

Site-Specific Nutrient Management

For Nutrient Management Planning To Improve Crop Production, Environmental Quality, and Economic Return

Micronutrient: Chapter 7 of 10

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Chapter 7:

Micronutrient Management

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Introduction

Micronutrients are those essential elements required in small quantities for plant growth and reproduction. The quantity needed varies with plant species and the specific element. Seven essential elements are considered micronutrients, and include boron (B), copper (Cu), chlorine (Cl), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). To better understand the relative amounts needed by plants, we can look at the crop removal rate. For example, harvest of a 150 bu/acre corn grain crop will remove approximately 135 pounds of N, 53 pounds of phosphorus (P_2O_5) and 40 pounds of potassium (K_2O) per acre. In comparison to these macronutrients, the removal amount for the micronutrients B, Cu, Fe, Mn and Mo, and Zn are only 0.06, 0.06, 0.10, 0.09, 0.03 and 0.15 pound per acre, respectively. While the needed micronutrient amounts are small, without them plants would not grow and reproduce.

Traditionally, the most important sources of micronutrients for crop growth have been those naturally present in soil and amounts added as impurities in fertilizers and pesticides. Specific soil and related crop situations, however, result in deficiency of one or more micronutrients and potentially serious limitation to crop production. An example is iron deficiency chlorosis in soybean, which coincides with soils having alkaline pH and free carbonates. In some areas, deficiencies of micronutrients have been diagnosed frequently and producers are taking a closer look at their general availability. For high yields and positive economic return to crop production, it is important to correctly recognize and correct micronutrient deficiencies. When micronutrients become a limiting factor, other inputs such as seed, water, fertilizer, etc. are less efficiently utilized and may be wasted. Table 1 lists the amount of each micronutrient (except chlorine) taken up by several crops.

Table 1. Approximate per acre micronutrient uptake by corn, soybean and alfalfa.

Micronutrient	Corn	Soybean	Alfalfa
	150 bu	60 bu	6 ton
	----- lb/acre -----		
B	0.16	0.1	0.3
Cu	0.1	0.1	0.06
Fe	1.9	1.7	1.8
Mn	0.3	0.6	0.6
Mo	0.008	0.01	0.02
Zn	0.27	0.2	0.24

Source: <http://www.ces.purdue.edu/extmedia/AY/AY-239.html>

A brief description of the importance of each micronutrient is presented below, along with the situations in which micronutrient deficiencies are more likely to occur and a general description of fertilization practices.

Boron

A primary function of B is related to cell wall formation, so B deficient plants may have stunted growth. Since B is not readily translocated from older to actively growing tissues, when deficiency occurs the terminal bud can stop growing and will die if the deficiency persists. Sugar transport in plants, flower retention and pollen formation, and germination also are affected by B deficiency. Boron deficiency symptoms first appear at the growing points. This results in a stunted or bushy appearance near the top of the plant, yellowing of newer leaves, barren ears due to poor pollination, hollow stems and fruit (hollow heart), and brittle, discolored leaves and loss of fruiting bodies.

Boron deficiencies are found mainly in sandy soils, in regions of highly weathered soils, low soil organic matter, exposed subsoil, and pH above 7.0. Organic matter contains much of the B in soils. Boron is present in the soil solution mainly as the undissociated boric acid form $B(OH)_3$, or the ionized form $B(OH)_4^-$ at high pH values, and these are the predominant B forms taken up by plants. The B forms are somewhat mobile in soil and can be leached from the root zone, but they move less than other anions like nitrate or chloride. Sorption by clays and association with organic matter will help retain B in soils and provide sources of available B for crops. Boron deficiencies are more pronounced during drought periods when root activity is restricted in the upper profile where available B is typically higher. Crops more sensitive to B deficiency include alfalfa.

Boron fertilizer application can correct deficiencies, but the application rate, method and crop should be carefully considered because toxicity can easily occur. Band application in the seed furrow generally is not recommended because high B concentration can be toxic to seedlings and also can result injury to developing plants. Crops most sensitive to B deficiency include alfalfa, canola, and sugar beet; and many crops are sensitive to B toxicity.

Copper

Copper is a component of enzymes that play a key role in photosynthesis, respiration, lignin synthesis, and carbohydrate and N metabolism. Copper deficiency results in stunting of plants, and since Cu is required for lignin synthesis, deficiency affects cell wall strength and prevention of wilting. Copper deficiency symptoms include reduced nodulation and N fixation in legumes, delayed flowering and maturity; pollen sterility; dieback of leaf tips, stems, and twigs; yellowing of leaves; stunted growth; and pale green leaves that wither easily.

Copper deficiencies are mainly found on organic soils, sandy soils, and soil with pH above 7.5. Copper uptake decreases as soil pH increases. Plants roots take up Cu as the Cu^{2+} ion. Copper uptake by plants can be reduced by excessive P and Fe availability. Cool and wet conditions favor Cu deficiency. Crops more sensitive to Cu deficiency include corn, wheat, and oat.

Broadcast application of Cu mixed with N, P, or K fertilizers is a common application method. Since Cu is slowly converted to unavailable forms in most soils, an application can correct deficiencies for several years with the exception being very sandy soils. Repeated application should be monitored closely for total Cu application, however, and further application discontinued when suggested maximum rates have been applied. If Cu is applied in bands, sprayed to foliage, or from a chelated material, the application rates can be lower than with broadcast applications.

Iron

Iron is involved in the production of chlorophyll in plants; therefore, Fe deficiency (called iron chlorosis) is easily recognized on sensitive crops by yellowing of leaves due to low levels of chlorophyll. Iron also is a component of many enzymes associated with energy transfer, N reduction and fixation, and lignin formation. Iron is associated with S containing compounds that catalyze several other reactions. Leaf yellowing first appears on the younger upper leaves in interveinal tissues. Severe Fe deficiencies cause leaves to turn completely yellow or almost white, and then brown and tattered as leaf tissues die.

Iron deficiencies are found mainly on high pH soils (usually above pH 7.2 and with free carbonates) due to low Fe solubility, in sandy soils, and in organic soils. Cool, wet soil conditions enhance Fe deficiency, especially with marginal levels of available Fe. Poorly aerated or compacted soils also reduce Fe uptake by plants. Uptake of Fe is adversely affected by very high levels of available P, Mn, and Zn in soils; and in soybean Fe chlorosis is aggravated by high concentrations of soil nitrate. Plants roots take up Fe as the Fe^{2+} (ferrous) and Fe^{3+} (ferric) ions, and as a component of organic complexes of low molecular weight. Plant species vary significantly in their sensitivity to low Fe supply. Sensitive crops include soybean and grain sorghum.

Due to soil interaction that greatly reduces Fe solubility and plant availability, foliar or planter-band applications often are the most effective Fe fertilization methods. Research has shown that variety selection is typically a more effective solution than Fe fertilization.

Manganese

Manganese is involved in enzyme activation for plant photosynthesis, N metabolism, and synthesis of various compounds. Interveinal chlorosis is a characteristic Mn deficiency symptom in many plants, and has similar appearance as Fe deficiency chlorosis. In severe deficiency situations, brown necrotic spots appear on leaves and there is premature leaf drop. Delayed maturity is another deficiency symptom in some species. White or gray spots on leaves of some cereal crops are typical signs of Mn deficiency, such as “grey speck” in oat due to tissue breakdown.

Plant roots take up Mn mainly as the Mn^{2+} ion. Manganese deficiencies mainly occur on organic soils with pH above 5.8, high pH mineral soils with free carbonates (calcareous), soils with poor drainage and high organic matter levels, saturated conditions with poor aeration, sandy soils, and over-limed soils having low cation exchange capacity. Crops sensitive to Mn deficiency include soybean, oat and wheat.

Due to interaction with soil that greatly reduces Mn solubility and plant availability, foliar or band applications often are the most effective Mn fertilization method. A common foliar treatment is application of manganese sulfate, but use of chelates is becoming more common. Use of a chelated Mn fertilizer for foliar or band application allows for lower application rates compared with broadcast application. In marginally deficient soils, banding acid forming fertilizers with the planter can prevent or alleviate Mn deficiency by solubilizing soil Mn compounds.

Molybdenum

Molybdenum is involved in enzyme systems related to symbiotic N fixation in legumes, N and S metabolism, and protein synthesis. Molybdenum has a significant effect on pollen formation, so fruit and grain formation are affected in Mo deficient plants. Because Mo requirements are very low, most plant species do not exhibit Mo deficiency. Deficiency symptoms in legumes mimic N deficiency because of the primary role of Mo in N fixation. Unlike most other micronutrients, Mo deficiency symptoms are not confined to the youngest leaves because Mo is mobile in plants. The characteristic Mo deficiency symptom in some crops is irregular leaf blade formation known as whiptail, but interveinal mottling and marginal chlorosis of older leaves also have been observed.

Molybdenum deficiencies are found mainly on very acid, highly weathered, sandy soils in humid regions. Plant roots take up Mo as the MoO_4^{2-} ion. Molybdenum availability and uptake by plants increases with increasing soil pH, which is the opposite of other micronutrients. Liming acidic soils is the most practical and cost-effective way of correcting Mo deficiency and acidity problems at the same time. However, if fertilization is needed, a low Mo rate usually is applied banded with the planter or as a seed treatment.

Zinc

Zinc is an essential component of enzymes important for energy production, carbohydrate metabolism, protein synthesis, and growth regulation. Zinc is not mobile in plants, so Zn deficiency symptoms occur mainly in new growth early in the season. The most visible Zn deficiency symptoms are short internodes, a decrease in leaf size, and a broad band of bleached tissue that goes across leaf veins.

Zinc deficiencies are mainly found on sandy soils low in organic matter, eroded soils with exposed high pH subsoil, soil pH above 7.3, severe root growth restrictions, and organic soils. Plant roots take up Zn mainly as the Zn^{2+} ion. Crops sensitive to Zn deficiency include corn, grain sorghum, and soybean. Zinc deficiencies occur more often during cold, wet spring weather, which is related to reduced root growth and activity as well as less microbial activity and thus less Zn release from soil organic matter. Uptake of zinc can also be adversely affected by application of high P fertilizer rates when soil Zn availability is marginal.

Application to the soil is a common method of applying Zn fertilizers. There are many Zn fertilizers available, with choice depending on the intended application method (broadcast or banded), rate desired, and solubility of the fertilizer. Zinc oxide is the least soluble form and must be finely ground

for enhanced availability. Zinc sulfate, oxysulfate, and zinc-ammonia complex are inorganic sources that provide varying degrees of available Zn. Zinc chelates enhance availability due to lower Zn^{2+} ion interaction with the soil. In marginally deficient soils, banding acid forming fertilizers with the planter can prevent or alleviate Zn deficiency in high-pH soil by solubilizing soil Zn compounds.

Chloride

The chlorine (Cl) elemental form is not found in soils or plants, and it is present as the chloride ion form (Cl^-). Plants take up the chloride ion. Because Cl^- is a mobile anion within the plants, most of its functions relate to osmotic effects (stomatal opening, for example) and electrical charge balance in several physiological functions. Wilting and restricted, highly branched root systems, are the main Cl^- deficiency symptoms, which are found mainly in cereal crops. The role of Cl^- in decreasing the incidence of various diseases in small grains is perhaps more important than its nutritional role.

Most soils contain sufficient levels of Cl^- for adequate plant nutrition. However, Cl^- deficiencies have been reported on sandy soils in humid regions or soils derived from low Cl^- containing parent materials. Crops sensitive to Cl^- deficiency include wheat, potato, and barley, but a few crops (tobacco, for example) are very sensitive to high Cl^- levels. There are few regions with Cl^- deficiency, mainly because Cl^- is applied to soils with KCl, the predominantly used K fertilizer. However, in regions with naturally high available soil K (such as in the central and northern Great Plains), no Cl^- containing K fertilizer is normally applied so Cl^- deficiency is more common.

Diagnosing Micronutrient Deficiencies

Diagnosing a micronutrient deficiency can be a difficult process because diagnostic tools, such as soil or plant analysis, are less reliable than for the macronutrients (as explained below).

Soil sampling and testing

Soil tests aid in determining whether a particular nutrient is responsible for poor crop production and provides the basis for deciding the type and amount of fertilizer needed to correct a nutrient deficiency. Soil samples collected for laboratory analysis must consist of a number of cores and a number of samples from the field. Various soil extractants are calibrated for use in different geographic areas and can extract widely different amounts of micronutrients. Therefore, for proper interpretation of test results, one must use the test calibrated for a particular region, soil, nutrient, and crop. The reliability of most micronutrient

soil tests, compared to other tests like P and K for example, is very low. Also, some soils with low micronutrient levels in the surface layer may not respond to fertilization because they have higher levels of the nutrient in the subsoil. Therefore, confirmation of a deficiency with trial nutrient application, tissue testing, and visual symptoms is helpful to confirm deficiency.

Tissue sampling and testing

Plant tissue tests can aid in determining if a particular nutrient is responsible for poor crop growth. When a deficiency is detected by tissue testing, a reduction in yield due to restricted crop growth has likely already occurred. As with soil analysis, plant tissue tests must be calibrated with field fertilization trials. Calibration of tissue tests is far more complex than for soil tests because measured nutrient concentrations vary considerably with the stage of plant development and the portion of the plant sampled. Special care is required in taking plant tissue samples, including soil contamination. Tissue test interpretation should be based on calibrations with yield response for specific crops, plant part sampled, and stage of plant growth. An appropriate number of samples should be collected to appropriately represent the field area of interest. Fresh samples should be taken quickly to a lab or air-dried to remove excess moisture before they are shipped to a lab. Collecting soil and plant tissue samples at the same time can aid in determining if a micronutrient is deficient.

Micronutrient Fertilizer Sources

Micronutrient fertilizers are applied to the soil or foliage. Foliar or planter-band applications often are more effective than broadcast applications to the soil because the nutrient is applied directly to the foliage or for some micronutrients (not Cl⁻) banding minimizes reactions of soluble forms with the soil that reduces crop availability. The decision regarding whether to use a foliar or soil application, and associated product, will depend on the nutrient, production system, potential soil interaction, and cost of material and application. In addition, because toxicity can occur easily for some micronutrients (such as B), the fertilizer form, placement, and rate should be carefully considered and based on reliable local research information.

Table 2 lists common micronutrient fertilizers and analyses. There are four main categories of micronutrient fertilizers: inorganic, synthetic chelates, natural organic complexes, and fritted glass. Common inorganic fertilizers include oxides, sulfates, and oxysulfates.

Sulfates, due to their high solubility and low cost, are the most common metallic micronutrient salts used as fertilizers. Table 2 gives some examples. The sulfate fertilizer forms can be applied as a granular material or dissolved in liquid fertilizers. Oxides, due to being relatively insoluble, must be finely ground to be effective and more quickly converted to plant available forms when applied to soil. Application well in advance of crop need also increases effectiveness. Oxysulfates are mixtures of oxides and partially dissolved oxides, commonly dissolved with sulfuric acid. Solubility should be greater than 40% to be effective agronomically.

Some micronutrient metals can be complexed with ammonia. The most common is Zn-ammonia complex, which in the soil converts to plant available Zn^{2+} . The Zn-ammonia complex mixes readily with liquid fertilizers.

Chelates are formed by coordinate bonding between an organic chelating agent and the micronutrient metal ion. Chelating agents can be synthetic organic compounds (manufactured) or natural (citric acid, lignosulfonates, phenols, and polyflavinoids). Examples of synthetic chelating agents are EDTA, HEDTA, EDDHA, and DTPA. Chelates generally have higher stability, provide less metal micronutrient interaction with the soil, and are preferred for applications to soil. Chelated micronutrients also are commonly used for foliar application. Due to the enhanced effectiveness, chelates are used at lower rates than other micronutrient fertilizer forms.

Fritted glass micronutrients are specialty fertilizers not widely used, but can be useful for highly leachable soils in areas with high rainfall. They are produced by combining the micronutrient with silicates and then fired in a furnace. The fritted glass matrix controls the release of the micronutrient, and these fertilizers can contain multiple micronutrients.

Manure contains all plant essential nutrients, and like macro- and secondary nutrients, is a valuable source of micronutrients. Therefore, manured fields typically do not have micronutrient deficiencies nor require micronutrient applications.

Table 2. Some example common micronutrient fertilizer sources.

Micronutrient	Fertilizer Name	Formula	Nutrient Percentage (elemental basis)
B	Sodium tetraborate	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$	14
	Boric acid	H_3BO_3	17
	Solubor	$\text{Na}_2\text{B}_8\text{O}_{13} \cdot 4\text{H}_2\text{O}$	20
Cl	Potassium chloride	KCl	47
Cu	Copper sulfate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	25
	Copper chelates	Various	Varies
Fe	Ferrous sulfate	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	20
	Ferric sulfate	$\text{Fe}_2(\text{SO}_4)_3 \cdot 4\text{H}_2\text{O}$	23
	Iron chelates	Various	Varies
Mn	Manganese sulfate	$\text{MnSO}_4 \cdot 3\text{H}_2\text{O}$	27
	Manganese chelates	Various	Varies
Mo	Ammonium molybdate	$(\text{NH}_4)_2\text{MoO}_4$	49
	Sodium molybdate	$\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$	39
Zn	Zinc sulfate	$\text{ZnSO}_4 \cdot \text{H}_2\text{O}$	36
	Zinc oxide	ZnO	78
	Zinc-ammonia complex	$\text{ZnSO}_4 \cdot \text{NH}_3$	10
	Zinc chelates	Various	Varies

Practical Recommendation Summary

Due to the low plant nutrient requirement, crop specificity for deficiency, and soil/climate/nutrient interaction, for many crops and geographic regions practical experience with micronutrient deficiencies is often the best system for determining micronutrient application need. And, given the often poor reliability of soil and plant tissue testing for micronutrients (mainly for soil testing), the large variety of conditions that affect micronutrient supply to crops, and the large variety of fertilizer sources, the following steps are recommended to identify and correct a micronutrient deficiency.

- Ensure that poor crop growth in a field or portion of a field is not the result of a macronutrient or secondary nutrient deficiency, compaction, excess moisture, drought, salinity, disease or insect problem, or herbicide injury.
- Find out if a micronutrient deficiency has been identified before in a particular crop or soil type in the area.
- Examine the affected crop for known specific micronutrient deficiency symptoms.

- Take separate soil and plant tissue samples from affected and unaffected areas for complete analysis, and analyze samples for other nutrients in addition to micronutrients.
- If most indications point to a micronutrient deficiency, apply the micronutrient to a specific, clearly marked, affected area in order to observe results and compare with non-treated areas.
- In choosing a micronutrient fertilizer, consider the solubility, safety concerning damage to seedlings or foliage, advantages and disadvantages for foliar or soil application such as potential for interaction with soil, and cost.
- Consider that other crop inputs such as pesticides, lime, or manure can supply micronutrients or may affect the availability of micronutrients present in the soil. For example, liming acid soils is a very cost effective way of increasing crop availability of Mo, but excess lime application to soil that is slightly acid to neutral pH, or liming alkaline soils, can decrease the availability of Cu, Fe, Mn, Zn and sometimes B.