CONTROL - An automated irrigation system that waters based on the calculated amount of water loss found through mathematical modeling, using a model that accounts for environmental and plant requirement factors.

MOISTURE CONTENT - The amount of water being held within a material, like a soil/ media or plant tissue. See MATRIC TENSION.

MOISTURE RETENTION - The ability of a soil/media to hold onto moisture. Retentiveness is dependent upon the type and percentage of materials the soil/media is comprised of, and it is generally expressed as a percentage.

MOISTURE TENSION - The force, as a negative pressure, which holds water with in a soil/growing media and in plants. It can be measured in bars, Pascals, or atmospheres of pressure.

MOLER CONCENTRATION (M) - The amount of a substance, in moles, in a volume. A one molar (1M) solution contains 1 mol/L of a substance.

MOLE (mol) - A relative unit of measurement for a quantity of a chemical substance used to allow for a constant method for converting between the number of atoms and the weight in grams. It is used when describing a chemical reaction to denote an amount of a substance. It represents the quantity of a substance relative to the number of particles found in 12 g of carbon-12. There are $6.02x10^{23}$ particles in 12 g of carbon-12, which is referred to as Avogadro's number. e.g
KCI (potassium chloride), 1 mol = 74.6 g
$MgSO_4$ (magnesium sulfate), 1 mol=120 g

MOLECULAR WEIGHTMASS - The sum of the average mass of the atoms that make up one molecule of a substance.

MOLECULES - An electrically neutral compound of two or more covalently bonded atoms.

MUCK - A highly decomposed organic soil material developed from peat. Muck typically has a higher mineral or ash content than peat, and is decomposed to the point that the original plant parts cannot be identified.

MULCH - A material applied to the ground to prevent excessive drying of the soil surface, rapid changes in soil temperature, as a soil amendment, for decorative purposes, and/or to prevent weed growth.

MURIATE OF POTASH - Also called potassium chloride, this metal halide salt is used as a source of potassium in fertilizer production.

NECROSIS - A type of plant injury which results in the death of the injured tissue from external forces like an infection, exposure to toxins, or trauma. In regards to plant nutrition, these injuries can also be a result of many nutrient deficiencies and will cause brown, scorched, or dead areas on plant organs.

NEPHELOMETER - An instrument that measures the concentration of suspended particulates in a colloid. This is done by measuring the amount of light from the source light of the machine that is reflected by the particles in suspension onto a light detector, which is typically set up at a 90º angle from the source light. This machine is also sometimes referred to as a turbidimeter.

NEPHELOMETRIC TURBIDITY UNITS (NTU) - A standard unit of measurement for the turbidity a colloid. This measurement represents the concentration of suspended particles in the solution based on the amount of light that is scattered by the particulates but it also accounts for the color, shape, and reflective properties of the particles to some extent. NTU is measured with a nephelometer using formazin as a reference standard.

NEUTRAL FERTILIZERS - A fertilizer that does not significantly alter the pH of a soil or growing media when applied.

NEUTRALIZATION - A chemical reaction between an acid and a base that forms a salt and, in many cases, water.

NITRATE - An inorganic nitrogen source in fertilizers, with the formula NO_3^-, which is the most stable form of nitrogen in most soils/growing media.

NITRIFICATION - The formation of nitrates and nitrites from ammonia (or ammonium compounds). In soils, this is performed by microorganisms in a two-step process. In the first step the bacterium *Nitrosomonas* converts ammonium (NH_4^+) is to nitrate (NO_2^-). In the second step the bacterium *Nitrobacter* converts the nitrite (NO_2^-) to nitrate (NO_3^-).

NITROGEN FIXATION - The conversion of free nitrogen to nitrogen compounds. In soils specifically, the assimilation of free nitrogen from the soil air by soil organisms and the formation of nitrogen compounds that eventually become available to plants. The nitrogen-fixing organisms associated with legumes are called symbiotic, while those not definitely associated with the higher plants are called non-symbiotic or free-living.

NONSALINE-SODIC SOIL - A soil which contains a high enough amount of exchangeable sodium to interfere with the growth of most plants, but which does not contain appreciable quantities of soluble salts. This means that the exchangeable sodium is <15%, the conductivity of the saturation extract is less than 4 deciSiemens/meter (at 25°C). The pH of one of these soils usually ranges between 8.5-10.0.

NORMAL SOLUTION (N) - A solution where there is 1 equivalent (eq.) of a substance for every liter of water.

NUTRICOTE - A brand of pelletized polymer resin coated controlled release fertilizer. It contains the essential macronutrients (N, P, and K) and micronutrients. The rate of release varies, with formulas available with release rates from 70 to 360 days.

NUTRIENT - A chemical necessary for an organism to live and grow that it must obtain from the surrounding environment. In regards to plant nutrition, the 17 essential elements for plant life and growth are: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl), nickel (Ni), carbon (C), hydrogen (H), and oxygen (O). While carbon, hydrogen, and oxygen are supplied through water or the air, the other 14 elements are supplied by the soil, growing media, or fertilizers.

NUTRIENT FILM TECHNIQUE (NFT) - A hydroponic method of sub-irrigation where the plants are rooted in cubes or containers in a shallow sloped trough in which a continuous flow of very shallow volume (ideally a "thin film') of nutrient solution runs, supplying water and nutrients to the plants.

NUTRIENT SOLUTION - See HOAGLAND SOLUTION.

NUTRIENT, PLANT - Any element taken in by a plant that is essential to its growth and is used by the plant in elaboration of its food and tissue.

NUTRITIONAL CHARTING - A method of monitoring plant nutrition by plotting the results of routine analysis to illustrate the changes in the nutritional levels over the life of the crop.

ORGANIC - Compounds with a carbon backbone, other than inorganic carbonates. Typically used to describe something biological in origin, but when used in reference to fertilizers it includes synthetically produced compounds, like urea, as well as natural plant or animal products, like manure. When the term is used to describe growing media components it generally refers to plant based products, like pine bark or peat moss.

ORGANIC SOIL - A general term applied to a soil or a soil horizon that consists primarily of organic matter. This includes peat soils, muck soils and peaty soil layers.

ORNAMENTAL HORTICULTURE - The branch of horticulture specializing in the areas of nursery stock production, floriculture, turfgrass management, and landscaping.

ORTHOPHOSPHATE - A salt of orthophosphoric acid (PO_4^{3-}). It can bind with ammonium, calcium, or potassium, where each molecule formed would contain a single phosphorus atom.

ORTHOPHOSPHORIC ACID - A mineral acid with the formula H_3PO_4, it can be used as a source of phosphorus and is also used in hydroponic pH solutions to lower pH.

OSMOCOTE® - A brand of resin-coated controlled release fertilizer. The fertilizers under this brand all contain the macronutrients N, P, and K but there are several specialized formulas marketed for vegetables, flowering plants, etc. The rate of release available for these fertilizers varies due to different coating formulations, ranging from a few months to over a year.

OVERHEAD IRRIGATION SYSTEM - A type of irrigation system designed to spray onto plants from above.

OXIDATION - The portion, or half-reaction, of a redox reaction in which an atom, molecule, or ion loses an electron, increasing its oxidation number. e.g.:
Ca (calcium) + O (oxygen)→ CaO (calcium oxide)
Fe^{+2} (bivalent iron ion)→ Fe^{+3} (trivalent iron ion) + 1 electron

OXIDE - A chemical compound which consists of a two different elements one of which is oxygen, eg calcium oxide (CaO), silicon dioxide (SiO_2), carbon dioxide CO_2, and water or dihydrogen oxide (H_2O).

OZONATION - A water treatment process that kills microorganisms through the introduction of ozone (O_3) into the wastewater.

PARENT MATERIAL - The loose material, such as rock or peat, from which the soil profile develops.

PARTICLE DENSITY - The average density of the soil particles, usually expressed in grams per cubic centimeter. It is sometimes referred to as real or grain density.

PARTS PER MILLION (ppm) - A unit used to describe the concentration of a substance on a per million basis. Because the unit describes the relationship of between quantities it has no associated unit of measurement and can be used to describe a concentration by weight, volume, or number. The metric equivalent of this unit, which is commonly used in plant nutrition, is mg/L.

PASCAL - A unit of measurement of pressure tension. In soil science it is commonly used to express the matric or moisture tension in soil/growing media, as expressed as megaPascals (Mpa, i.e., 1 million Pa) or as kiloPascals (Kpa, i.e., 1 thousand Pa) in soilless growing media, where 1 megaPascal = 10 bar = 9.87 atmospheres = 7500 mm Hg = 145 psi of pressure and 1 kiloPascal = 0.01 bar = 0.00987 atm = 7.5 mm Hg = 0.145 psi.

PEAT - Partially decomposed mosses, reeds, and sedges harvested from wet, swampy areas which is used as a component of, or sometimes directly as, a growing media. The most commonly used and highest quality peat is *Sphagnum* peat from bogs in Canada and northern Europe, but hypnum and reed-sedge peat is also used.

PEAT MOSS - See PEAT.

PEAT-LITE MIX - A term used to describe a soilless growing media comprised of peat and either perlite or vermiculite. The first of these types of mixes were developed by Boodley and Sheldrake at Cornell University in the 1970's. A common name used to describe soilless growing media mixes containing peat and either.

PEARCHED WATER TABLE - An aquifer that occurs above the regional water table. This term can also refer to the segment of media at the bottom of a container that remains saturated with water even after all the drainage from the force of gravity has occurred

PERCOLATION - The process by which a fluid is filtered or trickled through a porous material, such as water's movements through a soil.

PERENNIAL PLANT - A plant whose lifecycle is longer than two years.

PERLITE - Alumino silicate volcanic rock that has been mined, crushed, screened to size, and then expanded into a lightweight, white aggregate by heating it to 1,800F (3215C) that can be used as a component or directly as an inorganic growing media. An

inorganic growing-media, component made from alumino silicate volcanic rock that is mined, crushed, screened to size, then is heated to 1,800F (3215C), which causes it to. expand into a lightweight, white aggregate.
PERMANENT WILTING PERCENTAGE - The percentage of soil moisture at which plants will wilt and fail to recover turgidity (at 15 atmospheres). The expression has significance only for non-saline soils. Typically, it is determined using dwarf sunflowers.

PERMEABILITY, SOIL - The quality of a soil horizon that enables water or air to move through it. It can be quantitatively measured as the rate of flow of water through a cross-sectioned unit of soil during a unit of time, at a specified temperature and hydraulic condition. The values for saturated soils usually are called their hydraulic conductivity. The permeability of a soil is controlled by the least permeable horizon, even though the others may be more permeable.

pH - (latin: *potentia hydrogenii*) A numerical descriptor of acidity or alkalinity, determined through the reciprocal logarithm of. the hydrogen ion concentration (where (H^+) 1 eq. - 1.g.) of a solution. A pH of 7.0 indicates precise neutrality, higher values from 7.1-14 indicate increasing alkalinity, and lower values from 6.9-0 indicate increasing acidity.

PHOSPHATE ROCK - A phosphate-bearing ore composed largely of tricalcium phosphate. Phosphate rock can be treated with strong acids or heat to produce available forms of phosphate, and finely ground rock phosphate is sometimes used in long-time fertility programs.

PHOSPHATE - A salt of phosphoric acid which is made by combining ions such as ammonium, calcium, potassium or sodium with phosphoric acid.

PHOSPHORIC ACID - Also known as orthophosphoric acid, it is a mineral acid with the chemical formula H_3PO_4. The solid form of phosphoric acid is phosphoric oxide (P_2O_5).

PHOTOSYNTHESIS - The conversion of light energy into chemical energy, which green plants harness using the pigment chlorophyll and use to combine water and carbon dioxide to form carbohydrates.

POLYAMIDE-TYPE MEMBRANES - A membrane built of polyamide polymers that is used in reverse osmosis in water purification systems, which is resistant to pH but sensitive to chlorine.

POLYPHOSPHATE - A salt of polyphosphoric acid, such as ammonium, calcium or potassium polyphosphate, containing multiple linkages of phosphorus in each molecule, which can be used as a source of phosphorus and also as weak chelating agent of the heavy metal micronutrients (Fe, Zn, Cu, Mn).

POLYPHOSPHORIC ACID - Condensed phosphoric acid to form one molecule, pyrophosphoric acid, ranging from 68-83% P_2O_5.

POLYSTYRENE - A synthetic polymer used to make Styrofoam.
POROMETER - An instrument developed by the North Carolina State University Horticultural Substrates Laboratory to determine the porosity of a soil/growing media.

POROSITY - The fraction of a volume of soil not occupied by soil particles.

POST PLANT FERTILIZER - The application of a fertilizer made to the plant/growing media after sowing or transplanting.

POTASH - Potassium oxide (K_2O).

POTENTIAL ACIDITY - The amount of calcium carbonate ($CaCO_3$), in pounds, estimated to be required to neutralize the acidity caused by adding 1 ton of an acid-forming fertilizer to soil/growing media. A fertilizer with a higher potential acidity will be more likely to cause the soil/growing media pH to decrease over time (i.e., become more acid).

POTENTIAL BASICITY - The amount of calcium carbonate ($CaCO_3$), in pounds, estimated to be equal to the addition of 1 ton of a base-forming fertilizer to the soil/growing media. A fertilizer with a higher potential basicity will more likely cause the pH of the soli/growing media to increase over time. (i.e., become more basic or alkaline).

POTTING MIX - A mixture of various organic and inorganic constituents, which can include soil that is used for growing plants in containers or beds.

PREPLANT FERTILIZER - The application of a fertilizer that is incorporated into the growing substrate prior to seeding, transplant, or potting. A fertilizer application incorporated into growing media prior to sowing seed, transplanting, or potting.

PRIMARY PLANT NUTRIENTS (plant foods) - Nitrogen (N), phosphate as phosphorus oxide (P_2O_5) and potassium as potassium oxide (K_2O).

PRODUCTIVITY - In simplest terms, the ability of the soil to produce. This differs from fertility to the extent that a soil may be fertile but still unable to produce due to other limiting factors.

PROFILE, SOIL - A vertical section of soil, which encompasses all of the horizons and extends into the parent material.

PROTEIN - A member of a group of high-molecular-weight nitrogen-containing compounds that yield amino acids on hydrolysis They are a vital part of living matter and are one of the essential food substances for animals.

PROTOPLASM - The jellylike substance found in plant and animal cells that is required for all life processes.

PUDDLED SOIL - Dense soil that is artificially compacted when wet causes it to have no regular structure. The condition is commonly a result of tillage or heavy traffic on a clayey soil when it is wet.

PULSED SUBIRRAGATION - See ebb-and-flow system.

QUICK LIME - See hydrated lime.

QUICK TESTS - Simple and rapid chemical tests designed to give an approximation of the nutrients available to plants from soils.

RADICAL - An atom, molecule, or ion that has one or more free covalent bonds due to an unpaired valence electron or an open electron shell. Because of this, they are very reactive, with few exceptions, towards other substances and themselves. An example of a radical is the hydroxyl radical (HO^{2-}), which differs from the hydroxyl anion (HO^{-}) in that a hydroxyl anion can be resolved through reduction while the hydroxyl radical must be resolved through the production of a covalent bond.

RATIO - An expression of the relationship of two numbers of the same measurement.

REACTION - An interaction of chemical entities or in the state of a single chemical that alters or changes the properties of the original substance. In regards to fertilizers, it can also be used for to describe the interaction of a fertilizer on a solutions pH, for example a fertilizer which increases the $[H^{+}]$ is said to have an acid "reaction".

RECIRCULATING SYSTEM - A type of closed irrigation system where the irrigation water is reused through recirculation through the system. The water is applied to the plants, and then recollected into tanks for reuse. Typically, the irrigation solution is only reused within a zone of a production family.

RECLAMATION - A process in which excess soluble salts or exchangeable sodium is removed from a soil to restore their productivity.

RECYCLED WATER - Water that has been previously used, but not excessively treated, for domestic, industrial, or agricultural purposes.

RECYCLING SYSTEM - In respect to irrigation: a system in which the runoff of production facility's irrigation system is collected, treated, and stored to be reused for irrigation.

REDOX REACTION - a chemical reaction where the oxidation state of a substance is changed. They consist of two half-reactions, reduction and oxidation, where the oxidation state of an atom, molecule, or ion is changed through the transference of an electron from one, the reductant, to another, the oxident.

REDUCING AGENT (REDUCTANT) - The atom, molecule, or ion in a oxidation reactant that loses electron(s) resulting in a product with an increased oxidation state.
REDUCTION - The portion, or half-reaction, of a redox reaction in which an atom, molecule, or ion gains an electron, reducing its oxidation number. e.g.:
Mn^{4+} (tetravalent manganese ion) + 2 electrons → Mn^{+2} (bivalent manganese ion).

REVERSE OSMOSIS SYSTEM - A method of water purification where dissolved solutes are separated out by a very thin membrane when water is forced through it.

REVERSION - A reaction involving a plant nutrient that results in the nutrient being less available. An example of this is phosphate reversion through the overuse of ammonia in the ammonization of phosphates in the manufacturing of fertilizers.

ROCK WOOL - An inorganic growing substrate that may be used as a media component or directly as cubes (stock plant production) or slabs/cubes (cut flower production). It is produced from basalt rock, steel mill slag, or other minerals that have been heated until liquefied, and spun into fibers.

ROCK WOOL CULTURE - A growing system where plants are rooted into containers or bags of rock wool and are subirragated using drip tubes or periodic flooding.

ROOTBOUND - A condition of container grown plants where the root system had grown too large for the volume of the container, causing it to form into a closely packed mass of roots.

RUNOFF POTENTIAL - A measure of the tendency a pesticide has to move along with sediment in runoff water.

SALINE SOIL/MEDIA - A soil/media for which the growth of most crop plants is inhibited by the concentration of exchangeable sodium but which does not contain an excess of exchangeable sodium.

SALINE-SODIC SOIL - A soil for which the growth of most crop plants is inhibited by the concentration of exchangeable sodium but which also contains an appreciable amount of soluble salts. A saline-sodic soil/media will have an exchangeable sodium percentage of at least 15% and in saturation will have an electrical conductivity of greater 4 decisiemens per meter (at 25°C). Typically, the saturation will have a pH of less than 8.5.

SALINITY - A measure of the salt content of a soil, growing media, or water. Commonly reported in terms of mg/L or ppm.

SALT - An ionic compound that is produced, along with water, from the neutralization reaction of an acid and a base. They can dissociate into cations and anions, but can be either readily soluble or practically insoluble. Soluble fertilizers are comprised of salts which what makes them readily available to plants.

SALT INDEX - A method of comparison for the solubilities of chemical compounds by a measure of the salt concentration they induce in the soil solution. Nitrogen and potash compounds have high indexes, while phosphate compounds will have low indexes. Those compounds with high salt indexes can cause damage if applied directly to plant tissue or too close to seed, resulting in wilting or death.

SALTING OUT - The precipitation of dissolved salts from solution through the reduction of temperature. The specific temperature where this reaction occurs is called the salting out point.

SAND FILTER - A filter used to remove particulates from water comprised of layers of different sized sand particles and gravel. A filter composed of layers of different sized sand and gravel that is used to filter particulate material out of water.

SAND - A particle of rock or mineral fragment with a diameter of 0.05 millimeters or greater, generally consisting of quartz. It is also the term for the textural class of a soil containing 85 percent (%) or more sand particles and no more than 10 percent (%) clay particles.

SATUTATED MEDIA EXTRACT (SME) - An extraction method for soil/media where the substrate is mixed with water just to the point where it forms a paste. The water is then vacuumed or squeezed out for analysis. A method of soil/growing media extraction where the. soil/growing medium is mixed with just enough water to make a paste, and then some of the water is vacuumed out or squeezed out for testing.

SATURATED SOIL PASTE - A mixture of soil and water, where just enough water has been added to the soil for the mixture to form a paste that reflects light, flows slightly when the container is tipped and slides freely and cleanly from a spatula. This is true for all soils except those with high clay content. Commonly used to produce soil extracts for nutritional analyses.

SATURATION EXTRACT - Extract from a soil solution at its saturation percentage.

SATURATION PERCENTAGE - The percentage of moisture in a saturated soil paste, as expressed on a dry-weight basis.

SCALING - The buildup of calcium and/or magnesium carbonate, hydroxide, or hemihydrate deposits that can be found at waterlines in tanks and other pluming.

SECONDARY PLANT NUTRIENTS - Nutrients that are essential for crop development, they are needed in lower amounts. The secondary plant nutrients are calcium (Ca), magnesium (Mg), and sulfur (S).

SEDIMENTATION PIT - The tank, pit, or reservoir used in the production of clarified water, where the removal of floating debris and sediment from waste or recycled water takes place.

SENSOR BASED IRRIGATION CONTROL - An automatic irrigation system that uses moisture sensors (tensiometers), placed in the soil/media to determine when the system is turned on or off.

SEPARATE, SOIL - A member of one of the three soil-size groups of mineral soil particles: sand, silt or clay.

SERIES, SOIL - A category in the classification of a soil, which is used to define a group of soils which originate from the same type of parent material, whose soil horizons share the same soil profile arrangement as well as other differentiating characteristics but which excludes the texture of the surface soil. Each series is given proper names from a place near the first recorded occurrence. For example: Yolo, Panoche, Hanford and San Joaquin are names of soil series that appear on soil maps, where each name represents the unique combination of defining soil characteristics.

SEWAGE SLUDGE - An organic amendment produced from treated sewage, the composition of which varies depending on the method of treatment.

SIEMENS (S) - The currently accepted unit for expressing electrical conductivity, replacing the formerly and most commonly used term: mhos. It is reported as deciSiemen/meter and is abbreviated ds/m

SILT DENSITY INDEX (SDI) - The measurement of a waters turbidity or clarity due to the concentration of suspended colloids, silica, bacteria, or mineral precipitates.

SILT - A soil separate where the individual mineral particles of the soil range in diameter from upper size of clay, 0.002 mm, and the lower size of very fine sand, 0.05mm. This term may also be used to describe a soil of the textural class silt, which is defined as containing at least 80% or more silt and less than 12% clay. It also refers to sediment deposited from water. In this instance, the individual grains are approximately the size of silt, although the term is sometimes applied loosely to sediments containing considerable sand and clay.

SILVICULTURE - A subset of forestry that is concerned with the establishment, development, and care of forests and woodlands.

SINGLE SUPERPHOSPATE - See superphosphate.

SLOW-RELEASE FERTILIZER (SRF) - See controlled-release fertilizer.

SLURRY FERTILIZER - A fluid mixture of dissolved and undisolved plant nutrients that easy separates and must be agitated to assure homogeneity in the solution.

SODIC SOIL / MEDIA - A soil/media which contains a disproportionately high concentration of sodium ions in their cation exchange complex. The concentration of exchangeable sodium is great enough to interfere with the growth of most plants, either with or without appreciable quantities of soluble salts. (See also NONSALINE-SODIC SOIL and SALINE-SODIC SOIL / MEDIA.)

SODIUM ADSORPTION RATIO (SAR) - A calculation used to measure the potential sodium hazard of irrigation water. It is used to express the relative ability of sodium ions to commit exchange reactions in a soil or media, displacing calcium and magnesium. This equation accounts for the presence of calcium and magnesium in relation to the sodium content. Similar measurements that are used to evaluate sodium hazard are: sodium absorption ratio (SAR), adjusted sodium absorption ratio (SAR_{adj}), exchangeable sodium percentage (ESP), sodium percentage, and residual sodium carbonate.

SODIUM PERCENTAGE - The percent, by milliequivalent not weight, of sodium cations (Na^+) in a soil.

SOIL MOISTURE STRESS - The combination of forces, soil moisture tension and the osmotic pressure of the soil solution, which must be overcome by a plant to withdraw the moisture from a soil.

SOIL MOISTURE TENSION - The negative pressure exerted by a soil on moisture, which is relative to the amount of work a plant must exert to draw moisture from the substrate. This type of force does not account for osmotic pressure values.

SOIL PERMEABILITY - The measure of a soils ability to have gas and liquids to travel through it. The higher the permeability the faster the rate of travel.

SOIL SORPTION INDEX - The comparison of the tendencies for pesticides to attach to soil particles as expressed in Koc value, or the ration of the mass of a chemical to be absorbed per unit of soil mass. The higher value indicates a stronger attachment while lower value indicating a higher potential for leaching.

SOLENOID VALVE - An electrically activated valve used to manage water flow in irrigation systems.

SOLUBLE SALTS - A salt that will separate into its parts, cations and anions, when exposed to water. This includes most inorganic fertilizers (such as ammonium, nitrate, potassium, sulfate, phosphate) and mineral salts that are dissolved in irrigation water (such as sodium, bicarbonate).

SPAGHETTI IRRAGATION SYSTEM - A type of drip irrigation where the water is delivered through small diameter (spaghetti) tubes, which are often weighted at the end to keep them in place when irrigating pots or hanging baskets.

SPHAGNUM PEAT MOSS - Generally considered the highest quality peat; it is derived from bogs consisting primarily of mosses from the genus *Sphagnum*. To be classified as sphagnum moss peat, it must contain at least 75% *Sphagnum* moss fiber and 90% organic matter.

STRUCTURE, SOIL - The physical arrangement of the soil components, how the soil particles aggregate and. resulting airspace. Soil structure is a major factor in ability of air and water to flow through a soil.
STYROFOAM - An inorganic growing media component made from expanded and solidified polystyrene foam, and is formed into small flakes or beads.

SUBIRRIGATION SYSTEM- An irrigation system in which water is delivered onto a surface where containerized plants are placed. The water enters the container by capillary action through drainage holes on the bottom of the container. The surface may be an absorbent mat (capillary mat), through, tray, or molded concrete floor (ebb-and-flow).

SUBSOIL - A layer of a soil located below the topsoil or below plow depth.

SUBSTANCE (chemical) - A form of matter that has a consistent chemical composition and characteristic properties and that cannot be separated into components by physical separation methods.

SUBSTRATE - See growing media.

SUB-SURFACE IRRIGATION SYSTEM - See sub-suface irrigation system.

SUB-SURFACE IRRIGATION - Where the irrigation water is distributed through conduits beneath the plants. This term is also applicable to water available to the plants from a water table.

SUFFICIENCY RANGE - The range of a recommended nutrients in plant tissue which yields acceptable growth, and is also referred to as normal, acceptable, or optimum range

SULFUR-COATED FERTILIZER - A slow-release fertilizer composed of a pellet of soluble fertilizer coated with a layer of sulfur to slow the release of the fertilizer. The most common type is sulfur-coated urea (SCU), but other nutrients are available. Some sulfur-coated urea products may also include a light polymer coating to further control release.

SUPERPHOSPATE - A granular phosphorus fertilizer that is derived by dissolving raw rock phosphate with acid. The use of sulfuric acid produces single superphosphate (0-20-0, plus Ca and S), and the use of phosphoric acid produces treble (or triple) superphosphate (0-45-0).

SUPERPHOSPHORIC ACID - See POLYPHOSPHORIC ACID.

SUSPENSION - A heterogeneous mixture containing solid partials whose sizes are large enough to eventually fall out of solution.

SUSPENSION FERTILIZER - A liquid with a mixture of dissolved and undissolved plant nutrients, The suspension of the undissolved plant nutrients is either due to the physical attributes of the materials, mechanical agitation, or through the use of a non-fertilizer suspension agent.

TEXTURE (SOIL/MEDIA) - The relative proportions of the various size groups, specifically of sand, silt, and clay, in a mass of soil/media.
THIN-FILM COMPOSITE MEMBRANE - A very thin layered membrane that contains a polyamide layer that is used in reverse osmosis water purification systems. They are resistant to pH but are sensitive to chlorine.

TILTH - The physical condition of a soil with respect to its fitness for the growth of plants.

TISSUE ANALYSIS - The determination of the nutritional content of plant tissue through the use of analytical techniques.

TOTAL CARBONATES (TC) - The sum of the bicarbonates and carbonates which is often used to express alkalinity.

TOTAL DISSOLVED SOLIDS (TDS) - The sum of the nonvolatile solutes dissolved in a water, often called total dissolved salts, usually expressed as ppm or mg/1. For most waters, it reflects the soluble salt content.

TOTAL POROSITY - The percent volume (volume/volume) of soil/growing media that is comprised of pores. The pores can be filled with air and/or water.

TOXICITY - The concentration at which a nutrient or chemical becomes high enough in a plant to cause damage.

TRACE ELEMENTS - See MICRONUTRIENTS.

TRANSPERATION - The process by which water moves through a plant and the evaporation of it from the aerial portions of the plant.

TRIPLE SUPERPHOSPHATE - An inorganic source of phosphorous containing 40-50% available phosphoric acid, but in comparison to other superphosphates contains very little calcium sulfate. It is sometimes referred to as treble superphosphate, concentrated superphosphate, double superphosphate and multiple superphosphate. See superphosphate. Formed by treating rock phosphate with phosphoric acid. Also called concentrated superphosphae.

TROUGH CULTURE - A sub-irrigation growing system where containerized plants are placed in sloped troughs, down which nutrient solution may flow as needed. The nutrient solution is usually then collected and re-circulated.

TURF - A grassy area used for playing fields, lawns, and roadsides that is maintained, such as through fertilization, watering, and mowed regularly.

TURFGRASS – One or more species of grasses that is maintained as a mowed turf, typically with a spreading habit.

UC MIX - A group of media mixes that contain various ratios of sand to peat. Developed by Baker at the University of California in the 1950's.

UNAVAILABE WATER (PWP)- The percent volume (volume/volume) of the soil or growing media that is occupied by water unavailable to the plant, as determined by measuring the percent of water present at a moisture tension of 1.5 megaPascals (approximately 15 bars or atm). This is also referred to as the permanent wilting percentage (PWP), as it is the water content at which the plant permanently wilts and will not recover without additional water.

UNCOATED ORGANIC COMPOUNDS - Organic compounds, generally nitrogen and typically urea based, which releases nitrogen gradually over a period of time.

UNIT - The official definition adopted by the AOAC is, "A unit of plant food is twenty (20) pounds, or one percent (1 percent) of a ton."

UREA - A soluble organic nitrogen fertilizer [$CO(NH_2)_2$] which can be taken up directly by the plant. In the soil/growing media it is readily converted by the bacterial enzyme urease to ammonium and carbon dioxide, causing it to behave as an ammonium fertilizer.

UREA FORMALDEHYDE - A slow-release nitrogen fertilizer that is composed of a polymer of urea and formaldehyde, which can also be called ureaform. The slow-release properties are dependent on. low solubility and biological breakdown.

VALENCE - The relative ability of an atom to combine based on the number bonds an atom can form, using hydrogen atoms ability to do so as the standard.

- univalent: K^+, Na^+
- bivalent: Mg^{+2}, $SO^2{}_4^-$
- trivalent: $PO^3{}_4^-$.

VERMICULITE - A hydrous silicate mineral clay, which is used as an inorganic component for growing media. It expands greatly when heated, which is the form it is used in as a media component, and has a high cation exchange capacity.

VOLATILIZATION - The process through which a substance vaporizes, changing from a liquid or solid stage into a gas.

WATER POLLUTION CONTROL ACTS - The laws set by Congress (Public Law 84-660 and 92-500) which set the standards for clean water.

WATER SOFTENER - A water treatment system in which a cation exchange resin is used to remove the hard water salts, calcium and magnesium, and replaces them with the soft water salt sodium, and in some applications potassium.

WATER TABLE, PERCHED - The surface of a body of free ground water which is separated from the underlying ground water in a zone of saturation by a layer of unsaturated material.
WATER TABLE - The surface of a ground water, where the water pressure head is equal to the atmospheric pressure.

WATER-HOLDING CAPACITY - The volume of water that a volume of absolutely dry soil or media can hold at saturation.

WEATHERING - The decomposition and disintegration of a parent material in formation of a soil.

WILTING PERCENTAGE - See PERMANENT WILTING PERCENTAGE.

WINDBREAKS - A grouping of plants whose placement and arrangement are designed to lessen the effects of winds and snow drift by acting as a screen around a house or landscape.

WINTER HARDINESS - The ability of a plant to successfully withstand the pressures of winter.

Table of Atomic Weights

Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	227.0278	Mercury	Hg	80	200.59
Aluminum	Al	13	26.98154	***Molybdenum***	Mo	42	95.94
Americium	Am	95	(243)	Neodymium	Nd	60	144.24
Antimony	Sb	51	121.75	Neon	Ne	10	20.179
Argon	Ar	18	39.948	Neptunium	Np	93	237.0482
Arsenic	As	33	74.9216	***Nickel***	Ni	28	58.70
Astatine	At	85	(210)	Niobium	Nb	41	92.9064
Barium	Ba	56	137.33	***Nitrogen***	N	7	14.0067
Berkelium	Bk	97	(247)	Nobelium	No	102	(259)
Beryllium	Be	4	9.01218	Osmium	Os	76	190.2
Bismuth	Bi	83	208.9804	***Oxygen***	O	8	15.9994
*Boron**	B	5	10.81	Palladium	Pd	46	106.4
Bromine	Br	35	79.904	***Phosphorus***	P	15	30.97376
Cadmium	Cd	48	112.41	Platinum	Pt	78	195.09
Calcium	Ca	20	40.08	Plutonium	Pu	94	(244)
Californium	Cf	98	(251)	Polonium	Po	84	(209)
Carbon	C	6	12.011	***Potassium***	K	19	39.0983
Cerium	Ce	58	140.12	Praseodymiu	Pr	59	140.9077
Cesium	Cs	55	132.9054	m	Pm	61	(145)
Chlorine	Cl	17	35.453	Promethium	Pa	91	231.0359
Chromium	Cr	24	51.996	Protactinium	Ra	88	226.0254
Cobalt	Co	27	58.9332	Radium	Rn	86	(222)
Copper	Cu	29	63.546	Radon	Re	75	186.207
Curium	Cm	96	(247)	Rhenium	Rh	45	102.9055
Dysprosium	Dy	66	162.50	Rhodium	Rb	37	85.4678
Einsteinium	Es	99	(254)	Rubidium	Ru	44	101.07
Erbium	Er	68	167.26	Ruthenium	Sm	62	150.4
Europium	Eu	63	151.96	Samarium	Sc	21	44.9559
Fermium	Fm	100	(257)	Scandium	Se	34	78.96
Fluorine	F	9	18.998403	Selenium	Si	14	28.0855
Francium	Fr	87	(223)	Silicon	Ag	47	107.868
Gadolinium	Gd	64	157.25	Silver	Na	11	22.98977
Gallium	Ga	31	69.72	Sodium	Sr	38	87.62
Germanium	Ge	32	72.59	Strontium	S	16	32.06
Gold	Au	79	196.9665	***Sulfur***	Ta	73	180.9479
Hafnium	Hf	72	178.49	Tantalum	Tc	43	(97)
Helium	He	2	4.00260	Technetium	Te	52	127.60
Holmium	Ho	67	164.9304	Tellurium	To	65	158.9254
Hydrogen	H	1	1.0079	Terbium	Tl		204.37
Indium	In	49	114.82	Thallium	Tl	81	204.3833

Iodine	I	53	126.9045
Iridium	Ir	77	192.22
Iron	Fe	26	55.847
Krypton	Kr	36	83.80
Lanthanum	La	57	138.9055
Lawrencium	Lr	103	(260)
Lead	Pb	82	207.2
Lithium	Li	3	6.941
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.305
Manganese	Mn	25	54.9380
Mendelevium	Md	101	(258)
Thorium	Th	90	232.0381
Thulium	Tm	69	168.9342
Tin	Sn	50	118.69
Titanium	Ti	22	47.90
Tungesten (Wolfram)	W	74	183.85
Uranium	U	92	238.029
Vanadium	V	23	50.9414
Xenon	Xe	54	131.30
Yttberium	Yb	70	173.04
Yttrium	Y	39	88.9059
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22

***Essential elements**

Conversion values.

1 milligram (mg)	=	0.001 grams (g)
1 gram (g)	=	0.001 kilograms (kg)
1 gram (g)	=	0.035273962 ounces
1 ounce	=	28.34952312 grams (g)
1 ounce	=	0.0625 pounds
1 pound (lb)	=	16 ounces
1 pound (lb)	=	0.45359237 kilograms (kg)
1 kilogram (kg)	=	1000 grams
1 kilogram (kg)	=	35.273962 ounces
1 kilogram (kg)	=	2.20462262 pounds (lb)
1 percent	=	10,000 ppm
1 liter	=	1,000 ml

Agronomic and Plantation Crops
Bedding Plants
Conifers
Cut Flower Crops
Ferns and Related Plants
Florist Pot Crops
Foliage Plants
Forages
Fruit and Nut Crops
Herbaceous Perennials
Landscape and Forest Trees
Ornamental Grasses, Sedges and Bamboos
Ornamental Vines and Ground Covers
Palms
Turfgrasses
Vegetables
Woody Ornamental Shrubs

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