SECONDARY AND MICRO NUTRIENTS

Calcium

Absorbed form the soil as the cation, Ca^{2+}. Most calcium uptake occurs near the root tip.

Poorly translocated within the plant. Deficiencies of Ca first affect the growing points of plants, including root tips. Calcium is important for cell wall formation and the integrity of cell membranes.

Sensitive crops to Ca deficiency and characteristic symptoms.

Crop	Symptoms
Peanuts	Old leaves have pitted undersides. Fruits do not fill if Ca is low 15 days after pegging.
Alfalfa	Does not grow.

Magnesium

Absorbed form the soil as the cation, Mg^{2+}.

Magnesium is at the center of the chlorophyll molecule and is important to photosynthesis. Magnesium is also a catalyst for enzymes needed for carbohydrate and nitrogen metabolism. Magnesium is readily translocated within the plant, therefore deficiency symptoms occur first on the older plant tissues.

Sensitive crops to deficiency and characteristic symptoms.

Crop	Symptoms
Corn	Older leaves show interveinal chlorosis.
Cotton	Interveinal chlorosis, purpling of leaf tissue, then leaf shedding.
Tobacco	Interveinal chlorosis, slender stalks. Roots are long with few branches and slimy appearance.

Sulfur

Most plant S is adsorbed from the soil as the $S0_4^{2-}$ anion, but some S can be absorbed as SO_2 by the leaf tissue. Sulfur is contained in the amino acids cystine, cysteine, and methionine and is therefore, important for protein synthesis. Nitrogen and S are present in protein in a 15:1 ratio. Often the ratio of N:S in plant tissue is used a diagnostic tool for identifying S deficiency.

Sulfur is also a component of the vitamins and coenzymes, thiamin, biotin, coenzyme A, and lipoic acid. Sulfur occurs in plants in the sulfate form as well as in amino acids. Sulfur is only slowly mobile in plant tissue, therefore, deficiency symptoms often occur over the entire plant with increased severity on the youngest plant tissues.

Crop deficiencies in S became more prevalent when high-analysis fertilizers devoid of S became used more frequently. Previously incidental applications of S prevented deficiencies from occurring. Atmospheric deposition of S is around 10-15 lb S/acre/year, which also contributes to the crop's S supply. Cycling of organic-S is important in providing S to crops -- high organic matter soils rarely show S deficiency.

Sulfate-S is strongly adsorbed to the surfaces of iron and aluminum oxides, clay particles and organic matter. More adsorption sites exist at low soil pH, than at high pH. Sulfate is excluded from the adsorption sites when phosphate is present. Consequently, little adsorption of $S0_4^{2-}$ occurs in the surface of well-managed cultivated soils. However, subsoils often have high clay contents, low soil pH, and low P contents and, therefore, considerable capacity to adsorb $S0_4^{2-}$. In general, the plants requirement for S can be provided by the subsoil if it is within 15 inches of the soil surface, and no chemical (extreme acidity) or physical (hardpan) barriers to root growth and proliferation exist.

Sensitive crops to S deficiency. Corn, wheat, bermudagrass.

MICRONUTRIENT

General factors affecting micronutrient supply and availability

Supply

Parent material -- Mn, Cu, Zn greater in basalt than granite (Davidson vs Cecil)
Mo, B low in both types of parent material.

Weathering -- Old highly weathered soils, SC soils, have lower micronutrient contents than young soils.

Availability

Crop sensitivity

Organic matter - increased O. M. decreases Cu avail.

Drainage -- poor drainage enhances leaching of Mn

pH -- decreases availability of all micronutrients ***except Mo which increases***

Climate -- deficiencies more pronounced when weather cool and cloudy

Manganese

Manganese uptake occurs in the Mn^{2+} and chelated form. Manganese is immobile in plants and deficiency symptoms occur on the youngest plant tissues. Manganese is important in many enzyme systems and for energy transfer during photosynthesis.

Soil conditions conducive to Mn deficiency

Manganese occurs in soils in several oxidation state with Mn^{2+} and Mn^{4+} the predominant forms. The relative existence of these two forms are controlled by pH, redox potential (oxygen level of the soil), and organic matter complexation. The lower the pH and oxygen content of the soil the greater the amount of Mn^{2+} in the soil. Plant uptake of Mn is primarily in the Mn^{2+} form. The availability of Mn^{2+} at pH < 5.5 and with low soil oxygen levels can be sufficient to induce toxicity. High pH and well drained soils can result in Mn deficiency.

Sensitive crops to Mn deficiency and characteristic symptoms.

Crop	Symptoms
* Soybeans	Interveinal chlorosis of new leaves with veins remaining green. Necrotic spots appear adjacent to the midrib and leaf veins. Leaves turn yellow throughout and are shed.
Wheat	Young leaves become brownish yellow and then necrotic. Plants frequently die with only 3-4 leaves present.

Zinc

Zinc uptake occurs in the Zn^{2+} and chelated form. Zinc is immobile in plants and deficiency symptoms occur in the youngest plant tissues. Zinc is important in many enzyme systems.

Zinc availability is decreased greatly by increased soil pH. Liming sandy acid soils can induce Zn deficiency. Zinc is the most common micronutrient deficiency worldwide.

Soil conditions conducive to Zn deficiency

Deep sandy soils that have little organic matter.
Soils that have been limed to a high pH.
Soils with excessive P levels and high pH.
Cool wet weather causes deficiency to be more pronounced. Often disappears with warmer weather and increased plant growth.

Sensitive crops to Zn deficiency and characteristic symptoms.

Crop	Symptoms
*Corn	Chlorotic stripes along the leaf. A white stripe may develop between the midrib and the edge of the leaf. Severe cases result in shortened internodes.
Peaches	Chlorosis on young foliage; leaves become crinkled and form a rosette.
Pecans	New growth has a rosette appearance.

Zinc toxicity occurs frequently in peanuts. The initial effects of high zinc are a cessation of root growth. The stem at the base of the plant splits and the plant yellows. Often times plants are dead about 8 weeks after seedling emergence. Soybeans also show some sensitivity to high levels of soil Zn, but most other crop plants are tolerant of high soil Zn levels.

Boron

Boron is absorbed in any one of a number of forms; H_3BO_3, $B_4O_7^{2-}$, H_2BO^{3-}, HBO_3^{2-}, or BO_3^{3-}. Boron is immobile in plant tissue. Young leaves and growing points show deficiency symptoms first.

Soil conditions conducive to B deficiency

Soils limed to high pH and high Ca levels.
Deep sandy soils that are low in organic matter.
Drought often induces B deficiency.

Boron is highly mobile in soils and easily leached. Because of this mobility in soil and immobility in the plant, fertilizer recommendations for B often recommend several small applications to insure B supply throughout the growing season.

Sensitive crops to B deficiency and characteristic symptoms.

Crop	Symptoms
*Cotton	Shedding of squares, flower buds, and young bolls.
Soybeans	Young leaves show interveinal chlorosis, with downward curling of tips. Older leaves may be crinkled and tips dieback when deficiency is severe.
Peanuts	Hollow heart.
Tobacco	Leaf puckering and deformed buds. Small deformed leaves with severe deficiency.
Corn -- high yield	Barren ears and kernel abortion at the tip of the ear.
Apples	Witches-broom on terminal growth. Cork spot on fruit.
Alfalfa	Plants are dwarfed and show reddened or yellowed top leaves. Plant growth and stand longevity are reduced.

Copper

Copper uptake occurs in the Cu^{2+} and chelated form. Copper is immobile in plants and deficiency symptoms occur in the youngest plant tissues. Copper is a catalyst in many enzyme systems and is involved in carbohydrate and N metabolism, lignification, and pollen formation.

Soil conditions conducive to Cu deficiency

Copper is strongly fixed by organic matter, clays, and iron and aluminum oxides, and is therefore immobile in the soil. Deficiencies are most likely to occur on peat and muck soils and overlimed high organic matter poorly drained mineral soils of the Coastal Plain. Copper deficiency may also occur on deep sandy soils low in organic matter.

The difference between deficient and toxic levels of soil Cu is small and Cu applications to soils should be made carefully so that toxic levels are not attained.

Sensitive crops to Cu deficiency and characteristic symptoms.

Crop	Symptoms
Wheat	New leaves appear chlorotic at the tip, become twisted, and develop a grayish cast. Eventually tips become necrotic. Older leaves are limp and appear wilted.
Corn	Moderate deficient plants have interveinal chlorosis. Severely deficient show loss of turgor and bending.

Molybdenum

Plants accumulate Mo in the anionic form, MoO_4^-.

A primary role of molybdenum in the plant is nitrate reduction. In addition, the bacteria associated with leguminous plants also have a requirement for Mo that tends to be greater than that for the plant. Because of these roles in plant nutrition Mo deficiency in legumes and nonlegumes often resembles N deficiency.

Soil conditions conducive to Mo deficiency

Molybdenum is strongly adsorbed by Fe and Al oxides, clay particles, and organic matter. Adsorption is greater at low pH, than at high pH, consequently liming an acid soil increases the availability of Mo.

Sensitive crops to Mo deficiency and characteristic symptoms.

Crop	Symptoms
Soybeans	Plants are pale yellow throughout showing N deficiency.
Peanuts	Plants are pale yellow throughout showing N deficiency.
Alfalfa	Leaves show interveinal chlorotic spots that spread over the entire leaf. Symptoms are more severe on the older leaves. Nitrogen deficiency symptoms appear.

Molybdenum toxicity in plants is rare, but Mo toxicity in animals is not. Forages high in Mo consumed by ruminants may induce Cu deficiency (molybdenosis).

Iron

Iron is absorbed in ionic or chelated form. Although ferric iron (Fe^{2+}) is the form absorbed by plants ferrous (Fe^{3+}) is the active form in plants. Iron is immobile in plants and deficiency symptoms occur on the youngest plant tissues. Deficiencies are common in azaeleas, camellias, and blueberries, but not in crop plants. Young leaves turn chlorotic with veins remaining dark green. Deficiencies generally occur when soil pH is above 6.5.

Iron is a catalyst in several enzyme systems and is essential for chlorophyll and chloroplast formation.

Chloride

Absorbed by plants in the Cl^- form. Little is known of its role in plant nutrition. Deficiencies occur infrequently and symptoms are not distinct. Agronomic applications of chlorine coincidental with potassium fertilization can be detrimental to tobacco and potato.

REFERENCES

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