Micronutrients: Functions, Sources and Application Methods

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The Essential Nutrients: C, H, O, N, P, K, S, Ca, Mg, Fe, Mn, B, Cl, Zn, Cu, Mo, Co, V, Na, Si

There are about 20 nutrients required for plant health. Three of them, carbon, hydrogen, and oxygen (C, H, and O) are considered part of the protoplasm, and the remainder are considered to be mineral elements. When fresh plant material is dried down, the dry matter remaining will be roughly 10% to 20% of the fresh weight. More than 90% of the dry weight will consist of carbon, hydrogen, and oxygen. Corn contains these elements in about the same proportions as in carbohydrate – that is one part carbon to two parts hydrogen to one part oxygen (CH_2O). The bulk of the dry weight is in cell walls which are made of cellulose, a carbohydrate polymer.

If only 10% to 20% — let's say 15% — of a plant's fresh weight is dry matter and all but 10% of the dry matter is represented by carbon, hydrogen, and oxygen, it follows that all the other mineral elements that make up the plant account for only 1.5% of the dry weight (0.15 x 0.10 = 0.015). Three main elements are nitrogen, phosphorus, and potassium (N, P, K) and are required in abundance. They must be readily available through soil medium or fertilizer. The secondary elements are sulfur, calcium, and magnesium (S, Ca, Mg). The quantities required are much less than the macro elements but they are needed in reasonably large quantities. Generally, soil supplies are adequate but added benefits from fertilizer additions may be common depending on the area and soil conditions. For example, fertilizer addition of sulfur to low organic matter soils often results in economically positive yield responses.

Micronutrients are needed in very small amounts. Their adequate concentrations in plants are generally below the 100 parts per million (ppm) level (Table 1). The essential micronutrients are zinc (Zn), iron (Fe), manganese (Mn), boron (B), chlorine (Cl), copper (Cu), molybdenum (Mo), cobalt (Co), vanadium (V), sodium (Na), and silicon (Si). Deficiencies of the last four minerals are very rare. Sodium is probably essential for only a few plants indigenous to saline soils. Silicon may be considered more of a secondary or macronutrient but it is "quasi-essential" in that it has been shown to enhance growth in certain laboratory experiments but plants grown in its absence still thrived. Silicon is second only to oxygen in its abundance in soil because most soil mineral are silicates or aluminosilicates.

The micronutrients that practicing agronomists and crop production people can reasonably do something about are zinc (Zn), iron (Fe), manganese (Mn), boron (B), chlorine (Cl), copper (Cu), and molybdenum (Mo). Zinc is likely the most common micro that is in short supply. Iron is perhaps the most difficult to make available because it is needed in relatively large amounts and soil chemical processes sometimes quickly make it unavailable. Knowing how an element functions in the plant and some of its associated soil chemical interactions helps diagnose problems and prescribe solutions. In this paper we can describe in a general way how each element works and point the reader to resources that will help in specific diagnoses. Additionally, we need to know a little about fertilizer chemistry so we can make application of technology later on. First let's look at each element separately.

Table 1. Selected Nutrient Element Adequate Concentrations and Ranges in Plants (dry weight basis).

Element	Symbol	Range of Concentrations	Adequate Concentration
Nickel	Ni	0.05-5 ppm	0.05 ppm
Molybdenum	Mo	0.10-10 ppm	0.10 ppm
Cobalt	Co	0.05-10 ppm	0.10 ppm
Copper	Cu	2-50 ppm	6 ppm
Zinc	Zn	10-250 ppm	20 ppm
Sodium	Na	0.001-8 %	10 ppm
Manganese	Mn	10-600 ppm	50
Boron	B	0.2-800 ppm	20 ppm
Iron	Fe	20-600 ppm	100 ppm
Chlorine	Cl	10-80,000 ppm	100 ppm
Silicon	Si	0.10%-10%	0.10%
Sulfur	S	0.10%-1.50%	0.10%
Phosphorus	P	0.15%-0.50%	0.20%
Magnesium	Mg	0.05%-1%	0.20%
Calcium	Ca	0.10%-6%	0.50%
Potassium	K	0.80%-8%	1.00%
Nitrogen	N	0.5%-6%	1.50%
Oxygen	O		45%
Carbon	C		45%
Hydrogen	H		6%

Zinc: Zinc has been the micronutrient most often needed by western crops. It is common for citrus crops to be given foliar zinc treatments one or more times per year. Other tree crops, grapes, beans, onions, tomatoes, cotton, rice, and corn have generally required zinc fertilization.

Unlike other metal ions such as copper, iron, and manganese, zinc is a divalent cation (Zn^{++}) that does not undergo valence changes and therefore has no redox activity in plants. High concentrations of other divalent cations such as Ca^{++} inhibit zinc uptake somewhat. Zinc acts either as a metal component of enzymes or as a functional, structural, or regulatory cofactor of a large number of enzymes. More than 80 zinc-containing proteins have been reported. The rate of protein synthesis and the protein content of zinc-deficient plants are drastically reduced. The accumulation of amino acids and amides in these plants demonstrates the importance of zinc for protein synthesis. Zinc is an essential component of RNA polymerase and if the zinc is removed, the enzyme is inactivated. Zinc is also a constituent of ribosomes and is essential for their structural integrity. The decrease in protein content of zinc-deficient plants is also the result of enhanced rates of RNA degradation. Higher rates of RNase activity are a typical feature of zinc deficiency.

Large applications of phosphorus fertilizers to soils low in available zinc may induce zinc deficiency and increase the zinc requirement of plants. Part of the induced deficiency may be due to the inhibition of uptake by other divalent cations or a dilution of plant zinc due to increased growth from the added phosphorus. Soil chemical processes may cause enhanced zinc adsorption to hydroxides and oxides of iron and aluminum and to $CaCO_3$. Several experimental results indicate that there are additional phosphorus-zinc interactions in plants, including inhibition of zinc translocation from the roots to the shoot and “physiological inactivation” of zinc within the shoots. The latter suggestion is based on the observation that symptoms of zinc deficiency are related to the phosphorus/zinc ratio rather than to the zinc concentration in the shoots.

Phosphorus-zinc interactions in soil are complicated by the infection of roots with vesicular-arbuscular mycorrhiza. Infected roots take up more zinc than noninfected roots. Mycorrhizal infection of roots is strongly depressed by an increase in phosphorus supply. There is some evidence that zinc may have a role in mitigating phosphorus toxicity. Experimental results with ochra showed toxic levels of phosphorus in leaves of plants grown without adequate zinc. Although the connection between zinc deficiency and phosphorus toxicity is not well understood, there is substantial evidence that zinc affects phosphorus metabolism in the roots and increases the permeability of the plasma membranes of root cells to phosphorus and to chloride. Zinc stabilizes biomembranes and may therefore have specific function in the structural orientation of macromolecules within membranes and thus in membrane integrity.

Zinc deficiency is widespread among plants grown in highly weathered acid soils and in calcareous soils. In the latter case, zinc deficiency is often associated with iron deficiency. The low availability of zinc in calcareous soils of high pH results mainly from the adsorption of zinc to clay or $CaCO_3$. In addition, zinc uptake and translocation to the shoot are strongly inhibited by high concentrations of bicarbonate (HCO_3^-). In contrast to iron deficiency, zinc deficiency can be corrected fairly easily by the soil application of zinc salts such as $ZnSO_4$.

Symptoms of zinc deficiency in plants include:

1. Decrease in stem length and shortening of internodes, rosetting of terminal leaves.
2. Reduced fruit bud formation.
3. Mottled leaves, interveinal chlorosis. Sometimes, a red. spot-like discoloration (caused by anthocyanins) on the leaves often occurs. Symptoms of chlorosis and necrosis on older leaves of zinc-deficient plants are most likely the result of phosphorus toxicity.
4. Dieback of twigs after the first year.
5. Striping or banding on corn leaves.

Iron: Iron (Fe) is required for the formation of chlorophyll in plant cells. It serves as an activator for biochemical processes such as respiration, photosynthesis and symbiotic nitrogen fixation. Iron deficiency can be induced by high levels of manganese or high lime content in soils. Iron is taken up by plants as ferrous (Fe^{2+}) or ferric (Fe^{3+}) ions. The function of iron in plants depends on the ready transitions between its two oxidation states in solution. Plants store iron as ferritin, a protein that encapsulates ferric iron.

Under aerobic soil conditions, iron is largely insoluble as a constituent of oxides and hydroxides. Ferric iron tends to be tied up in organic chelates. Hence, the concentration of free iron in the soil solution is exceedingly low in many soils. Plants have mechanisms to mobilize iron and make it available for absorption by their roots.

Some of these mechanisms are not specific to absorption of iron. Roots extrude protons and thereby lower the pH of the rhizosphere: the lower the pH, the higher the solubility and availability of iron. Roots also release organic acids into the soil. That has a dual effect on the availability of iron: it lowers the external pH and the acids may form soluble complexes with iron.

There are two mechanisms specific to iron absorption. The first (characteristic of dicots and non-graminaceous monocots) acidifies the rhizosphere by extruding protons. Ferric iron is reduced to ferrous iron by an inducible Fe^{3+} reductase enzyme at the plasma membrane. The reduced iron is transported across the membrane by Fe^{2+} specific ion transport system. The second mechanism (characteristic of corn, barley, and oat) involves the extrusion of siderophores (Greek meaning “iron carriers”) by the roots. No reduction to ferrous iron takes place.

Crops often affected by iron deficiency are corn, sorghum, certain soybean varieties, turf, and certain tree crops and ornamentals.

Symptoms of iron deficiency include:

1. Interveinal chlorosis of young leaves. Veins remain green except in severe cases.
2. Twig dieback.
3. In severe cases, death of entire limbs or plants.

Manganese: Manganese serves as an activator for enzymes in growth processes. It assists iron in chlorophyll formation. It is part of the system where water is split and oxygen gas is liberated. The splitting of water is an oxidation, namely $2\ H_2O \rightarrow O_2 + 4\ H^+ + 4\ e^-$. The other protein in which manganese is an integral constituent is the manganese-containing superoxide dismutase. This enzyme is widespread in aerobic organisms. The function of this enzyme is to provide protection from free oxygen radicals formed when O_2 receives a single electron. Superoxide dismutases convert this highly toxic free radical into hydrogen peroxide (H_2O_2) which is subsequently broken down to water.

High manganese concentration may induce iron deficiency. Manganese uptake is primarily in the form of Mn^{++}. Manganese is generally required with zinc in foliar spraying of citrus. Other tree crops may show deficiencies, but otherwise there is no common recognition of requirements for this element. There is a growing body of knowledge suggesting that manganese additions may enhance glyphosate resistant soybean yield.

Symptoms of manganese deficiency include:

1. Interveinal chlorosis of young leaves. Gradation of pale green coloration with darker color next to veins. No sharp distinction between veins and Interveinal areas as with iron deficiency.
2. Development of gray specks (oats), interveinal white streaks (wheat), or interveinal brown spots and streaks (barley).

Boron: Boron functions in plants in differentiation of meristem cells. The general consensus is that its major function has to do with the structure of the cell wall and the substances associated with it. The range in plant tissues is wide (Table 1) with values generally higher in dicotyledons than in monocotyledons. It is present in soil solutions with a pH less than 8 mainly as undissociated boric acid ($B(OH)_3$), the principle form taken up by roots, and disassociates to $B(OH)_4^-$ only at higher pH values.

Boron deficiency is a widespread nutritional disorder. Under high rainfall conditions boron is readily leached from soils as $B(OH)_3$. Boron availability decreases with increasing soil pH, particularly in calcareous soils and soils with a high clay content. Availability also sharply decreases under drought conditions, probably because of both a decrease in boron mobility by mass flow to the roots and polymerization of boric acid.

Symptoms of boron deficiency in the shoots are noticeable at the terminal buds or youngest leaves, which become discolored and may die. Internodes are shorter, giving the plants a bushy or rosette appearance. Deficiency is found mainly in the youngest plant tissues. Interveinal chlorosis on mature leaves may occur, as might misshapen leaf blades. Drop of buds, flowers, and developing fruits is also a typical symptom of boron deficiency. With boron deficiency, cells may continue to divide, but structural components are not differentiated. Boron also apparently regulates plant metabolism of carbohydrates. Boron is non-mobile in plants, and a continuous supply is necessary at all growing points.

Chlorine: Chlorine is a strange mineral nutrient. Its normal concentration in plants is more typical of a macronutrient and yet the chlorine requirement for growth is more like a micronutrient (Table 1). Chlorine is ubiquitous in nature and it occurs in aqueous solutions as chloride (Cl^-). Evidence indicates that it is highly mobile and its main higher plant functions relate to charge compensation and osmoregulation.

Because chlorine is usually supplied to plants from various sources (soil reserves, rain, fertilizer and air pollution) there is much more concern about toxic levels than about deficiency. Nonetheless, a few cases have been noted of positive responses to the application of chloride as a fertilizer for wheat.

Symptoms of chlorine deficiency include:

1. A blue-green shiny appearance of young leaves.
2. Wilting, followed by chlorosis.
3. Excessive branching of lateral roots.
4. Bronzing of leaves.
5. Chlorosis and necrosis in tomatoes and barley.

Copper: Copper is present in plants in complexed form. Like other potentially toxic heavy metals, copper in excess is bound to phytochelatins (Greek meaning “plant claws”) and sulfur containing peptides. Copper in solution is present as cuprous (Cu^{+}) and cupric (Cu^{++}). Cuprous copper is readily oxidized to cupric and so cuprous copper is only found in complexed forms. Cuprous complexes are usually colorless, whereas the cupric complexes are often blue or brown.

Copper is an activator of several enzyme systems in plants and functions in electron transport and energy capture by oxidative proteins and enzymes. It may play a role in vitamin A production. A deficiency interferes with protein synthesis.

Native copper supply has been recognized only rarely as needing supplementation. Some tree crops grown on organic soils or sands may need supplementation. Copper can be toxic at low levels so a need should be firmly established prior to supplementation. Deficiency symptoms vary greatly among species.

Symptoms of copper deficiency include:

1. Leaves may be chlorotic or deep blue-green with margins rolled up.
2. The bark of trees is often rough and blistered, and gum may exude from fissures in the bark.
3. Young shoots die back.
4. Flowering and fruiting may fail to develop in annual plants and they may die in the seedling stage.
5. Stunted growth.
6. Formation of gum pockets around central pith in oranges.

Molybdenum: Although molybdenum is a metal, it occurs in aqueous solution mainly as molybdate anion, $MoO_4^{=}$. Molybdate seems to be relatively mobile in plants and higher concentrations can be found in roots than leaves when supplies are limited. Leaf concentrations may rise as molybdenum supplies increase. The molybdenum requirement is lowest of any mineral except, in certain species, nickel. The functions of molybdenum as a plant nutrient are related to the valency changes it undergoes as a metal component of enzymes.

Only a few enzymes have been found to contain molybdenum in plants. In higher plants two molybdenum containing enzymes, nitrogenase and nitrate reductase, are of vital importance in crop production. All biological systems fixing N_2 require nitrogenase. Each nitrogenase molecule contains two molybdenum atoms, which are associated with iron. Therefore, the root nodule requirement is relatively high. As would be expected, the growth of plants relying on N_2 fixation is particularly stimulated by the application of molybdenum to deficient soils. The response of root nodule activity to molybdenum is spectacular and indirectly reflects the increase in the capacity for N_2 fixation brought about by molybdenum additions.

In soils with low molybdenum availability, the effect of application of molybdenum to legumes depends on the form of nitrogen supply (fixed N_2 or added inorganic N fertilizer). The yield enhancement of adequately rhizobial infected soybeans from added molybdenum will be higher when fertilizer nitrogen is not added because N_2 fixation is facilitated by molybdenum.

Molybdenum serves as a cofactor for the enzyme nitrate reductase. Molybdenum deficiency reduces the nitrate reductase activity, which inhibits the plant’s ability to synthesize proteins. There are conflicting reports as to whether there is any molybdenum requirement for plants supplied exclusively with reduced N such as ammonium or urea. Conventional wisdom is that plants supplied a mixed N regime thrive best (therefore establishing a molybdenum requirement).

Molybdenum deficiency is widespread in legumes and certain other plant species grown in acid mineral soils with a large content of reactive iron oxide hydrates. Liming may increase molybdenum availability to the point where luxury consumption occurs. This may be dangerous to ruminant livestock, which are very sensitive to excessive concentrations of molybdenum. Plants generally have a wide range of acceptable molybdenum concentrations. High, but nontoxic, molybdenum concentration in seeds ensures proper seedling growth and higher final grain yield. There is an inverse relationship between seed molybdenum content and yield response to added molybdenum fertilizer. Uptake rate of molybdenum is extremely low in the first 4 weeks after germination. Thus, the molybdenum requirement has to be met by retranslocation from the seed.

Symptoms of molybdenum deficiency include:

1. Interveinal chlorosis. Veins remain green producing a mottled appearance.
2. Stunting and lack of vigor. This is similar to nitrogen deficiency due to the key role of molybdenum in nitrogen utilization by plants.
3. Marginal scorching and cupping or rolling of leaves.

Choosing a Micronutrient Application

Neither the treatment nor prevention of micronutrient deficiencies is complicated or expensive. The drag on yield and waste of time and resources caused by the deficiency costs plenty. Knowing how micronutrients behave in plants and soils will help determine if you need to take remedial or preventative action. It really depends on how and when you make a diagnosis. Soil applications are nearly always more effective and economical than foliar. However, if a problem expresses itself after the crop is emerged, then foliar treatment is the logical remedy. Tissue tests offer additional evidence of a problem but may not paint a complete picture. They will augment the soil test. Unfortunately, soil tests will not provide a completely accurate representation either. Generally, micronutrient soil tests will provide an indicator of the potentially available nutrient or give the total amount found. They usually have not been subjected to the correlation and calibration effort that the macronutrients have been subjected to. This is not to say that they are wrong or totally inaccurate, but the will serve better as guidelines and verifiers of a field's capabilities. Finally, soil micronutrient concentrations have been shown to vary widely in a field. It is important to obtain representative soil samples for analysis.

There are a myriad of micronutrient products available. Each may claim a stake in how available the product is but the true test is how well it works in your field. Chelates are not better because they are chelated (more on chelates to follow). An example would be chelated manganese. Manganese chelates, when applied to soils high in iron are usually ineffective because the available iron replaces the Mn in the chelate. Manganese is kicked out into the soil chemical complex and is rendered unavailable. Sometimes, an efficiency factor is applied to a chelate. Authors (including universities) will recommend using a fraction of the recommended rate. These efficiency factors are often based on economics rather than agronomics. Efficiency factors may be appropriate in certain circumstances, but don't be fooled into thinking you bought 40 pounds of nutrient in a ten-pound container. There is evidence that there are differences in plant availability of different products. Researchers in Colorado did greenhouse studies to investigate whether there was a relationship between plant available zinc and the amount of water-soluble zinc in various fertilizers. They found that plants grown in zinc deficient soils increased yield and absorbed zinc directly in proportion to the degree of water-soluble zinc in the fertilizer material. In this case, the greenhouse study is applicable to field conditions and verifies a positive relationship.

Efficiency is also related to application method. Generally, banding is more efficient than broadcast. One of the easiest ways to band fertilizer is as starter (fertilizer applied with the planter unit). Broadcasting of some micronutrients is not recommended because the use rates are so low. However, broadcasting may be the only alternative in some systems. You can expect that chelated forms (where available) are likely to move in the soil more than non-chelated. This may be especially important in no-till systems where starter is not used. This scenario is likely to be rare since the value of starter has been shown to be great in no-till systems.

Diagnosis

When a micronutrient deficiency is diagnosed the soil test can be augmented with a tissue test. Together, the two tools will provide a more complete picture. Testing times are given in the chart below but you may not want to wait until the ideal time arrives. You may want to send in a sample immediately so you can set up remedial efforts. Collect samples from both normal and problem areas so you have a base to work from.

Table 2. Plant Sampling Guide for Diagnosis of Micronutrient Deficiencies*.

Crop	Stage of development	Plant part to sample	Quantity needed
Corn	Up to 12 inches tall	Entire plant above ground	30 plants
	12 inches to tasseling	Topmost fully-developed leaf	20 leaves
	At silk initiation (too late	Top ear leaf	15 leaves
	if silks have turned brown)		
Soybeans	Up to 12 inches tall	Entire plant above ground	30 plants
	12 inches to early bloom	Uppermost fully-expanded trifoliate 50 leaves	
	leaves (leaves only, discard		
	petiole or stem)		
Small grains	Up to 12 inches tall	Entire plant above ground	30 plants
	Before heading	Uppermost leaves	30 leaves
Legumes for hay	Before flowering until early bloom	Top 6 inches of the plant	30 plants

*From: Publication AY-239, Soils (Fertility), Purdue University Cooperative Extension Service, West Lafayette, IN 47907

The remaining information in this document has been excerpted directly from: The Ohio State Universtiy Bulletin E-2567, *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa*, M.L. Vitosh (Michigan State University), J.W. Johnson (The Ohio State University), D.B. Mengel (Purdue University).

Table 3. Crop and Coil Conditions Under Which Micronutrient Deficiencies May Occur.

Micronutrient	Soil	Crop
Boron (B)	Sandy soils or highly weathered soils low in organic matter	Alfalfa and clover
Copper (Cu)	Acid peats or mucks with pH < 5.3 and black sands	Wheat, oats, corn
Manganese (Mn)	Peats and mucks with pH > 5.8, black sands and lakebed/depressional soils with pH > 6.2	Soybeans, wheat, oats, sugar beets, corn
Zinc (Zn)	Peats, mucks and mineral soils with pH > 6.5	Corn and soybeans
Molybdenum (Mo)	Acid prairie soils	Soybeans

Table 4. Nutrient Sufficiency Ranges for Corn, Soybeans, Alfalfa and Wheat.

Element	Corn	Soybeans	Alfalfa	Wheat
	Ear leaf sampled at initial silking	Upper fully developed leaf sampled prior to initial flowering	Top 6 inches sampled prior to initial flowering	Upper leaves sampled prior to initial bloom
	---------------- Percent (%) ----------------			
Nitrogen	2.90-3.50	4.25-5.50	3.76-5.50	2.59-4.00
Phosphorus	0.30-0.50	0.30-0.50	0.26-0.70	0.21-0.50
Potassium	1.91-2.50	2.01-2.50	2.01-3.50	1.51-3.00
Calcium	0.21-1.00	0.36-2.00	1.76-3.00	0.21-1.00
Magnesium	0.16-0.60	0.26-1.00	0.31-1.00	0.16-1.00
Sulfur	0.16-0.50	0.21-0.40	0.31-0.50	0.21-0.40
	------------ Parts per million (ppm) ------------			
Manganese	20-150	21-100	31-100	16-200
Iron	21-250	51-350	31-250	11-300
Boron	4-25	21-55	31-80	6-40
Copper	6-20	10-30	11-30	6-50
Zinc	20-70	21-50	21-70	21-70
Molybdenum	-	1.0-5.0	1.0-5.0	-

Table 5. Micronutrient Sources Commonly Used for Correcting Micronutrient Deficiencies in Plants.

Micronutrient	Common fertilizer sources
Boron (B)	Sodium tetraborate (14 to 20% B) Solubor® (20% B) Liquid boron (10%)
Copper (Cu)	Copper sulfate (13 to 35% Cu Copper oxide1 (75 to 89% Cu)
Manganese (Mn)	Manganese sulfate (23 to 25% Mn) Manganese oxysulfates (variable % Mn)
Zinc (Zn)	Zinc sulfate (23 to 36% Zn) Zinc-ammonia complex (10% Zn) Zinc oxysulfates (variable % Zn) Zinc oxide1 (50 to 80% Zn) Zinc chelate (9 to 14% Zn)
®Registered trade name of U.S. Borax.	
[1]Granular oxides are not effective sources of micronutrients.	

Table 6. Manganese Fertilizer Recommendations for Responsive Crops Grown on Mineral Soils[1].

Soil test Mn[2]	Soil pH 6.3	6.5	6.7	6.9	7.1	7.3	7.5+
ppm	--- lb Mn per acre[3]---						
2	2	4	5	6	7	9	10
4	2	3	4	5	7	8	9
8	0	2	3	4	5	6	8
12	0	0	0	3	4	5	6
16	0	0	0	0	2	4	5
20	0	0	0	0	0	2	4
24	0	0	0	0	0	0	2

[1]Recommendations are for band applications of soluble inorganic Mn sources with acid-forming fertilizers. Broadcast applications of Mn fertilizer are not recommended.

[2]0.1 N HCl extractable Mn

[3]Recommendations are calculated from the following equation and rounded to the nearest pound:

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       XMn = -36 + 6.2 x pH - 0.35 x ST
 Where XMn = lb Mn per acre
        pH = soil pH
        ST = ppm Mn soil test
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Table 7. Manganese Fertilizer Recommendations for Responsive Crops Grown on Organic Soils[1].

Soil test Mn[2]	**Soil pH**						
	5.8	**6.0**	**6.2**	**6.4**	**6.6**	**6.8**	**7.0+**
ppm	**---lb Mn per acre[2]---**						
2	2	4	5	7	9	10	12
4	1	3	5	6	8	10	11
8	0	1	3	5	7	8	10
12	0	0	2	4	6	7	9
16	0	0	1	3	4	6	8
20	0	0	0	1	3	5	6
24	0	0	0	0	2	4	5
28	0	0	0	0	1	2	4
32	0	0	0	0	0	1	3
36	0	0	0	0	0	0	1

[1]Recommendations are for band applications of soluble inorganic Mn sources with acid-forming fertilizers. Broadcast applications of Mn fertilizer are not recommended.

[2]0.1 N HCl extractable Mn

[3]Recommendations are calculated from the following equation and rounded to the nearest pound:

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      XMn = -46 + 8.38 x pH - 0.31 x ST
Where XMn = lb Mn per acre
       pH = soil pH
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ST = ppm Mn soil test

Table 8. Zinc Fertilizer Recommendations for Responsive Crops Grown on Mineral and Organic Soils[1].

Soil test Zn^2	Soil pH 6.6	6.8	7.0	7.2	7.4	7.6+
ppm	--- lb Zn per acre[3] ---					
1	1	2	3	4	5	6
2	0	1	2	3	4	5
4	0	0	1	2	3	4
6	0	0	1	2	3	4
8	0	0	0	1	2	3
10	0	0	0	0	1	2
12	0	0	0	0	0	1

[1]Recommendations are for band applications of soluble inorganic Zn sources. Synthetic Zn chelates may be used at one-fifth this rate. For broadcast applications, use 5 to 10 lb Zn/acre.

[2]0.1 N HCl extractable Zn

[3]Recommendations are calculated from the following equation and rounded to the nearest pound:

$$XZn = -32 + 5.0 \times pH - 0.4 \times ST$$

Where XZn = lb Zn per acre
pH = soil pH
ST = ppm Zn soil test

Table 9. Copper Recommendations for Corn Grown on Organic Soils[1].

Soil test Cu^2 ppm	Copper recommendation lb Cu per acre[3]

1	4
4	4
8	3
12	2
16	1
20+	0

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[1]Recommendations are for band applications of soluble inorganic Cu sources. For broadcast applications, use 5 to 10 lb Cu/acre.
[2]1.0 N HCL extractable Cu
[3]Recommendations are calculated from the following equation and rounded to the nearest pound:

$$XCu = 6.3 - 0.3 \times ST$$

Where XCu = lb Cu per acre
ST = ppm Cu soil test

Boron recommendations for Michigan, Ohio, and Indiana are not based on any soil test — they are based on soil type and the responsiveness of the crop. Boron is recommended annually at a rate of 1 to 2 pounds per acre broadcast applied on established alfalfa and clover grown on sandy soils. Boron applications on fine-textured high clay soils have not proven to be beneficial.

Molybdenum deficiency of soybeans has been found on certain acid soils in Indiana and Ohio. Most molybdenum deficiencies can be corrected by liming soils to the proper soil pH range. The recommended molybdenum fertilization procedure is to use 1/2 ounce of sodium molybdate per bushel of seed as a planter box treatment or 2 ounces of sodium molybdate per acre in 30 gallons of water as a foliar spray. Extreme care should be used when applying molybdenum because 10 ppm of Mo in forage may be toxic to ruminant animals.

Table 10 gives foliar micronutrient recommendations for responsive crops listed in Table 3. Foliar rates of suggested sources should be based on the size of the plant — use higher rates for larger plants and lower rates with smaller plants. Use 20 to 30 gallons of water for sufficient coverage of the foliage to ensure good uptake of the micronutrient. When foliar sprays of chelates are used, follow the labeled rate — using too much can cause foliar injury and reduced uptake. At reduced rates, chelate foliar sprays are usually less effective than the suggested inorganic sources.

Table 10. Common Micronutrient Fertilizer Sources and Suggested Rates for Foliar Application[1].

Micronutrient	lb of element per acre	Common fertilizer sources
Boron (B)	0.10.3	Sodium borate (20% B) Boric acid (17% B)
Copper (Cu)	0.5-1.0	Copper sulfate (13 to 25% Cu
Manganese (Mn)	1.0-2.0	Manganese sulfate (28% Mn)
Zinc (Zn)	0.3-0.7	Zinc sulfate (36% Zn)
Molybdate (Mo)	0.01-0.07	Ammonium molybdate (49%) Sodium molybdate (46%)
[1] Use sufficient water (20 to 30 gallons) to get good coverage of foliage.		

References

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