Essential Plant Nutrients:
their presence in North Carolina soils and role in plant nutrition

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October 1999

Baron Justus von Liebig, a German scientist in the mid-19th century, showed that nutrients are essential for plant life. He stated, "We have determined that a number of elements are absolutely essential to plant life. They are essential because a plant deprived of any one of these elements would cease to exist. . . ." He also authored the term "law of the minimum," which states that "plants will use essential elements only in proportion to each other, and the element that is in shortest supply—in proportion to the rest—will determine how well the plant uses the other nutrient elements."

Knowing the nutrients required to grow plants is only one aspect of successful crop production. Optimum yield also requires knowing the rate to apply, the method and time of application, the source of nutrients to use, and how the elements are influenced by soil and climatic conditions.

There are 16 nutrient elements required to grow crops (Table 1). Three essential nutrients—carbon (C), hydrogen (H), and oxygen (O_2)—are taken up from atmospheric carbon dioxide and water. The other 13 nutrients are taken up from the soil and are usually grouped as primary nutrients, secondary nutrients, and micronutrients.

The *primary nutrients*—nitrogen (N), phosphorus (P), and potassium (K)—are commonly found in blended fertilizers such as 10-10-10, or equivalent grades. Primary nutrients are utilized in the largest amounts by crops, and therefore, are applied at higher rates than secondary nutrients and micronutrients.

The s*econdary nutrients*—calcium (Ca), magnesium (Mg), and sulfur (S)—are required in smaller amounts than the primary nutrients. The major source for supplementing the soil with calcium and magnesium is dolomitic lime (aglime), although these nutrients are also available from a variety of fertilizer sources. Sulfur is available in fertilizers such as potassium and magnesium sulfate, gypsum (calcium sulfate), and elemental sulfur.

Micronutrients—iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), and molybdenum (Mo)—are required in even smaller amounts than secondary nutrients. They are available in manganese, zinc and copper sulfates, oxides, oxy-sulfates and chelates, as well as in boric acid and ammonium molybdate.

Table 1. Nutrients essential for plant growth

Nutrients from air & water	Nutrients from soil, lime and commercial fertilizers		
	primary nutrients	secondary nutrients	micronutrients
carbon (C)	nitrogen (N)	calcium (Ca)	boron (B)
hydrogen (H)	phosphorus (P)	magnesium (Mg)	chlorine (Cl)
oxygen (O)	potassium (K)	sulfur (S)	copper (Cu)
			iron (Fe)
			manganese (Mn)
			molybdenum (Mo)
			zinc (Zn)

Primary Nutrients and Plant Growth

Nitrogen's Role

Of the three major nutrients, plants require nitrogen in the largest amounts. Nitrogen promotes rapid growth, increases leaf size and quality, hastens crop maturity, and promotes fruit and seed development. Because nitrogen is a constituent of amino acids, which are required to synthesize proteins and other related compounds, it plays a role in almost all plant metabolic processes.

Nitrogen is an integral part of chlorophyll manufacture through photosynthesis. Photosynthesis is the process through which plants utilize light energy to convert atmospheric carbon dioxide into carbohydrates. Carbohydrates (sugars) provide energy required for growth and development. The chemical equation for photosynthesis is

$$6CO_2 + 12H_2O + 672 \text{ Kcal radiant energy} = C_6H_{12}O_6 + 6H_2O + 6O_2$$

North Carolina soils contain low levels of nitrogen and require annual applications to sustain crop growth. Little of the applied nitrogen is carried over to subsequent growing seasons due to crop removal, leaching and denitrification. Of all the elements required for crop production, nitrogen poses the greatest environmental threat through contamination of surface and ground water.

Nitrogen fertilizer is available in both organic (manures) and inorganic forms. The amount of nitrogen in organic sources varies with source material and its state of decomposition. However, for commercial crop production, the following inorganic fertilizers are primarily used: ammonium nitrate (33.5%N), potassium nitrate (13% N), sodium nitrate (16% N), calcium nitrate (15.5% N), urea (46% N), mono-ammonium phosphate (18% N), di-ammonium phosphate (46% N) and liquid nitrogen (30% N and 10-34-0).

Legume crops require little or no nitrogen fertilizer. Beneficial bacteria that live in the roots of these plants capture nitrogen from the atmosphere. This nitrogen is available for use by the plant. Nitrogen is also used by microbes to break down organic matter.

Nitrogen Deficiency

Nitrogen-deficient plants exhibit slow stunted growth, and their foliage is pale green. Deficiency symptoms generally appear on the bottom leaves first. In severe cases, the lower leaves have a “fired” appearance on the tips, turn brown, usually disintegrate, and fall off.

In leafy crops such as tobacco, vegetables, forage and pasture crops, low nitrogen results in low yield and quality. When grain crops, such as corn and small grains, are deficient, they generally exhibit yellow leaf tips, stunted growth with spindly stalks, and low yields of poor quality grain. In contrast, too much nitrogen causes excessive vegetative growth, delays maturity, increases lodging, fosters disease, and poses an environmental threat to surface and ground water.

Nitrogen deficiency generally stems from inadequate fertilizer application, denitrification by soil microbes, or leaching loss due to excessive rainfall. Leaching occurs most commonly in sandy-textured coastal plain soils during periods of excessive rainfall. Nitrogen is also lost through volatilization from surface applications during periods of hot, dry weather.

Nitrogen deficiency can be corrected with an application of nitrogen fertilizer. Crop response to fertilization with nitrogen is generally very prompt, depending on the source of nitrogen, stage of plant growth, rainfall, and temperature.

Phosphorus' Role

Normal plant growth cannot be achieved without phosphorus. It is a constituent of nucleic acids, phospholipids, the coenzymes DNA and NADP, and most importantly ATP. It activates coenzymes for amino acid production used in protein synthesis; it decomposes carbohydrates produced in photosynthesis; and it is involved in many other metabolic processes required for normal growth, such as photosynthesis, glycolysis, respiration, and fatty acid synthesis. It enhances seed germination and early growth, stimulates blooming, enhances bud set, aids in seed formation, hastens maturity, and provides winter hardiness to crops planted in late fall and early spring. The meristem region of growing plants is high in phosphorus.

The phosphorus content in North Carolina soils ranges from less than 20 ppm to over 800 ppm**.** The highest levels are found in soils where tobacco and vegetable crops have been grown. High concentrations are also found in fields where heavy rates of poultry litter have been applied.

Phosphorus Deficiency

Phosphorus deficient plants are characterized by stunted growth, dark green leaves with a leathery texture, and reddish purple leaf tips and margins. Reddish purple margins are characteristic of phosphorus deficiency on corn. Symptoms usually occur on young plants when the soil temperature is below 60 ^{0}F.

Deficiency symptoms may appear when soil phosphorus levels are adequate. When soil is cool, less phosphorus is available for plant uptake, whether or not an adequate amount is present. Symptoms related to cool weather generally disappear as soil temperature increases. Some corn growers apply a starter fertilizer containing phosphorus to offset the effects of cool weather during early season growth.

Phosphorus deficiency is rarely observed when the soil temperature is above 60 ^{0}F. Warm-season crops are more likely to show early season deficiency symptoms than cool-season crops are. Bud set of some ornamental and fruit crops is dramatically reduced by low phosphorus.

North Carolina soils typically contain very little phosphorus (<20 ppm). However, fields that have been in production for many years may have medium to high levels of phosphorus, depending the amount applied over time. Usually if soils are high in phosphorus, then rates of application have exceeded crop requirements over the years. Since phosphorus does not leach in mineral soils, any problems associated with surface water contamination can be attributed to soil erosion.

Phosphorus deficiency symptoms generally occur in soils with a low phosphorus content. An application of phosphate fertilizer based on rates recommended by a soil test will correct this problem. Phosphorus occurs in organic fertilizers (manures); inorganic blended fertilizers; and high phosphate materials such as mono-and di-ammonium phosphate (11-48-0 & 18-46-0), triple superphosphate (0-46-0), and liquid mixes such as 10-34-0.

Potassium's Role

Potassium has many functions in plant growth. It

1) is essential for photosynthesis,
2) activates enzymes to metabolize carbohydrates for the manufacture of amino acids and proteins,
3) facilitates cell division and growth by helping to move starches and sugars between plant parts,
4) adds stalk and stem stiffness,
5) increases disease resistance,
6) increases drought tolerance,
7) regulates opening and closing of stomates,
8) gives plumpness to grain and seed,
9) improves firmness, texture, size and color of fruit crops, and
10) increases the oil content of oil crops.

Although not an integral part of cell structure, potassium regulates many metabolic processes required for growth, fruit and seed development. Many vegetable and fruit crops are high in potassium, which is vital for animal and human nutrition. Indeed, the health and survival of man and beast is dependent on potassium.

The potassium content in North Carolina soil ranges from less than 50 ppm to 300 ppm. The lowest amount of potassium is found in sandy coastal plain soils where it is subject to leaching. The higher concentrations are found in the clayey soils of the piedmont and mountain regions. High potassium is also found in areas where animal and poultry wastes have been applied.

Potassium Deficiency

Potassium-deficient plants exhibit chlorosis (loss of green color) along the leaf margins or tips starting with the bottom leaves and progressing up the plant. In severe cases, the whole plant turns yellow, and the lower leaves fall off. As with other nutrients, lack of potassium causes stunted plants with small branches and little vigor. There are some crop-specific deficiency symptoms associated with potassium:

- Grain crops—such as corn, sorghum, and small grains—have weak stalks accompanied by reduced grain size and yield.
- Cotton leaves turn reddish-brown, appear scorched, become bronze then black, and eventually fall off. Bolls are generally knotty, resulting in low quality fiber and poor yield.
- Tomatoes exhibit uneven fruit ripening, poor texture, and soft fruit.
- The skin of stone fruits is distorted. The fruit is small and poor in quality.
- Yield of forage crops is low, and quality is poor.

An application of potassium fertilizer will correct a deficiency and, if diagnosed early in the growing season, will benefit the current crop. Otherwise, the benefit of applying potassium will be for the following crop. Potassium can be obtained from fertilizers such as potassium nitrate (13-0-44), muriate of potash (0-0-60), potassium sulfate (0-0-50), or a mixture of potassium and magnesium sulfate (22% K_2O). Most potash used for commercial crop production in North Carolina is either potassium chloride and potassium sulfate.

Secondary Nutrients and Plant Growth

Calcium's Role

Calcium is a constituent of cell walls and is involved in production of new growing points and root tips. It provides elasticity and expansion of cell walls, which keeps growing points from becoming rigid and brittle. It is immobile within plants and remains in the older tissue throughout the growing season. It acts as a base for neutralizing organic acids generated during the growing process and aids in carbohydrate translocation and nitrogen absorption. Indeed, calcium might be considered the bricks in plant assembly, without which cell manufacture and development would not occur.

The calcium content of North Carolina soils ranges from less than 200 ppm to over 2500 ppm, depending on soil type, liming practices, and cropping sequence. The lowest amount of calcium is found in the sandy coastal plain soils where pH has not been properly maintained or in soils that have a low nutrient-holding capacity and are more subject to leaching.

Calcium Deficiency

Calcium (Ca) deficiency symptoms appear in the meristem regions (new growth) of leaves, stems, buds, and roots. Younger leaves are affected first and are usually deformed. In extreme cases, the growing tips die. The leaves of some plants hook downward and exhibit marginal necrosis. Roots on calcium-deficient plants are short and stubby. In tomatoes and peppers, a black leathery appearance develops on the blossom end of the fruit (a disorder called blossom-end rot). In such cases, the fruit ceases to develop and eventually falls off. In peanuts, low calcium causes "pops," a condition that prevents nuts from developing.

Plants must obtain calcium from the soil. Soil reserves are replenished and maintained with frequent applications of lime. Calcium can also be supplied by applying fertilizers such as calcium nitrate (19.4% Ca), calcium sulfate (22.5% Ca), and normal superphosphate (20.4% Ca).

Calcium deficiency is generally an indication of the need for lime. Soils that are properly limed will provide adequate calcium for several years. For crops like peanuts that require a high calcium concentration near the soil surface at pegging, a banded or broadcast application of gypsum ($CaSO_4$, 22.5% Ca) will supply adequate calcium for normal crop production. For certain specialty crops, a foliar application of calcium nitrate is effective in correcting a deficiency.

Magnesium's Role
Magnesium is a constituent of the chlorophyll molecule, which is the driving force of photosynthesis. It is also essential for the metabolism of carbohydrates (sugars). It is an enzyme activator in the synthesis of nucleic acids (DNA and RNA). It regulates uptake of the other essential elements, serves as a carrier of phosphate compounds throughout the plant, facilitates the translocation of carbohydrates (sugars and starches), and enhances the production of oils and fats. Magnesium deficiency is most prevalent on sandy coastal plain soils where the native magnesium content is low.

Magnesium Deficiency
Magnesium deficiency is most prevalent on sandy-textured soils, which are subject to leaching, particularly during seasons of excess rainfall. The predominant symptom is interveinal chlorosis (dark green veins with yellow areas between the veins). The bottom leaves are always affected first. As the deficiency becomes more acute, the symptoms progress up the plant. Chlorotic leaves generally turn red and then develop spotted necrotic areas.

Crops that commonly exhibit magnesium deficiency include tobacco, corn, small grains, forages, and vegetable crops. On grain crops like small grains and corn, magnesium-deficient leaves have light green to yellow stripes that run parallel with the blade. In severe cases, the entire leaf turns yellow. Magnesium deficiency is the common cause of "grass tetany" in ruminant animals.

On tobacco, deficiency symptoms begin on the tips of the lower leaves and progress across the entire leaf. In acute situations, the entire plant becomes chlorotic. Deficiency symptoms generally appear after topping when the plant is growing most rapidly. The symptoms are commonly referred to as "sand drown" since they occur most frequently on very sandy soils during periods of excessive rainfall.

Magnesium deficiency occurs if soil pH is low or if only calcitic lime has been applied. Depending on the stage of growth and crop, magnesium deficiency can be corrected by soil application of lime or fertilizer. However, once a deficiency symptom has appeared, nothing can be done to correct the affected leaves. Application of a soluble magnesium fertilizer may prevent upper leaves from developing symptoms.

Foliar applications of magnesium are effective in emergency situations where immediate response is required to salvage a crop. Usually, magnesium is applied to the soil through use of commercial fertilizers or dolomitic lime. Dolomitic lime sold in N.C. must contain a minimum of 6% Mg. However, some quarries guarantee as much as 9% Mg.

Sulfur's Role
Sulfur is an essential component in the synthesis of amino acids required to manufacture proteins. Sulfur is also required for production of chlorophyll and utilization of phosphorus and other essential nutrients. Sulfur ranks equal to nitrogen for optimizing crop yield and quality. It increases the size and weight of grain crops and enhances the efficiency of nitrogen for protein manufacture. Crops that have a high nitrogen requirement must have adequate sulfur to optimize nitrogen utilization. Sulfur increases yield and protein quality of forage and grain crops along with production and quality of fiber crops.

Sulfur Deficiency
Sulfur deficiency is characterized by stunted growth, delayed maturity, and general yellowing of plants. Yellowed plants are also characteristic of nitrogen deficiency. However, unlike nitrogen deficiency which begins in the older leaves and progresses up the plant, sulfur deficiency symptoms begin in the young, upper leaves first. Sulfur deficiencies are often misdiagnosed as nitrogen problems, leaving growers to wonder why their nitrogen applications are ineffective.

In many crops, an acute sulfur deficiency causes the entire plant to turn yellow. In crops like corn and small grains, however, yellow stripes that run parallel to the leaf blade are common. Sulfur deficiency is most frequently observed on very sandy soils with a low organic matter content during seasons of excessive rainfall.

Fertilizers that provide sulfur include potassium sulfate (18% S), potassium-magnesium sulfate (23% S), magnesium sulfate (14% S), gypsum (16.8% S), ammonium sulfate (23.7% S), and elemental sulfur (90% S). Under most soil and climatic conditions, 15 to 25 lbs of sulfur per acre should be adequate. For crops that have a high nitrogen requirement (corn, small grains, tobacco, and cotton) and are grown on sandy soils, sulfur can be applied at planting or along with post-plant nitrogen applications.

Table 2. Rates of application to meet crop requirement

Element	Rate (lbs/acre)	Element	Rate (lbs/acre)
nitrogen (N)	60–200*	sulfur (SO_4)	15—25
phosphorus (P_2O_5)	30–150**	manganese (Mn)	10
potassium (K_2O)	30–200**	zinc (Zn)	6
calcium (Ca)	supplied by lime	copper (Cu)	2–6
magnesium (Mg)	supplied by dolomitic lime		

* The application rate for nitrogen depends on crop requirement . **Rate depends on soil content.

Table 3. Primary and secondary nutrient deficiency symptoms, the cause and method of correction

Element	General deficiency symptoms	Probable cause of deficiency	Method of correction
nitrogen (N)	yellow leaves, stunted growth, lower leaves turn brown, leaves abort	low soil N, leaching from the soil, inadequate N applied	apply N fertilizer
phosphorus (P)	small plants, reddish-purple leaves, slow growth, loss of plant vigor	low soil P; cool, wet soils; inadequate P applied	apply P fertilizer
potassium (K)	small plants, brown margins on lower leaves, small weak stems, lodging of plants, poor yield and quality	low soil K, leaching from the soil, inadequate K applied	apply K fertilizer
calcium (Ca)	small plants, deformed buds, distorted leaves, failure to grow, poor fruit development.	low soil pH, leaching from the soil, inadequate lime applied	apply lime or Ca fertilizer
magnesium (Mg)	lower leaves—in severe cases, entire plants—turn yellow with green interveinal areas	low soil pH, leaching from the soil, no Mg applied in lime or fertilizer	apply dolomitic lime or Mg fertilizer
sulfur (S)	yellow plants, slow growth, low vigor, no response to applied nitrogen, low crop yield and quality	low soil S, leaching from the soil, low organic matter content, no S fertilizer applied	apply S fertilizer

Micronutrients and Plant Growth

Manganese's Role

Manganese (Mn) acts as an enzyme activator for nitrogen assimilation. It is essential for the manufacture of chlorophyll. Low plant manganese, therefore, reduces the chlorophyll content causing leaves to turn yellow (chlorosis). The amount of manganese in North Carolina soils ranges from 3 to more than 100 ppm, with lowest levels in coastal plain soils and highest levels in piedmont and mountain soils. Organic soils usually have low to intermediate amounts of manganese. Due to the acidic nature of organic soils, manganese deficiency is rarely observed even when soil manganese is less than 4 ppm.

Manganese Deficiency

Manganese deficiency is typically characterized by interveinal chlorosis (dark green veins with yellow discoloration between the veins), but symptoms vary depending on the crop. Small grain crops may have grey specks and stripes that run parallel to the leaf blade. Known as "grey speck," this symptom occurs at random across a field. Leaves of deficient corn plants have yellow stripes that run parallel to the blade.

Leaves of tobacco and soybean seedlings exhibit a rusty, flecked appearance similar to ozone damage. In acute situations, tobacco leaves turn brown, disintegrate, and fall off. Older soybean plants show the typical interveinal chlorosis pattern, and plants are stunted. Peanuts exhibit an interveinal chlorosis that generally occurs in spots across the field.

Manganese deficiency is due to one of two factors: (1) the soil contains less than 4 ppm manganese; or (2) the soil contains more than 4 ppm manganese, but the pH is above 6.2. Deficiencies occur most frequently in sandy coastal plain soils that have been overlimed. In such cases, the deficiency becomes less severe as pH declines and may disappear when pH drops below 6.2. Banding acid-forming fertilizers increases the amount of manganese available for plant uptake.

However, in soils with a low manganese content, correct the deficiency by applying a minimum of 10 lbs Mn/acre as a broadcast application. Manganese sulfate (~28% Mn) is a good source. Chelated and foliar fertilizers are also effective when applied at the appropriate rate. Sources composed of oxides or oxy-sulfates are generally less effective in building the soil manganese content and correcting a deficiency.

In cases where manganese deficiency occurs following lime application, growers may often associate the problem with lime and ignore the need for applying manganese to the soil. In such cases, both lime and manganese need be applied to prevent crop losses due to soil acidity, on the one hand, and manganese deficiency, on the other. The yield response from applying lime more than pays for the additional cost of applying manganese.

Zinc's Role

Plants require zinc because it activates enzymes.

Zinc Deficiency

Zinc (Zn) deficiency in North Carolina is essentially nil because most soils have an adequate supply. Besides the soil's natural reserves, some liming materials contribute even more zinc to the soil. Application of zinc-containing fungicides and animal and poultry waste products can also add zinc to the soil.

The first obvious symptom of zinc deficiency is interveinal chlorosis of the upper (youngest) leaves. Afterwards, shoot growth slows down, giving the affected plant parts a rosette-like appearance.

Zinc deficiencies in corn and sorghum are typified by a wide band of white tissue on each side of the leaf midrib. This symptom is known as "white bud." "Little leaf" in cotton is also due to zinc deficiency.

Copper's Role

Copper (Cu) is involved as an enzyme activator and is thought to be involved in chlorophyll formation although its specific role is still unclear. It is also thought to be involved in protein synthesis.

Copper Deficiency

Copper (Cu) deficiency is not widespread across North Carolina. It is restricted primarily to sandy coastal plain and organic soils. The Cu content in North Carolina soils ranges from 0.2 to >10 ppm. The critical level required for normal crop production is around 0.5 ppm. Soils with Cu concentrations in excess of 20 ppm may occur in areas where copper fungicides or poultry and swine wastes have been applied.

Small grains, particularly oats, are more sensitive to copper deficiency than other crops. Symptoms generally appear on young plants. The first symptoms are yellowing of the youngest leaves accompanied by slightly stunted growth. In cases of severe deficiency, the younger leaves turn pale yellow. Then, leaf tips curl downward, eventually turn brown, and die. This symptom is referred to as "leaf tip die back" and is most pronounced on small grains. In extreme cases, leaves become shriveled, twisted, broken, and ragged, and ultimately the plant dies.

Copper deficiency can be corrected by adding a small amount of copper fertilizer to the soil. The recommended rates for North Carolina soils are 2.0, 4.0, and 6.0 lbs Cu/acre for mineral, mineral-organic, and organic soils, respectively.

Table 4. Micronutrient deficiency symptoms, the probable cause and method of correction

Element	General deficiency symptoms	Probable cause of deficiency	Method of correction
manganese (Mn)	interveinal chlorosis of leaves, stunted plants, yellow cast over deficient areas, reduced yield & quality	low soil Mn, high soil pH due to over liming	lower soil pH, apply foliar spray or add Mn to soil
zinc (Zn)	chlorotic leaves, slow growth, reduced vigor, white streaks parallel to leaf blade	low Zn in soil, high soil pH, high soil P	lower soil pH, apply foliar spray, or add Zn to soil
copper (Cu)	reduced growth, leaf-tip dies back, leaf tip breaks down, leaves ragged	low soil Cu, high organic matter	apply foliar spray or add Cu to soil
boron (B)	terminal bud dies, multiple lateral branches (rosette with short internodes, older leaves thick and leathery, petioles short, twisted, and ruptured), hollow heart (in vegetables), small deformed fruit (in grapes), cork spot (in apples)	low soil B, esp. on sandy soils	apply foliar spray or add B to soil
molybdenum (Mo)	reduced growth; pale green color; necrotic areas adjacent to midrib, between veins and along leaf edges; twisted stems	low soil pH, low Mo content in soil	inoculate seed with Mo, apply foliar spray, or add Mo to soil
chlorine (Cl)	reduced growth; stubby roots; interveinal chlorosis; nonsucculent tissue (in leafy vegetables)	low soil Cl, esp. in soils subject to leaching	apply Cl-containing fertilizer

Several materials are available for supplying copper and are available in both liquid and solid forms. Since the amount required is quite small compared to other fertilizers, blending dry micronutrient sources uniformly with regular fertilizer materials is difficult to achieve. Granular copper sulfate (25% Cu) and liquid copper (8% Cu) are the most common sources used for blending. Maximum benefit is achieved by uniform application and incorporation into the soil. A single application will generally be adequate for several years.

Boron's Role

Boron (B) is an enzyme activator and is involved in the production of starch required for production of cellulose. The major function of boron is in sugar transport to meristem regions of roots and tops. This is evidenced by the fact that transport of sugars is retarded in boron-deficient plants, resulting in reduced growth.

Boron is also thought to be involved in cell formation and development; nitrogen metabolism; flower fertilization; active salt absorption; hormone, fat, and phosphorus metabolism; and photosynthesis. However, the general consensus is that all of these metabolic processes benefit directly from the influence of boron in sugar transport throughout the plant.

Boron Deficiency

The first visible symptom of boron deficiency is death of the growing tips. This disorder is generally followed by growth of lateral shoots, the tips of which may also be deformed or die. The leaves of boron-deficient plants are usually thick, have a coppery texture, and become curled and brittle.

Other symptoms include stunted roots, failure to set flowers, or flower abortion. Boron deficiency causes internal tissues to disintegrate, causing abnormalities such as distorted, cracked, or hollow stems.

Some crops exhibit specific symptoms. Beets, turnips, and potatoes exhibit poor tuber development. Apples have cork spot. Grapes form mixed clusters of small and large fruit, known as "hen and chicks."

Cotton leaves become thick and leathery with abnormally long spongy petioles. The shorter leaf petioles are often twisted and have small ruptures along the stem. The fruit and leaves exude a sticky substance. Flower buds become chlorotic with flared bracts. The squares and bowls dry up and often abort. Bolls that survive generally are deformed, are smaller in size, and fail to open fully.

Soil analysis does not measure levels of boron because no reliable tests are available. However, a report may recommend applying boron for crops that are known to respond to it, such as alfalfa, apple, cotton, peanut, sweet potato, and several vegetable and flower crops. Rates range from 1.0 to 3.0 lbs B/acre, depending on the crop.

Molybdenum's Role

Molybdenum (Mo) is required for symbiotic nitrogen fixation (nodulation) by legumes and reduction of nitrates for protein synthesis. Plants require molybdenum levels of 0.1 to 2.5 ppm in their tissues for normal growth. Recommended soil application rates for molybdenum fertilizer, however, range only from 0.1 to 0.5 lb Mo/acre. Applying higher rates can create problems.

Overapplication of molybdenum on forage crops can cause a disease called “molybdenosis,” heart disease, and scouring in ruminant animals. High molybdenum content in forage crops can also interfere with copper uptake in ruminant animals ultimately causing a copper deficiency. Therefore, caution is needed when applying molybdenum to crops scheduled for grazing or silage.

The amount of molybdenum found in North Carolina soils is less than 1 ppm. Its availability increases with soil pH, meaning deficiency symptoms occur most frequently under acid soil conditions. Molybdenum availability varies with soil type, being highest on organic soils, less on clays, and least of all on sandy-textured soils.

Molybdenum Deficiency

Molybdenum deficiency symptoms are very similar to those for nitrogen: pale-green to yellow leaves; yellow spots on leaves; marginal chlorosis along side and tip of blade; thick cupped leaves; reddish-brown coloration of stems and petioles; and whiptail leaves (narrow irregular growth). The marginal chlorosis exhibited by some plants looks similar to potassium deficiency. A low rate of foliar sprays can generally correct a deficiency.