Secondary and Micronutrients for Vegetables and Field Crops
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M.L. Vitosh, D.D. Warncke, and Robert E. Lucas, Extension Specialists, Department of Crop and Soil Sciences
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By **M.L. Vitosh, D.D. Warncke** and **R.E. Lucas**
Department of Crop and Soil Sciences
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COVER: Zinc response on dry edible beans. Four rows between the two stakes received zinc in the starter fertilizer. The rest of the field received starter fertilizer without zinc.

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GENERAL INFORMATION

Plant nutrients in fertilizers are classified as major nutrients and micronutrients. The most important major nutrients are nitrogen (N), phosphorus (P) and potassium (K). Plants require these nutrients in relatively large amounts, and these are the nutrients most likely to be deficient for plant growth. The other major nutrients, also called secondary nutrients, are calcium (Ca), magnesium (Mg) and sulfur (S). They are also required in relatively large amounts but are less likely to be deficient. Micronutrients are essential for plant growth, but plants require relatively small amounts of them. They include boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn). These elements may also be referred to as minor or trace elements, but "micronutrients" is preferred.

Extent of Secondary and Micronutrient Deficiencies

Secondary and micronutrient deficiencies in Michigan are not widespread, but a deficiency of any of these elements can cause plant abnormalities, reduced growth or reduced yield. Increased need for these nutrients in crop production has drawn attention for the following reasons:

- More information on crop responses and availability of nutrients in various soil types has been accumulated.
- Today's higher crop yields require larger amounts of these nutrients.
- Long-time cropping has removed measurable amounts of these nutrients.
- Today widespread use of animal manures has decreased and use of high-analysis fertilizers low in nutrient impurities has increased.
- High potassium levels in the soil and greater use of nitrogen fertilizer can cause a magnesium imbalance in some plants that creates the potential for hypomagnesia (grass tetany) problems in livestock.
- High phosphorus levels in the soil may induce zinc deficiency in plants.
- Air pollution abatement practices have reduced sulfur emissions from industry and decreased the amount of sulfur added to the soil by precipitation.
- More attention is being given to crop quality and nutritional value of today's crops.

Identifying Problem Areas

The information used to help identify secondary and micronutrient problems are soil tests, plant analyses, soil type, crop species and plant symptoms. A good way to confirm a suspected nutrient deficiency is to obtain plant and soil samples from adjacent areas with normal and abnormal plant growth and have them tested.

The MSU Soil Testing Laboratory will test soil samples for pH, available phosphorus, exchangeable (available) potassium, calcium, magnesium and extractable (available) zinc, manganese and copper. Some laboratories may also offer soil tests for sulfur, boron and iron.

Many soil testing laboratories also offer plant tissue analyses. Table 1 shows the acceptable or sufficiency nutrient concentrations required for production of several important Michigan crops. The values reported for vegetables are general and should be used only as guidelines. Nutrient values below the sufficiency concentration may indicate a deficiency. Values above the sufficiency concentration may be excessive and possibly toxic.

When using tissue analysis to diagnose nutrient deficiencies, it is important to sample the specified plant tissue at the proper time. It may also be helpful to note whether deficiency symptoms existed on the plant or tissue sampled and any climatic conditions that might have caused the symptoms to occur.

Secondary and Micronutrient Fertilizers

There are several ways to add secondary and micronutrients to nitrogen, phosphorus and potassium (N-P-K) fertilizers. They may be incorporated into granulated fertilizers during the granulation process so that each granule of fertilizer contains an equal amount of all nutrients. They may be blended with N-P-K fertilizers at a bulk blending plant. If the particle size of secondary and micronutrients is greatly different from the size of particles containing the primary nutrients, a sticker may be needed to prevent particle size separation. Separation can lead to segregation of particle sizes and non-uniform application. These nutrients may also be added to liquid or suspension fertilizers. Chelated secondary and micronutrient formulations of these nutrients are generally preferred to non-chelated materials for mixing with liquid fertilizer because a larger amount of the nutrient can be added before precipitation occurs.

The amount of secondary or micronutrients required in mixed fertilizers depends on the application rate. Table 2 can be used to determine the appropriate percentage of elements needed in mixed fertilizers based on the amount of fertilizer to be applied and the amount of element required per acre. In this bulletin,

TABLE 1.
Nutrient sufficiency ranges for corn, soybeans, alfalfa, wheat, sugar beets, potatoes and vegetables.

ELEMENT	CORN	SOYBEANS	ALFALFA	WHEAT	SUGAR BEETS	VEGETABLES	POTATOES
	Ear leaf sample of initial silk	Upper fully developed leaf sampled prior to initial flowering	Top 6 inches sampled prior to initial flowering	Upper leaves sampled prior to initial bloom	Center fully developed leaf sampled in midseason	Top fully developed leaves	Petioles from most recently matured leaf sampled in midseason
Percent (%)							
Nitrogen	2.76-3.50	4.26-5.50	3.76-5.50	2.59-3.00	3.01-4.50	2.50-4.00	2.50-4.00
Phosphorus	0.25-0.50	0.26-0.50	0.26-0.70	0.21-0.50	0.26-0.50	0.25-0.80	0.18-0.22
Potassium	1.71-2.50	1.71-2.50	2.01-3.50	1.51-3.00	2.01-6.00	2.00-9.00	6.00-9.00
Calcium	0.21-1.00	0.36-2.00	1.76-3.00	0.21-1.00	0.36-1.20	0.35-2.00	0.36-0.50
Magnesium	0.16-0.60	0.26-1.00	0.31-1.00	0.16-1.00	0.36-1.00	0.25-1.00	0.17-0.22
Sulfur	0.16-0.50	0.21-0.40	0.31-0.50	0.20-0.40	0.21-0.50	0.16-0.50	0.21-0.50
Parts per million (ppm)							
Manganese	20-150	21-100	31-100	16-200	21-150	30-200	30-200
Iron	21-250	51-350	31-250	11-300	51-200	50-250	30-300
Boron	4-25	21-55	31-80	6-40	26-80	30-60	15-40
Copper	6-20	10-30	11-30	6-50	11-40	8-20	7-30
Zinc	20-70	21-50	21-70	21-70	19-60	30-100	30-100
Molybdenum	0.1-2.0	1.0-5.0	1.0-5.0	0.03-5.0	.15-5.0	0.5-5.0	0.5-4.0

all secondary and micronutrient recommendations are given in pounds of element per acre.

Fertilizer Laws

The Michigan Fertilizer Law requires each fertilizer manufacturer who claims secondary and micronutrients are present in fertilizer to guarantee the minimum composition of these nutrients in the fertilizer. Some states have set minimums for claims at levels recommended by the Association of American Plant Food Control Officials (AAPFCO). These levels are lower than those permitted by Michigan regulations. We believe that these low levels often do not supply sufficient quantities to correct a deficiency. For example, one application of 300 pounds of fertilizer containing 0.05 percent manganese (minimum set by AAPFCO) per acre will supply 0.15 pounds of manganese. In deficient soils, field trials have shown a need for at least 5 pounds per acre—a 32-fold difference.

Some manufacturers claim that small amounts of secondary and micronutrients are needed to maintain soil fertility. Such claims may have merit for some micronutrient elements in very sandy soils. However, for most agricultural soils, the problem is not replacing the nutrients at a maintenance level, but maintaining the nutrients in an available form. Most soils have adequate total iron and manganese, but these nutrients are largely in an unavailable form. The availability of copper and zinc is also governed by their adsorption to soil particles. Boron is a highly mobile element that does not accumulate to a great extent in sandy soils. Therefore, it may be difficult to maintain boron in these soils at sufficiently high levels for certain crops. In other soils, boron may be adsorbed and unavailable for crop use.

CALCIUM

Calcium, an essential part of plant cell wall structure, provides for normal transport and retention of other elements and strength in the plant. It is thought to counteract the effect of alkali salts and organic acids within the plant. Calcium is absorbed as the Ca^{++} ion and exists in a delicate balance with magnesium and potassium in the plant. Too much of any one of these three elements may cause insufficiencies of the other two.

TABLE 2.
Percentage of the element needed in mixed fertilizer, based on the amount of fertilizer applied.

Lbs. of fertilizer per acre	Pounds of the element desired per acre						
	0.5	1	2	4	6	10	20
Percent in the fertilizer							
100	½	1	2	5	5	—	—
200	¼	½	1	2	3	5	—
300	¼	½	1	1	2	3	—
400	⅛	¼	½	1	2	2	5
600		¼	½	½	1	2	3
800		⅛	¼	½	1	1	2
1000			¼	½	½	1	2
1500			⅛	¼	½	½	1
2000			⅛	¼	¼	½	1

Calcium Deficiency Symptoms

Calcium deficiency is usually observed as a failure of terminal buds and apical root tips to develop. In corn, new leaves fail to emerge from the whorl because of a sticky, gelatinous material on the edges of the leaves. The tips of these leaves are also very chlorotic (yellowish). The young leaves of new plants are the first to be affected. They are often distorted and small, the leaf margins are often irregular, and the leaves may show spotted or necrotic areas.

Disorders such as blossom end rot in peppers and tomatoes, blackheart in celery, internal tip burn in cabbage and cavity spot in carrots are attributed to calcium deficiency. These disorders are usually related to the inability of the plant to translocate adequate calcium to the affected plant part rather than to insufficient soil calcium levels.

In Michigan, calcium deficiency occurs only on very acid soil ($<$ pH 5.0) or where excessive quantities of potassium or magnesium have been used. Soils that are adequately limed are high in calcium. Even soils that are moderately acid (between pH 5.0 and 6.0) generally contain sufficient calcium for plants. Poor plant growth on these soils is usually due to excess soluble aluminum, manganese and/or iron rather than inadequate calcium. In Michigan, calcium deficiency symptoms sometimes occur when the root system has been so damaged by nematodes, insects or diseases that the plant can not take up adequate calcium.

Correcting Calcium Deficiency

Calcium in plants is a relatively immobile element. Where deficiencies exist and foliar sprays are used to correct the deficiency, it is very important to cover the young terminal growth with calcium. Applications on older leaves will not benefit the plant. The suggested rate for foliar application of calcium is 1 to 2 pounds of calcium in 30 gallons of water, using either calcium chloride or calcium nitrate. Agricultural lime should be used to correct calcium deficiency on acid soils. Calcitic lime is suggested when the Ca/Mg equivalent ratio is less than 1.

Calcium Toxicity

Excessive levels of calcium are rarely detrimental to plant growth, though excessive calcium carbonate in the soil may result in other nutritional problems associated with high pH. Band applications of acid-forming fertilizer may lower pH in the band and increase availability of other nutrients. Spreading or spraying calcium oxide over the top of plants may burn the foliage.

Excessive amounts of soluble calcium, such as calcium chloride or calcium sulfate, have been known to cause problems in certain instances, but the problem is generally associated with the anions Cl^- or $SO_4^=$ rather than calcium per se.

MAGNESIUM

Magnesium is a part of the chlorophyll molecule in all green plants and is essential for photosynthesis. It also helps activate many plant enzymes needed for growth. Magnesium, a relatively mobile element in plants, is absorbed as the Mg^{++} ion and can be readily translocated from older to younger plant parts in case of a deficiency.

Magnesium Deficiency Symptoms

In corn, magnesium deficiency symptoms first appear as interveinal chlorosis in the older leaves (Figure 1). Symptoms often appear early in the season in cold, wet soils and may disappear as the soil warms up and dries. Severe deficiency may cause stunting.

In oats and wheat, the older leaves show a distinctive chainlike yellow streaking. In potatoes, the loss of green color begins at the tips and margins of the older leaves and progresses between the veins toward the centers of the leaves. The leaves become brown or reddish and very brittle during the advanced stages of the deficiency.

In celery, chlorosis begins on the tips of the older leaves and progresses around the leaf margins (edges) and inward between the veins. The oldest leaves are also the first to show symptoms of chlorosis in greenhouse tomatoes. The veins remain green while the interveinal tissues become yellow and then brown, and

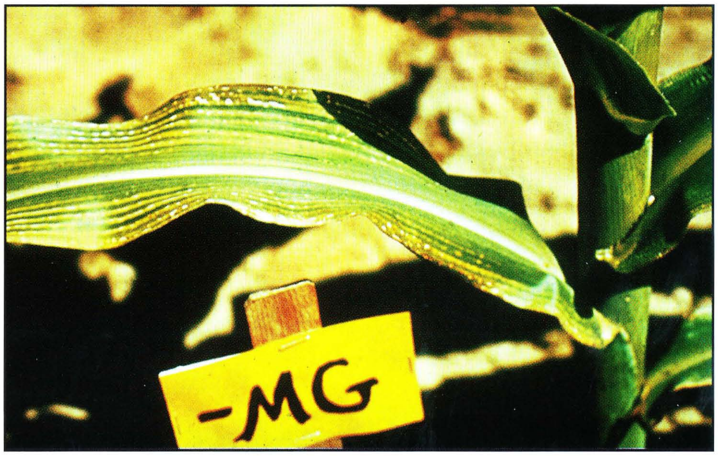

Figure 1. Magnesium-deficient corn. Older leaves show interveinal chlorosis. Symptoms usually appear early but may later disappear. Severe deficiency causes stunting.

the leaves become very brittle.

Other responsive crops in Michigan are cauliflower, muskmelons, peas and rye. When deficiency occurs in these crops, the oldest leaves are mottled or lighter green than normal or new leaves.

Correcting Magnesium Deficiency

Present soil test criteria used for recommending magnesium in Michigan, Indiana, and Ohio are: (1) if the exchangeable magnesium level is less than 100 pounds per acre for mineral soils (150 pounds per acre for organic soils); (2) if the equivalents of potassium exceed magnesium (on a weight basis, this is about 3 parts of potassium to 1 part magnesium); (3) if the soil magnesium (as a percent of total bases) is less than 3 percent; or (4) if the equivalent ratio of calcium to magnesium is greater than 10. Similar criteria have been adopted by other North Central states.

On acid soils where magnesium need is indicated, at least 1,000 pounds of dolomitic limestone should be applied per acre. On non-acid soils, a magnesium deficiency may be corrected with 50 to 100 pounds of soluble Mg per acre broadcast, or 10 to 20 pounds Mg per acre row applied. Magnesium sulfate, potassium magnesium sulfate, or finely ground magnesium oxide are all satisfactory sources of magnesium.

Magnesium can also be applied as a foliar spray. Suggested rates per acre are 10 to 20 pounds of magnesium sulfate (Epsom salts) in 30 gallons of water.

Magnesium deficiency may be induced by high rates of potassium. Inadequate liming and excessive potassium applications will depress magnesium uptake. In some states, agronomists strive for at least 10 percent magnesium in the total exchangeable bases (equivalent basis). These rates are aimed at preventing grass tetany disorders in livestock that feed on lush grass. Anyone concerned about grass tetany should avoid excessive rates of potassium fertilizer and feed legume hay, which is generally higher in magnesium than grasses. Some magnesium carriers can be mixed with grain or salt rations. Contact your animal feed specialist for amounts and sources.

Magnesium uptake by celery may be related to its genetic makeup. Some celery varieties are unable to take up enough magnesium from the soil, resulting in magnesium deficiency, while other varieties grow normally. For those varieties that are inefficient users of soil-applied magnesium, foliar application of 5 to 10 pounds of magnesium sulfate per acre sprayed at 10-day intervals may be necessary.

Magnesium Toxicity

Excess magnesium has not been a problem in Michigan. Studies in Ohio and Wisconsin have shown that widely different levels of exchangeable calcium and magnesium can exist without causing a nutrient imbalance in the plant. Many farmers have used dolomitic limestone for years and have not had any nutrient imbalance.

SULFUR

Plants take up sulfur primarily as sulfate ions ($SO_4^{=}$). In the plant, it is reduced and assembled into organic compounds. Sulfur is a constituent of certain amino acids (cystine, cysteine, glutathione and methionine) and the proteins that contain these amino acids. It is found in vitamins, enzymes and co-enzymes. Sulfur is present in glycosides, which give the characteristic odors and flavors to mustard, onion and garlic plants. It is also required for nodulation and nitrogen fixation of legumes. As the sulfate ion, it may be responsible for activating some enzymes.

Sulfur in Michigan Soils

In soil, sulfur is present primarily in the organic form, which becomes available when organic matter decomposes. The available sulfate ion ($SO_4^{=}$) remains in soil solution, much like the nitrate ion (NO_3^-), until it is taken up by the plant. In this form, it is subject to leaching as well as microbial immobilization. In waterlogged soils, it may be reduced to elemental sulfur (S) or other unavailable forms. Fertilizer impurities also contribute to the total supply of available sulfur in soils.

Figure 2. Sulfur-deficient dark red kidney beans. Light–green color and reduced growth, left. Resembles nitrogen deficiency. Plants mature early. Normal plant, right.

Atmospheric deposition supplies a considerable amount of plant-available sulfur. For rural areas of Michigan, the amount will generally vary from 8 to 15 pounds per acre annually, depending on proximity to an industrial emission source. Precipitation within several miles of certain industrial sites may contain 10 to 20 times as much sulfur as precipitation in more rural areas. Sulfur dioxide in the atmosphere can also be absorbed through the leaves of plants. Once absorbed, it is rapidly converted to the sulfate ion.

Because of the many light-colored sandy soils in Michigan, more intensive cropping systems and increased use of fertilizers low in sulfur, one might expect sulfur deficiency to be widespread. Field trials, however, have shown little need for additional sulfur fertilizer. Soil mineral sources and sulfur fallout from the atmosphere currently provide adequate sulfur for crop production in Michigan.

Figure 3. Sulfur-deficient corn. Light green plants growing on sandy soil low in organic matter. Plants usually grow out of the deficiency as the roots penetrate the subsoil.

Sulfur Deficiency Symptoms

Sulfur-deficient plants are generally light green, similar to plants with nitrogen deficiency (Figures 2, 3). The most likely crops to show a sulfur deficiency are those grown on sandy, low organic matter soils in northern Michigan. Legumes, especially alfalfa and others with a high sulfur requirement, will normally be the first crops to respond to sulfur fertilization. Dry edible beans that were not adequately fertilized with nitrogen have been shown to respond to sulfur fertilizer. Corn, small grains and other grasses are less likely to show sulfur deficiency.

Correcting Sulfur Deficiency

Sulfur research in other states has led to the development of several methods for extracting available sulfur from soils. The interpretation of these tests, however, continues to be a problem. Consideration of available sulfur from subsoil and atmospheric contributions may be necessary to accurately predict response to added sulfur fertilizer.

Application rates of 20 to 40 pounds of sulfur per acre will correct a sulfur deficiency. Soluble sources of sulfur—such as potassium sulfate, potassium magnesium sulfate, Epsom salts, ammonium sulfate or gypsum—are usually preferred to elemental sulfur. For most soils, one application is sufficient for 2 or 3 years. Very sandy soils, where leaching is a problem, may require larger or more frequent applications.

Sulfur Toxicity

Sulfate/sulfur toxicity symptoms begin as an interveinal chlorosis and scorching of the leaf margins, which gradually proceeds inward. Sulfur toxicity has not been observed in Michigan.

Irrigation water high in sulfate and/or soluble salt, a potential problem source normally occurring in arid and semi-arid regions, is often remedied by thorough leaching. Excessive sulfur in some organic soils and so-called Kett clay soils can cause extreme acidity when sulfur is oxidized because of drainage.

Sulfur dioxide in the atmosphere is an air pollutant that can injure plants. Plants relatively sensitive to sulfur dioxide injury are soybeans, dry edible beans, alfalfa, small grains and many vegetable crops. The symptoms of sulfur dioxide injury may resemble damage from frost, other air pollutants, chemical sprays or herbicide residues in soils. This often makes it very difficult to identify the cause of injury. Positive identification can be made only after all foliar symptoms and related evidence have been considered.

In general, symptoms are either chronic or acute, depending on the rate of sulfur accumulation in the leaf tissues. Chronic injury is characterized by a slow accumulation causing a general chlorotic appearance. Some plants may be ivory or white, while others show a strong reddish brown or black coloration. Later symptoms resemble normal senescence.

Acute injury appears as marginal areas of dead tissue, which at first have a grayish green, water-soaked appearance. Later these areas take on a bleached ivory color in most plants. In small grains, tip dieback is a common symptom.

MANGANESE

Manganese deficiency in crops is the most common micronutrient problem in Michigan. The micronutrient manganese should not be confused with magnesium, a secondary nutrient. Manganese is mainly absorbed by plants in the Mn^{++} ionic form. Manganese may substitute for magnesium by activating certain phosphate-transferring enzymes, which in turn affect many metabolic processes. A high manganese concentration may induce iron deficiency in plants.

Manganese availability is closely related to the degree of soil acidity. Deficient plants are usually found on slightly acid (pH 6.6-7.0) or alkaline soils (pH >7.0), e.g., lake beds, glacial outwashes, peats and mucks. Acid soils that have been limed are more likely to be manganese deficient than naturally neutral or alkaline soils.

Manganese-deficient organic soils and dark-colored sandy loams usually have a pH greater than 5.8. The pH of deficient mineral soils is usually above 6.5. The mineral soils are usually dark at the surface and have a gray subsoil. Manganese deficiency is seldom found on glacial till or moraine soils.

TABLE 3.
Relative response of selected crops to micronutrient fertilizers.[1]

	Response to micronutrient					
Crop	**Mn**	**B**	**Cu**	**Zn**	**Mo**	**Fe**
Alfalfa	low	high	high	low	medium	
Asparagus	low	low	low	low	low	medium
Barley	medium	low	medium	low	low	medium
Blueberry	low	low	medium			
Broccoli	medium	high	medium		high	high
Cabbage	medium	medium	medium	low	medium	medium
Carrot	medium	medium	medium	low	low	
Cauliflower	medium	high	medium		high	high
Celery	medium	high	medium		low	
Clover	medium	medium	medium	low	high	
Corn	medium	low	medium	high	low	medium
Cucumber	high	low	medium			
Dry edible bean	high	low	low	high	medium	high
Grass	medium	low	low	low	low	high
Lettuce	high	medium	high	medium	high	
Oats	high	low	high	low	low	medium
Onion	high	low	high	high	high	
Parsnip	medium	medium	medium		low	
Pea	high	low	low	low	medium	
Pepper	medium	low	low		medium	
Peppermint	medium	low	low	low	low	low
Potato	high	low	low	medium	low	
Radish	high	medium	medium	medium	medium	
Rye	low	low	low	low	low	
Snapbean	high	low	low	high	medium	high
Sorghum	high	low	medium	high	low	high
Soybean	high	low	low	medium	medium	high
Spearmint	medium	low	low	low	low	
Spinach	high	medium	high	high	high	high
Sudangrass	high	low	high	medium	low	high
Sugar beet	high	medium	medium	medium	medium	high
Sweet corn	high	medium	medium	high	low	medium
Table beet	high	high	high	medium	high	high
Tomato	medium	medium	high	medium	medium	high
Turnip	medium	high	medium		medium	
Wheat	high	low	high	low	low	low

[1]Highly responsive crops will often respond to micronutrient fertilizer additions if the micronutrient concentration in the soil is low. Medium responsive crops are less likely to respond, and low responsive crops do not usually respond to fertilizer additions even at the lowest soil micronutrient levels.

Field and vegetable crops vary in their response to manganese fertilizer. The degree of response to manganese fertilizer for several crops is given in Table 3. Dry edible beans, cucumbers, lettuce, oats, onions, peas, potatoes, radishes, sorghum, soybeans, snap beans, spinach, Sudangrass, sweet corn, table beets and wheat are the most responsive crops.

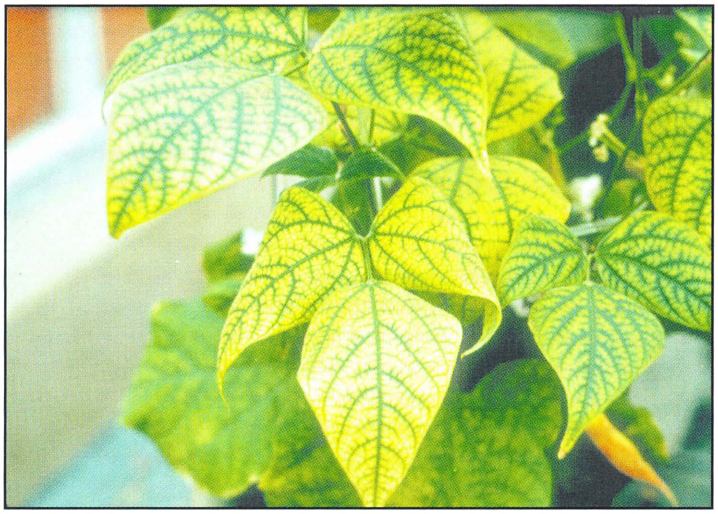

Figure 4. Manganese-deficient dark red kidney beans. Yellowing between the leaf veins. Veins remain green.

Figure 5. Manganese-deficient celery. Chlorosis of the leaves between the dark veins.

Figure 6. Manganese-deficient cabbage. Interveinal chlorosis of the leaves generally over the entire plant, center. Healthy plant in front.

Figure 7. Manganese-deficient onions. Olive green leaves may appear wilted, right. Normal plants were treated with manganese starter fertilizer, left.

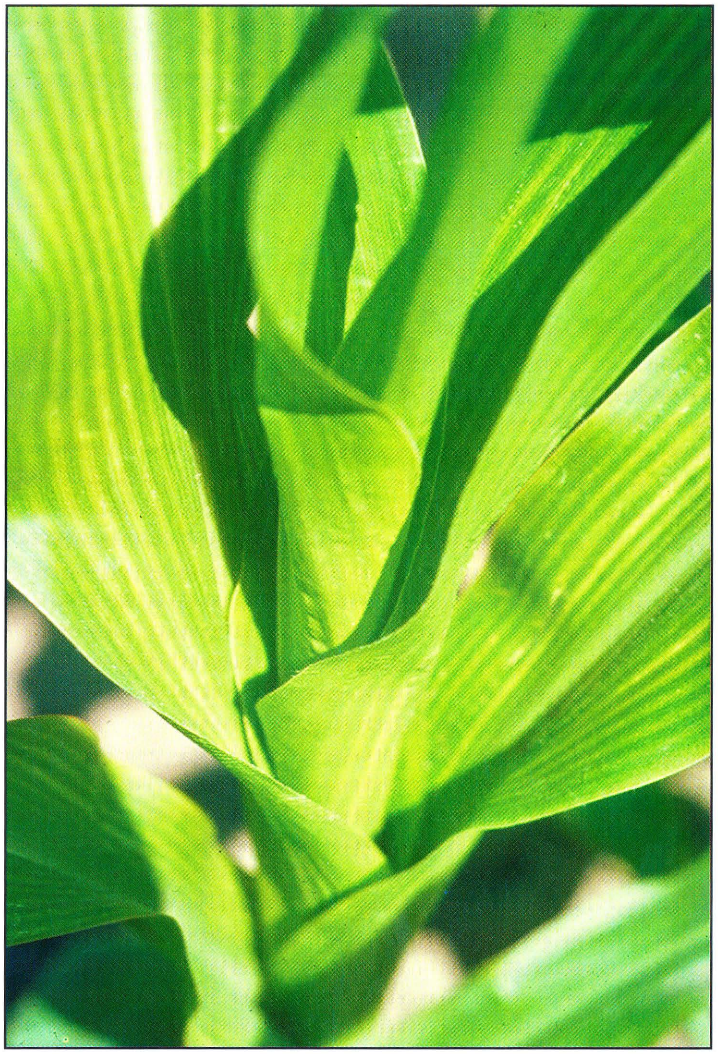

Figure 8. Manganese-deficient corn grown on organic soil. Leaves are light green with yellowish stripes.

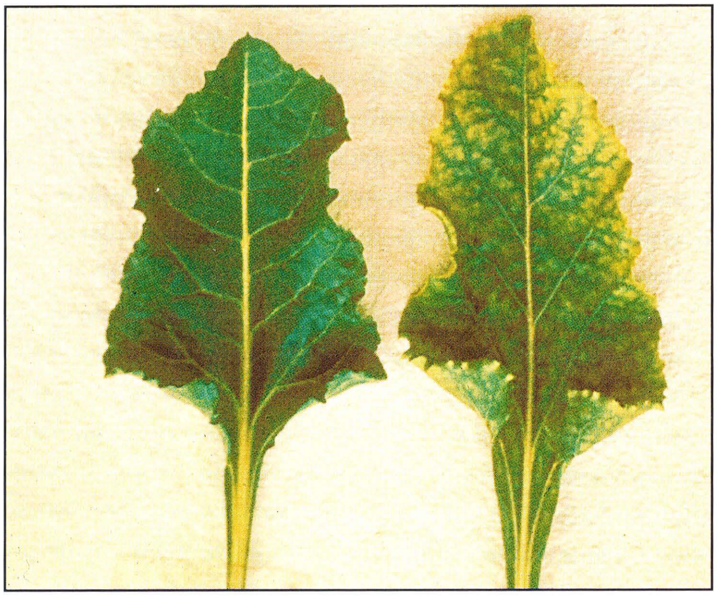

Figure 9. Manganese-deficient sugar beets. Mottling between the veins, right. Chlorosis usually begins on the younger leaves. Severe deficiency causes gray and black specks along the veins.

Figure 11. Manganese-deficient soybeans. Symptoms are yellowing between the leaf veins with the veins remaining dark green. Found most often on organic soils and high pH soils.

Figure 10. Manganese-deficient wheat. Leaves are discolored and yellowish and may resemble diseased leaves. Found most often on high pH soils.

Figure 12. Manganese-deficient soybeans on organic muck soil, center. Caused by a manganese chelate that created iron-manganese imbalance in the plant. The manganese chelate was converted to an iron chelate in the soil after application.

Manganese Deficiency Symptoms

Most crops deficient in manganese become yellowish to olive-green. Potatoes show reduced leaf size. Grain crops have a soft, limber growth, which often appears diseased. In oats, this may be described as "gray specks." Wheat and barley often show colorless spots.

Manganese-deficient corn plants grown on organic soils show light yellow-green pinstriping of the leaves, also described as interveinal chlorosis (Figure 8). Manganese deficiency in field corn has seldom been observed on mineral soils in Michigan.

Manganese deficiency in soybeans, dry edible beans, snap beans, sugar beets, celery, cucumbers and cabbage often causes marked yellowing between the leaf veins; the veins themselves remain dark green (Figures 4-7). This pattern is similar to iron deficiency but occurs more generally over the plant—iron deficiency is most pronounced on new growth. In sugar beets and potatoes, chlorosis begins in the younger leaves. Later, gray and black freckling may develop along the veins.

Manganese-deficient onions are olive-green and the leaves may appear wilted. Manganese deficiency is sometimes confused with nitrogen deficiency. To separate the two, make a nitrogen tissue test. A tissue test for nitrate N easily determines which nutrient is deficient. Manganese-deficient plants usually test higher than normal in nitrate nitrogen because of the lack of Mn enzymes required to convert nitrate to protein N.

Correcting Manganese Deficiency

Manganese deficiency in crops can be prevented by band applying manganese fertilizer to the soil, spraying it on the foliage or making the soil more acidic. Steam or chemical fumigation will also correct it temporarily. Generally, when manganese is deficient, manganese sulfate or manganous oxide is mixed with the fertilizer and applied in a band near the seed. Commercial manganese sulfate is 26 to 28 percent manganese (Mn); manganous oxide is usually 41 to 68 percent manganese.

Studies have shown that manganous oxide should be finely ground to be effective. Granular manganous oxide (8 mesh) was largely ineffective. Manganous oxide powders (200 and 325 mesh) were less effective than manganese sulfate but were acceptable. These materials do not blend well with other fertilizer materials—segregation problems occur because of differences in particle sizes. However, the use of a sticker such as liquid fertilizer has made it possible to use these finely ground materials in the bulk blending process.

Manganic oxide (MnO_4), which has been used in Michigan, is insoluble and ineffective as a manganese fertilizer regardless of mesh size. Chelated manganese materials have not performed satisfactorily on organic soils and have been less effective on mineral soils than manganese sulfate.

Broadcast application of manganese is not recommended because of high fixation in the soil. Residual carryover of available manganese fertilizer is usually low. Therefore, manganese must be applied every year on a deficient soil. Suggested rates of application based on soil tests can be found in MSU Extension Bulletins E-550A and E-550B.

Foliar applications of manganese are recommended when: (1) fertilizer is not applied in a band near the seed, (2) deficiency symptoms appear on the foliage, or (3) regular fungicide and insecticide sprays are applied. The recommended rate is 1 to 2 pounds of manganese per acre in 30 gallons of water, using the 1-pound rate if plants are small and the 2-pound rate if plants are medium to large. Spray grades of the manganese carriers are recommended to prevent nozzle plugging. Some fungicides contain manganese but generally not enough to correct a deficiency.

Acidifying the soil with materials such as sulfur and aluminum sulfate can correct manganese deficiency. These treatments cost more than manganese fertilizers. Acid-forming nitrogen and phosphorus fertilizers promote the release of fixed soil manganese, especially if banded near the plant. Soil around the fertilizer band may be one pH unit more acid than soil farther from the fertilizer band. Some of the benefits accredited to band placement of fertilizer may be due to the release of fixed soil manganese.

Manganese Toxicity

Excessive manganese is a problem in extremely acid soils ($<$ pH 5.0), especially if the soil is steamed or fumigated. A toxic manganese situation may also develop in plants if excessive soil and/or foliar applications are used. Liming soils to the desired pH range for the crop will usually prevent any manganese toxicity.

In the early stages of plant growth, manganese toxicity symptoms may be similar to deficiency symptoms. The interveinal chlorosis caused by toxicity in soybeans is more distinctive than that caused by deficiency. The typical spotting is followed by scorching on leaf margins and leaf cupping. In potatoes, the symptoms are chlorosis and black specks on the stems and undersides of the leaves, followed by death of the lower leaves.

The following crops are sensitive to excess manganese: alfalfa, cabbage, cauliflower, clover, dry edible beans, potatoes, small grains, sugar beets and tomatoes.

Plant tissue analysis is helpful in diagnosing manganese status. Values below 20 parts per million (ppm) are usually considered deficient. Readings of 30 to 200 ppm are normal, and those over 300 ppm are considered excessive or toxic.

Some growers have experienced plant damage from certain combination pesticide-manganese sulfate sprays. Soybeans and other crops have been damaged when 8 pounds of manganese sulfate per acre was applied by an air-blast sprayer. To prevent extensive damage, growers should always try out a spray program on a limited acreage. Injury is evident within 48 hours after application.

ZINC

Zinc is essential for plant growth because it controls the synthesis of indoleacetic acid, which dramatically regulates plant growth. Zinc is also active in many enzymatic reactions and is necessary for chlorophyll synthesis and carbohydrate formation. Because zinc is not readily translocated within the plant, deficiency symptoms first appear on younger leaves. Research shows a need for zinc in many areas where dry edible beans are grown. Corn, onions, soybeans and barley have also shown benefits from zinc applications at some locations. Several other states report that Sudangrass, sorghum, tomatoes and potatoes have been responsive.

Soils associated with zinc deficiency are usually neutral to alkaline in reaction. The more alkaline the soil, the greater the need for zinc. Deficiency is particularly noticeable on crops growing where calcareous subsoils have been exposed by land leveling or erosion, or where subsoil is mixed with topsoil, such as after tiling and spoil-bank leveling. Lake bed soils and organic peats show the greatest zinc deficiencies in Michigan.

Observations and field tests show that dry edible beans following sugar beets often need zinc. The large quantities of phosphorus fertilizer used for sugar beets and the high zinc requirement of dry edible beans are believed to cause the problem. A recent reduction in phosphorus use on sugar beets and the long-term use of zinc fertilizers have reduced the incidence of zinc deficiency.

Zinc deficiency varies from year to year. Wet, cool, cloudy weather during the early growth season increases the deficiency. Zinc deficiency in corn is occasionally noted in June, but the deficiency disappears after the soils dry out and warm up. Crops on poorly drained organic soils show a deficiency probably because of restricted root growth. Field and vegetable crops often show differences in response to zinc fertilizer. The relative crop response to fertilizer zinc is given in Table 3. Dry edible beans, corn, onions, sorghum, snap beans, spinach and sweet corn are the most responsive crops.

High soil phosphorus levels have been known to induce zinc deficiency, especially in responsive crops (see Figure 17). For years, the cause of this interaction was suspected to be the formation of an insoluble zinc phosphate, which reduced the concentration of zinc in the soil solution to deficiency levels. Zinc phosphate has since been shown to be soluble in soil and is an acceptable source of zinc when finely ground. High levels of phosphorus in plants have been shown to restrict zinc movement within the plant, resulting in accumulation in the roots and deficiency in the tops. Therefore, large applications of phosphorus fertilizer may contribute to zinc deficiency in zinc-responsive crops.

Figure 13. Zinc-deficient corn. Yellow or white striping of the leaves usually developing near the stalk. Plants are often stunted with shortened internodes. Found most often on high pH soils and organic soils.

Figure 14. Zinc-deficient corn. White to yellow striping of the leaves near the stalk. Shortened internodes with reddish discoloration of the nodal tissues.

Zinc Deficiency Symptoms

Zinc-deficient dry edible beans first become light green. When the deficiency is severe, the area between the leaf veins becomes pale green and then yellow near the tips and outer edges. In early stages of deficiency, the leaves are deformed, dwarfed and crumpled. In later stages, they look as if they have been killed by

Figure 15. Zinc-deficient dry edible beans, front. Beans in the back received zinc in the starter fertilizer.

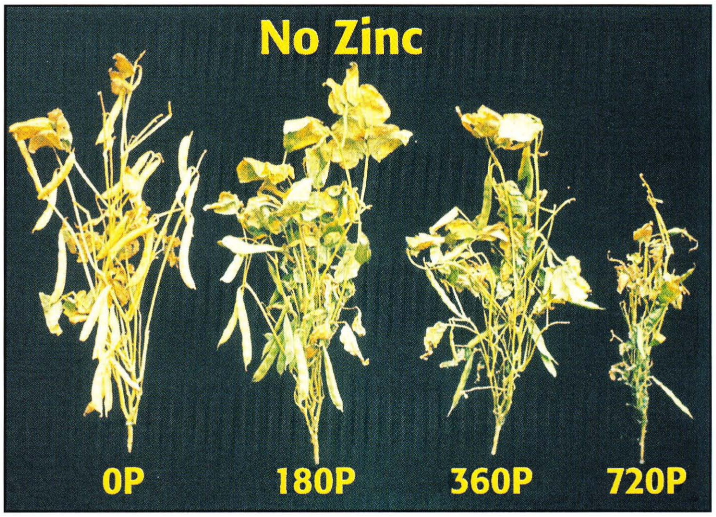

Figure 17. Phosphorus-zinc interaction in dry edible beans. Brownish leaf discoloration, stunted plants and pods fail to develop. Beans above received increasing rates of phosphorus fertilizer without zinc.

Figure 16. Zinc-deficiency dry edible beans. Pale green leaves, yellow near the tips and outer edges at or soon after emergence. Leaves later become dwarfed or deformed and die. Plants are slow to mature.

Figure 18. Zinc-deficient dark red kidney beans. Yellow to whitish areas between the darker green veins. Similar to manganese deficiency but dark veins are not as prominent. Leave size may be distorted and irregular.

sunscald (Figures 15, 16 and 18). On zinc-deficient plants, the terminal blossoms set pods that drop off, delaying maturity.

Zinc deficiency in corn appears as a yellow striping of the leaves. Areas of the leaf near the stalk may develop a general white to yellow discoloration. In severe deficiency, the plants have shortened internodes and the lower leaves show a reddish or yellowish streak about one-third of the way from the leaf margin (Figures 13, 14). Plants growing in dark sandy or organic soils usually show brown or purple nodal tissues when the stalk is split. This is particularly noticeable in the lower nodes.

Deficiency in onions shows up as stunting, with marked twisting and bending of yellow-striped tops (Figure 19). In potatoes, early symptoms are similar to leaf roll. The plants are generally more rigid than normal, with smaller than normal leaves and shorter upper internodes.

Zinc Fertilizer Carriers

Several zinc compounds can be used to correct a deficiency. Zinc sulfate, zinc oxide, zinc chloride, zinc sulfide and zinc carbonate are common inorganic salts.

Figure 19. Zinc-deficient onions. Yellow striping, twisting and bending of the tops.

Organic compounds such as zinc chelates (zinc EDTA and zinc NTA) are about five times more effective than inorganic salts with equivalent amounts of zinc. Organic carriers, however, have a lower zinc concentration, ranging from 9 to 14 percent.

The zinc concentration of zinc sulfate ranges from 25 to 36 percent, and that of zinc oxide, 70 to 80 percent. In field tests, granular zinc oxide was not as effective as the powdered formulation. The test also showed that mixing the zinc carrier with the fertilizer was more effective than incorporating the carrier in the granule.

Rates and Methods of Applying Zinc Fertilizer

To be effective, soil-applied zinc must be applied near the seed at planting time. Mixing zinc with a phosphate fertilizer, such as 6-24-24, is acceptable.

Seed treatment with zinc oxide is not recommended. Tests have shown that 1 pound of zinc per acre from zinc oxide applied on bean seed reduced emergence and yields. Sidedress applications of zinc after the crop has emerged have not been very effective. If a zinc deficiency problem is diagnosed after emergence, spray the foliage with 0.5 to 1 pound of zinc per acre. This amount can be found in 1.5 to 3 pounds of zinc sulfate. The solution should not exceed 5 pounds of the salt per 100 gallons of water. Response to spray applications is usually obvious within 10 days. It may be apparent in five days if the treatment is applied when the plants are growing vigorously. For plants with waxy leaves, such as onions, a wetting agent in the water may be needed to obtain good foliage cover.

Spraying crops such as corn, onions and potatoes has had mixed results. The reason for poor results may be inadequate zinc being translocated into the roots. If foliage sprays are used, they should be applied when plants are small to obtain best results.

Some fungicides that contain zinc can be used as foliar treatments. These fungicides may help correct zinc deficiency; however, they should not be relied on entirely because the amount of zinc applied in fungicides is very small.

Zinc Carryover

Residual carryover of available zinc varies from slight to moderate, increasing as soils become less alkaline. On highly responsive soils, zinc broadcast at rates above 25 pounds per acre showed good carryover for seven years after application. When zinc is banded at the rate of 3 to 4 pounds per acre, yearly applications are needed. After adding a total of 25 pounds of zinc per acre through smaller annual applications, growers can often reduce the rate of zinc application or eliminate application altogether. Growers should use the zinc soil test to decide if continued use of zinc fertilizer is necessary.

Soil and Plant Tissue Tests for Zinc

Plant tissue tests can help diagnose a need for zinc. Tissues containing less than 20 ppm of zinc are often deficient. Values of 30 to 100 ppm are normal; values over 300 ppm may be considered excessive or toxic. Zinc response and suggested rates of banded zinc for soil test levels can be found in MSU Extension Bulletins E-550A and E-550B. Recommendations are based on soil pH and available zinc level.

Zinc Toxicity

Excessive soil zinc levels may occur on extremely acid soils (< pH 5.0) or in areas where zinc-enriched municipal sewage sludge or industrial waste has been added to cropland as a soil amendment. Though instances of plant zinc toxicity are rare in Michigan, the crop and variety being grown are critical.

High levels of available soil zinc that result in 100 to 300 ppm zinc in crown leaf tissue seldom result in zinc toxicity in corn, which is very zinc tolerant. However, if the soil levels result in 40 to 50 ppm or more of zinc in the leaf tissue of some varieties of dry edible beans, toxicity may occur because dry edible beans are a zinc-sensitive crop. Soybeans and most small grains fall somewhere between corn and dry edible beans in zinc tolerance. Vegetable crops are generally sensitive to high zinc levels, while grasses usually tolerate high levels of available soil zinc.

A general guide for zinc concentration in mature leaf tissue is as follows: deficient—less than 20 ppm; sufficient—25 to 150 ppm; excessive or toxic—300 ppm or more. Because plant tolerance to zinc toxicity varies greatly, specific soil extractable levels, which might indicate toxicity, have not been established.

COPPER

Copper is essential for plant growth and activation of many enzymes. A copper deficiency interferes with protein synthesis and causes a buildup of soluble nitrogen compounds.

Normal plants contain 8 to 20 ppm copper; deficient plants usually contain less than 6 ppm. Each ton of dry hay contains about 0.002 pounds of copper.

Without copper all crops fail to grow. Fortunately, most Michigan soils have sufficient copper. Peaty soils, which have a low ash content, are generally the only soils deficient in copper. If the problem does appear on mineral soils, it will most likely be on acid soils that have been heavily cropped but well fertilized with N, P and K. Copper applied to soil is not easily leached; nor is it extensively used by the crop. Consequently, no further copper fertilization is needed on organic soils if a total of 20 pounds per acre has been applied for low responsive crops and 40 pounds per acre for highly responsive crops.

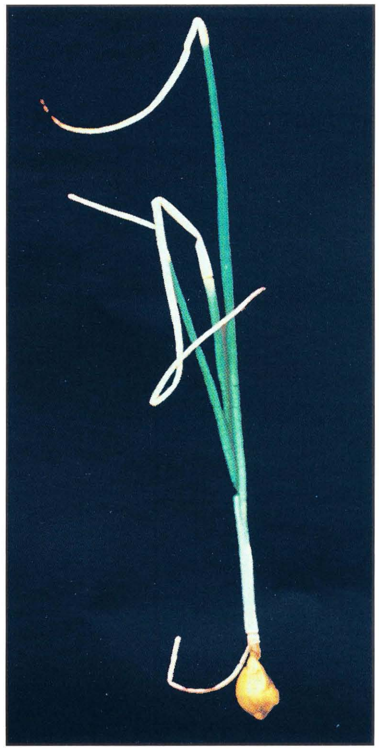

Figure 20. Copper-deficient onion. Tip dieback of the tops. Poor pigmentation of the bulb.

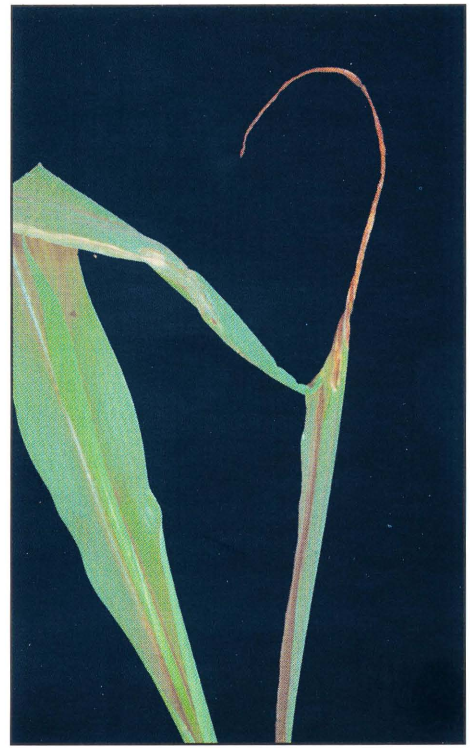

Figure 21. Copper-deficient Sudangrass. Wilting and eventual death of the leaf tips. Symptoms may resemble frost damage.

Copper Deficiency Symptoms

Copper deficiency in many plants shows up as wilting or lack of turgor and development of a bluish green tint before leaf tips become chlorotic and die (Figures 20-22). In grains, the leaves are yellowish and the leaf tips look frost damaged. Carrot roots, wheat grain and onion bulbs show poor pigmentation. Table 3 shows the relative crop response to copper fertilizer. Alfalfa, lettuce, oats, onion, spinach, Sudangrass, table beet and wheat are the most responsive crops on organic soils.

Correcting Copper Deficiency

Application rates for organic soils based on soil tests are given in MSU Extension Bulletin E-550B. Rates of copper commonly used in highly responsive crops are 3 to 6 pounds per acre, depending on the soil test level. These rates should be doubled on fields that have never received copper.

Figure 22. Copper–deficient corn. Development of bluish green leaves and wilting or lack of turgor in the plant. Tips of the leaves later become chlorotic and die under conditions of severe deficiency.

Common carriers of copper are the sulfate and the oxide. Copper sulfate is blue and easily identified in most fertilizers. It has a copper concentration of 22.5 percent. Copper oxide, a brown material, has a copper concentration of 60 to 80 percent. In field tests, this material has been as effective as copper sulfate.

Copper Toxicity

Excessive soil copper levels have not been a problem in crop production. However, the potential for copper toxicity does exist because copper is applied annually for some vegetables, either as a soil amendment or a component of some fungicides. Copper toxicity often results in plant stunting, a bluish tint to leaf color, and leaf cupping followed by chlorosis or necrosis. When the copper concentration exceeds 150 ppm in mature leaf tissue, toxicity may occur. Cumulative copper applications of 100 pounds per acre have reduced cucumber and snap bean yields on sandy soils.

Copper is tightly adsorbed by most soils and will not leach. Therefore, once a copper toxicity problem develops, it may be very difficult, if not impossible, to alleviate it.

IRON

Iron is a constituent of many organic compounds in plants. It is essential for synthesizing chlorophyll, which gives plants their green color. Iron deficiency can be induced by high levels of manganese. High iron levels can also cause manganese deficiency.

Iron Deficiency Symptoms

Deficiency symptoms are marked and show up first in terminal leaves as a light yellowing. The symptoms are very similar to those of manganese deficiency (Figure 23). A lack of iron in field and vegetable crops is not common in soils with pH below 7.0.

Iron deficiency is common in the western states, where the soils contain considerable sodium and calcium. In Michigan, woody plants such as pines, pin oaks, roses, certain ornamentals and acid-demanding plants such as blueberries, azaleas and rhododendrons may need iron. Lawns, particularly putting greens on golf courses, sometimes show a lack of iron because of high pH and high levels of phosphorus.

Iron deficiency in many woody plants appears when they are grown in soils low in organic matter and high in pH. Mixing in organic materials such as manure or acid peat will help increase the availability of the iron.

Sphagnum peat moss in mixtures with sand, perlite or vermiculite intensifies the need for iron fertilizer in the production of petunias, snapdragons, tomatoes and other bedding plants.

Correcting Iron Deficiency

Soil treatments usually require applications of iron chelates at a rate equivalent to 1/2 to 1 pound of iron per acre. Often it is difficult to correct iron deficiency with soil applications when soils are alkaline. Soil applications are effective if soils are acid or neutral in reaction. Under alkaline soil conditions, foliage sprays are recommended. Use iron sulfate, iron chelates or iron citrate according to the supplier's recommendations. Wet foliage thoroughly. Iron chelates, though more expensive than iron sulfate, persist longer.

Sometimes the best cure for Fe deficiency is to grow varieties that are not sensitive to Fe deficiency. For instance, some soybean varieties are more sensitive to Fe deficiency than others. For bedding plant production, use 1 to 2 ounces of elemental iron per cubic yard of soil mix.

To help prevent an iron problem, avoid using excessive amounts of lime or phosphate. Apply chemicals or fertilizers to increase the soil acidity and add organic matter.

Iron Toxicity

Injury due to high soil iron concentrations is not common under neutral or high pH soil conditions. Toxic situations occur primarily on acid soils (< pH 5.0) and where excess soluble iron salts have been applied as foliar sprays or soil amendments. The first symptoms of iron toxicity are necrotic spots on the leaves.

An unusual form of iron toxicity has been observed in Michigan on organic soils and high organic sands. Some iron-rich, low pH, low manganese soils create an environment in which an interaction between the iron

Figure 23. Iron–deficient corn. Light yellowing of the terminal leaves, with interveinal chlorosis of the leaves similar to that caused by manganese deficiency. Seldom found in Michigan field crops. More commonly found in woody plants, ornamental and turf crops.

and manganese in the soil reduces manganese uptake by plants. The symptoms observed on the plants are of manganese deficiency, but the low plant uptake of manganese is caused by excessive available iron in the soil. The addition of iron chelates or manganese chelates, which rapidly convert to the iron form under these soil conditions, aggravates the situation by increasing the amount of available iron and without solving the manganese deficiency problem.

BORON

Boron primarily regulates the carbohydrate metabolism in plants. It is essential for protein synthesis, seed and cell wall formation, germination of pollen grains and growth of pollen tubes. Boron is also associated with sugar translocation.

Boron requirements vary greatly from crop to crop. Rates required for responsive crops such as alfalfa, celery, sugar beets and table beets can cause serious damage to small grains, beans, peas and cucumbers. Boron deficiency may occur under a wide range of soil conditions. Alkaline soils have reduced uptake of boron due to high pH. Leached soils may be boron deficient because of low boron reserves. The soil types most frequently deficient in boron are sandy soils, organic soils and some fine-textured lake bed soils. Boron deficiency frequently develops during drought periods when soil moisture is inadequate for maximum growth.

Boron Deficiency Symptoms

Boron deficiency in crops causes a breakdown of the growing tip tissue or a shortening of the terminal growth. This may appear as rosetting. Internal tissues of beets, turnips and rutabagas show breakdown and corky, dark discoloration.

Boron deficiency and leafhopper damage in alfalfa are often confused. Boron deficiency shows up as a yellowish to reddish yellow discoloration of the upper leaves, short nodes and few flowers (Figures 24, 25). Growing tips of alfalfa may die, with regrowth coming after a new shoot is initiated at a lower axis. Leafhopper damage shows up as a V-shaped yellowing of the affected leaves and may appear on any or all parts of the plant; the growing tip is usually normal and the plant may support abundant flowers. When the soil is dry and plant growth is retarded, both boron deficiency and leafhopper injury often occur in the same field.

Deficiency in cauliflower shows up as a darkening of the head and is associated with hollow and darkened stems. Hollow stem can also be caused by adverse weather conditions. Boron deficiency usually appears in small spots and may spread until the entire head is discolored.

In sugar beets, the first symptoms are white, netted chapping of upper blade surfaces or wilting of tops. Later, if the deficiency becomes severe, transverse (crosswise) cracking of petioles develops, the growing point dies and the heart of the root rots (Figure 26).

In celery, the first symptoms are brownish mottling along the margins of the bud leaves and brittle stems with brown stripes along the ribs. Later, crosswise cracks appear on the stems.

Acute deficiency in corn appears on the newly formed leaves as elongated, watery or transparent stripes; later, the leaves turn white and die. Growing points also die and, in severe cases, sterility is common. If ears develop, they may show corky brown bands at the bases of the kernels. Boron deficiency in corn has not been observed in Michigan.

Correcting Boron Deficiency

Crops grown in Michigan show a wide range of response to boron fertilizer (see Table 3). The most responsive crops are alfalfa, cauliflower, celery, table beets and turnips. The boron recommendations for soil applications are 1.5 to 3 pounds for highly responsive crops and 0.5 to 1 pound per acre for medium responsive crops. Occasionally, certain deficient soils may require up to 5 pounds of boron per acre for cauli-

Figure 24. Boron-deficient alfalfa. Yellow to reddish yellow discoloration of the upper leaves. Often confused with leafhopper damage, which also causes yellowing of the tips of leaves.

flower and table beets. The suggested rate for foliage application is 0.3 pound of boron per acre in 30 gallons of water for highly responsive crops and 0.1 pound for low to medium responsive crops.

The boron carrier most frequently used in fertilizer is sodium borate, which ranges from 10 to 20 percent boron. "Solubor" is a trade name for a sodium borate that is 20.5 percent boron. This compound is commonly used in foliar sprays or in liquid fertilizers.

Because boron is fairly mobile in soils, several methods of application can be used. Boron may be mixed with regular N-P-K fertilizer, applied separately on the soil, sprayed on the plant, topdressed (for alfalfa) or sidedressed (for row crops). Be sure to mix completely when boron is combined with other fertilizers. Segregation due to particle size differences is often a problem. Boron should never be used in combination seedings containing legumes and grass or small grains because it will injure the grass or small grains. Boron for the legume should be topdressed after the grass has become well established or the small grain companion crop has been harvested. Be careful when banding fertilizers containing boron near the seed or plants. Too much boron near the seed or plant may be toxic to young plants or germinating seeds.

Figure 25. Boron-deficient alfalfa. Shortening of terminal growth and few flowers with yellow to reddish yellow leaves, left. Normal plant, right.

Figure 26. Boron-deficient sugar beets. Advance stage of severe boron deficiency. First symptoms are white, netted chapping of the upper leaves and wilting of tops. Plants later exhibit crosswise cracking of petioles, death of the growing point and heart rot of the root.

Boron Toxicity

Boron toxicity on Michigan crops is usually limited to situations where boron-containing fertilizers are used at planting time on highly sensitive crops such as dry edible beans, corn, grass and small grains. Toxicity to crops has also occurred when sensitive crops were planted where fertilizers containing boron had been used earlier in the season. Similar problems may occur where sensitive vegetable crops are planted with high rates of boron in the starter fertilizer.

Unlike copper, zinc and manganese, boron is rapidly leached out of the soil or fixed in the soil so there is little potential for toxic carryover from year to year. Some wastewaters used for irrigation may have high boron levels, but irrigation waters are not a problem in Michigan.

Boron toxicity is characterized by yellowing of the leaf tips, interveinal chlorosis and progressive scorching of the leaf margins (Figure 27). In soybeans, the leaves may have a rust-like appearance. High levels of calcium may increase the boron tolerance of plants. Average boron concentrations in mature leaf tissues can be used to estimate plant boron status as follows: deficient—less than 15 ppm; sufficient—20 to 100 ppm; and excessive or toxic—over 200 ppm.

MOLYBDENUM

Molybdenum functions largely in the enzyme systems of nitrogen fixation and nitrate reduction. Plants that cannot fix adequate N or incorporate nitrate into their metabolic system because of inadequate molybdenum may become nitrogen deficient. The usual carriers of molybdenum are sodium or ammonium molybdate. These salts contain about 40 percent of the element.

Molybdenum is required in very small amounts. Normal tissues usually contain between 0.8 and 5 ppm; some plants may contain up to 15 ppm. Deficient plants usually contain less than 0.5 ppm. Certain non-responsive crops such as grass and corn may contain as little as 0.1 ppm. The responsive crops are clover, cauliflower, broccoli, lettuce, onions, spinach and table beets. Very few soils in Michigan show a need for molybdenum fertilizers. Those that do are fibrous peats, acid sandy soils and organic soils that contain large amounts of bog iron.

Molybdenum Deficiency Symptoms

Molybdenum deficiency in clover shows up as a general yellow to greenish yellow foliage color, stunting and lack of vigor. The symptoms are similar to those caused by nitrogen starvation. Early stages of the deficiency in cauliflower and broccoli appear as a marginal scorching, rolling or curling upward, and withering and crinkling of the leaves (Figure 28). In later growth stages, the deficiency shows up as "whiptail," especially in the younger leaves. The leaf blade is often very narrow or non-existent. Older leaves show crinkling and marked yellow mottling between the veins. In onions, molybdenum deficiency shows up as dying leaf tips. Below the dead tip, the leaf shows 1 or 2 inches of wilting and flabby formation. As the deficiency progresses, the wilting and dying advance down the leaves. In severe cases, the plant dies.

Correcting Molybdenum Deficiency

Molybdenum deficiency can be corrected by seed treatment and/or foliar applications. For seed treatment, dissolve .5 ounce of the molybdenum compound in 3 tablespoons of water and mix with sufficient seed to plant one acre. Using excess water can cause the chemical to penetrate and injure the seed embryo. Mix the seed thoroughly and let dry. It is advisable to use a suitable fungicide dust to help dry the seed.

For foliar sprays, apply 2 to 3 ounces of the compound per acre. Use wetting agents in the spray when applying the solution to cauliflower or onions. For some cauliflower varieties, repeated applications at two-week intervals are beneficial.

Soil acidity has a marked influence on the need for molybdenum—the greater the acidity, the greater the need for molybdenum. Research plots on a Montcalm sandy soil showed that liming from pH 4.9 to pH 6.7 increased the molybdenum concentration of cauliflower fivefold. In a Houghton muck, raising the pH from 5.4 to 7.2 increased the concentration of molybdenum more than threefold. Liming severely deficient soils, however, will not completely correct the deficiency.

Molybdenum Toxicity

Plants appear quite tolerant of high soil molybdenum concentrations. There is no record of molybdenum toxicity under field conditions. In greenhouse studies, tomato leaves turned golden-yellow and cauliflower seedlings turned purple. Animals fed foliage high in molybdenum may need supplemental copper to counteract the molybdenum.

Figure 27. Boron toxicity in navy beans. Yellowing of the leaf tip followed by interveinal chlorosis of the leaves and scorching of the margins.

Figure 28. Molybdenum-deficient cauliflower. Yellow mottling between the leaf veins, rolling or curling upward and crinkling of the leaves.

FOLIAR APPLICATION OF SECONDARY AND MICRONUTRIENTS

Nutrients can be absorbed through plant leaves. In some situations, foliar-applied micronutrients are more readily available to the plant than soil-applied micronutrients, but foliar applications do not provide continuous nutrition as do soil applications. Foliar spray programs may be used to supplement soil applications of fertilizer or to correct deficiencies that develop in mid-season.

**TABLE 4.
Suggested rates and sources of secondary and micronutrients for foliar application.[2]**

Element	Lbs. element per acre	Suggested source
Calcium (Ca)	1-2	Calcium chloride or calcium nitrate
Magnesium (Mg)	1-2	Magnesium sulfate (Epsom salts)
Manganese (Mn)	1-2	Soluble manganese sulfate or finely ground manganese oxide
Copper (Cu)	0.5-1.0	Basic copper sulfate or copper oxide
Zinc (Zn)	0.3-0.7	Zinc sulfate
Boron (B)	0.1-0.3	Soluble borate
Molybdenum (Mo)	0.06	Sodium molybdate (2 ounces)
Iron (Fe)	1-2	Ferrous sulfate

[2]*Use a minimum of 30 gallons of water per acre.*

**TABLE 5.
Pounds of secondary or micronutrient carrier needed to obtain the desired amount of the element per acre.[3]**

Analysis of secondary or micronutrient carrier (%)	Pounds of element desired per acre							
	.1	.2	.3	.4	.5	1.0	1.5	2.0
1	10.0	20.0	30.0	40.0	50.0	100.0	150.0	200.0
2	5.0	10.0	15.0	20.0	25.0	50.0	75.0	100.0
4	2.5	5.0	7.5	10.0	12.5	25.0	37.5	50.0
6	1.7	3.4	5.0	6.0	8.3	16.7	25.0	34.0
8	1.2	2.5	3.8	5.0	6.2	12.5	18.7	25.0
10	1.0	2.0	3.0	4.0	5.0	10.0	15.0	20.0
12	.8	1.7	2.5	3.4	4.2	8.4	12.6	17.0
14	.7	1.4	2.1	2.9	3.6	7.2	10.8	14.0
16	.6	1.3	1.9	2.5	3.2	6.3	9.5	13.0
18	.5	1.1	1.7	2.3	2.8	5.6	8.4	11.0
20	.5	1.0	1.5	2.0	2.5	5.0	7.5	10.0
25	.4	.8	1.2	1.6	2.0	4.0	6.0	8.0
30	.3	.7	1.0	1.4	1.7	3.4	5.1	7.0
35	.2	.6	.9	1.2	1.5	2.9	4.4	6.0

[3] To convert from dry to liquid: 1 pint equals about 1 pound.

When spray equipment is available, secondary and micronutrient needs of plants may be met with a good spray program. Suggested secondary and micronutrient sources and spray rates per acre are given in Table 4. Use low rates for young plants and higher rates when plants develop dense foliage.

Micronutrient chelates are generally no more effective than water-soluble inorganic sources when foliar applied. Chelates, however, are more compatible when mixed with other spray materials.

For a preventive spray program, spray the crop about four weeks after emergence or transplanting. Because many micronutrients are not readily translocated within the plant, a second spray will be needed two weeks later to cover the new foliage. When a known nutrient deficiency develops, spray the crop with the appropriate nutrient at the recommended rate every 10 days until the deficiency is corrected. Complete coverage of the foliage is important, especially for iron. Adding a wetting agent to the spray solution will improve the coverage and may increase absorption, especially in crops with waxy surfaces, such as cauliflower and onions. Micronutrients may be mixed with most fungicides and insecticides. However, some combinations are incompatible and may injure crops. When in doubt, spray only a limited acreage until compatibility is established. Any injury will usually appear within 48 hours. Table 5 provides a guide for obtaining the desired mixture of various secondary and micronutrient carriers.

In developing a spray program, remember that some fungicides and insecticides contain copper, manganese or zinc. The amounts of micronutrients present in these materials may or may not be sufficient to correct a deficiency but should be considered when determining a spray program.