Cooperative Extension Service
College of Tropical Agriculture and Human Resources
University of Hawai'i at Mānoa

Soil and Crop Management
July 2002
SCM-4

Nutrient Deficiencies and Excesses in Taro

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Identifying and correcting plant nutrient deficiencies and toxicities are essential for good crop management and contribute to higher economic returns. Failure to correct soil problems or to apply sufficient amounts of fertilizers can result in poor yields and wasted effort. Applying too much or the wrong kind of fertilizer can have many negative consequences, including

- nutrient toxicities or imbalances that reduce plant growth and yield
- excessive foliage growth that invites damage by plant diseases and insect pests
- environmental contamination from runoff into surface water bodies and leaching into the groundwater, and
- economic loss due to wasted fertilizer.

This publication explains the role of essential plant nutrients in taro (*Colocasia esculenta*) and shows the visual symptoms that occur when there is a nutrient inadequacy (deficiency) or excess (toxicity) in the taro plant.

Diagnosis of nutrient imbalances using visual symptoms

Diagnosis of nutritional disorders must be done in a systematic manner. Deficiency symptoms first appear on either the younger or the older leaves of the plant, depending on the way the particular nutrient is mobilized by the plant's metabolism. Deficiency symptoms first appear on *younger leaves and growing points* if the plant is not able to break down stored organic compounds containing the nutrient in mature leaves and then transport it to young, growing tissues. If the plant *is* able to do this, deficiency symptoms appear first on *older leaves*. Toxicity symptoms appear first on older leaves, because excess mineral elements tend to accumulate in mature leaves. The diagram on page 2 provides a systematic key for diagnosing visual mineral deficiency and toxicity symptoms in taro.

Normal taro leaf blades, without signs of nutrient deficiency.

Methods to determine deficiencies and toxicities in taro

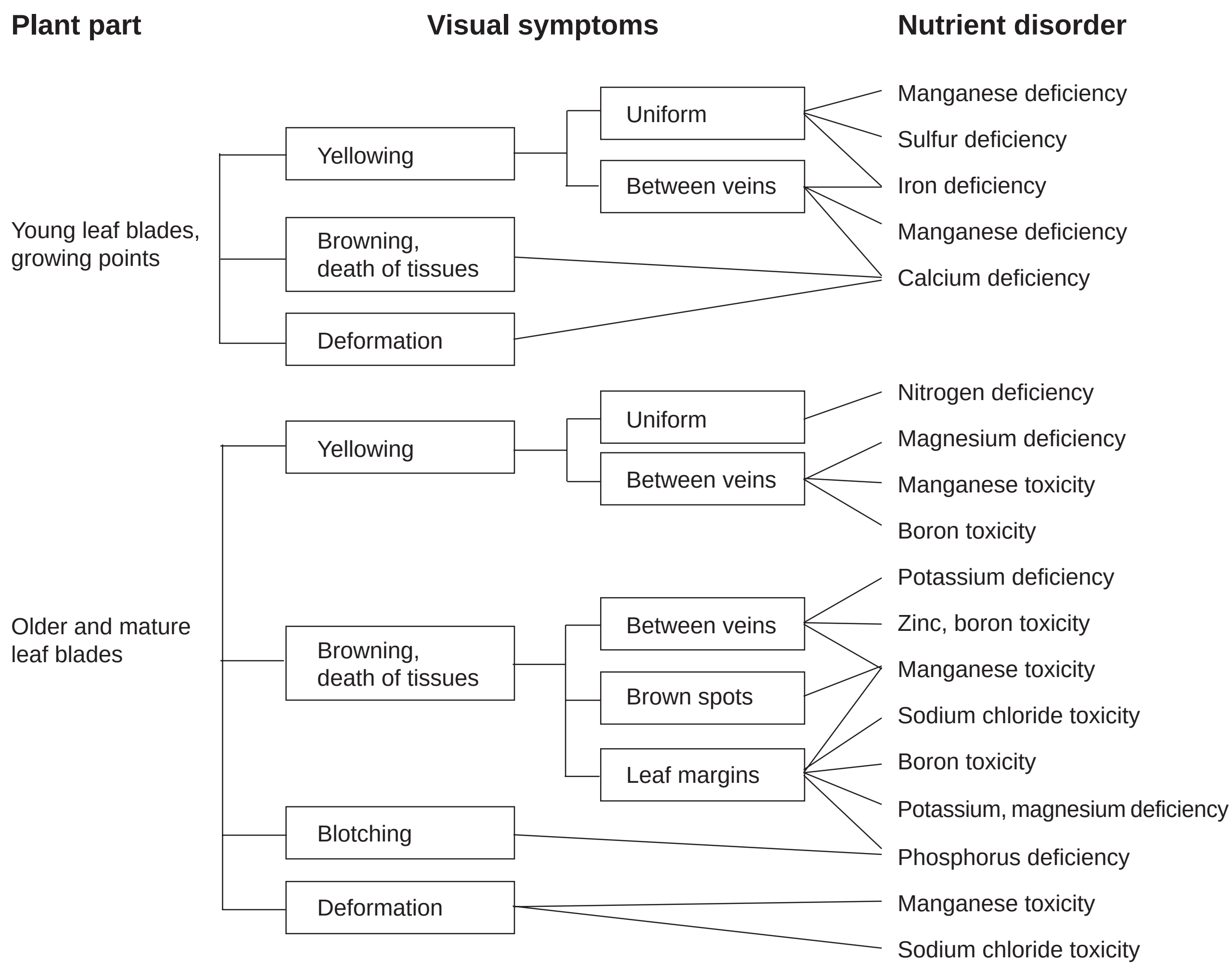
Three different methods were used to determine symptoms of nutrient deficiencies and toxicities of taro. First, taro plants were grown in hydroponic culture, and the element of interest was reduced or deleted from the nutrient solution. Second, taro plants were grown in pots with a soil that had been identified previously to result in a particular nutrient deficiency or toxicity. Third, plants in farmers' fields were diagnosed as having a particular nutrient deficiency or toxicity, based on symptoms and analyses of the soil and the plant tissues; then, correction of the particular nutrient problem was done in the field to confirm the diagnosis.

Essential plant nutrients

Thirteen essential mineral nutrients are required by all plants. Six of these minerals are required in large amounts and are called macronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). The seven minerals required by plants in only small amounts are called micronutrients: iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), and chlorine (Cl). The metallic element aluminum (Al) is not essential as a nutrient, but it is considered here because it is toxic to plants when taken up in excessive amounts.

Published by the College of Tropical Agriculture and Human Resources (CTAHR) and issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Andrew G. Hashimoto, Director/Dean, Cooperative Extension Service/CTAHR, University of Hawai'i at Mānoa, Honolulu, Hawai'i 96822. An equal opportunity/affirmative action institution providing programs and services to the people of Hawai'i without regard to race, sex, age, religion, color, national origin, ancestry, disability, marital status, arrest and court record, sexual orientation, or status as a covered veteran. CTAHR publications can be found on the Web site <http://www.ctahr.hawaii.edu/freepubs>.

Key to taro nutrient disorders (deficiencies and toxicities)



Effect of the taro cropping system on plant nutrients

Taro is grown under both "upland" (nonflooded) and "wetland" (flooded) soil conditions. In a wetland system, where the soil is anaerobic (oxygen-depleted), nitrogen can be lost through denitrification. Also, in an anaerobic environment certain elements can be chemically "reduced," increasing their availability to plants; these elements include phosphorus, manganese, and iron. Taro's adaptation to flooded conditions apparently involves a tolerance of high levels of manganese. In experiments, Mn toxicity was not observed until its concentration in the leaf blade exceeded 2000 parts per million. Under anaerobic conditions soil pH increases, and thus soil acidity and aluminum toxicity are not problems in wetland taro.

Soil testing

A basic soil test measures the soil pH and the plant-available levels of the nutrient elements phosphorus, potassium, calcium, and magnesium. This information is used to determine which type of soil amendment (such as lime) might be needed and to estimate the amounts of fertilizers required to supplement nutrients in the soil to produce a good crop. Other specialized soil analyses can provide information on the levels of soil salinity, organic carbon, aluminum, nitrogen, and micronutrients. For information on soil analysis, see *Testing Your Soil, Why and How to Take a Soil-Test Sample*, CTAHR publication AS-4.

Plant tissue analysis

Plant tissue analysis is done to monitor the nutrient levels in plant tissues. Nutrient content data are most useful in combination with soil analysis data and records of past fertilizer applications and crop performance. Plant tissue analysis measures the elements in an "index tissue," a particular plant part determined by experimentation to be the most reliable indicator of the plant's nutrient status.

For taro, the index tissue is the "leaf number 2," the second leaf blade below the first, youngest expanded leaf blade with a new leaf beginning to emerge from its petiole (see figure at right). The newly emerging leaf blade is counted as "leaf zero," the first fully expanded (mature) leaf blade is counted as "leaf number 1," and the next older mature leaf blade is counted as "leaf number 2." To sample taro for tissue analysis, collect index tissue from at least five relatively healthy main ("mother") plants randomly located throughout one distinct planting area (such as a field or *lo'i*). Remove leaf number 2 with a sharp knife, discarding the petiole and placing the leaf blade into a clean plastic bag. Avoid collecting diseased or damaged leaves. Protect the sample from overheating during transport by placing it into an ice chest.

Earlier recommendations called for the third leaf blade ("leaf number 3"), but *Phytophthora* leaf blight often resulted in diseased tissue, making this older leaf unsuitable for sampling.

The tissue nutrient analysis results are compared with sufficiency ranges (standards) established for the particular crop. Within the sufficiency range for a nutrient, adequate growth can be expected, as far as that particular nutrient is concerned. In the deficiency range, visible nutrient deficiency symptoms are evident and crop yield is reduced. When levels of a nutrient are in excess (above the sufficiency range), nutrient imbalances can occur, and the plants may become prone to diseases or physiological disorders. For example, it was found that excessive nitrogen can promote taro leaf blight caused by *Phytophthora colocasiae* when conditions are conducive to disease development.

The index tissue for taro is leaf blade 2

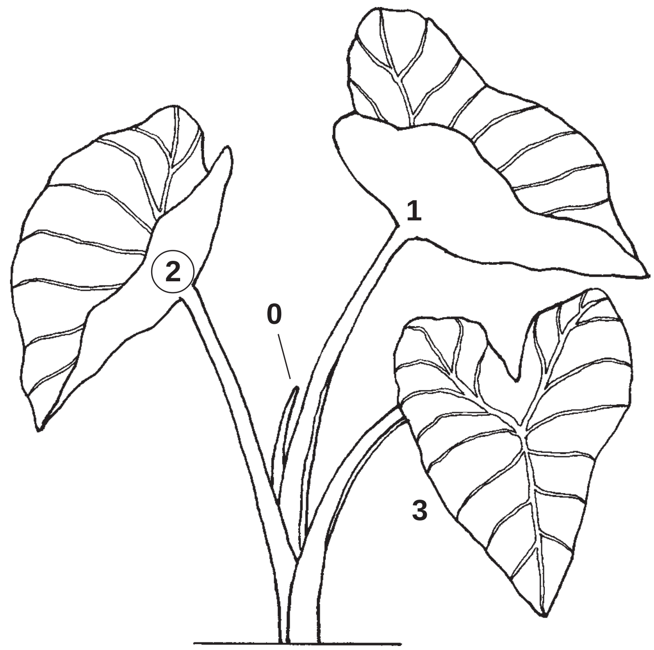


Table 1 (p. 4) gives the ranges of nutrient concentrations in taro associated with deficiency, sufficiency, and toxicity. A gap between sufficient and toxic levels of a nutrient could occur because the plant is able to absorb amounts of a nutrient in excess of what is required.

In Hawaii, research is ongoing to calibrate soil fertility levels with taro plant tissue levels and crop yields. Best management practices and interim fertilizer recommendations are used to assist taro growers to help increase yields, avoid excessive fertilizer applications and costs, limit disease severity resulting from over-fertilizing with nitrogen, and reduce environmental pollution. Best management practices are given in *Taro, Mauka to Makai: A Taro Production and Business Guide for Hawaii Growers*. Fertilizer recommendations for wetland taro are given in *Interim Fertilizer Recommendations for Wet (Flooded) Taro*, CTAHR publication PM-1a. Additional information on soil management, plant nutrition and diagnosis of nutrient deficiencies is available in CTAHR's *Plant Nutrient Management in Hawaii's Soils: Approaches for Tropical and Subtropical Agriculture.*

Table 1. Taro leaf blade nutrient concentrations associated with deficiency, sufficiency, and toxicity. [m]

Mineral element	Measured in	Deficiency range	Sufficiency range [n]	Toxicity range
N	%	< 4.0 [o]	4.0–4.5 [p]	
P	%		0.3–0.5	
K	%		3.2–5.5 [p]	
Ca	%	< 0.7 [q]	0.7–1.5	
Mg	%	< 0.2 [r]	0.2–0.5	
S	%	< 0.2 [s]	0.2–0.3	
Cl	%			> 2.0 [t]
Fe	ppm	< 100 [u]	100–200 [p]	
B	ppm		20–50 [p]	
Mn	ppm		50–300 [p, v]	> 2000 [v, w, x]
Zn	ppm		20–40 [p, y]	> 400 [y]
Cu	ppm		10–20 [z]	Unrelated [z]

[m] Actual deficient, sufficient, and toxic concentrations of elements in leaf blades may vary depending on taro variety, environmental conditions, and quantities of other nutrients present. [n] Sufficiency ranges are based on concentrations of elements in leaf blades of healthy taro plants grown under upland or wetland conditions (Uchida, 2000). [o] Osorio et al. (2002). [p] Silva, J.A. (personal communications). [q] Miyasaka (1979). [r] Austin et al. (1994) found that 0.14% Mg was associated with 95% of maximum growth. [s] Kelly and Jansen (unpublished) showed that 0.18% S was associated with 95% of maximum growth. [t] Hill et al. (1998). [u] Ares et al. (1996) found that a range of 55–70 ppm Fe was associated with 95% of maximum growth. [v] R.T. Hamasaki (personal communications). [w] Taro is tolerant to high levels of Mn and foliar concentrations between 1400–2000 ppm have been observed without detrimental effects. [x] Miyasaka and Webster (1994). [y] O'Sullivan et al. (1996). [z] Hill et al. (2000) found levels ranging from 14–18 ppm Cu in taro plants supplied with sufficient Cu. Foliar Cu concentrations cannot be used to predict toxicity, because they did not increase in leaf blades under toxic Cu levels.

Nitrogen

Nitrogen is a component of amino acids and proteins, which are important as enzymes that catalyze chemical reactions in plant cells. Nitrogen is also a component of nucleic acids in deoxyribonucleic acids (DNA) and ribonucleic acids (RNA), which are important for storing and transmitting genetic information.

Plants absorb nutrients from the soil solution. The chemical form of elements when they are in solution is called the ionic form. Plants must absorb an equal number of anions (negatively charged ions) and cations (positively charged ions)*. Nitrogen can be taken up by plants as either an anion (nitrate) or a cation (ammonium). Because nitrogen is one of the elements taken up by plants in the most quantity, the ionic form of the nitrogen absorbed has an enormous impact on the plant's charge

*Elements taken up by plants in the form of cations (pronounced cat′-i′-un) are N (ammonium form, NH_4^+), K, Ca, Mg, Fe, Mn, Zn, Cu, and Al; elements taken up as anions (pronounced an′-i′-un) are N (nitrate form, NO_3^-), P, S, Mo, and Cl. Boron is thought to be taken up as a neutral molecule.

100% nitrate | 75% nitrate 25% ammonium | 50% nitrate 50% ammonium | 25% nitrate 75% ammonium | 100% ammonium

1A. 'Bun long' grown in hydroponic solutions containing varying ratios of nitrate to ammonium. Plants grew best in solutions containing either 100% or 75% nitrate. Roots of plants grown in solutions containing high ammonium levels appeared to be injured by acidic pH levels that occurred.

balance and its ability to take up other anions and cations. To maintain charge balance, plants that absorb nitrate will tend to excrete hydroxyl anions (OH^-) and thus alkalinize the medium around their roots. Plants that absorb ammonium will tend to excrete hydrogen ions (H^+) and acidify the medium around their roots. Taro plants grow best when available soil nitrogen is mostly in the nitrate form (Fig. 1A). When predominantly ammonium was present in hydroponic conditions, the solution became very acidic and plant growth was reduced.

Nitrogen deficient taro plants have stunted roots, main shoots, and suckers. Yellowing of the leaf blade starts in older leaves (Fig. 1B). As the deficiency progresses, all of the leaf blades turn yellow. Premature death of older leaves often results in fewer numbers of active leaf blades, which reduces growth and lowers crop yield.

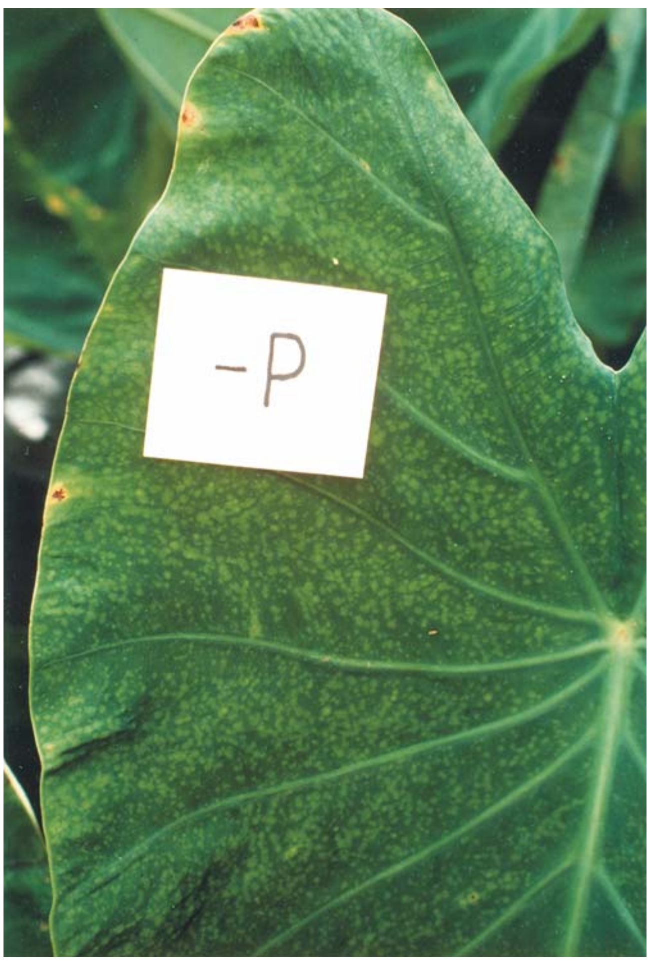
1B. Nitrogen deficient 'Lehua maoli' grown in hydroponic solution lacking nitrogen. Yellowing starts with the oldest leaf blades. As the deficiency progresses, all of the leaf blades eventually turn yellow, suckers become stunted, and the plant as a whole decreases in size.

Phosphorus

Phosphorus, like nitrogen, is a component of nucleic acids. It is also a component of adenosine triphosphate (ATP), an important compound that is involved in energy transfer, powering metabolic activity within plant cells. In addition, P is a component of phospholipids in membranes that form the outer boundary of living tissues.

Phosphorus deficient taro plants have stunted root and shoot growth. Older leaf blades may appear darker green (Fig. 2A) due to greater retardation of leaf expansion relative to chlorophyll (green pigment) reduction. In taro cultivar 'Lehua maoli', phosphorus deficiency is characterized by light-colored dots on the surface of leaf blades (Fig. 2B). As the deficiency progresses, areas of the leaf margins begin to yellow and turn brown.

2A. **'Bun long' grown in hydroponic solutions containing varying levels of phosphorus; from left to right, no phosphorus, low phosphorus, and sufficient phosphorus. Phosphorus deficient leaf blades appear darker green compared to leaf blades grown with sufficient phosphorus.**

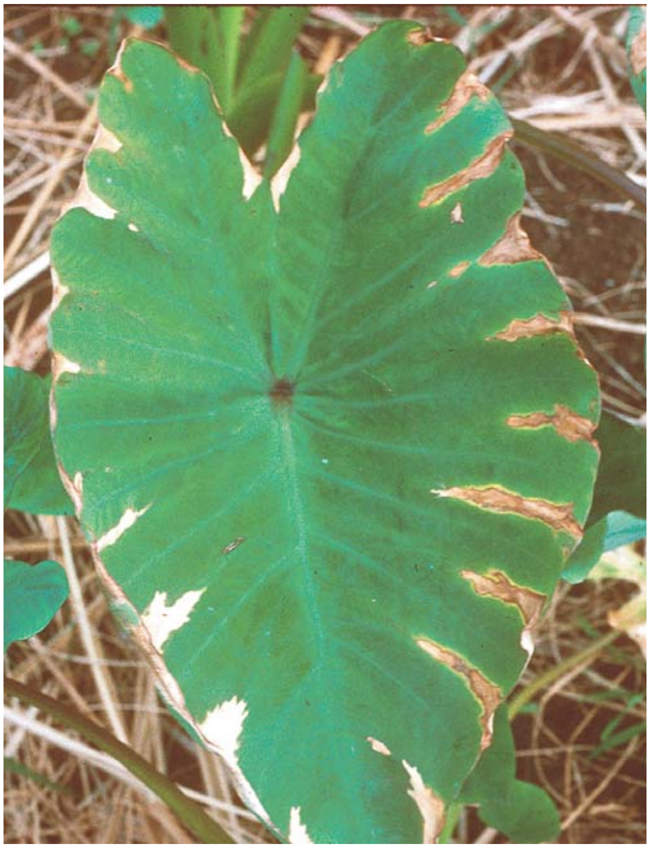


2B. **Phosphorus deficient 'Lehua maoli' grown in a hydroponic solution lacking phosphorus. A large number of light-colored dots form between the leaf veins. Yellowing and death of the leaf margins follow.**

Potassium

Potassium is the most abundant cation in plant tissues. It is required for maintaining plant turgidity, cell extension, and opening the pores in leaves for gas exchange. Potassium is also needed to provide the appropriate cellular environment for protein synthesis.

Potassium deficient taro is characterized by slower growth, increased tendency to wilt, reduced size of leaf blades, and interveinal or marginal "scorching"—a burnt appearance between the veins (Fig. 3A) or around the leaf margins. In 'Lehua maoli', potassium deficiency is characterized by irregularly shaped brown spots in the center of older leaf blades (Fig. 3B). As the deficiency progresses, the spots may coalesce, with the whole leaf turning yellow or brown.



3A. **Potassium deficient 'Bun long' grown under dryland conditions at Kahuku, Oahu on the Waialua soil series with 1.8% potassium in the leaf blades.**

3B. **Potassium deficient 'Lehua maoli' grown in a hydroponic solution lacking potassium. Several irregularly shaped brown spots appeared between the veins of older leaf blades. As the deficiency progresses, the spots may coalesce and the whole leaf turns brown.**

Calcium

Calcium is important in stabilizing cell membranes and cell walls. It activates enzymes and is required as an intermediary between environmental signals and plant responses. A constant supply of this cation is required in the root environment for continued root growth.

Calcium deficient taro is characterized by reduced root and shoot growth (Fig. 4A). Under mildly deficient conditions, the youngest leaf blade yellows between the veins (Fig. 4B). Under severely deficient conditions, the leaf blades become cup-shaped, with yellow areas between the veins and brown areas around the leaf margins (Fig. 4C). Finally, leaf blades can fail to unfurl, and the shoot dies. Calcium deficiency can predispose plants to soil-borne diseases when roots die back and become open to invasion by pathogens.

4A. 'Bun long' grown in hydroponic solutions with varying levels of calcium; from left to right, no calcium, low calcium, and sufficient calcium. Roots grown with no or low calcium appeared severely stunted.

4B. Calcium deficient 'Lehua maoli' grown in a hydroponic solution lacking calcium. Under mildly deficient conditions, the youngest leaf blade exhibits yellowing between the veins.

4C. Calcium deficient 'Lehua maoli' grown in a hydroponic solution lacking calcium. Under severely deficient conditions, leaf blades become cup-shaped with yellowing and death of tissues between the veins and around the leaf margins.

Magnesium

Magnesium is a component of chlorophyll, the green pigment that traps the energy of sunlight. Magnesium is also required for protein synthesis and the activation of enzymes.

Magnesium deficient taro has leaf blades with yellowing between the veins, particularly in older leaves. As the deficiency progresses, the margins of the leaf blades turn brown and die (Fig. 5).

5. Magnesium deficient 'Bun long' grown in hydroponic solutions with varying magnesium levels; the three leaf blades on the left were grown in no magnesium and the leaf blade on the right was grown in low magnesium. Yellowing between the leaf blades occurs first in the older leaves. As the deficiency progresses, the margins and the areas between the leaf blades turn brown and die.

Sulfur

Sulfur is a component of sulfur-containing amino acids and proteins. It is important for stabilizing protein structures and participating in reactions catalyzed by enzymes.

Sulfur deficient taro has reduced root and shoot growth (Fig. 6A). Sulfur deficiency is characterized by reduced leaf size and uniform yellowing of the leaf blades (Fig. 6B), particularly in younger leaves.

6A. 'Veo' grown in hydroponic solutions with varying sulfur levels, from left to right, no sulfur, low sulfur, and sufficient sulfur. Taro grown without sulfur has stunted root growth, reduced leaf blade size, and yellowing of the leaf blades, particularly in the younger leaves.

6B. 'Veo' grown in hydroponic solutions containing varying levels of sulfur, clockwise from top left, no sulfur, low sulfur, high sulfur, and sufficient sulfur. Note the reduced leaf size and uniform yellowing of the sulfur deficient leaf blade.

Iron

Iron is a component of proteins involved in oxidation-reduction reactions important for photosynthesis and metabolism.

Iron deficient taro is characterized initially by younger leaf blades having yellowing between the veins (Fig. 7A). As the deficiency progresses, a uniform bleaching occurs in the younger leaves (Fig. 7B). In addition, lateral root formation is depressed.

7A. **Iron deficient 'Lauloa keokeo' grown under dryland conditions in Poamoho, Oahu on the Wahiawa soil series. Leaf blades contain 21 parts per million of iron, and younger leaves exhibit yellowing between the veins.**

7B. **'Bun long' grown in a hydroponic solution lacking iron. The leaf on the right is the younger leaf blade; note its uniform, bleached color. The older leaf on the left has yellowing and dead tissue between the veins.**

Manganese

Manganese is a component of several proteins. It is required for photosynthesis, and it activates many enzymes.

Manganese deficient taro has reduced growth. Initially there is yellowing between the veins of the younger leaf blades (Fig. 8), and as the deficiency progresses, the leaf blade turns uniformly yellow.

An excessive amount of Mn can result in toxicity, reducing root and shoot growth. It may also interfere with the uptake of iron, resulting in symptoms similar to iron deficiency (Fig. 9A). Manganese toxicity symptoms start first in the older leaf blades, but they vary among taro cultivars and growing conditions. Leaf blades of 'Bun-long' have yellowing and brown spots between the veins and at the leaf margins (Fig. 9A). In 'Lehua maoli', older leaf blades appear deformed and cup-shaped, similar to calcium deficiency (Fig. 9B).

8. **'Lehua maoli' grown in a hydroponic solution lacking manganese. Manganese deficiency starts in the youngest leaves, and is characterized by yellowing between the veins.**

9A. **'Bun long' grown under dryland conditions at Opaeula, Oahu, on the Wahiawa soil series. The leaf blade contained 2040 ppm of manganese, indicating Mn toxicity; note the browning of the areas between the veins and at the leaf margins. The yellowing of the areas between the veins appears similar to iron deficiency (see Fig. 7A),but the leaf blades contained 117 ppm Fe, which should be a sufficient amount. Apparently excess Mn interferes with the utilization of absorbed Fe.**

9B. **'Lehua maoli' grown in a hydroponic solution containing high manganese. Older leaf blades appear deformed and cup-shaped, somewhat similar to calcium deficiency (see Fig. 4C).**

Zinc

Zinc is a component of over 80 enzymes, and it is required to activate many enzymes.

Zinc deficient taro is stunted, but other symptoms are not obvious (Fig. 10). Excessive zinc uptake can result in toxicity characterized by dead spots between the veins in the leaf blades. For a photograph of zinc toxicity symptoms, refer to O'Sullivan et al., 1996 (see *References*).

10. **'Bun long' grown in hydroponic solutions containing varying levels of zinc, from left to right, no zinc, low zinc, and sufficient zinc. Plants grown in no zinc had stunted root and shoot growth. No other obvious symptoms were noted.**

Chlorine

Chlorine is an anion of major importance in plant nutrition because it balances the positive charge of potassium. Along with potassium, it is needed for cell extension, opening of leaf pores for gas exchange, and cell turgidity.

Chlorine deficiency is rarely found, because adequate amounts occur in rainwater. Sodium chloride toxicity can occur due to salt-contaminated water or saline soil. At moderate salt levels, the margins of taro leaf blades yellow (Fig. 11, left leaf). As the salt level increases, the leaf blades cup and crinkle, and die-back occurs at the leaf margins (right leaf). Extremely high salt levels kill the entire plant.

11. **'Bun long' grown in hydroponic solutions containing varying salt levels, from left to right, moderate and high levels of salt. At moderate salt levels, the margins of the leaf blade turn yellow (chlorotic). At higher salt levels, cupping and crinkling of the leaf blades will occur along with die-back of the leaf margin.**

Boron

Boron is required for cell wall synthesis to cross-link wall components and regulate wall porosity. It is needed for root elongation and pollen tube growth. Deficiency symptoms in taro are characterized by stunted growth of shoots and roots.

Excessive boron uptake can result in toxicity characterized by depressed growth and yellowing or brown spots in older leaf blades. For a photograph of boron toxicity on *C. esculenta* var. antiquorum, refer to O'Sullivan et al., 1996 (see *References*).

Copper

Copper is similar to iron in that it participates in oxidation-reduction reactions. It is a component of copper-containing enzymes required for respiration and photosynthesis.

Copper deficiency has not been shown for taro. Excessive copper uptake can result in copper toxicity, which is characterized by stunted plant growth, a transient change in green coloration of the leaf blades, and increased death of older leaves resulting in a reduced number of leaves.

Molybdenum

Molybdenum is a component of enzymes required for nitrate metabolism. Its deficiency has not been shown for taro.

Aluminum

Aluminum toxicity is a major factor limiting plant growth in acid soils. Many soils are composed of clay minerals containing aluminum, and when the soil pH is low (acidic; around pH 4.5 and below), this aluminum is released into the soil solution, where it becomes available for plant uptake. Excessive aluminum restricts root elongation. Aluminum ions can bind to cell walls and to phosphate-containing compounds (such as DNA) in cells, disrupting normal plant metabolism and growth.

Aluminum-toxic soils at pH 4 resulted in dramatically reduced taro root growth (Fig. 12). Liming the soil prevents this detrimental effect by changing the soil chemical environment so that aluminum ions precipitate out of the soil solution into a form that is not taken up by plants.

12. **Roots of 'Lehua maoli' grown in pots containing an aluminum-toxic soil (Paaloa soil series) at varying pH levels; from left to right, pH 4.0 (very acidic), 4.5 (acidic), 5.0 (amended with gypsum), and 5.0 (limed with dolomite). Aluminum toxicity was found in plants grown at the very acidic pH and was characterized by severely stunted root growth.**

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Acknowledgments

The graduate students who conducted hydroponic research on taro in the University of Hawaii at Manoa course Agronomy/Horticulture 710, "Mineral Nutrition of Tropical Crops," were Robert Abaidoo, Derrick Agboka, Maqbool Akhtar, Falaniko Amosa, Aaron Araki, Albert Arcinas, Adrian Ares, Michael Austin, Jocelyn Bajita, Ting Ting Cai, Melody Calisay, Thomas Cole, Michael Constantindes, Christine Crosby, Jennifer Ehrenberger, John Hanley, Todd Fujii, Bonnie Gay, Darrell Herbert, Steve Hill, I-Feng Ho, Guilherme Holtz, XueXin Huang, San-Gwang Hwang, James Jackman, Sandy Jansen, Cheryll Kelly, Phoebe Kilham, Mengbo Li, JiaCai Liu, Zhong Ma, Ashariya Manenoi, Ty McDonald, Xiangjia Min, Kullanart Obsuwan, Awana Onguene, Ikpotokin Osemwota, Nelson Osorio, Leslie Poland, Martinus Pandutama, Ted Radovich, Rick Shirey, Xiufu Shuai, Shawn Steiman, Darren Strand, Cindy Tanuwidjaja, Surya Tewari, Silvio Vega, Bingtian Wang, Koon-Hui Wang, XinMin Wang, William Wigmore, and Yi Zou. In addition, we thank Dennis Ida, Farm Manager of CTAHR's Waiakea Research Station, for making the taro drawing; Dr. John Cho of the CTAHR Department of Plant and Environmental Protection Sciences for generously donating taro propagation materials for several hydroponic studies; and Dr. Bruce Mathews of the University of Hawaii at Hilo for cooperating on studies of the effects of lime on taro grown in two acid soils. Finally, we thank our colleagues James Silva, Nguyen Hue, Russell Yost, and Ray Uchida for their helpful suggestions on nutrient sufficiency ranges and the recommended index tissue for taro.