WHAT IS PLANT NUTRITION?

Plants use inorganic minerals for nutrition, whether grown in the field or in a container. Complex interactions involving weathering of rock minerals, decaying organic matter, animals and microbes take place to form inorganic minerals in soil. Roots absorb mineral nutrients as ions in soil water. Many factors influence nutrient uptake for plants. Ions can be readily available to roots or could be "tied up" by other elements or the soil itself. Soil too high in pH (alkaline) or too low in pH (acidic) makes many minerals unavailable to plants.

Fertility or Nutrition

The term "fertility" refers to the inherent capacity of a soil to supply nutrients to plants in adequate amounts and in suitable proportions. The term "nutrition" refers to the interrelated steps by which a living organism assimilates food and uses it for growth and replacement of tissue. Previously, plant growth was thought of in terms of soil fertility or how much fertilizer should be added to increase soil levels of mineral elements. Most fertilizers were formulated to account for deficiencies of mineral elements in the soil. The use of soilless mixes and increased research in nutrient cultures and hydroponics as well as advances in plant tissue analysis have led to a broader understanding of plant nutrition. Plant nutrition is a term that takes into account the interrelationships of mineral elements in the soil or soilless solution as well as their role in plant growth. These interrelationships involve a complex balance of essential and beneficial mineral elements for optimum growth.

Essential Versus Beneficial

The definition of an essential mineral element (or mineral nutrient) was proposed by Arnon and Stout in 1939. They concluded that three criteria must be met for an element to be considered essential. These criteria are: 1. A plant must be unable to complete its life cycle in the absence of the mineral element. 2. The function of the element must not be replaceable by another mineral element. 3. The element must be directly involved in plant metabolism. These criteria are important guidelines for plant nutrition but exclude beneficial mineral elements. Beneficial elements are those that can compensate for toxic effects of other elements or may replace mineral nutrients in some other less specific function such as the maintenance of osmotic pressure. The omission of beneficial nutrients in commercial production could mean that plants are not being grown to their optimum genetic potential but are merely produced at a subsistence level. This discussion of plant nutrition includes both the essential and beneficial mineral elements.

What Mineral Elements Do Plants Need?

There are 20 mineral elements essential for plant growth. Carbon (C), hydrogen (H), and oxygen (O) are supplied by air and water. The six macronutrients, nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S), are required by plants in large amounts. The rest of the elements are required in trace amounts (micronutrients). Essential trace elements include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), sodium (Na), zinc (Zn), molybdenum (Mo), and nickel (Ni). Studies have also shown that a number of other mineral elements are beneficial to the growth of plants and are required for some plants. Beneficial mineral elements include silicon (Si) and cobalt (Co). While the beneficial elements are known to be essential to some plants, they are not deemed to be essential for all plants. The distinction between beneficial and essential is often difficult in the case of some trace elements. Cobalt for instance is essential for nitrogen fixation in legumes. It may also inhibit ethylene formation and extend the life of cut roses. Silicon, deposited in cell walls, has been found to improve heat and drought tolerance and increase resistance to insects and fungal infections. Silicon, acting as a beneficial element, can help compensate for toxic levels of manganese, iron, phosphorus and aluminum as well as zinc deficiency. A more holistic approach to plant nutrition would not be limited to nutrients essential to survival but would include mineral elements at levels beneficial for optimum growth. With developments in analytical chemistry and the ability to eliminate contaminants in nutrient cultures, the list of essential elements will most likely increase in the future.

The Mineral Elements In Plant Production

The use of soil for greenhouse production before the 1960s was common. Today a few growers still use soil in their mixes. The bulk of production is in soilless mixes. Soilless mixes must provide support, aeration, nutrient and moisture retention just as soils do, but the addition of fertilizers or nutrients are different. Many soilless mixes have calcium, magnesium, phosphorus, sulfur, nitrogen, potassium and some micronutrients incorporated as a pre-plant fertilizer. Nitrogen and potassium still must be applied to the crop during production. Difficulty in blending a homogeneous mix using pre-plant fertilizers may often result in uneven crops and possible toxic or deficient levels of nutrients. Soilless mixes that require addition of micro and macronutrients applied as liquid throughout the growth of the crop actually give the grower more control of his crop. To achieve optimum production, the grower can adjust nutrient levels to compensate for other environmental factors during the growing season. The uptake of mineral ions is dependent on a number of factors in addition to weather conditions. These include the cation exchange capacity or CEC and the pH or relative amount of hydrogen (H+) or hydroxyl (-OH) ions of the growing medium, and the total alkalinity of the irrigation water.

CEC or Cation Exchange Capacity

The Cation Exchange Capacity refers to the ability of the growing medium to hold exchangeable mineral elements within its structure. These cations include ammonium (nitrogen), potassium, calcium, magnesium, iron, manganese, zinc and copper. Peat moss and mixes containing bark, sawdust, and other organic materials all have some level of cation exchange capacity.

pH: What Does It Mean?

The term pH refers to the alkalinity or acidity of a growing medium water solution. This solution consists of mineral elements dissolved in ionic form in water. The reaction of this solution whether it is acid, neutral or alkaline will have a marked effect on the availability of mineral elements to plant roots. When there is a greater amount of hydrogen (H+) ions the solution will be acidic (pH<7.0). If there are more hydroxyl (-OH) ions, the solution will be alkaline (pH>7.0). A balance of hydrogen and hydroxyl ions results in a pH neutral soil (pH=7.0). The optimum pH range for most crops is 5.5 to 6.2 or slightly acidic. This creates the greatest average level for availability of all essential plant nutrients. Different mineral elements are available at diffferent pH levels. Extreme variations in pH can cause mineral deficiencies or toxicity by binding up or releasing large amounts of various elements.

Enzymes: The Workhorses of Life

Enzymes are proteins which are involved in increasing the rate and efficiency of biochemical reactions. Most enzymes require metal ions for activation and function. Without proper enzyme function, growth would cease in an organism. Most of the essential mineral elements affect enzymes in multiple ways.

The Elements of Complete Plant Nutrition

The following is a brief summary of the role of essential and beneficial mineral nutrients crucial to plant growth. If any one of the essential elements is eliminated from a plant's nutrition, it will display abnormalities of growth, symptoms of deficiency, and may not reproduce normally.

Essential Macronutrients:

Nitrogen is a major component of proteins, hormones, chlorophyll, vitamins, nucleic acids. Nitrogen metabolism is a major factor in stem and leaf growth (vegetative growth). Over applications of nitrogen will be detrimental to growth. Deficiencies can reduce yields, cause yellowing of the leaves and stunt growth.

Phosphorus is necessary for seed germination, photosynthesis, protein synthesis and almost all aspects of growth and metabolism in plants. Phosphorus is a component of RNA and DNA, the genetic makeup of life. It is essential for flower and fruit formation. Low pH (<4) results in phosphate being chemically locked up in organic soils. Deficiency symptoms include stunted growth are dark green leaves. Purple coloring may also appear due to anthocyanin accumulation.

Potassium is an activator of many enzymes that are required in photosynthesis and respiration. It is involved in osmotic potential in cells. Potassium is also required for protein synthesis and phloem transport.

Sulfur is a structural component in proteins and vitamins. Sulfur is essential in respiration and lipid metabolism. It imparts flavor to many vegetables. Deficiency symptoms appear as chlorosis throughout the leaves, but sulfur deficiencies are rarely encountered. Sulfur is readily lost by leaching from soils and should be applied with a nutrient formula. Many water supplies contain sulfur.

Magnesium is a critical structural component of the chlorophyll molecule and is necessary for functioning and/or activation of plant enzymes to produce carbohydrates, sugars, proteins, and fats. It is used for fruit and nut formation and is essential for germination of seeds. In essence, magnesium is essential to every metabolic pathway in plants. Deficient plants appear chlorotic, show yellowing between veins of older leaves; leaves may droop. Magnesium is leached by watering and must be supplied when feeding. It can be applied as a foliar spray to correct deficiencies.

Calcium activates enzymes, is a structural component of cell walls, influences water movement in cells and is necessary for cell growth and division. Calcium is required for membrane function in all cells. Some plants must have calcium to take up nitrogen and other minerals. Calcium is easily leached. Calcium, once deposited in plant tissue, is immobile (non-translocatable), so there must be a constant supply for growth. Deficiency causes stunting of new growth in stems, flowers and roots. Symptoms range from distorted new growth to black spots on leaves and fruit.

Essential Micronutrients:

Iron is a component of many structural and enzymatic proteins. It is essential for electron transport and chlorophyll biosynthesis. It is therefore required for photosynthesis and respiration. Iron is also essential for lipid metabolism. A well-known symptom of iron deficiency is interveinal chlorosis. High soil pH can cause iron deficiency. Toxic levels of iron are associated with waterlogged soils.

Manganese activates many enzymes, but to date, only two are considered manganese-containing enzymes. One of these enzymes is directly involved with the photosynthetic evolution of oxygen. Manganese is required for respiration and carbohydrate and lipid metabolism. Deficiency symptoms in dicots appear as chlorosis between the veins (interveinal) of young leaves. In grasses, greenish gray spots on the more basal leaves is a sign of manganese deficiency. In neutral or alkaline soils, plants often show deficiency symptoms. In highly acidic soils, manganese may be available in toxic levels.

Zinc is a structural component of many enzymes and also acts as a cofactor in others. Zinc is essential to DNA replication, gene expression, protein synthesis, IAA synthesis, membrane integrity, and carbohydrate metabolism. Deficiency symptoms in dicots include shortened internodes and a reduction in leaf size. Chlorosis often accompanies these symptoms. At low soil pH, zinc may accumulate to toxic levels. Raising the pH is the most effective method of reducing zinc availability in soils.

Copper is an integral component of several enzymes and other critical biological proteins. It is required in photosynthesis, respiration, lignin biosynthesis, and in carbohydrate, nitrogen, and lipid metabolism. Copper is also required for pollen grain formation. A copper deficiency can cause die back of the shoot tips, stunted growth, and terminal leaves may develop black necrotic spots. Copper deficiency affects fruit and seed formation much more drastically than vegetative growth.

Molybdenum is a structural component of the enzyme *nitrate reductase* that reduces nitrates to ammonia. This enzyme is found in all higher plants. Many plants (i.e. legumes) reduce atmospheric nitrogen to ammonia via bacteria located in root nodules. These bacteria use the enzyme *nitrogenase* which also contains molybdenum. Not surprisingly, other biologically important enzymes beside the two mentioned contain molybdenum. One of the most common signs of molybdenum deficiency is interveinal chlorosis of young leaves. Other symptoms include stunted seedling growth and those symptoms associated with nitrogen deficiency.

Chlorine is involved in osmoregulation, the regulation of movement of water and other solutes into and out of cells. Chlorine is essential for cell division in leaves and in the regulation of opening and closing of stomata. Chlorine is also involved in the photosynthetic evolution of oxygen and nitrogen metabolism. Deficiency symptoms include wilting of leaves, chlorosis, and stunted root growth. High levels of chlorine can be severely detrimental to plant growth.

Nickel has recently been determined to be an essential trace element for plants by the Agricultural Research Service (ARS) in Ithaca, New York. It is required for the enzyme *urease*, which most plants use to break down urea into usable forms of nitrogen. Nickel is also a necessary component for the function of other enzymes. Nickel is essential for iron absorption. Seeds require nickel in order to germinate. Plants grown without an adequate supply of nickel will gradually reach a deficient level at about the time they mature and begin reproductive growth.

Boron is involved with root elongation, nucleic acid metabolism, cell wall synthesis, and pollen tube formation. Its uptake is closely related to the soil pH. It becomes more readily available as the pH increases. Deficiency symptoms include discoloration or death of young leaves and terminal buds. Plants will also fail to set seed and fruit.

Beneficial Micronutrients:

Sodium is involved in osmotic (water movement) and ionic balance and is required for some plants.

Cobalt is required for nitrogen fixation in legumes and in root nodules of nonlegumes because it is a component of enzymes essential for nitrogen fixation. Deficient levels could result in nitrogen deficiency symptoms.

Silicon is found as a component of cell walls. Plants with supplies of soluble silicon produce stronger, tougher cell walls creating a mechanical barrier to the mouth parts of piercing and sucking insects. Silicon significantly enhances plant heat, drought and cold tolerance. Foliar sprays of silicon have also shown benefits reducing populations of aphids on field crops. Tests have also found that silicon can be deposited by the plants at the site of infection by fungus to combat the penetration of cell walls by the attacking fungus. Improved leaf erectness, stem strength and prevention or depression of iron and manganese toxicity have all been noted as effects from feeding soluble silicon. Silicon is known to be essential to some members of *poaceae* (grasses) but has shown benefits to a wide variety of plants.